MATrA : *M*eta-modelling *A*pproach to *Tr*aceability for *A*vionics

Paul Andrew James Mason

Submitted in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

Department of Computing Science

University of Newcastle

March 2002

Abstract

Traceability is the common term for mechanisms to record and navigate relationships between artifacts produced by development and assessment processes. Effective management of these relationships is critical to the success of projects involving the development of complex aerospace products.

Practitioners use a range of notations to model aerospace products (often as part of a defined technique or methodology). Those appropriate to electrical and electronic systems (avionics) include Use Cases for requirements, Ada for development and Fault Trees for assessment (others such as PERT networks support product management). Most notations used within the industry have tool support, although a lack of well-defined approaches to integration leads to inconsistencies and limits traceability between their respective data sets (internal models).

Conceptually, the artifacts produced using such notations populate four traceability dimensions. Of these, three record links between project artifacts (describing the same product), while the fourth relates artifacts across different projects (and hence products), and across product families within the same project.

The scope of this thesis is to define a meta-framework that characterises traceability dimensions for aerospace projects, and then to propose a concrete framework capturing the syntax and semantics of notations used in developing avionics for such projects which enables traceability across the four dimensions. The concrete framework is achieved by exporting information from the internal models of tools supporting these notations to an integrated environment consisting of: i) a *Workspace* comprising a set of structures or meta-models (models describing models) expressed in a common modelling language representing selected notations (including appropriate extensions reflecting the application domain); ii) *well-formedness* constraints over these structures capturing properties of the notations (and again, reflecting the domain); and iii) *associations* between the structures. To maintain consistency and identify conflicts, elements of the structures are verified against a system model that defines common building blocks underlying the various notations.

The approach is evaluated by (partial) tool implementation of the structures which are populated using case study material derived from actual commercial specifications and industry standards.

Acknowledgements

I owe a debt of gratitude to my supervisor Dr. Amer Saeed for shaping my ideas and for his continued help, guidance and encouragement throughout. Thanks are also due to Amer's wife and family for understanding my demands on his time, especially during the period of distance supervision.

With Amer based in the South East for the last two years, it befell Professor Tom Anderson to provide me with managerial supervision in Newcastle. Thank you Tom for ensuring I saw things through.

Further thanks go to my examiners, Dr. Julian Johnson and Dr. Nick Rossiter for their valuable comments and observations.

I would also like to thank all at the Centre for Software Reliability for providing a convivial and stimulating research environment.

Thanks are due to BAE SYSTEMS for their sponsorship and intellectual support and for affording me the opportunity to evaluate my research in an industrial context. I am also grateful to the EPSRC for their financial support.

A special mention goes to my dad James for his love and generosity and to my Uncle Bill who has encouraged me throughout. Thank you both.

And to my mum Joyce whose strong will and resilience I inherited; you are never far from my thoughts.

Finally to Chompoo, for the times we had and for being there almost every day during the past four and a half years. You gave me perspective, encouragement and so much more. You tolerated my grumpiness, not to mention relentless and often *clu-el* (sorry cruel) sarcasm. And what's more, you did it with a smile. Khob Khun Krub, babe!!!

Table of Contents

List of Figures

List of Tables

Author's Declaration

All work contained within this thesis represents the original contribution of the author. However, some of the material presented has previously appeared in the following:-

- Mason & Saeed, 1998 — Mason, P. & Saeed, A. - Tracing Support for Safety Properties: An Object-Oriented and Deductive Approach, Proc. 16th Int'l System Safety Conference, Seattle, WA, Sept.
- Mason, 1998 — Mason, P. - An Introduction to Traceability, University of Newcastle upon Tyne/BAe Dependable Computing Systems Centre Technical Note, TN DCSC/TN/98/04

Chapter 1 An Introduction to Traceability

1.1 Introduction

As systems complexity has increased, so too has the complexity of their development processes. In effect, this usually implies a greater number of sub-processes and hence more intermediate artifacts. Consequently, interest has grown in the study of relationships between these artifacts[1]. Traceability is the common term for mechanisms used to record and navigate such relationships.

In the remainder of Chapter One, we provide a context for work in this thesis. Specifically, the next section describes our domain of interest, namely the aerospace industry. We then introduce the thesis argument to be maintained throughout. Next, we consider traceability as a topic of interest among the wider software and systems engineering communities. This includes a brief history of the subject, defining terminology and forces 'driving' recent growth. Finally, we provide a synopsis of the overall thesis structure. The chapter is based on an extensive review of existing traceability literature which we underpin with views of practitioners from several business units within BAE SYSTEMS.

1.2 Aerospace Industry Characteristics: The Need for Traceability

This thesis considers traceability for aerospace systems engineering, in particular, traceability of artifacts describing systems in which (often safety-critical) functions are allocated to avionics (i.e. electrical and electronic equipment, such as communications and datalink systems, flight control systems, instruments, navigation systems, radar, mission planning systems and weapons). Certain characteristics make traceability an issue for most aerospace projects; this section considers five key characteristics influencing the need for traceability within that domain.

C1. Product Life-cycle

A major difference between projects in the aerospace sector and those in other industries is 'time-to-market'. Civil aircraft may be a decade or more in development, whilst military systems can be planned around twenty years hence. During this time, strategic and mission needs (and hence requirements) may be revised, sometimes instigated by sudden and unforeseen events (like the end of the cold war or the terrorist attacks of September 11, 2001). Moreover, total product life-cycles, particularly those for civil aircraft, can exceed thirty years. Inevitably over such a long period, manufacturers revise their designs to incorporate the likes of new technologies and changes in safety regulations. They may also develop variants of aircraft to accommodate specific market needs. Managing the 'evolving product' is therefore a significant problem on projects with protracted life-cycles.

Because few engineers are involved throughout the duration of such projects, a further and often overlooked problem is retention of knowledge capturing what is best described as 'engineering

[1] In keeping with the literature, we use the terms (trace) relation(ship), association and linkage interchangeably and synonymously throughout to describe any mechanism for linking artifacts produced by an engineering process.

judgement', i.e., the rationale for key development and assessment decisions. This is especially important when engineers must revisit the design of an in-service aircraft (normally following an accident) that has remained static for many years - an obvious example being Concorde which first flew in 1969, but which required a number of modifications following the Paris crash in July 2000[2].

Traceability may be viewed as the common denominator in managing these and other *time* related problems, both by structuring the relationships between multiple versions of artifacts, and by providing means to capture rationale relating to options, argumentation and intent.

C2. Process Characteristics

The development context for aerospace systems containing safety-critical functions or components can be described in terms of two concurrent processes (yielding two sets of artifacts) - development and assessment - each comprising a number of tightly coupled sub-processes. Development proceeds top-down through several iterations of requirements and design, gradually refining abstract aircraft level requirements, into systems or sub-systems and eventually detailed hardware and software component designs[3].

For each iteration, safety analysis determines whether the mission requirements contain any inherent hazards and what safeguards (safety requirements) are required to exclude them. Design proposals are also analysed to ensure they themselves do not introduce any hazards, that they satisfy the safety requirements and that they preserve the original intent (i.e., mission requirements). Following implementation and further safety analysis to ensure no new hazards have been introduced, assessment proceeds bottom up with the integration of components and verification that safety requirements have been satisfied at each level of abstraction.

A major problem with complex processes such as this is lack of visibility, especially where enactment extends over a protracted period (as described in C1). However, process visibility can be enhanced by effective traceability. In simplistic terms, if we consider all artifacts as inputs (I) to, and outputs (O) from the various sub-processes, then a traceability association between two artifacts, **from** $i \in I$ **to** $o \in O$, may be regarded as an abstraction of the activity involved in producing o from i (where i and o denote requirements and designs, for example).

C3. Complex Integrated Systems

Aircraft functions such as automatic landing, auto-stabilisation and stall-protection are implemented by systems that are not only individually complex, but which involve a considerable number of interfaces between systems; e.g., a relatively simple automatic rudder control function with a yaw-damper to correct "Dutch-roll" characteristics will interconnect sensors, actuators, hydraulics, mechanical systems

---

[2] In particular, engineers needed to consider rationale for location of the wheel assembly, relative to the engines and engine intakes. Interested readers are referred to Weir (2001) for more information.

[3] Note the process we describe is simplified and takes no account, for example, of the complex interaction between technical definition and procurement activities.

power plant and cockpit display units[4]. Artifacts describing such systems are often similarly large and complex, as are the relationships between them. Therefore practitioners require means to support traceability not only within descriptions of individual systems, but also between these descriptions, in particular for impact analysis and change control purposes. Traceability can also help maintain consistency across such complex, high-volume data sets.

C4. Fault Tolerant Architectures

Aircraft systems having a direct bearing on safety employ *fault tolerant architectures* to guard against the risk of faults with the potential to cause a system failure. As the name suggests, these architectures allow continued and correct functioning in the presence of faults, where a fault is defined as some defect within a system (Storey, 1996)[5].

Fault tolerance is achieved through redundancy, i.e., multiple modules that replicate means of achieving the same function. Fault tolerant architectures include those employing majority voting mechanisms which compare outputs from *N* modules based on identical inputs. Where a single fault means the output from one module differs, voter output corresponds to the majority view. Simple configurations use triple modular redundancy (capable of tolerating a single fault), whilst greater use of redundant modules affords increased protection - termed *N*-modular redundancy (hardware) and *N*-version programming (software). Dynamic hardware redundancy schemes and software recovery blocks are further, comparable techniques where fault detection mechanisms switch operation to stand-by modules when a unit fails[6].

A corollary of using fault tolerant architectures is that multiple redundant modules yield an increase in development and assessment artifacts describing them, and hence even greater need for effective traceability so that these descriptions may be related back to their original requirement(s). In addition, traceability can provide means of managing assumptions made to justify claims associated with fault tolerant architectures (Popov *et al.*, 2001).

C5. Certification

Finally, certification is normally a legal requirement before new aircraft or aircraft systems can enter operational use. Certification is undertaken by an appropriate regulatory body, with different authorities governing projects within particular aerospace sectors; e.g., in the UK, all civil aircraft require approval by the Civil Aviation Authority. One of the most important documents submitted in support of an application for certification is the safety case, a rigorous argument and supporting evidence stating why the system is safe for its intended use. A safety case may run to several volumes and so maintaining this body of evidence is often extremely difficult. Again, traceability can help practitioners alleviate such problems.

---

[4] Dutch roll occurs when the aircraft has relatively strong lateral stability and weak directional stability. Readers are referred to Mair & Birdsall (1992) for more information.
[5] Readers are referred to works by Laprie (1989), Leveson (1995) and Storey (1996) for definitions of the safety-critical vocabulary used in this thesis.
[6] For more information on these and other approaches, the reader is referred to Anderson & Lee (1991).

However, since certification often requires conformance to a particular standard, and since many standards demand traceability, then traceability can itself be a requirement for certification; e.g., DO-178b (EUROCAE, 1992), an international standard covering certification of software in airborne systems, requires that safety requirements should be traceable through various stages of development to specific elements of the low-level implementation.

This combination of factors demonstrate why traceability is of major significance to the aerospace industry and also why the traceability concerns of practitioners differ markedly from those in other sectors. We are unaware of any further work considering traceability from such a specialised and domain specific perspective.

1.3. Thesis Argument

Issue - We assert that characteristic properties of aerospace systems cause several distinct traceability problems, whilst magnifying those of a more 'traditional' nature[7]. The aim is to propose a theoretical basis for a practical solution to these problems.

Position - Practitioners use a range of notations to model aerospace systems (often in conjunction with a process as part of a technique or methodology). For avionics, notations fall into two broad categories: those with a *well-defined* syntax and semantics (for example Circuit Diagrams and Ada) and those that are less rigorously defined but which offer *flexibility* as a result (such as Use Cases and Scenarios). Practitioners also require the ability to conduct safety assessment over these models using established techniques for hazard analysis (e.g., Fault Tree and Failure Modes and Effects Analyses) and to manage operations using further techniques for planning and control (notably Critical Path Analysis and PERT). Most of the above have tool support (normally bespoke or a commercial CASE tool), however a lack of well-defined approaches to integration limits traceability between their respective data sets.

We argue that traceability across tools can be achieved by exporting these data sets to an integrated environment consisting of: i) a *Workspace* comprising a set of structures or meta-models (literally, models describing models) capturing data elements for a representative set of development, assessment and product management notations; ii) a further structure capturing fundamental elements of the emerging product that maintains consistency within the Workspace (where 'fundamental elements' refers to system components, their functions and behaviour, etc.); iii) well-formedness constraints over these structures; and iv) associations and consistency constraints between the structures.

We also argue that development and assessment information populates four traceability dimensions, of which three record links between project artifacts (conceptualised as a cube), while the fourth relates artifacts across different projects (i.e., cubes) and across product families within the same project. Hence, the structures must provide coverage across four dimensions.

---

[7] 'Traditional' traceability problems concern the following: what kind of information and relationships to record?; how to organise the information into coherent structures reflecting stakeholder viewpoints?; how to populate the structures with information from development and assessment activities?; and how to analyse the populated structures? (Pohl, 1996)

Conceptual data modelling techniques have been used previously to define traceability structures (including meta-models) to represent and trace between semiformal notations for IS development; first their syntactic structure is expressed in an appropriate notation or modelling language and then well-formedness constraints are added to give these constructs a semantics. Some requirements management tools (e.g., DOORS) already adopt this approach to an extent, although failure to capture both syntax *and* semantics undermines their potential use in developing safety or mission critical systems.

Our position is that capturing the syntax and semantics of appropriate notations as traceability structures embedded in a conceptual modelling language (along with means to verify and create linkages between these structures) provides the theoretical basis for a practical traceability environment for avionics engineering.

Evidence - To substantiate our argument, we do the following:-

- Develop an approach towards tackling practitioner concerns stated by our position using traceability structures. The approach known as MATrA (*M*eta-modelling *A*pproach to *Tr*aceability for *A*vionics) provides:
    1. custom representations that define the syntax and well-formedness constraints for flexible notations (applicable to the aerospace domain);
    2. meta-models capturing the syntactic elements and well-formedness constraints of well defined notations and custom representations;
    3. a seamless environment (afforded by 1 and 2) that enables traceability between these meta-models;
    4. a mechanism for ensuring consistency across the meta-models;
    5. coverage of the traceability dimensions.
- Demonstrate the approach using material supplied by aerospace practitioners, including actual commercial specifications and industry standards.

1.4 Survey of Traceability Literature

This subsection provides a survey of traceability literature. Among the areas considered are key traceability concepts and factors motivating interest in the subject, both generally and throughout the aerospace industry.

1.4.1 A Brief History of Traceability

Clearly, any engineering endeavour requires an orderly means of tracking between its initial set of objectives and the overall finished product. Hence traceability is nothing new! Even in software engineering, primitive traceability mechanisms were evident as far back as the early seventies (Teichroew & Sayani, 1971).

Alford (1994) observes that traceability's emergence as a topic of concern coincided with the 'birth' of systems engineering in late fifties America where it was used as a means of demonstrating compliance with requirements under Contract Law. The term itself is thought to originate from the US military who subsequently introduced it as a requirement for all defence contracts. However, it was the mid-seventies before explicit references began to appear in published literature (Alford & Burns, 1976; Belford & Taylor, 1976; Boehm, 1976; Dreyfus & Karacsony, 1976; Stallman & Sussman, 1977), so clearly the concepts significantly pre-date the actual term. Calls for improvement (Alford, 1977) were initially realised as languages with inherent support for traceability (Bell *et al.*, 1977; Davis & Vick, 1977), followed by the first purpose built tools (Pierce, 1978; Johnson & Merrithew, 1978).

The eighties were marked by further calls for improved traceability (Distaso *et al.*, 1980; Hoffnagle & Beregi, 1985; Roman, 1985; Tamanaha *et al.*, 1989), as well as a succession of proprietary and research tools (*cf.* Bigelow, 1988; Dorfman & Flynn, 1984; Garg & Scacchi, 1989; Horrowitz & Williamson, 1986; Lueders, 1984; Nejmeh *et al.*, 1989; Pirnia & Hayek, 1981; and Sciortino & Dunning, 1984).

However, for reasons to be discussed in subsection 1.4.6, the 1990s saw an (ongoing) surge in the popularity of traceability, with further calls for improvement (Fickas & Finkelstein, 1993; IEEE, 1993b; Morris *et al.*, 1995; Plant & Tsoumpas, 1995) and growing academic interest, e.g. the AMES, CREWS, NATURE, 2RARE and LESD projects. It is worth noting that whereas with some techniques, say formal methods, where the 'push' has generally been from academia into industry, traceability has moved in the other direction - i.e., from industry to academia.

1.4.2 Literature Definitions

Greenspan & McGowan (1978) were among the first to propose a definition of traceability. It offers a useful early perspective before the scope of definitions widened and different types of traceability became a feature (as will become evident).

> *"Traceability is a property of a system description technique that allows changes in one of the three system descriptions - requirements, specifications, implementation - to be traced to the corresponding portions of the other descriptions"* Greenspan & McGowan (1978).

Until recently, the most commonly cited 'definition' of traceability featured in the ANSI/IEEE Guide to Software Specifications (ANSI/IEEE Std. 830, 1984):-

> *"A SRS (software requirements specification) is traceable if the origin of each of its requirements is clear and it facilitates the referencing of each requirement in future development and enhancement documentation"* ANSI/IEEE Std. 830 (1984).

This is actually not so much a definition as a statement of the conditions necessary to establish traceability. However, it *is* notable for prescribing traceability of artifacts leading to production of the SRS. This contrasts with early definitions (including Greenspan & McGowan) which view the specification as a 'black-box'. Equally significant is the fact that it explicitly recommends *backward* traceability to previous development stages and *forward* traceability to all documents spawned by the SRS, thereby introducing the notion of direction which features prominently in later work.

However, Davis arguably shaped current attitudes towards traceability with the following definition:-

> *"traceability can be defined as the ability to describe and follow the life of an artifact, in both a forward and backward direction, i.e. from its origin to development and vice versa"* Davis (1990).

The influence of this definition can be clearly seen in later interpretations (notably that of Gotel, 1995). More significant is that Davis distinguishes between different types of traceability in two further sub-definitions, *pre-traceability* and *post-traceability*. These recognise the fact that producing an SRS involves tasks, problems and information which differ in content and structure from those that follow (a point affirmed by Feather, 1991 and Goguen, 1996a). This distinction is supported in studies by Ramesh & Edwards (1993) and Gotel (1995) who proposed the following definitions:-

> *"pre-requirements traceability refers to the ability to describe and follow those aspects of a requirement's life prior to its inclusion in the requirements specification in both a forwards and backwards direction"* Gotel (1995).

> *"post-requirements traceability refers to the ability to describe and follow those aspects of a requirement's life that result from its inclusion in the requirements specification in both a forwards and backwards direction"* Gotel (1995).

Davis (1990) also reinforced the notion of direction by specifying a need for i) backward traceability (from requirements); ii) forward traceability (from requirements); iii) backward traceability (to requirements); and iv) forward traceability (to requirements). This has greater scope than ANSI/IEEE Std. 830-1984 (which merely recommends tracing backwards and forwards *from* the SRS), Ince *et al.*, 1993 (whose definitions of forward and 'reverse' traceability disregard pre-traceability) and Ramesh & Edwards, 1993 (who confine their interpretation to traceability between requirements and design).

Pearson (1996) extended the existing divisions with definitions of Pre-Formal-RS and Post-Formal-RS traceability which take into account the production of a formal requirements specification document. Pohl (1996) meanwhile further emphasises the need to maintain traceability between requirements expressed using natural language and their corresponding formal representation.

Some authors also use the terms *horizontal* and *vertical* traceability (e.g., Bersoff & Davis, 1991; Boldyreff *et al.*, 1996; Gotel, 1995; Nejmeh, 1989; Ramesh & Edwards, 1993) in referring to associations between life-cycle objects of the same type, i.e., same development (or assessment) phase (e.g., a parent and its child requirement(s)) and different types (e.g. a requirement and its corresponding design element(s)). Although usage of these terms is fairly standard, it is worth noting that Bohner (1995) applies them visa versa, as does Lindvall (1997), whereas Choi & Scacchi (1989), Fiksel & Hayes-Roth (1993) and Lanubile & Visaggio (1995) use the designations *internal* and *external* traceability in preference to horizontal and vertical. Corriveau's (1996) interpretation of horizontal traceability is different again. Based on an incremental, object-oriented approach, he uses it to describe the tracking of artifact versions through various *macro-iterations*, where each iteration represents a 'complete' development life-cycle.

Consultation with practitioners revealed a further distinction in which horizontal traceability refers to artifacts related *within* a tool and vertical traceability refers to artifacts related *between* tools (though the original intent is often preserved since a separate tool is typically associated with each development stage). Similarly, Kalinsky *et al.* (1989) and Lindvall (1997) view traceability as relating dependent items *within* a model and corresponding items *between* models. Finally, in a document-centric approach based on syntax-trees, Han (1995, 1996 and 1997b) differentiates between inter-document relationships and intra-document relationships. Again, as he considers a separate document to be produced by each stage in development, Han also preserves the usual intent implied by horizontal and vertical traceability.

Apart from the early interpretation by Greenspan & McGowan, all definitions considered to date are what Gotel (1995) termed *direction-driven.* Other direction-driven definitions were proposed by Corriveau (1996), ESA (1991), Gieszl (1992), Ince *et al.* (1993), Johnson *et al.* (1991), Nejmeh *et al.* (1989) and Shilling & Sweeney (1989).

Most definitions of traceability fit into this category. However, Gotel (1995) proposes some additional groupings as part of a simple taxonomy which also describes definitions as:-

Purpose-driven - defined in terms of what traceability should do, for example:-

> *"Traceability provides software developers with facilities to track the history of every feature of a system and the impact of changes to these features on the system design, cost and schedule"* Tran *et al.* (1997).

Other purpose-driven definitions include those proposed by Kelley (1990), Wright (1991), Jackson (1991) and Hughes & Martin (1998). The main weakness of such definitions is their tendency to define usage rather than meaning.

Solution-driven - defined in terms of how traceability should be done, for example:-

> *"Traceability refers to the ability of tracing from one entity to another based on given semantic relations"* Ramamoorthy *et al.* (1986).

Other solution-driven definitions include those proposed by Ecklund jr. *et al.* (1996), Gardner (1994) and Roman (1985). The main weakness of these definitions is their tendency to be overly prescriptive.

Information-driven - emphasising the information to be traced between, for example:-

> *"The characteristic of a software system that allows identification and control of relationships between requirements, software components, data and documentation at different levels in the system hierarchy"* NASA-Std-2202 (1993).

Other information-driven definitions include those by Bergstein (1993), Castell *et al.* (1993), DO-178b (EUROCAE, 1992) and IEEE (1993a). The main weakness of such definitions is their tendency to over state (and hence restrict) what artifacts should be traced.

1.4.3 Author's Definitions

Most definitions of traceability (including those featured above) originate from software engineering literature and are couched in terms that prohibit their wider application to systems engineering. Moreover, they normally imply a single level of decomposition and single system perspective, while showing bias towards software life-cycle models. Also, the notion of traceability between artifact revisions (i.e., the maturation of an artifact) and between 'base' artifacts and their variants (modifications developed for use on different products) - we collectively term these different forms of evolution *versions* - is either not considered or else is captured by overloading definitions for horizontal traceability (i.e. between artifacts of the same type).

Clearly therefore significant aspects are lost when the intent of software based definitions is 'stretched to fit' a systems engineering context. We therefore provide our own taxonomy which, to keep as general as possible:- i) states meaning not usage; ii) is free of bias towards particular methods of realisation; and iii) avoids excessively delimiting the artifacts to trace[8]. The taxonomy itself comprises definitions of horizontal and vertical, revision and variant, pre and post requirements and forward and backward traceability. These are then used to provide a definition of traceability itself.

Note: vertical/horizontal traceability is adequate for 'normal' systems engineering, but for avionics (and aerospace systems generally), characteristics C2 and C3 (subsection 1.2) imply more complex products and hence more complex processes. Therefore richer definitions of traceability are required. The terms *micro* and *macro* are introduced to differentiate traceability within and across decomposition levels (e.g., system, sub-system, component). Similarly, the terms *intra* and *inter* distinguish traceability within and across system descriptions (i.e., systems that interact with one another).

- **Inter-Macro-Vertical Traceability** - the ability to describe and navigate relationships across system descriptions, across levels of decomposition, between development or assessment artifacts of different types.
- **Inter-Macro-Horizontal Traceability** - the ability to describe and navigate relationships across system descriptions, across levels of decomposition, between development or assessment artifacts of the same type.
- **Inter-Micro-Vertical Traceability** - the ability to describe and navigate relationships across system descriptions, within a decomposition level, between development or assessment artifacts of different types.
- **Inter-Micro-Horizontal Traceability** - the ability to describe and navigate relationships across system descriptions, within a decomposition level, between development or assessment artifacts of the same type.
- **Intra-Macro-Vertical Traceability** - the ability to describe and navigate relationships within a system description, across levels of decomposition, between development or assessment artifacts of

[8] Following Gotel's classification, these properties imply a direction driven approach.

different types.

- **Intra-Macro-Horizontal Traceability** - the ability to describe and navigate relationships within a system description, across levels of decomposition, between development or assessment artifacts of the same type.
- **Intra-Micro-Vertical Traceability** - the ability to describe and navigate relationships within a system description, within a decomposition level, between development or assessment artifacts of different types.
- **Intra-Micro-Horizontal Traceability** - the ability to describe and navigate relationships within a system description, within a decomposition level, between development or assessment artifacts of the same type.

These definitions are shown graphically in figure 1.1 and summarised in table 1.1.

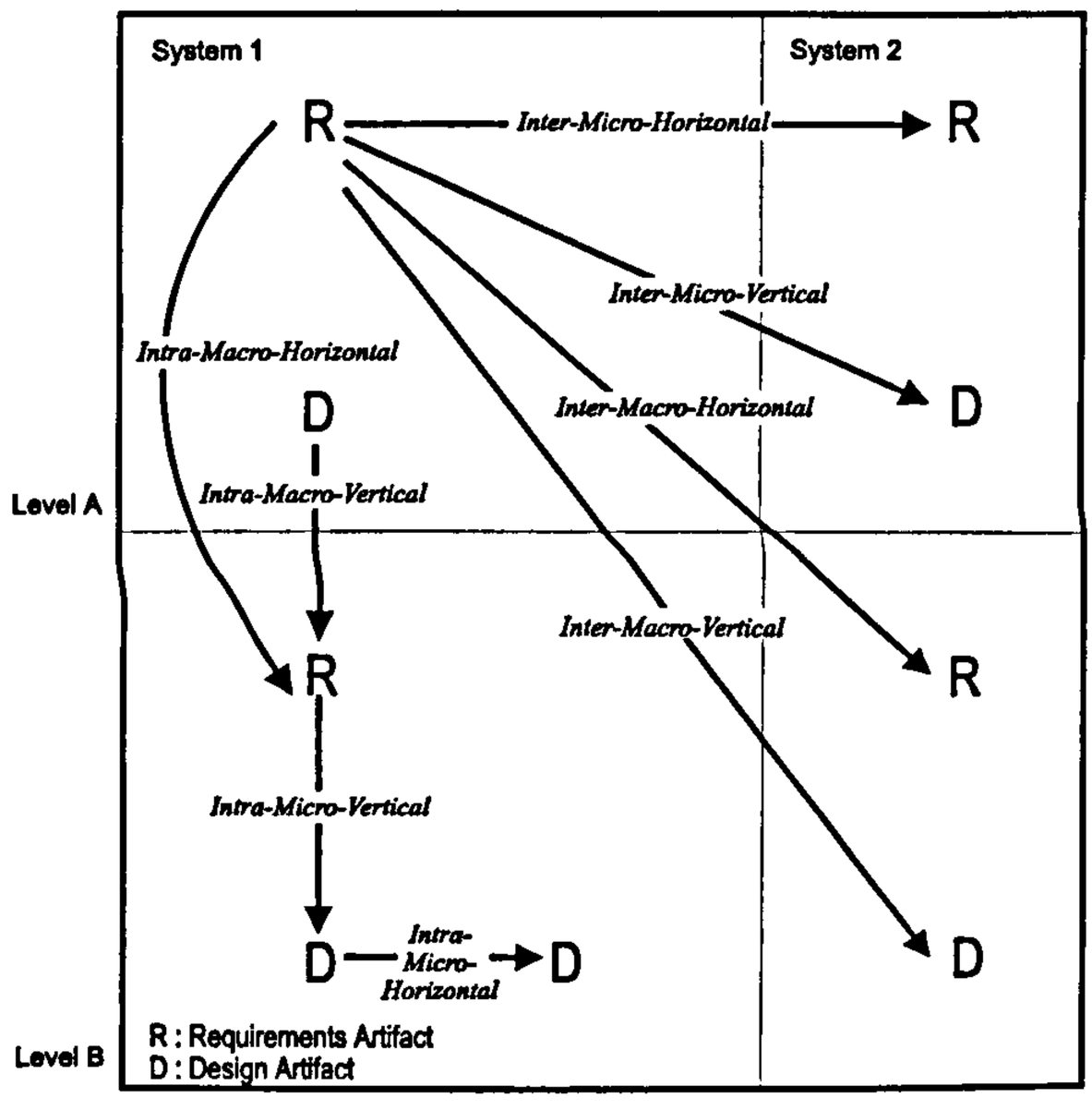


Figure 1.1 - 'Inter/Intra, Macro/Micro Horizontal/Vertical Traceability Types'

Traceability Type	Within System	Within Decomposition	Same Type
Inter Macro Vertical	✗	✗	✗
Inter Macro Horizontal	✗	✗	✓
Inter Micro Vertical	✗	✓	✗
Inter Micro Horizontal	✗	✓	✓
Intra Macro Vertical	✓	✗	✗
Intra Macro Horizontal	✓	✗	✓
Intra Micro Vertical	✓	✓	✗
Intra Micro Horizontal	✓	✓	✓

Table 1.1 - 'Summary of Inter/Intra, Macro/Micro Vertical/Horizontal Traceability Types'

- **Revision Traceability** - the ability to describe and navigate relationships between instances of the same artifact at different stages of maturity[9].
- **Variant Traceability** - the ability to describe and navigate relationships across different projects (and across product families within the same project), between base artifacts and their derivatives.
- **Pre-Requirements Traceability** - the ability to describe and navigate relationships between a requirement and its originating artifacts.
- **Post-Requirements Traceability** - the ability to describe and navigate relationships between a requirement and any artifacts relating to its development, assessment or evolution.
- **Forward Traceability** - the ability to describe and navigate relationships between i) artifacts originating a requirement and (verification of) its realisation; ii) $revision_i$ and $revision_n$ of an artifact; and iii) base artifacts and their variants.
- **Backward Traceability** - the ability to describe and navigate relationships between i) (verification of) some hardware or software feature and the artifacts originating its requirement(s); ii) $revision_n$ and $revision_1$ of an artifact and iii) a variant artifact and its base.
- **Traceability** - the ability to describe and navigate relationships, forwards and backwards, within and across system descriptions, within and across decomposition levels, between artifacts of the same or different types, their revisions and variants, pre and post requirements specification.

1.4.4 On Formal Definitions of Traceability

At present, no formal definition of traceability exists. However, we *can* formally conceptualise what is meant by claims that a project is *traceable* (where a project refers to a completed product and all its documentation) based on the above definitions.

For the following *types* of traceability, inter (ir), intra (ia), macro (ma), micro (mi), horizontal (ht), vertical (vt), revision (re), variant (va), forward (fw), backward (bw), pre-RS (pr) and post-RS (ps), we introduce the predicates, **ir_ma_vt, ir_ma_ht, ir_mi_vt, ir_mi_ht, ia_ma_vt, ia_ma_ht, ia_mi_vt, ia_mi_ht, re, va, pr, ps, fw** and **bw**. These are of the form *type*: $\mathbf{P} \rightarrow \mathbb{B}$, where **P** represents the hypothetical set of all projects. Each predicate holds for a project P, *iff* the project complies with the predicated type of traceability. We also introduce a predicate **T**, which holds when the project complies with our definition of traceability. We now assert the following relations:-

$$\mathbf{T(P) = ir\_ma\_vt\ (P) \wedge ir\_ma\_ht\ (P) \wedge ir\_mi\_vt\ (P) \wedge ir\_mi\_ht\ (P) \wedge}$$
$$\mathbf{ia\_ma\_vt\ (P) \wedge ia\_ma\_ht\ (P) \wedge ia\_mi\_vt\ (P) \wedge ia\_mi\_ht\ (P) \wedge}$$
$$\mathbf{re\ (P) \wedge va\ (P)}$$

$$\mathbf{T(P) = pr\ (P) \wedge ps\ (P)}$$

$$\mathbf{T(P) = fw\ (P) \wedge bw\ (P)}$$

[9] Note the intersection of ideas with Configuration Management literature. Ramesh & Jarke (1999) suggest the main difference is one of granularity such that CM *mainly* concerns coarse-grained relationships, whereas traceability *can* be finer-grained.

1.4.5 Dimensions For Traceability

Figure 1.2 illustrates the concepts of pre-requirements and post-requirements traceability and horizontal, vertical and revision traceability[10]. Henceforth, the latter three are referred to as traceability *dimensions*; we therefore speak of the horizontal, vertical and revision dimensions. To aid readability, traceability is considered between just four basic artifact types (Requirement) Source, Requirement, Design and Implementation.

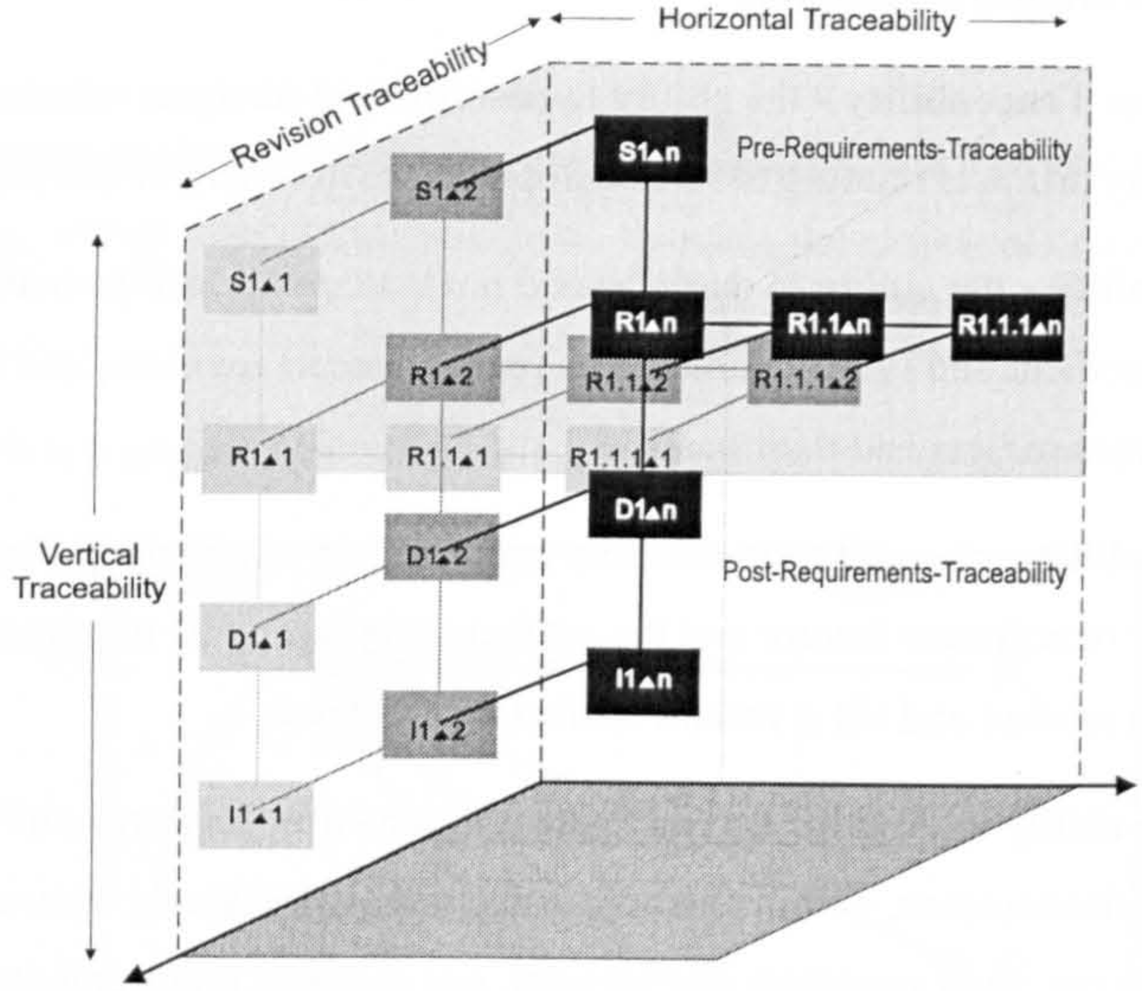


Figure 1.2 - 'Horizontal, Vertical and Revision Traceability Dimensions'

Figure 1.3 illustrates (one aspect of) variant traceability (i.e. the variant *dimension*), namely traceability across projects, using a subset of the Airbus 'family' of aircraft. It depicts hypothetical relationships between requirements and design artifacts for the A300 and A320, which together derive inputs for the A340. Note, where a project is composed of a 'family' of (e.g., A319, A320 and A321) rather than individual aircraft, then variant associations can exist within as well as between cubes.

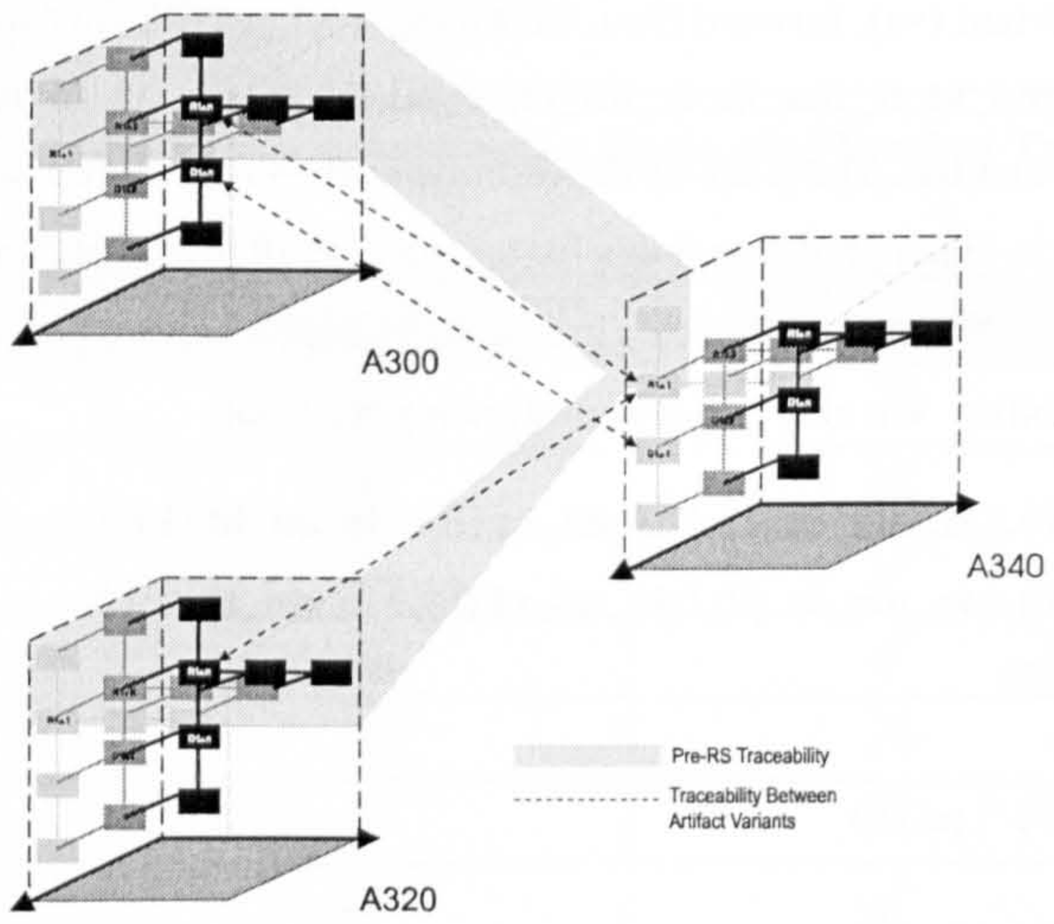


Figure 1.3 - 'Variant Traceability'

[10] In order to simplify figures 1.2 and 1.3, we only illustrate the intra-micro forms of horizontal and vertical traceability.

1.4.6 Drivers For Traceability

The introduction referred to a growing interest in traceability, with several authors (including Gotel, 1995; Kenny, 1996; Palmer, 1997; Ramesh *et al.*, 1995; Watkins & Neal, 1994; White, 1994a; and Wieringa, 1995) highlighting some general motivations for its increased use.

That said, traceability remains something of a paradox. Many still regard it as time-consuming, tedious and labour-intensive (as reported in Kotonya & Sommerville, 1998; Ramesh, 1993; Cockram *et al.*, 1998; and White, 1994a), with perceived 'benefits' such as reduction in rework (Palmer, 1997) and the ability to manage costs (Dömges & Pohl, 1998; Watkins & Neal, 1994), planning and scheduling (Ramesh & Edwards, 1993; Booth, 1993; Lindvall, 1997), performance (Hodge, 1994) and risk (Cross, 1996; Wilson *et al.*, 1997b) often seen as speculative. This is because while direct traceability costs are relatively easy to calculate, the return on investment is far more difficult to measure[11]. And yet, we estimate around ninety percent of published work on traceability has emerged during the last ten years.

The literature suggests two 'key drivers' have contributed to this growing interest. These are as follows:-

- The Emergence of Requirements Engineering
- Increased use of Quality Management & Compliance Frameworks

1.4.6.1 The Emergence of Requirements Engineering (RE)

The contribution of sub-standard requirements to systems that are delivered late, over budget and which don't fulfil the needs of users is well-known (Boehm, 1981). Traditionally, the requirements phase of a project was seen as little more than a front-end to development and as a result was not accorded the same degree of precision as down-stream activities.

Requirements *Engineering* (RE) is a relatively recent term encapsulating all of the activities involved in eliciting, understanding, analysing, documenting and managing requirements. The term *engineering* is intended to convey the impression that this is accomplished through a practical, systematic and repeatable process, even in areas with more philosophical and social underpinnings (e.g., ethnography; Sommerville *et al.*, 1993).

Though the idea of applying an engineering orientation to systems analysis dates back to the mid-seventies (IEEE, 1977), the last few years have seen an escalation of interest. The literature provides a useful barometer of this growth. Before 1990 material was both sparse and disjoint, whilst nowadays, in addition to being the subject of conferences, symposia and books (Kotonya & Sommerville, 1998; Pohl, 1996; Sommerville & Sawyer, 1997; Wieringa, 1996), RE now has its own journal, newsletter and BCS specialist group.

Moves to improve Requirements Engineering within the aerospace sector are evident from its

[11] Return on traceability investment has been *estimated* at four per cent of total expenditure on US DoD projects Ramesh (1994).

collaboration with academia. In Europe alone, recent or ongoing involvement includes such projects as 2RARE (Alcatel Espace), CREWS (GEC-Marconi), DCSC (BAE SYSTEMS), ISRE (GEC-Marconi), KARE (BAE SYSTEMS), REAIMS (Aerospatiale) and STEFFIE (Lucas Aerospace and GEC-Marconi). This is additional to a number of in-house initiatives also taking place (e.g., the Airbus Industrie CARE project; Airbus, 2001).

The emergence of RE and efforts to improve its attendant areas for eliciting, understanding, analysing, and documenting software requirements has had an *indirect* bearing on traceability. For example, the transition from analysis to design in object-oriented approaches is claimed to naturally enhance traceability by removing the 'air gaps' in disparate notations across the two sets of artifacts (Barbier, 1994; Jacobson *et al.*, 1993). Though beyond the scope of this thesis, a growing corpus of work reflects the issues (and problems) relevant to traceability for object-oriented development (*cf.* Börstler, 1996; Bosch, 1998; Buhr, 1995; Corriveau & Hayashi, 1994; Diagne & Kordon, 1996; Ecklund *et al.*, 1996; Galle, 1996); Gossain, 1995; Ihme *et al.*, 1995; Lindvall, 1997; Premerlani, 1994; Scalzo & Hugue, 1996; Wieringa, 1998; Wood, 1995).

However, the aspect of RE that has influenced growth in traceability more than any other is requirements management. It is widely acknowledged that requirements change is a major source of risk in terms of cost, schedule and quality (Strens, 1995), while with safety-critical systems, failure to properly manage its effects can pose a threat to human life (de Lemos *et al.*, 1995). To minimise these difficulties, such changes must be managed effectively and for that, traceability is required.

The first thing to say about requirements change is that it is unavoidable and while especially prevalent in the early phases of a project, normally occurs throughout. Indeed as Lehman & Belady (1985) maintain, systems must continually respond to their environment or become progressively less effective. Practitioners consulted during this study estimate that following the initial volatility, requirements typically change on average around three per-cent per month during the lifetime of a project; this is corroborated by published figures in Gries (1997). It is worth noting, as Chudge & Fulton (1994) and Harker & Eason (1993) point out, that early life-cycle based approaches had naively assumed a complete and *static* set of requirements were attainable prior to design. However, several alternative models have since emerged which accommodate change (Gladden, 1982; Lee & Yen; 1993; Rolland, 1994a), some with explicit traceability mechanisms (Brouse [1992], Martin *et al.* [1993], Tiel [1993] and Hugge & Lang [1995]).

The other key point to make is that requirements change need not necessarily reflect poor practice, such as basing requirements on erroneous assumptions (Ramesh & Jarke, 1999), failure to resolve conflicting viewpoints (Easterbrook *et al.*, 1994; Hughes *et al.*, 1995) or failure to identify missing information (Takahashi & Yamamoto, 1995). It can actually result from a combination of other factors, many of which are beyond a requirements engineer's control. For instance, customer's evolving knowledge of the target system is often a major source of instability whereby expectations grow (and their

requirements change) as the product emerges and they see new possibilities (Pohl & Jacobs, 1994); this is especially true for interface requirements (Lubars *et al.*, 1993). External or environmental factors can force further unforeseen change on both customer and developer, especially for systems with protracted life-cycles. Finally, technical problems encountered when implementing a requirement may also lead to change. This may be due for example, to timing issues discovered during systems integration, or the emergence of additional safety evidence (Kelly & McDermid, 1999). Interested readers are referred to Kotonya & Sommerville (1998) for other factors causing requirements change.

The main problem in change management lies in tracking the so-called *ripple-effect* (Collofello & Vennergrund, 1987; Yau & Tsai, 1987) where changes to one artifact can have an unforeseen impact elsewhere in the system. As Bohner (1995) observes, ripple-effects can be either direct (where connectivity between affected artifacts is immediate) or residual (where connectivity is transitive and the impact more difficult to detect). To a certain extent developers can minimise the problem by using modular development techniques. With software this often implies an object-oriented approach based on encapsulation, high cohesion and low coupling, etc. (Corriveau, 1996; Hoffman, 1990; Sugden & Strens, 1996). However, whilst such methods can localise the impact of change, developers still require means of making the ripple-effect more visible in order to address potential 'side-effects' of proposed changes (Freedman & Weinberg, 1981).

Horizontal and *vertical* traceability provide such means and are therefore pre-requisites for effective impact assessment (Escudie *et al.*, 1994; Sugden & Strens 1996; Tryggeseth & Nytro, 1997). From a (intra-micro) horizontal standpoint, suppose ultimate fuel pressure (UP) is defined as a function of a separate requirement for normal fuel pressure (NP); if NP were to change, then so too must the requirement for UP. Similarly, from a (inter-macro) horizontal perspective, changes to the specification of sensors calculating measured aircraft state may propagate to navigation system requirements and thence requirements for the flight control system; clearly intra/inter and micro/macro vertical traceability will also be needed to track any design changes arising. In addition, *revision* traceability is also useful for change management as it allows practitioners to re-construct the evolutionary history of an artifact which in turn, permits the point where errors were introduced to be identified, as well as providing useful volatility data for future projects. Finally, *variant* traceability is necessary for tracking the effects of change propagation between products. It is especially useful for changes instigated by requirements errors where one replicated error can potentially 'contaminate' an entire product family.

Besides dependencies among artifacts, the rationale underlying development decisions (i.e., decision rationale) provides important supplementary trace information to aid change management (Sugden & Strens, 1996)[12]. Most approaches to representing decision rationale are based on the argumentation structuring principles pioneered by Toulmin (1958); their underlying models are typically constructed from nodes (such as *issue*, *alternative* and *claim*) which are linked to form networked structures by relationships (such as *achieves*, *denies* and *pre-supposes*). Prominent examples of the form include

[12] Readers are referred to Bailin *et al.* (1990), Monk *et al.* (1995) Arango *et al.* (1991), Chandrasekaran *et al.* [(1993), Fischer (1991) and Pena-Mora, *et al.* (1995) for further examples of its potential application.

IBIS (Kunz & Rittel, 1970) and gIBIS (Conklin & Yakemovic, 1991), DRL (Lee, 1991) and QOC (MacLean *et al.* (1991). However, these early models have been widely criticised for representing decisions out of context. Therefore, more recent examples attempt to link the rationale to a model of development artifacts; *cf.* Monk *et al.* (1995), Potts (1994), Han (1997a) and Ramesh & Dhar (1992), as well as the DRCS proposed by Klein (1993a) which we consider further in relation to this work in Chapter Three.

It is important to remember that traceability is *not* about preventing change (Card, 1988). Rather it is a communication and control mechanism to be used, typically as part of a change control process, in managing its realisation (*cf.* Chudge & Fulton, 1994; Coyne, 1993; Kotonya & Sommerville, 1998; and Gries, 1997). With the trend towards larger and more complex systems, change control and impact analysis have become even more significant. Consequently, they rate among the more mature traceability sub-topics (*cf.* Bohner, 1995; Canfora *et al.*, 1995; Cimitile *et al.*, 1992; Fyson & Boldyreff, 1998; Han, 1996; Kelly & McDermid, 1999; Lanubile & Visaggio, 1995; Lindvall, 1997; Liu *et al.*, 1993; Madhavji, 1992; Ramamoorthy *et al.*, 1990; Westfechtel, 1989; Whitgift, 1991 and Yau *et al.*, 1988).

Historically, the traceability information most commonly maintained for requirements management purposes is requirements-requirements and requirements-design traceability. However, work within the RE community has succeeded in evolving the practice of tracing requirements back to their source (i.e., pre-requirements traceability) and hence potential change provocateurs. Examples include Brouse (1992), Curran *et al.* (1994), Gotel (1995), Johnson *et al.* (1991, 1992), Laubengayer & Spearman (1994), Leite *et al.* (1997), Moores & Champion, 1994, Morris *et al.* (1994), Pohl (1996), Ramesh (1994) and Sawyer *et al.* (1996).

It can be seen therefore that the emergence of Requirements Engineering has provided a focus for work on traceability and a forum for the exchange of views. Improvements in traceability-practice have come both *indirectly* as a by-product of methods for the elicitation, understanding, analysis and documentation of requirements, and *directly* through better techniques for their management.

1.4.6.2 Increased use of Quality Management & Compliance Frameworks

Evaluative frameworks are increasingly used as arbiters of acceptability with respect to quality, safety and other hallmark attributes. Where quality and safety often differ is that with the former, framework compliance may be *desirable* for commercial reasons (i.e., a recognised stamp of approval can help gild the corporate image), whereas with the latter, it is usually *necessary* to achieve certification.

The growing popularity of evaluative frameworks is largely attributable to two factors. First, the prevailing 'quality culture' that places great emphasis on achieving quality within all fields of endeavour; as Storey (1996) observes, it often seems our goals in life may be encompassed by driving a quality car, attaining a quality home and spending quality time with our family! And second, increased

use of safety-critical systems; growth in using computers instead of electromechanical or other components to control safety-critical applications is largely due to their processing power[13], physical size and weight, and flexibility[14] - all of which can lead to cost savings across a project (Storey, 1996; Leveson, 1995).

According to Sheard (1997), the two main forms of evaluative framework are process improvement models and standards and guidelines. We now briefly consider examples of each from a traceability standpoint, before considering one particular set of guidelines for the aerospace domain (subsection 1.4.6.2.1) which we refer to regularly throughout this thesis.

Process Improvement Models (PIM) are founded on established links between the quality of a product and the quality of process used to create it. Though PIMs have no formal ratification (unlike standards which are subject to industry approval), they provide a way in which to assess the capabilities of an organisation based on its key processes. Perhaps the most widely known PIM is the Software Engineering Institute's (SEI) Capability Maturity Model (CMM). Originally proposed by Humphrey (1988), but later revised by Paulk *et al.* (1993), it was devised to help the US Department of Defense assess the capabilities of software contractors. CMM provides a five-layer stratum which classifies software processes as: i) *initial*, ii) *repeatable*, iii) *defined*, iv) *managed* and v) *optimising*; traceability is necessary to achieve level two status (and above). The model itself provides only general guidance, although the need to support a minimum of post-requirements traceability may be assumed.

The systems engineering Capability Maturity Model (SE-CMM) and the systems engineering Capability Assessment Model (SECAM) are further examples of PIMs. SE-CMM (SEI, 1995) was again developed by the Software Engineering Institute and so has the advantage of association with the organisation that devised the original (software) CMM. As a minimum, traceability is necessary to support 'Process Area' Two of the model. Similarly, SECAM (INCOSE, 1996) - the product of an INCOSE working group - divides process capability into nineteen 'Key Focus Areas', with traceability influential in those on 'Tracking' (1.2) and 'Configuration Management' (1.5). The main difference between SE-CMM and SECAM is that the former includes non process characteristics.

Standards and guidelines meanwhile establish contractual and regulatory requirements for development and assessment. Notable examples include the ISO 9000 series which can be used to develop quality management systems across a range of organisations, from manufacturing to service based industries (Rothery, 1993). The most general of these standards is ISO 9001 which applies to systems and software inasmuch as it concerns the quality process of any organisations that design, develop and maintain products. A supporting document, ISO 9003 (implemented in the UK through TickIT), provides a further interpretation of ISO 9000 appropriate to the software industry. Traceability is necessary for accreditation to the ISO 9000 series; in particular, it is an explicit requirement for

---

[13] This enables complex control functions, as well as sophisticated safety mechanisms such as self diagnostics and interlocks.
[14] By flexibility, we mean system characteristics can be changed through software upgrades, without need for hardware alterations.

realising clause 4.8 of ISO 9001, whilst Ince (1994) further notes the implicit relevance of clauses 4.3, 4.4 and 4.16, as well as 5.3 and 6.1 from ISO 9003. Moreover, the generic language used to express these standards makes them applicable across the range of traceability dimensions[15].

Traceability is also evident in the requirements management sections of UK Def-Std. 00-55 (MoD, 1997), for example 31.2.3 to 31.2.6 (inclusive), as well as US Mil-Std-498 (DoD, 1994), notably 4.2.6, 5.4.2 and 5.9.3. ARP 4754 (EUROCAE, 1996a) meanwhile provides guidance on traceability for the development of highly integrated or complex aircraft systems, while DO 178b does likewise for the production of software for airborne systems and equipment; respectively, parts 7.3 and 5.12b (pre-RS), 8.43 and 6.2c (post-RS), 7.6.1 and 5.5a (horizontal), 5.2.1 and 5.5c (vertical), 9 and 7 (revision), and 11.3.3 and 12.1.5 (variant) demonstrate that traceability across all four dimensions is recommended by both documents. ARP 4754 is discussed further in the following subsection.

Clearly, the above-mentioned frameworks are proving to be a key driver for growth in traceability. From a quality perspective, organisations are increasingly obliged to tackle the issue in establishing processes that conform to the requirements of their industry. For instance, ISO 9000 accreditation is already mandatory for contractors to many European governments, while the US government normally favours a minimum of CMM level 2 or level 3 status when awarding defence contracts. From a safety perspective, standards such as DO 178b have been even more influential as conformance is normally a requirement for legal reasons. Note that ARP 4754 is defined in the context of Joint Aviation Regulations and Federal Aviation Regulations (JARs & FARs) which effectively makes it a *de facto* standard.

Accordingly, tools and approaches are now emerging which help manage and/or demonstrate framework and more especially, standards compliance (*cf.* Dawkins, 1998; Emmerich *et al.*, 1999; and Wilson *et al.*, 1997a). Other works with potential application to framework compliance include those addressing traceability of safety properties. In particular, the Safety Argument Manager (SAM) which supports construction and analysis of safety arguments, as well as managing the inter-relationships between assessment techniques. SAM provides traceability at two levels:- i) an underlying data model underpinning the analysis techniques (Wilson & McDermid, 1995); and ii) a goal structuring notation (GSN)[16] for tracing safety arguments (Wilson *et al.*, 1995; Wilson *et al.*, 1996; Kelly & McDermid, 1997). Further examples include Jenkins *et al.* (1997), Mason & Saeed (1998), Pearson *et al.* (1998), Leveson & Reese (1998) and with respect to tracing safety properties of COTS (commercial-of-the-shelf) components, Dawkins & Riddle (2000).

In the following subsections we introduce ARP 4754, together with accompanying guidelines for its realisation, ARP 4761, and provide a brief overview of the traceability requirements they 'impose'. This will serve as an aid to reader orientation for work in Chapters Five and Six.

---

[15] It should be noted that despite their common purpose (see Coallier, 1994 or Paulk, 1995 for a comparison), ISO 9000 and CMM are very different in approach as efforts to integrate them demonstrate (Rozman *et al.*, 1997).
[16] GSN is conceptually similar to a number of other goal oriented methods (*cf.* Landes & Studer, 1995; Alvarez & Castell, 1996; Dardenne *et al.*, 1993; van Lamsweerde *et al.*, 1995; Yu, 1993 and Mylopoulos *et al.*, 1992)

1.4.6.2.1 Aerospace Recommended Practice (ARP) 4754 & 4761

ARP 4754 and ARP 4761 (EUROCAE, 1996b) describe safety assessment guidelines and methods for the certification of civil aircraft[17]. Assessment runs parallel to development and comprises four primary sub-processes (see figure 1.4): Functional Hazard Assessment (FHA), Preliminary System Safety Assessment (PSSA), Common Cause Analysis (CCA) and System Safety Assessment (SSA); we briefly discuss these below. A number of interdependent analysis techniques are used to support assessment, each providing a different insight into failure behaviour of the target system. Those used with ARP 4754/4761 are Fault-Tree Analysis - FTA (Vesely *et al.*, 1981) and Failure Mode and Effects Analysis - FMEA (IEC, 1985).

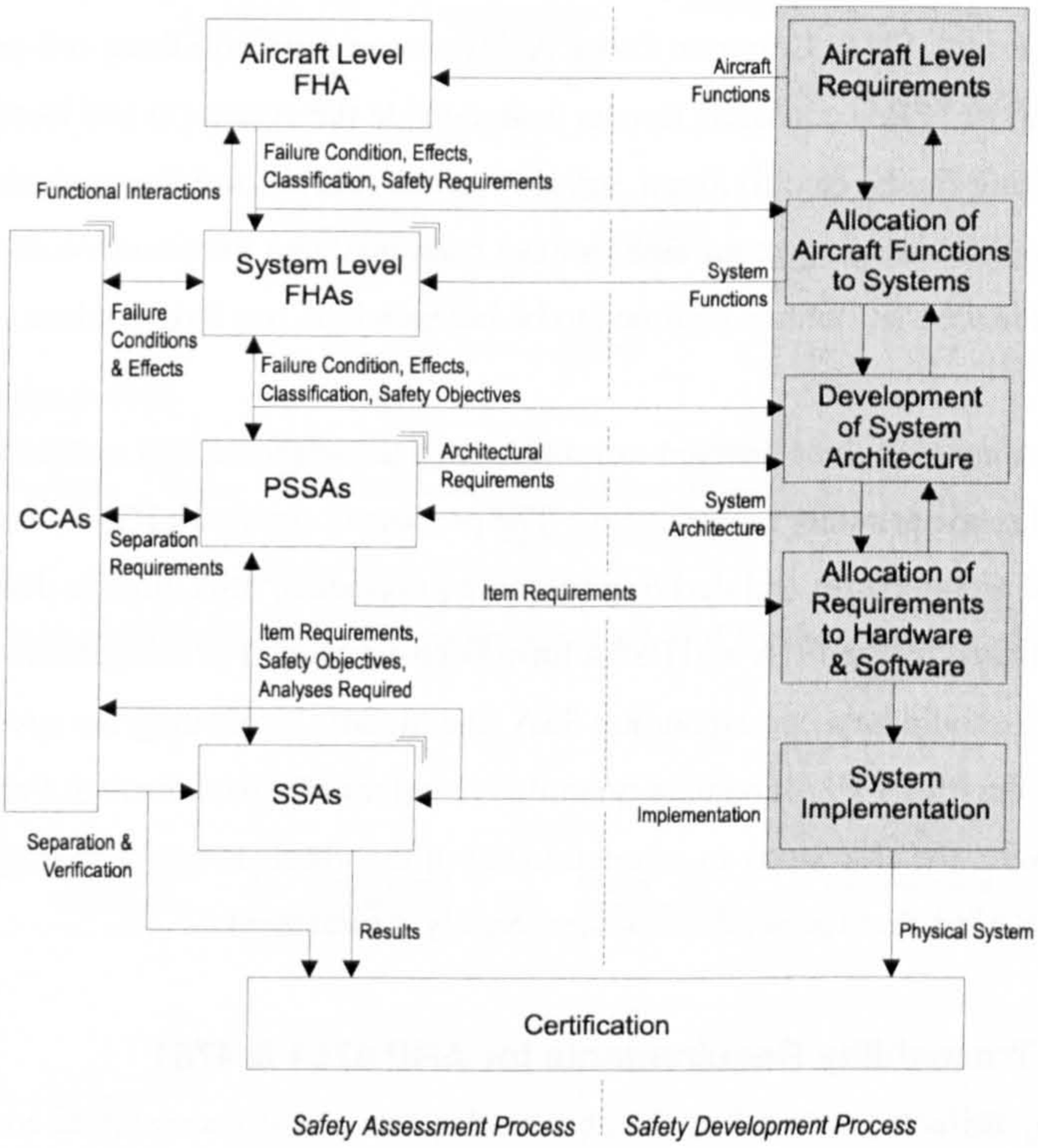


Figure 1.4 - 'Overview of ARP 4754/4761 Safety Assessment Process'

From ARP 4761, the primary assessment sub-process shown in figure 1.4 are summarised as follows:-

Functional Hazard Assessment is conducted at the beginning of the aircraft/system development life-cycle. It aims to identify and classify the failure conditions[18] associated with aircraft functions and combinations of aircraft functions and to establish the rationale for such classifications. Once aircraft functions have been allocated to systems, each system which integrates multiple aircraft functions is re-examined. The FHA is then updated to consider failure of single or combinations of aircraft functions allocated to a system. The output of FHA provides a starting point for conducting the PSSA.

Preliminary System Safety Assessment is a systematic examination of proposed system architectures

---

[17] Strictly, the former deals with the assessment process at a 'conceptual' level, whereas the latter considers application of specific assessment techniques in the context of that process.
[18] Classifications used with ARP 4754 and 4761 are catastrophic, hazardous, major, minor and no safety effect.

with the aim to identify failures that can lead to functional hazards identified by the FHA. The objective of PSSA is to establish safety requirements and to determine whether the proposed architecture can reasonably be expected to satisfy safety objectives identified by the FHA. PSSA is also an interactive process associated with design definition and is conducted at the system and item[19] stages of development. At the lowest level, PSSA determines the safety related design requirements of hardware and software[20]. The PSSA will usually take the form of a Fault Tree Analysis, and should also include Common Cause Analyses.

Common Cause Analysis supports development of system architectures by evaluating their sensitivity to common cause events. It is therefore largely conducted as part of PSSA, but may also form part of the SSA and to a lesser extent, FHA. Common Cause Analyses can comprise three sub-processes:- i) *Particular Risk Analysis (PRA)* considers threats from outside the system(s) and item(s) concerned; e.g. bird-strike, fire, leaking fluids, etc.; ii) *Zonal Safety Analysis (ZSA)* considers each aircraft zone to establish whether applicable safety requirements have been met; and iii) *Common Mode Analysis (CMA)* provides evidence that failures assumed to be independent, *are* independent.

System Safety Assessment involves detailed examination of the implemented system to show compliance with all relevant safety requirements. The process is similar to PSSA, except that instead of evaluating proposed architectures and deriving safety requirements, SSA aims to demonstrate that all requirements established by the FHA and PSSA have been satisfied. For each PSSA carried out at a different level, there should be a corresponding SSA (the highest level being the system SSA). The SSA is usually based on the PSSA FTA and uses quantitative values obtained through Failure Modes and Effects Analysis. Note, the case study in subsection 6.3 of this thesis is based on fragments from Appendix L of ARP 4761 that focus on the System Safety Assessment.

1.4.6.2.2 On Traceability Requirements for ARP 4754 & 4761

Traceability among artifacts produced by the above sub-processes is necessary to comply with various validation checks described in ARP 4754 (including those in the sections previously mentioned in 1.4.6.2). The checks themselves are phrased in broad terms and should be tailored to specific projects. For instance subsection 7.3 states the following check list item among an example set of questions for assessing requirements completeness at each hierarchical level:-

Do requirements trace to identified sources?

- functions, hazards and failure condition classifications identified in the FHA.

Figure 1.5 illustrates one interpretation of this check. It depicts traceability to a fragment of the aircraft FHA - featuring a single function, hazard and failure classification - from the safety requirement excluding this particular condition. Fault Tree Analysis is then used to derive lower level requirements from those identified by the aircraft FHAs; figure 1.5 summarises the overall relationship between FHA

[19] An 'item' is defined as one or more hardware and/or software components treated as a unit (ARP 4761).
[20] ARP 4754 and 4761 exclude detailed coverage of software and hardware issues which are considered respectively by DO-178B and the working document "Design Assurance Guidance for Airborne Electronic Hardware".

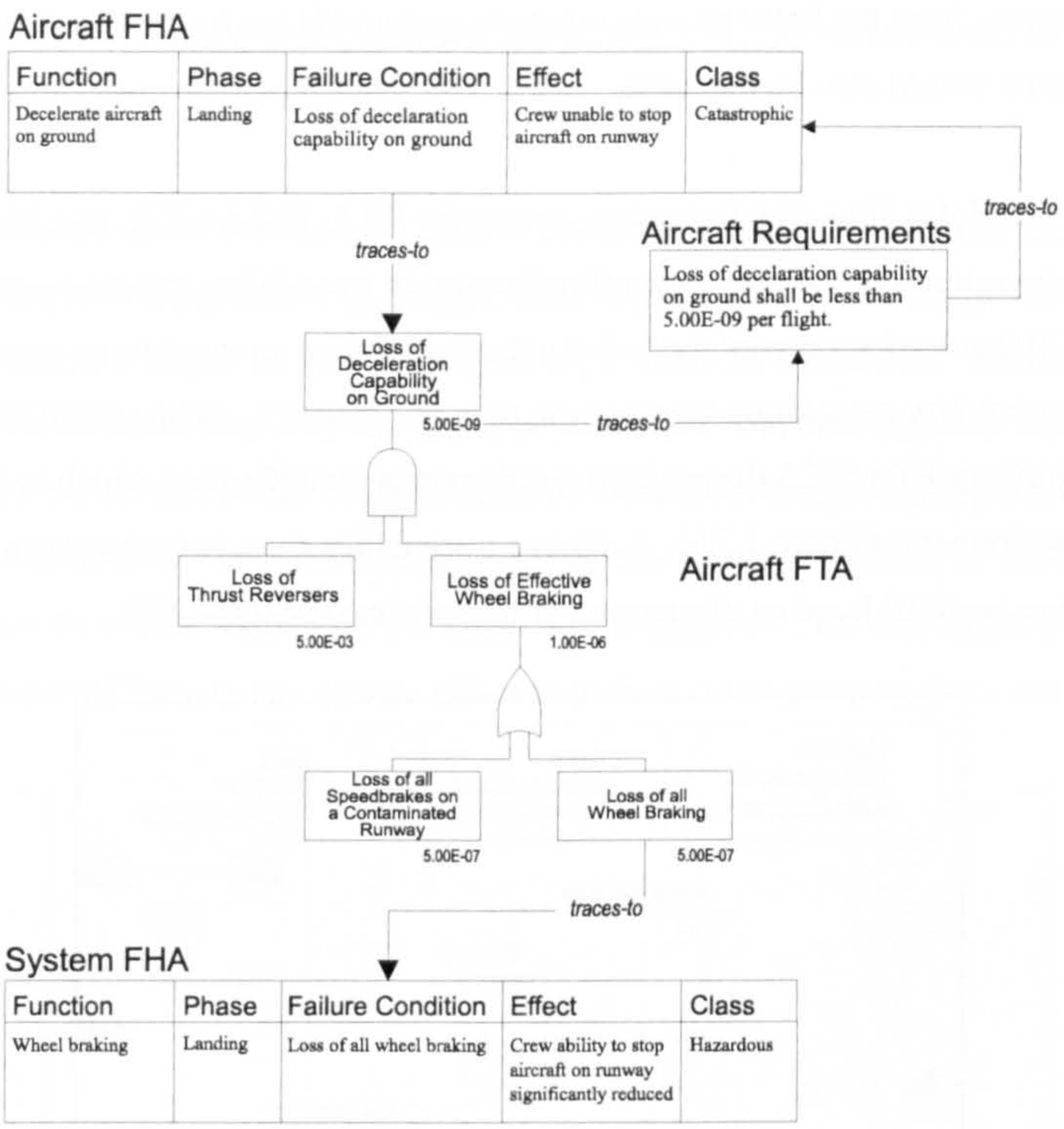


Figure 1.5 - 'Example Relationship Between Aircraft and System FHA and Aircraft FTA'

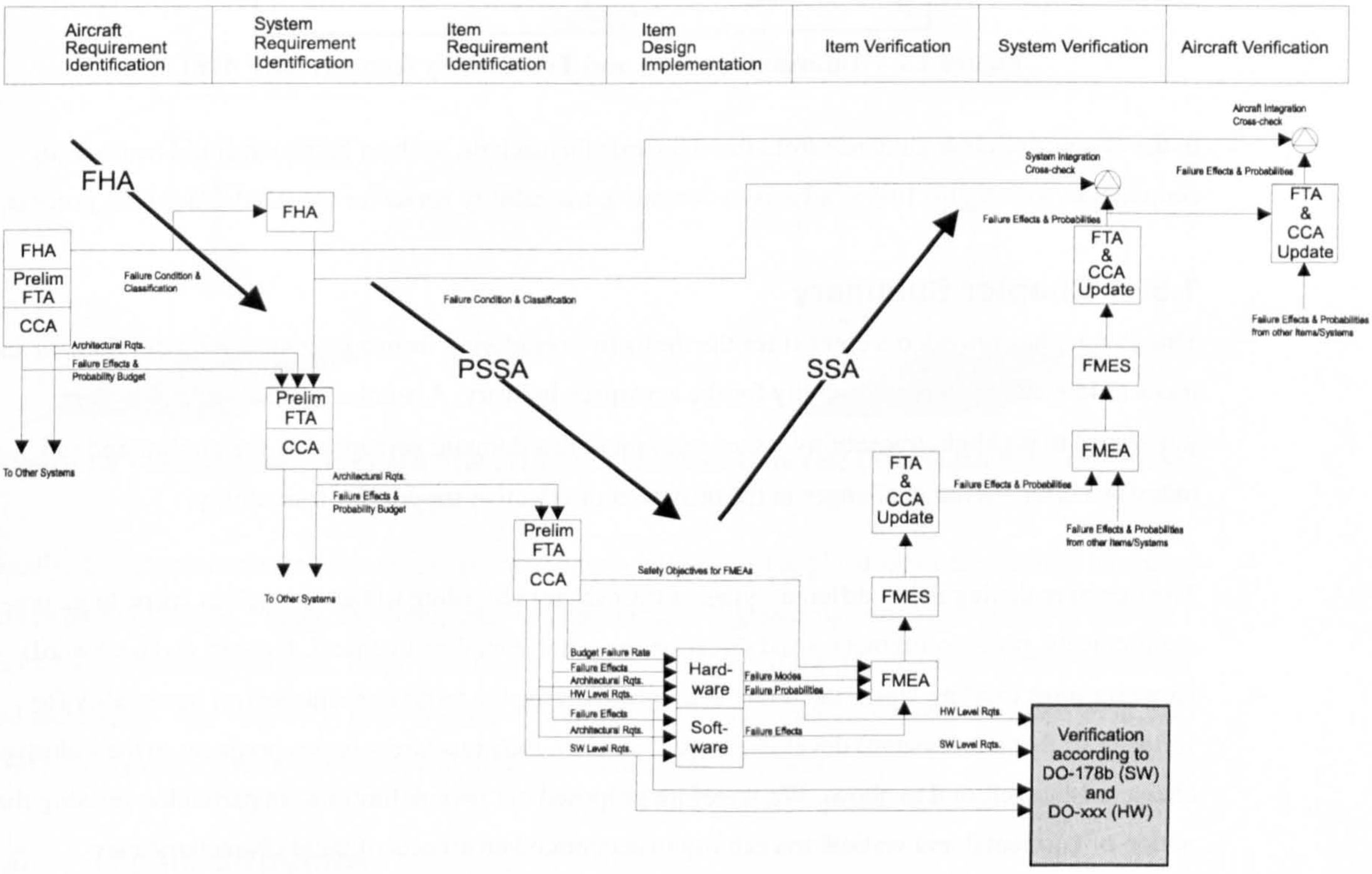


Figure 1.6 - 'Steps in ARP 4754/4761 Safety Assessment Process'

and FTA whereby aircraft FHAs generate top level events in the aircraft FTAs; likewise, catastrophic or hazardous basic events from the latter provide inputs to system FHAs. As section 3.2 of ARP 4761 indicates, these paths should also be traceable.

Figure 1.6 shows the global flow of information among the FHA, PSSA CCA, and SSA sub-processes[21]. However, it also provides a general indication of traceability requirements. Recall from subsection 1.2 (C2) that we may regard the activity that transforms an input to an output as an abstraction of a traceability association between the two. For instance, architectural requirements form inputs to the preliminary FTA/CCA during item requirements identification which in turn, derives hardware level requirements (figure 1.7A). A *derives* traceability association between these artifact types may therefore be considered an abstraction of this process (figure 1.7B).

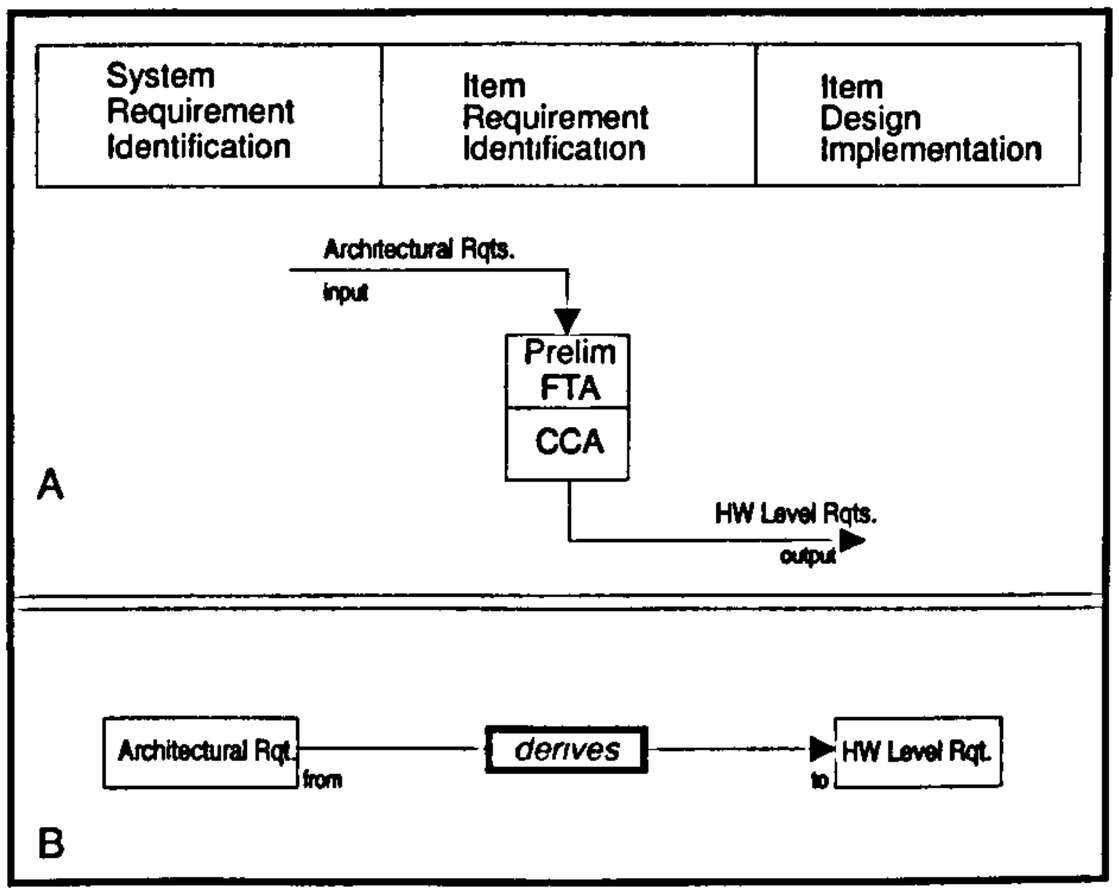


Figure 1.7 - 'Information Flow and Traceability (context ARP 4761)'

In the absence of clear guidance from the standards themselves, such an approach could be used (in conjunction with figure 1.6) as a basis to determine traceability needs for the ARP 4754/4761 process.

1.5 Chapter Summary

This chapter has provided a context for the thesis by considering from a *user* viewpoint our domain and focus of interest, namely traceability for the aerospace industry. A number of characteristics were introduced to highlight traceability issues relevant to this domain; perhaps only the nuclear and rail industries offer similar challenges in the provision of effective support for traceability.

The literature distinguishes different types of traceability according to factors such as scope (e.g., pre-requirements, post-requirements) and direction (e.g., horizontal and vertical, forward and backward). However most existing work (including attempts to define the term) concentrates on traceability for software (rather than system) development and as such, fails to address issues pertinent to the industry characteristics referred to above. We therefore proposed our own definitions, in particular, refining the notion of horizontal and vertical traceability to accommodate aspects of these characteristics.

[21] Not every step will be needed for assessment, but each must be considered for applicability.

A further visual conceptualisation was proposed by representing horizontal, vertical and revision traceability as dimensions of a cube, with variant traceability (i.e., the variant dimension) similarly depicted as traceability between cubes.

The dimensions concept can be viewed as a 'meta framework' relating abstractions from the different stages of development or assessment (e.g., requirements and design), whereas the Workspace concept (alluded to in subsection 1.3) can be viewed as (part of) a 'concrete framework' relating selected notations used in the different stages by aerospace practitioners. The Workspace is one actualisation of the dimensions with the artifact nodes being realised as meta-models representing selected notations, and the traceability dimensions realised through associations between elements of the meta-models. The relationship between these two frameworks is illustrated in figure 1.8; for the concrete framework, the meta-models are depicted by actual notations rather than their corresponding meta-models.

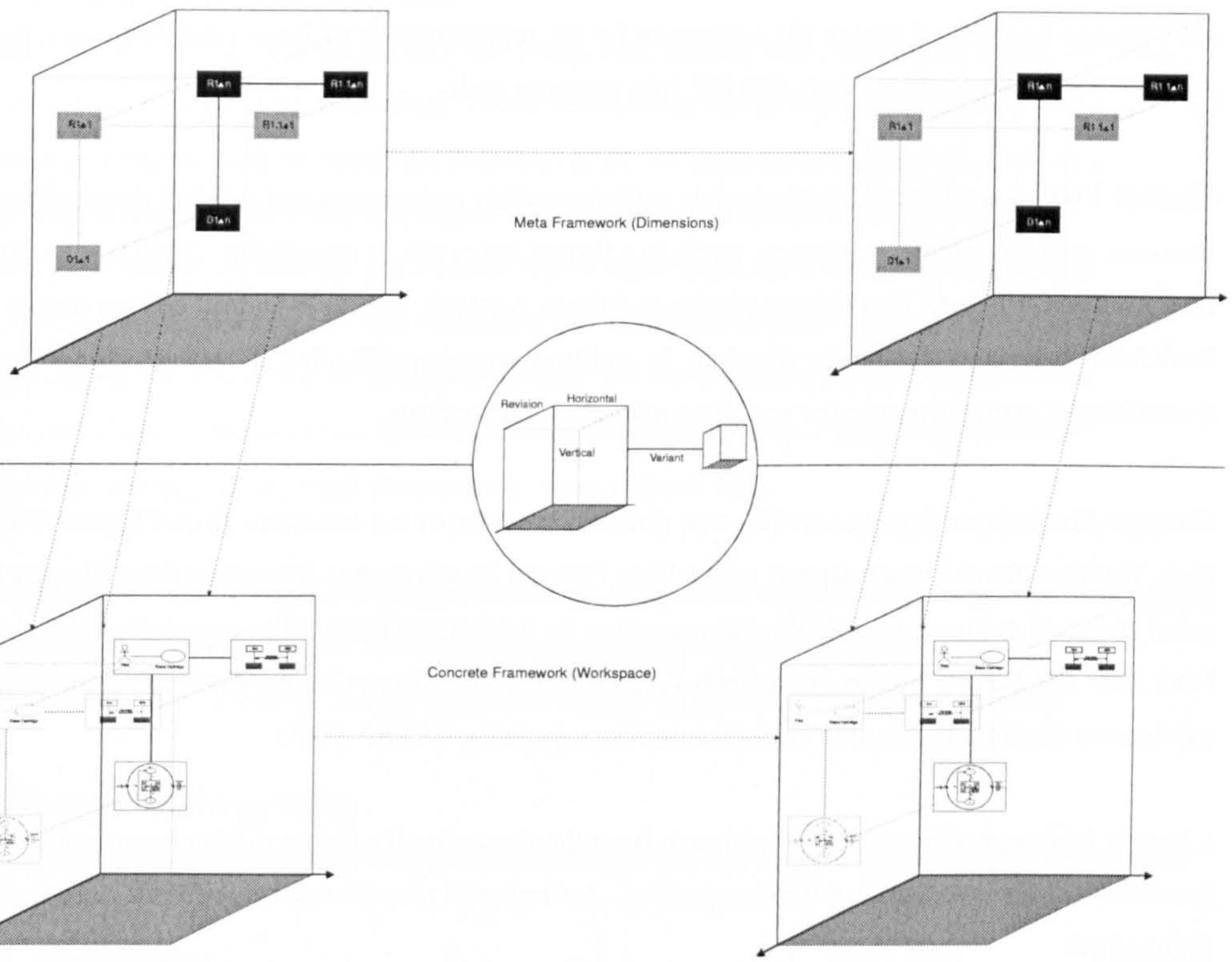


Figure 1.8 - 'Relationship Between Meta (Dimensions) and Concrete (Workspace) Frameworks'

Finally, this chapter asserted that recent growth in both interest and application of traceability has been driven by two factors. Firstly, the emergence of requirements engineering which has provided a direct focus for traceability research, while ensuring it is not overlooked in the development of new notations and techniques. And secondly, growth in use of compliance frameworks as arbiters of quality (e.g., ISO 9001), safety (e.g., ARP 4754/4761) and other non-functional attributes.

1.6 Thesis Structure

The remainder of this thesis is structured as follows:-

Chapter Two provides an overview of current traceability techniques, together with a basis for their classification. For reader orientation, we demonstrate means used in this thesis to represent and implement the traceability structures introduced in our thesis argument. Chapter Two also considers means of realising traceability using a variety of proprietary and commercial tools.

Chapter Three provides an introduction to the *M*eta-modelling *A*pproach to *Tr*aceability for *A*vionics (MATrA) proposed by this thesis. The main works that have influenced its development are considered (*foundations*), together with the nature of their influence and/or perceived weaknesses. The chapter goes on to introduce the key principles of MATrA (*fundamentals*), their purpose and composition.

Chapter Four presents a number of novel meta-models (traceability structures) capturing *development* notations used by avionics engineers in a format amenable to traceability. Specifically:- i) a Natural Language structure; ii) a User Centred Requirements Structure (featuring Use Case Models, Scenarios and Message Sequence Charts); iii) a structure for the representation of Real-Time Networks; and iv) a structure for the representation of SPARK Ada program code.

Chapter Five presents novel meta-models capturing *safety assessment and product management* notations used by avionics engineers, again in a format amenable to traceability. Specifically:- i) a Fault Tree Analysis structure; ii) a Failure Modes & Effects Analysis structure; and iii) a Programme Evaluation & Review Technique structure. In addition, we extend MATrA to include support for traceability of artifacts across the revision and variant dimensions.

Chapter Six features two case studies that illustrate a subset of the structures from Chapters Four and Five. The first demonstrates aspects of the User Centred Requirements Structure (from Chapter Four) using an actual commercial specification supplied by BAE SYSTEMS. The second demonstrates the Fault Tree and Failure Modes and Effects Analysis structures (from Chapter Five) using extracts from a contiguous example featured in aerospace industry guidelines (ARP 4761).

Chapter Seven presents conclusions drawn from the thesis and the extent to which work in the previous chapters supports our thesis argument. A number of areas for possible future work are also highlighted.

Appendix A provides some additional constraints and rules over the User Centred Requirements Structure from Chapter Four.

Appendix B presents material supplementary to the work on revisions and variants in Chapter Five.

Appendix C and **Appendix D** include further data for the two case studies featured in Chapter Six.

Appendix E contains material relevant to proposals for further work discussed in Chapter Seven.

Chapter 2 Techniques and Tools for Traceability

2.1 Introduction

At a reductionist level, traceability is simply a means of managing relations (or functions) on sets of artifacts; in other words, set theory provides the mathematical foundation for all traceability techniques. Therefore the level of sophistication afforded by a particular technique depends on what additional concepts it adds to basic set theoretic constructs. Working from such a premise, this chapter provides an overview of current traceability techniques, before considering the support provided for them by various proprietary and commercial tools. The aim of the survey is to establish a firm technical basis for MATrA.

2.2 Traceability Techniques

Traceability techniques broadly divide into two categories, namely *cross-referencing* and *conceptual data modelling* (or simply *data modelling*). Cross-referencing can be further partitioned into *higher* and *lower*-order techniques, both of which are founded on the set-oriented principles of graphs and matrices; the main difference being that higher-order approaches build on these underlying mathematical principles by introducing features which make them more amenable to practical application. In contrast, conceptual data modelling has its origins in software engineering which has spawned a number of rich semantic notations suited to the development of more sophisticated traceability techniques. We note that these notations can employ either a *graphical* or *lexical* representation, although as we shall demonstrate, some include both.

The basis of our classification considers three aspects:- i) *structure* (in particular, support for the typing of data elements and relationships); ii) *constraints* (the ability to specify restrictions on the way in which data elements are related); and iii) *operators* (means of manipulating data elements).

2.2.1 Cross-Referencing

This subsection introduces the cross-referencing technique and the support it provides for traceability.

2.2.1.1 Foundations

In describing the foundations of cross-referencing techniques, we distinguish higher-order cross-referencing from basic lower-order approaches.

2.2.1.1.1 Lower-Order Cross-Referencing

The simplest of all traceability techniques comprise a single set of 'traces-to' associations between a single set of 'artifact' types. This assertion may seem overly reductionist given the range of entities used in some data-modelling approaches (*cf.* Herzog & Törne, 1999; Oliver, 1994; Pyle *et al.*, 1993). However, if we regard the pairing as traceability super-classes of which all other types are simply specialisations (a view supported by Ramesh & Jarke, 1999 and Riddle & Saeed, 2000), then the

assertion becomes more credible. It is simply that the restriction of types within lower-order graph and matrix based schemes *forces* the extremes of abstraction.

Graph theory and directed graphs (digraphs) in particular are an intuitive and popular means of representing traceability relationships (*cf.* Attipoe, 1996; Bohner, 1995; Cimitile *et al.*, 1992; Fyson & Boldyreff, 1998; Lanubile & Visaggio, 1995; Luqi, 1990; Yau *et al.*, 1988). Formally, a digraph is an ordered triple *(N, A, g)* where *N* is a set of vertices or nodes, *A* is a set of edges or arcs and *g* is a *bijective* function associating with each arc *a*, an ordered pair (*x, y*) of nodes; i.e., the function is both *surjective* as all arcs in *A* are assigned, and *injective* because arcs have only one (*x, y*) pair.

As an example, consider the following function defined as:- *traces-to* : $(N \times N) \rightarrow A$ where the set of 2-tuples in the domain $\{<x, y>\}$ correspond to section numbers in a document text. As such, the nodes are carriers of information and therefore any graph of the function is said to be *labelled*. One possible graph is shown in figure 2.1 (centre). It should be stressed that such functions are likely to be partial since we would not expect an association between every section pair. A case in point is that of instances of 2-tuples where $x = y$, a feature which manifests as loops in the resultant graph and which makes little sense in a cross-reference context.

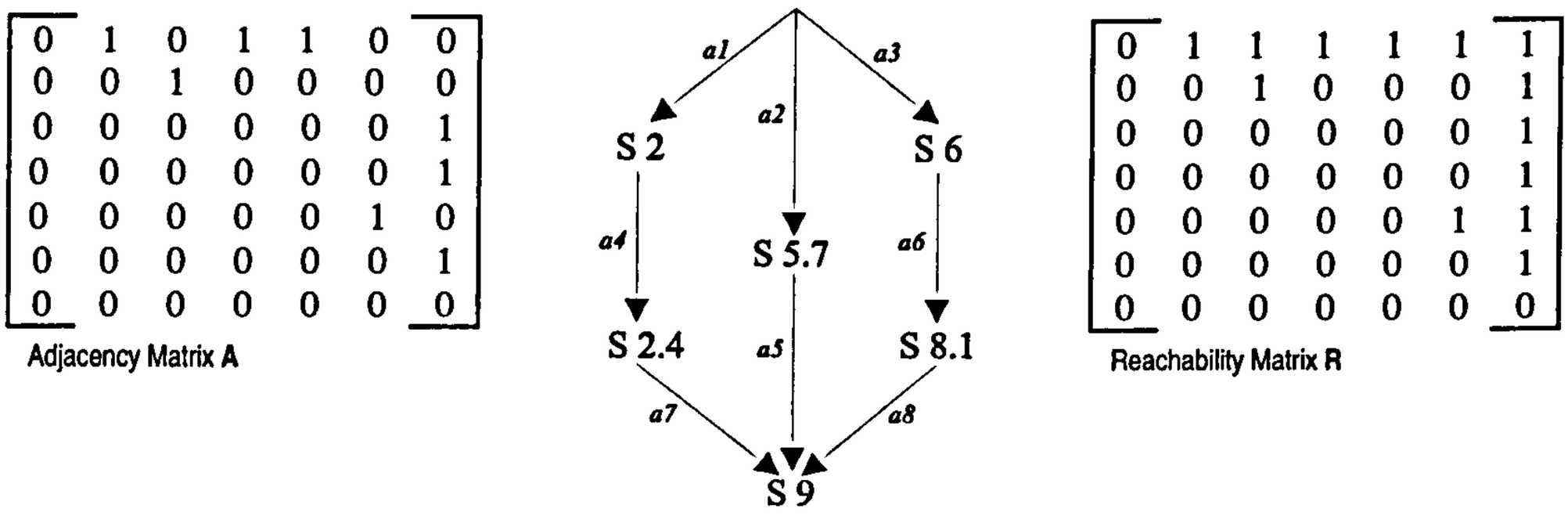


Figure 2.1 - 'Directed Graph, with Adjacency and Reachability Matrix Representations'

Further utility can be gained by making arcs (as well as nodes) carriers of information, specifically some numerical value or weight describing the 'strength' of association. We can therefore extend the digraph definition to accommodate these weightings which now reads (*N, A, g, W, w*), where *W* is the set of possible degrees of strength (e.g., {3, 6, 9} indicating low, medium and high) and *w* is a function from *A* into *W* (defined as $w: A \rightarrow W$) that associates a weighting with each arc *a*; *w* is neither surjective nor injective since a set of arcs may be assigned to a subset of *W*, whilst each weighting *w* may be assigned to $n > 1$ arcs in *A*.

We note that *pure* directed graphs of the form shown in figure 2.1 are generally limited to support for horizontal traceability (i.e., among artifacts of the same type) by virtue of their restriction to single node

types (i.e., from a single set)[1]. The exceptions are *bipartite* graphs which partition nodes into two (disjoint non-empty) subsets N_1 and N_2, such that each arc connects a node of N_1 to a node of N_2 (i.e., $x \in N_1 \wedge y \in N_2$). Hence bipartite graphs allow the possibility of associating, for example, artifact nodes of type requirements and design, thereby supporting a form of limited vertical traceability (a separate graph would be required for horizontal traceability).

As an alternative to the digraph representation shown in figure 2.1, the set of n nodes may be ordered and formed into an n^2 matrix (or $n_1 \times n_2$ for a bipartite graph), termed the adjacency matrix **A** (see figure 2.1 - left). Cell entries in **A** either indicate the presence or absence of an arc between nodes (using a 1 or a 0), or show the appropriate arc weighting. Thus, an adjacency matrix **A** describes *reachability* via paths of length:1. The property of reachability for a digraph is defined in terms of reachable nodes, such that a node n_j is reachable from node n_i if there is a path from n_i to n_j. Paths greater than length:1 are computed using boolean matrix multiplication of the adjacency matrix **A**; e.g., $\mathbf{A}^{(2)}$ gives reachability via length:2 paths and $\mathbf{A}^{(n)}$ reachability via length:n paths. Hence the reachability matrix **R** (figure 2.1 - right), which is computed as the boolean sum of **A**, $\mathbf{A}^{(2)}$, ... $\mathbf{A}^{(n)}$, indicates the presence of any path of length *1* to *n* between nodes. Furthermore, entries in **R** belong to the transitive closure of the relation p, the adjacency relation of a directed graph; i.e., for the set of nodes N, if (n_i, n_j) is an ordered pair of nodes, then the binary relation on the set N is $n_i \, p \, n_j \leftrightarrow$ there is an arc from n_i to n_j.

The graphs and matrices considered thus far adhere to basic mathematical principles and are what we term *lower-order* cross-referencing techniques. As such, any traceability approach utilising them represents a single function and therefore permits associations of one or at best, two artifact (node) types over one relationship (arc) type. In contrast, *higher-order* cross-referencing techniques relax some of the mathematical restrictions, whilst building on these techniques towards a more practical application. For traceability, this means being able to represent multiple node types corresponding to different development and assessment artifacts (e.g., requirements, designs, test-cases, etc.) and also multiple arc types between these nodes capturing the various semantic relationships that exist between artifact types (*allocated-to*, *derives*, *supersedes*, etc.). Therefore in the following paragraphs, we consider the additional facilities provided by higher-order techniques.

2.2.1.1.2 Higher-Order: Multiple Relations

The first extension permits representation of multiple functions over a single set of nodes. Formally we define this structure as an ordered pair (N, G) where N is a set of nodes (or optionally, the union of two disjoint subsets N_1 and N_2) and G is a set of digraphs defined as 4-tuples of the form $\{<A, g, W, w>\}$. As previously described, A is a set of arcs and g is a *bijective* function associating with each arc a, an ordered pair (x, y) of nodes. Also as described, W is a set of possible weightings, whilst w is a function associating a weighting with each arc a. We note that $|G| = 1$ corresponds to a single conventional graph structure, whereas $|G| > 1$ can be thought of as a set of graphs overlaid on top of one another; a matrix

[1] A single digraph node type can be overloaded to impart greater utility to lower-order cross-referencing; i.e., it may be regarded as an abstraction of $n > 1$ subtypes. For instance, the section number nodes in figure 2.1 may actually represent paragraphs, figures, tables and appendices, etc.

structure (modified to accommodate multiple cell entries) can again be used as an alternative representation.

Consider an example (N, $G = \{<A_a, a, W_a, w_a>, <A_c, c, W_c, w_c>, <A_s, s, W_s, w_s>\}$) where N is a partitioned set of artifact node subsets N_1 $\{r_1, r_2, r_3\}$ and N_2 $\{r_4, r_5, r_6\}$ and G is a set of graphs based on three functions a, c and s (denoting *alternative*, *conflicts* and *similar* respectively), each with its own set of arcs and strength weightings (again {3, 6, 9}). Here, the weightings are the same for each graph, though that need not necessarily be the case (indeed null weightings may be used where appropriate). It is therefore necessary to distinguish which weighting belongs to which particular function; hence we define the sets $W_a = \{\mu, \alpha, \pi\}$, $W_c = \{\Omega, \Phi, \Theta\}$ and $W_s = \{\propto, \sigma, \varpi\}$. The matrix in figure 2.2A integrates possible graphs of the functions a, c and s shown in figures 2.2B, 2.2C and 2.2D respectively.

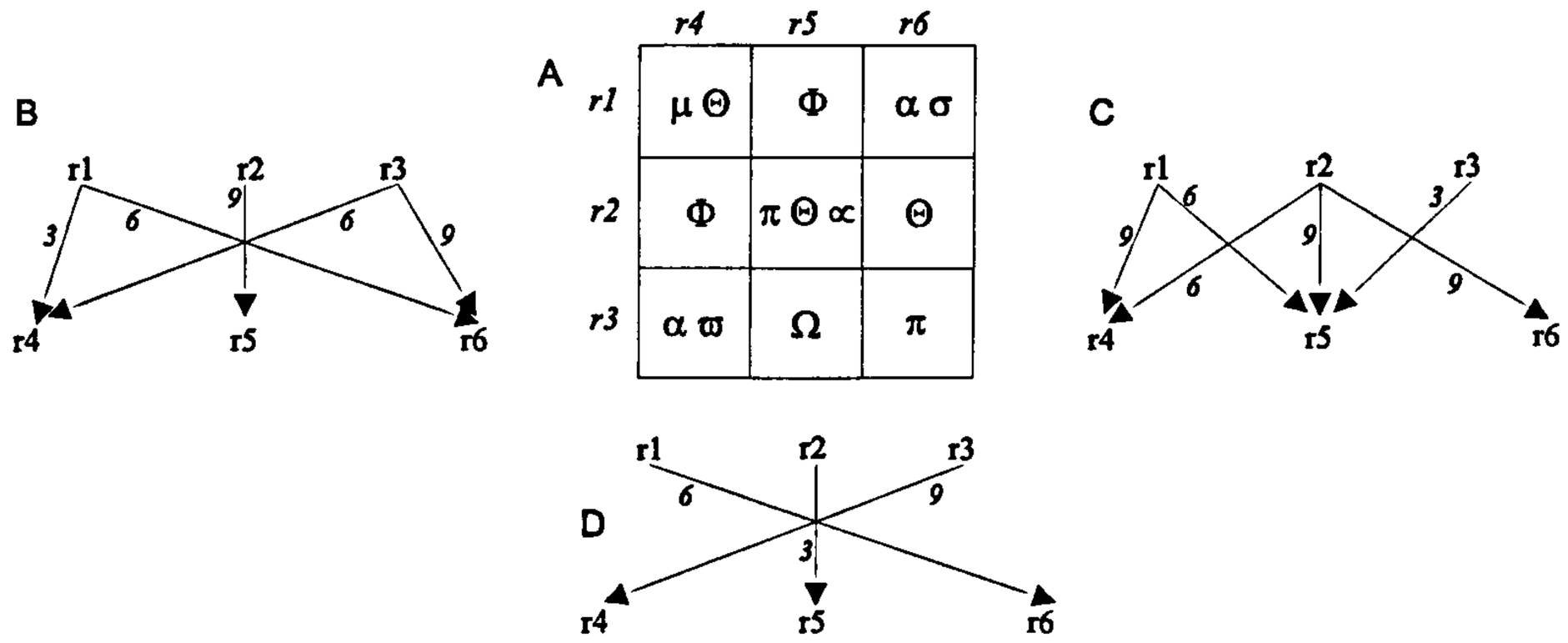


Figure 2.2 - 'Example Matrix Representation of Multiple Weighted Directed Graphs'

2.2.1.1.3 Higher-Order: Multiple Artifacts

Whilst the higher-order: multiple relation configuration improves on lower-order representations by allowing specification of $n > 1$ relationships, the restriction of (at most) two artifact (node) types still remains. In contrast, the final cross-reference based approach (higher-order: multiple artifact) supports both multiple association and multiple node types by effectively collocating the previous higher-order graphs (or their equivalent matrices) 'end-to- end'. Formally, this can be stated as $\{(N, G)\}$ where for each pair in the set, N is a set of nodes (or optionally, the union of two disjoint subsets N_1 and N_2) as before and G is again a set of digraphs defined as 4-tuples of the form $<A, g, W, w>$; end-to-end connections exist where $\exists\, g_1, g_2 \in \{(N, G)\} : g_1 \neq g_2 \wedge N(g_2) \subseteq N(g_1)$.

Two further augmentations worthy of note build on this last approach. The first uses symbols to annotate sets of node pairs that share a common domain; e.g., a requirement may relate to two design strategies as represented by the pairs (r, d_1) and (r, d_2). Such associations could be described as being either $\oplus$ (exclusive) or $\otimes$ (complementary). The second extension in which arcs are annotated with function names takes us into the area of semantic networks (Quillian, 1968), a classical knowledge representational technique used to state propositional information. An example of a semantic network

associating requirements (r), design (d), implementation (i), test (t) and test-result (tr) elements is shown in figure 2.3; note weightings could have been used to further enhance expressiveness of the *conflicts-with* function.

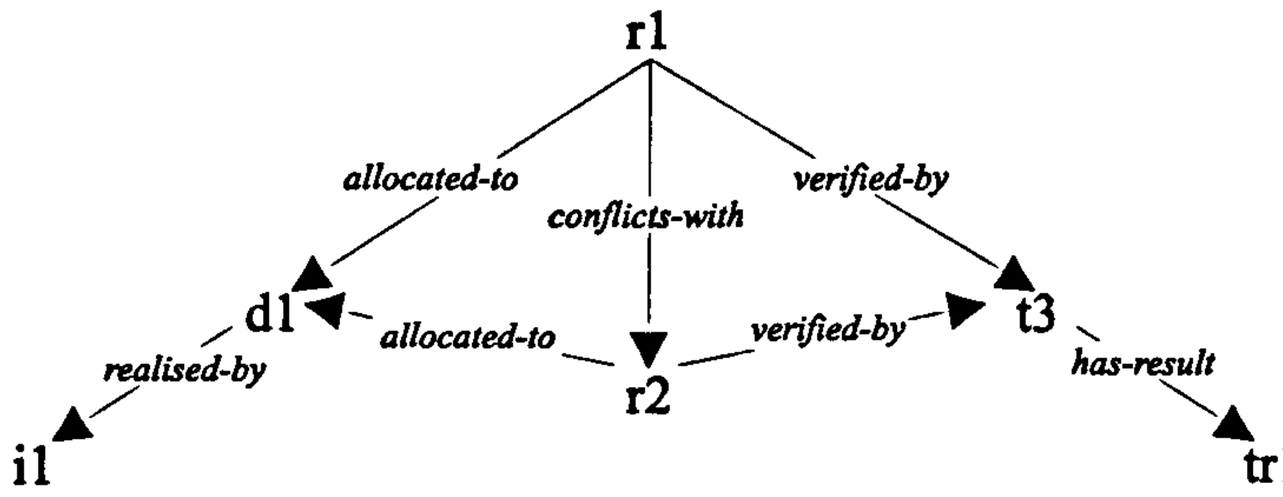


Figure 2.3 - 'Example Semantic Network'

2.2.1.2 Traceability Enhancements

From a traceability perspective, the means by which both lower and higher-order cross-referencing builds on the basic concepts of sets and relations can be seen to be largely structural; i.e., through the visual representation of underlying mathematical concepts. We note that predicate logic and standard set operations may be used to define implementation independent integrity constraints (e.g., preventing loops or cycles), and that the literature features a number of established graph algorithms, including those for traversal and computation of reachability matrices. However, since graph theory *per se* includes neither a constraint sub-language nor pre-defined operators for standard analyses (i.e., a graph calculus), it (and by implication, lower-order traceability approaches) can only be judged on the structural properties of links and nodes. Furthermore, (and as previously indicated) these properties are relatively weak when compared to such failings as the inability to represent elements from multiple sets, to describe these elements in terms of attributes and to capture the semantics (in a data modelling sense) of their associations.

The full extent of support for traceability afforded by lower-order approaches can therefore be said to come from combining *labelled* (bipartite) nodes with arcs enriched by *weighting* attributes. For this reason we assert that 'pure' graph-based approaches are the least sophisticated of all traceability techniques. In contrast, higher-order techniques that build on such basic approaches, and in particular semantic networks, enable representation of unlimited node and relationship types and hence support more detailed modelling of real world concepts. However, like lower-order approaches, the nodes themselves are atomic and so have no descriptive capabilities. In other words, both forms of technique tell us what elements are related, and how, but having navigated to a relevant node, we have to look elsewhere for the actual detail.

2.2.1.3 Traceability Applications

The principles of cross-reference based traceability are a feature of most development and assessment documents. Outwardly, footnotes and phrases like 'see section x' are merely navigational aids directing readers to a particular section, glossary or appendix. However, their underlying structures form graphs similar to those described above. Indeed, the use of such 'stock-phrases' implies a lower-order

approach based on a single function with either common or bipartite node types connected over a single set of (implicit) arcs.

In principle, the approach can be extended to support higher-order cross-referencing procedures by using multiple node and statement types; e.g., in figure 2.4, `Requirement A`, `Requirement B`, `Design Decision X` and `Text Case Y` (together with their respective section and paragraph numbers) are all (3-tuple) nodes, while the associations '*determines* (strong)' and '*determined-by* (strong)', etc. are labels with strength weightings on implicit (forward and backward) arcs[2].

Enumeration of different node and link types such as these, together with specific formats and guidelines on usage can be stipulated as part of an organisational traceability policy (Sommerville & Sawyer, 1997). However, without enforced typing it may be difficult to ensure all cross-references are rigorously maintained by project personnel.

[Requirement A | section i, paragraph j]

The Fuel System pipes and equipment shall be designed to a maximum normal working pressure of <V> psi (including surge). [*determines (strong) Requirement B, section x, para. y]; [fulfilled-by Design Decision X, section n, para. m]; [verified-by Test Case Y, section f, para. g]*

[Requirement B | section x, paragraph y]

The Fuel System pipes and equipment shall be designed such that the ultimate pressure equals 2.5 times the normal working pressure. *[determined-by (strong) Requirement A, section i, para. j]; [fulfilled-by Design Decision X, section n, para. m];]; [verified-by Test Case Y, section f, para. g].*

[Design Decision X | section n, paragraph m]

Use <X> to maintain Fuel System pipes and equipment within pressure tolerances ... *fulfills Requirement A, section i, para. j]; [fulfills Requirement B, section x, para. y].*

[Test Case Y | section f, paragraph g]

Test rig simulation of refuel, defuel (suction and pressure), and transfer operations ... *[verifies Requirement A, section i, para. j]; verifies Requirement B, section x, para. y].*

Figure 2.4 - 'Example of a Defined Text Based Cross-Reference Format'

In representing different perspectives on the target system, practitioners typically employ a range of modelling techniques, each of which introduces sets of named entities, processes, behaviours and so forth. To ensure the view the models provide is a coherent one, adequate mechanisms must exist to manage such data. For development artifacts this is normally accomplished through the data dictionary, a centralised (higher or lower-order) cross-reference base listing the name, format and usage of all

[2] The juxtaposition of the artifacts (nodes) shown in figure 2.4 and the inclusion of both forward and backward traceability links, suggests some redundancy. However, in reality these elements may be diffused across several hundred pages of a document, whereupon the links would become essential for navigational purposes.

elements employed across the set of system descriptions. The data dictionary also maintains constraints governing consistency of the data set and flows between the various models; e.g., all DFD (Data Flow Diagram) data stores and ELH (Entity Life History) entity types are traceable to the Entity-Relationship model, and all ELH events are referenced in DFDs. Likewise, for assessment artifacts, most regulated industries use a Hazard Log as the centralised safety document to cross-reference and track the results of analysis (Hansford *et al.*, 2000). Its main purpose is to enumerate the hazards identified at each stage, together with their severities, probabilities, risk, causes, consequences and intended measures for exclusion or mitigation. Also referenced are the actual models and analyses that derived this information, such as fault trees and FMEA. Again, the level of detail (i.e. whether the cross-references are maintained in higher or lower-order form) should be stated in either project specific procedures, or as part of general organisational traceability policy.

Explicit graphical traceability structures (where the visual representation is preserved, instead of being implicit to the underlying structure of some document or text) are also common. For instance, lower-order approaches based on single node and arc types lend themselves naturally to the representation of artifacts linked by some form of forward or backward chaining. Examples include the Dependency Structure (Riddle & Saeed, 1998) featuring an *influenced-by* function over a set of Module nodes, and the Impact Structure[3] (Saeed *et al.*, 1995) which is effectively a graph-based equivalent of traditional N×N charts (Lano, 1979). Meanwhile structurally at least, fault trees can be thought of as a basic form of higher-order approach which, despite representing a single set of arc types (causality) over a single set of node types (faults), include higher-order augmentations supporting disjunction and conjunction[4]. Goal-graphs (Mylopoulos et *al.*, 1992 and Chung *et al.*, 1995) are a further example of a higher-order approach; these structures relate a set of system development goals over *satisficing* and *correlation* link types with augmentations that include use of link correlation weightings and argument annotations to further enrich the arcs. Finally, examples of higher-order approaches based on $n > 1$ node and arc types include Safety-Specification Graphs (de Lemos *et al.*, 1995) and the Design Rationale Capture System referred to in Chapter One (and described further in Chapter Three).

Traceability applications of matrices are just as prominent in the literature. In particular, they form the basis of the Quality Function Deployment (QFD) methodology (Brown, 1991; Maier, 1993; West, 1991), a product realisation strategy developed in the motor industry, but since applied across a range of applications (*cf.* Bellagamba *et al.*, 1993, Jacobs & Kethers, 1994). As figure 2.5 indicates, the basic tenet of QFD (also known as 'House of Quality' or HoQ) is to ensure that each customer requirement is addressed by a design element and, that no design forms part of the final specification unless relevant to some customer requirement. Hence, analysis of the main relationship matrix seeks to identify empty rows (i.e., unfulfilled requirements) and empty columns (spurious design components). Figure 2.5 also shows how the correlation matrix (or *roof*) establishes complementary and conflicting strategies for in this case, designs parameters; e.g., Built-In-Test-Equipment can be seen to have a positive impact on

[3] We note that Impact Structures can support two types of *impacts* relationships, those derived from information in a specification document and those based on domain knowledge.
[4] In Mason & Saeed (1998), we represent disjunction and conjunction as two distinct forms of causality relation which strictly places FTA among the higher-order/multiple-relation cross-reference classification.

Mean Time To Repair, but a negative impact on Mean Time Between Failure (owing to the increased number of components).

The relationship matrix shown in figure 2.5 essentially captures the level of information in a *labelled, weighted, bipartite* graph (but with symbols instead of numbers to denote strength weightings). This particular example is therefore strictly a lower-order application of a potentially higher-order technique. In practice, it would normally be extended to include other artifact types (test cases, implementation elements, etc.) by combining matrices end-to-end to form so-called "*cities*" of quality and by capturing different functions using multiple cell entries.

In addition to QFD, Fischer & Walker (1979), Davis (1990), Ince *et al.* (1993) and Moore (1993) provide further (mostly lower-order) examples of matrix based traceability. Matrices are also an integral feature of the Hatley & Pirbhai (1987) methodology for real-time systems development, as well as popular documentation standards such as ESA-PSS-05 (ESA, 1991).

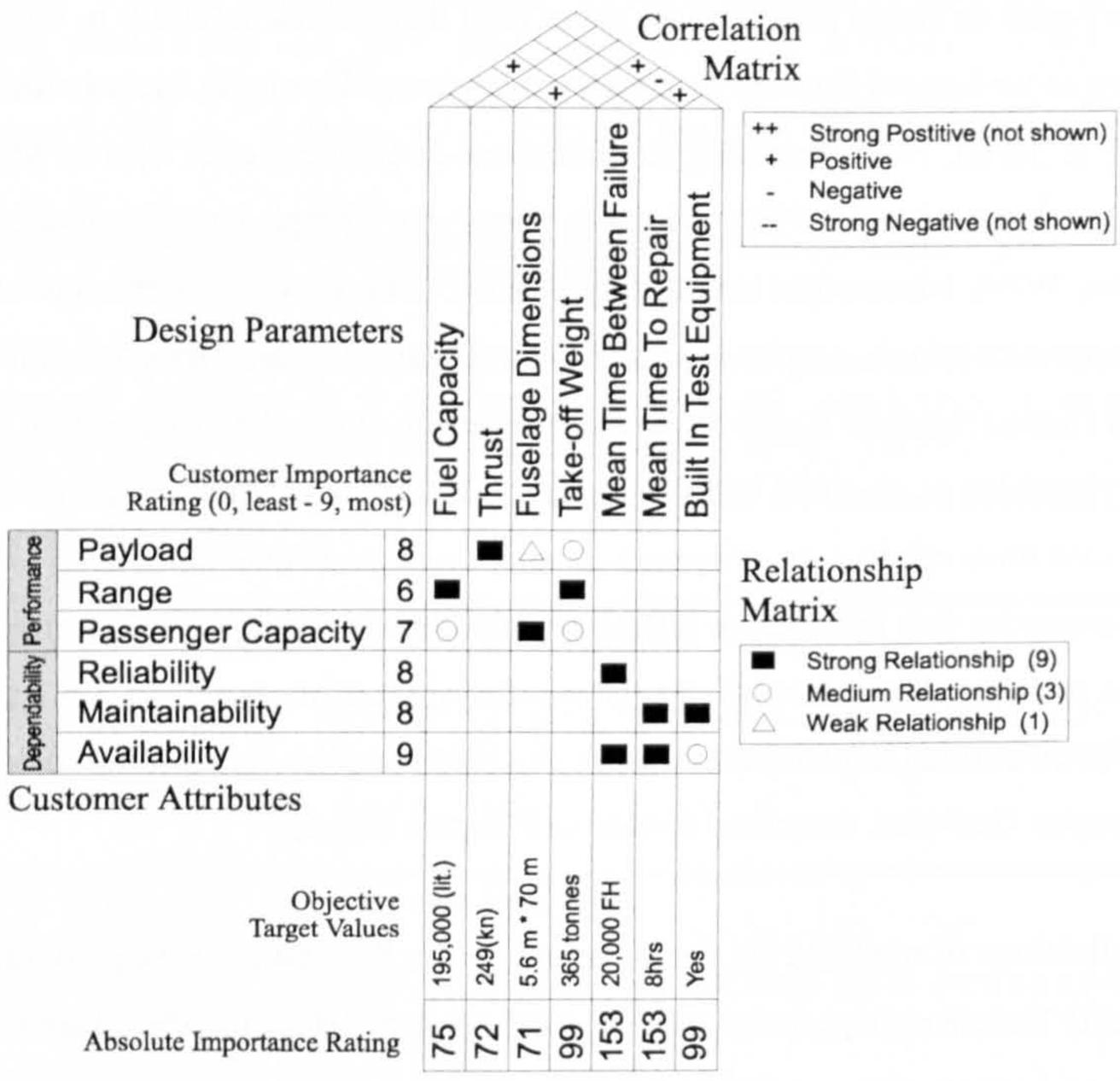


Figure 2.5 - 'An Example Quality Function Deployment (QFD) Matrix'

Most applications of cross-referencing trace artifacts in the horizontal and vertical dimensions. However, Dick (1999) uses matrices to manage revisions and variants using an extended lower-order approach. A Project/Features Index (PFI) lists past and current projects (x-axis), together with the features, or alternatively modules they incorporate (y-axis); alpha-numeric cell entries denote the variant (alpha) and revision (numeric) of modules used on each particular project. Figure 2.6 shows a hypothetical example cross-referencing component modules against aircraft projects; i.e., it captures the partial function *incorporates* : $(Module \times Variant \times Revision) \times Project \rightarrow A$ (where A is an implicit set of arcs). The main aim of PFI is to promote and help manage reuse. Where analysis shows sufficient

commonality exists, a previous requirements configuration can be simply copied as the baseline for a new project and then modified accordingly.

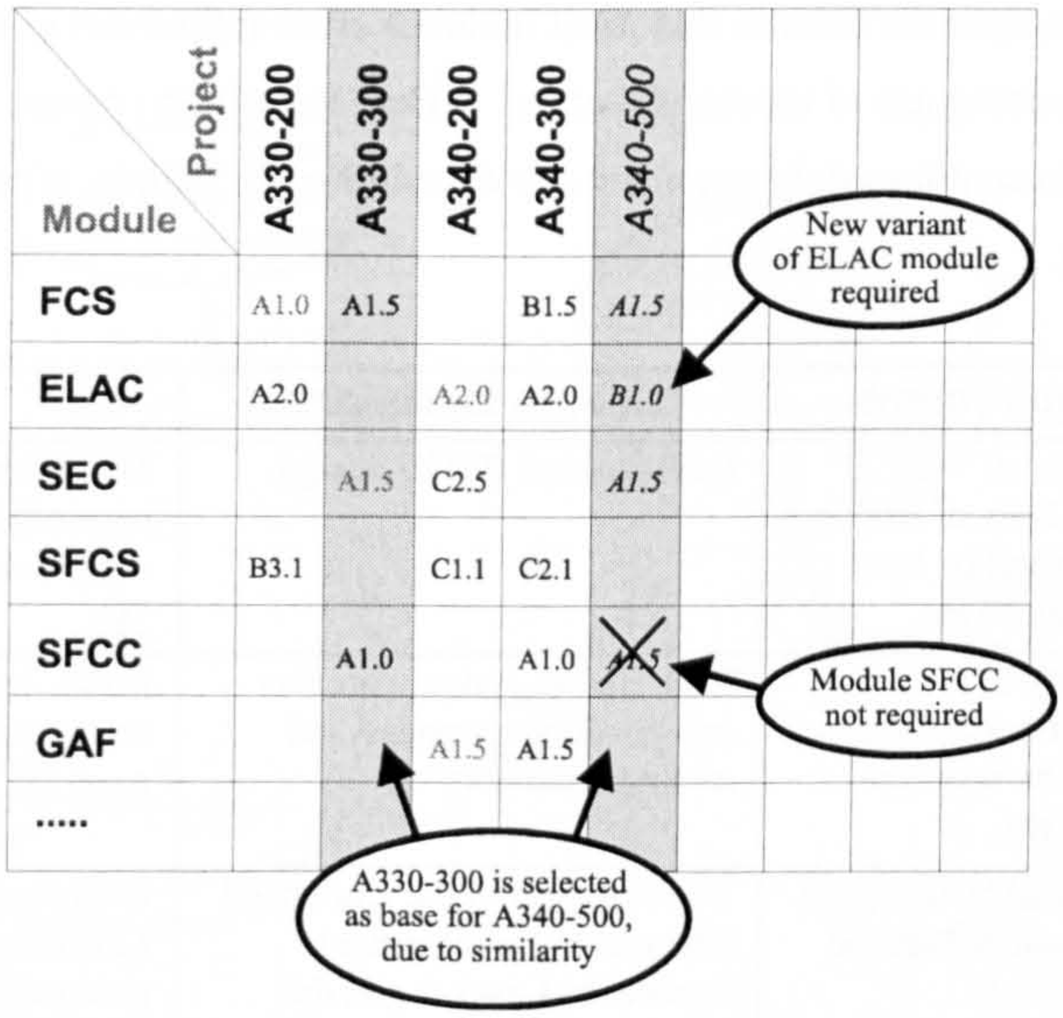


Figure 2.6 - 'An Example Project/Features Index (PFI)'

We note that the terms traceability *matrix* and traceability *table* are often used interchangeably (*cf.* Sommerville & Sawyer, 1997; Polack, 1990). However, whereas matrix cell entries may only indicate associations between up to two entity types, each row of a table is capable of representing relationships among $n > 1$ types (which is consistent with higher-order techniques). Furthermore, while matrices are essentially just collections of 'pointers' among identifiers, table entries normally contain actual information. Therefore, structurally at least, tables exhibit basic data modelling capabilities as is evident from the Relational Model considered in subsection 2.2.2.2.1.

A table can be said to comprise (in database terminology), an intension (column headings naming the entity sets concerned) and an extension (a set of occurrences consistent with the intension). Typically, the left-most column in a traceability table is used as an identifier on which the other column types are functionally dependent; if we adhere to the basic representation of cross-references used throughout (i.e., a set of (x, y) node pairings into a set of arcs), then that column becomes the first element of pairs in the domain of each function. Examples and variations of tabular traceability approaches are described by Armstrong (1993), Hermens (1991), Jackson & Renton (1993), Mejzak (1990) and Polack (1990). Note also the concept of a *traceability-list* (Sommerville & Sawyer, 1997), a two column table in which the first column is an identifier (typically a requirement) and the second, a set of identifiers of related artifacts.

Tables are also the staple means of representing safety information, be it the results of a particular analysis technique (*cf.* FMEA and HAZOP), or summaries of assessment sub-processes. Indeed tabular structures dominate the range of admissible certification data listed in ARP 4754. This includes FHA,

PSSA and SSA summary tables, validation and verification 'matrices' (again, strictly tables) and the configuration index (detailing all physical elements of a system and their interconnections). Table 2.1 features an example PSSA table showing (intra-micro) vertical traceability between requirements and designs (together with a remarks column that itself includes cross-references to supporting documents). Another standard advocating use of tabular structures is Def. Std. 00-55 (Annex E) which proposes them as a means of representing safety arguments (with columns for claims, arguments and evidence/assumptions).

Safety Requirement	Design Decisions	Remarks
1. The probability of "BSCU Fault Causes Loss of Braking Commands" shall be less than 3.3E-5 per flight.	Dual channel BSCU design.	The overall BSCU system can reasonably satisfy this requirement - See FTA page 'X'
2. The probability of "Inadvertent Braking due to BSCU" shall be less than 2.5E-9 per flight.	Each BSCU system contains independent command and monitor channels	BSCU integrity can achieve this requirement - See FTA page 'X'
3. The BSCU shall be designed to Development Assurance Level A.	Development of the Command Channel to Development Assurance Level A and the Monitor Channel to Level B	Development Assurance Levels assigned according to guidance in Section 5.4 of ARP 4754

Table 2.1 - 'PSSA Safety Requirements & Design Decisions Table' (source, ARP 4761)

Finally, we note that graphical and formal modelling techniques often provide their own built-in cross-referencing support. For instance, UML (Unified Modelling Language) includes the `<<trace>>` stereotype[5] indicating dependencies among elements of different models (figure 2.7A). The fault tree transfer symbol is a further example (figure 2.7B); each transfer is bound to a particular event and composed of two types (comparable to forward and backward traceability): a triangle with a vertical line from its top shows 'transfer-in' of a fault tree section from another branch of the tree, whereas a triangle with a horizontal line from its top indicates the event is 'transferred-out'. Similar to this are EXPRESS-G cross page symbols (figure 2.7C); relationships on separate pages terminate with a rounded box containing page and reference numbers. Page numbers indicate the location of the 'to' definition, whilst reference numbers distinguish multiple references onto a page. The 'to page' also contains page numbers of 'from pages' referring to a reference, whilst the 'from page' contains the name of the 'to definition'. Other approaches include DFD numbering schemes (enabling navigation between process decomposition levels), the ELH 'quit/resume' formalism (which relates an abnormal event termination to a resumption event elsewhere in the hierarchy) and the Z Δ (delta) symbol (which indicates where an operation in one schema definition causes a change to occur in the state space of another) - figures 2.7D, 2.7E and 2.7F respectively.

All the techniques in figure 2.7 differ slightly from previous higher and lower-order approaches. Specifically, they have fixed parameters in terms of purpose, and the association and node types they connect. They also carry varying degrees of semantic force; e.g., whilst the EXPRESS and FTA

[5] Stereotypes are an extensibility mechanism for defining new classes on top of the pre-defined UML kernel (Muller, 1997).

notations mean simply 'see page x', ELH 'quit and resumes' (analogous to GoTo statements) and Z deltas (similar to #include in C++, meaning 'look here' for schema variables, etc.) are actually control statements with inherent cross-referencing.

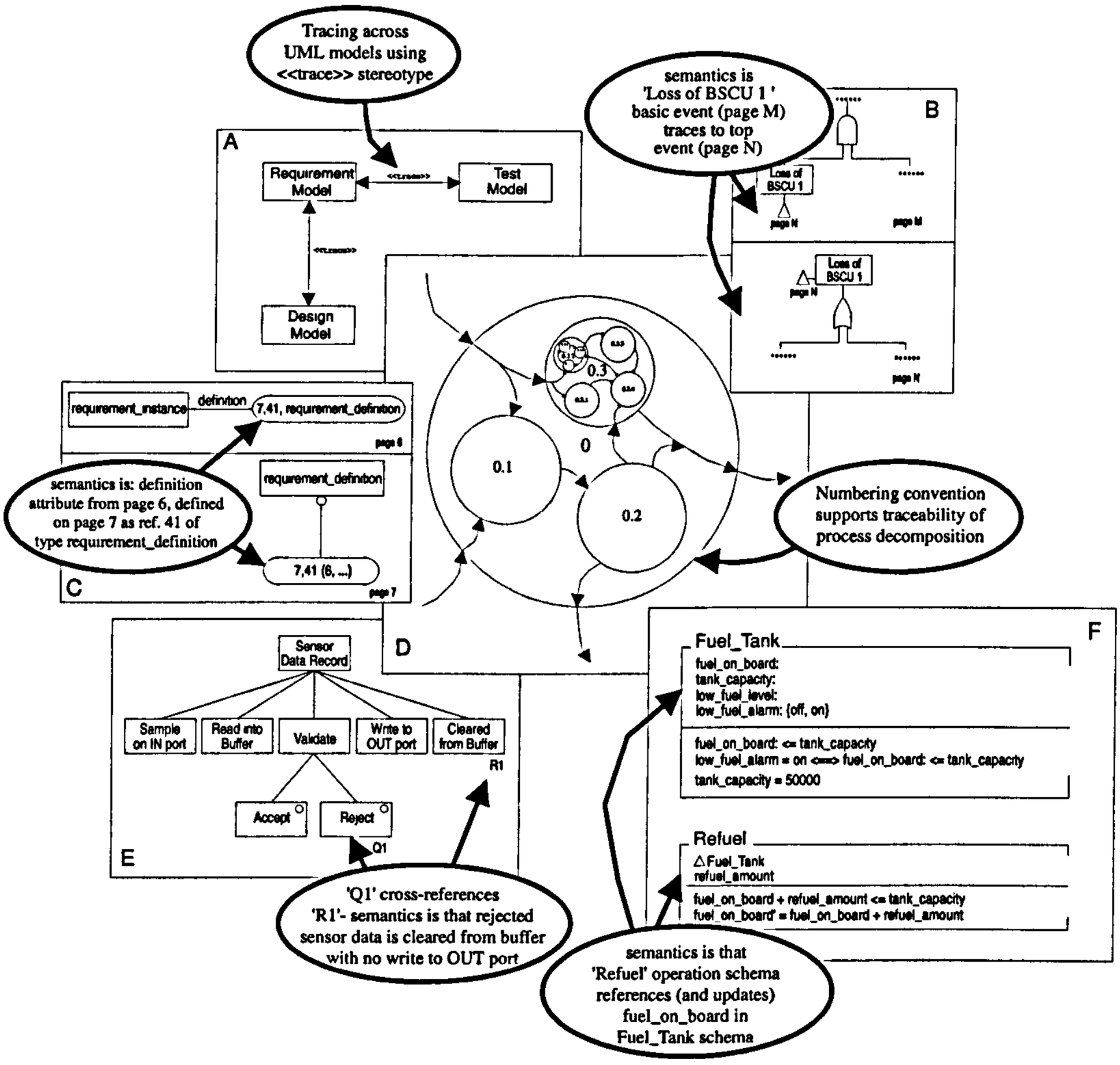


Figure 2.7 - 'Cross-Referencing Techniques of Modelling Notations'

Other applications of cross-reference based traceability schemes include those maintaining some form of explicit requirements labelling, numbering or indexing (Evans, 1989; Jenkins, 1994; Mays *et al.*, 1985; Ramsay & Bernsen, 1995; and Yu, 1994), as well as those expressing and maintaining specified relationships between keyphrase dependencies (Jackson, 1991).

2.2.1.4 Evaluation

In evaluating cross-reference based traceability we consider its potential from two perspectives:- i) as a framework for representing and navigating the underlying structure of relationships between project artifacts; and ii) as a means for reader orientation within complex, integrated texts. The first perspective concerns a basic practitioner need - to identify relationships among project artifacts. Such analysis is potentially an *end* in itself (e.g., where the goal is to verify non-existence of circular dependencies); else

it is the *means* of achieving an end such that consideration of artifact detail follows the traceability analysis (e.g., determining which design nodes relate to a particular requirement and then acting to modify them as a result)[6]. Practitioners of the second perspective meanwhile are again concerned with navigation, but only in a 'reader' sense and only of final deliverables (or interim baselines). Hence they use cross-references as embedded pointers to navigate within and between artifacts along paths pre-defined by the writer (developer)[7]. Together, the two perspectives provide an insight into the role of cross-referencing in the context of a development project. Further consideration should be given to the level of support for horizontal, vertical, revision and variant traceability

On the first perspective, directed graphs give a succinct visual representation of dependencies between nodes (artifacts) and are of practical benefit irrespective of whether the traceability activity is a means to an end, or an end in itself. They are however especially useful for highlighting instances of circular dependencies and general over use of cross-references. At a coarse granularity, graphs can also be used to aid reader orientation; e.g., the preface of a text with sections aimed at specific subsets of its readership may include a graphical steer showing suggested reading paths for analysts, designers, safety engineers, etc. Matrices derived from graphs offer an informationally equivalent though more concise abstraction of dependencies and are also amenable to automated analysis. Reachability matrices are particularly beneficial when preparing or checking artifacts containing multiple cross-references as they can help identify instances of poor structuring or unreachable nodes. They can also support change management by helping to highlight nodes along affected paths and to reaffirm their continued reachability once the changes have been made.

On the second perspective, we regard actual 'in-document' cross-references as a feature used mainly in presenting results to end-readers engaged in content analysis, rather than for the analysis of either artifact-relationships or document structures. Besides being vital to document navigation, cross-references are compatible with human thought processes. Indeed, readings from the social sciences suggest a purely linear exposition actually conflicts with the brain's non-linear character (Buzan, 1989). However, multiple cross-references (either high or low level) can disrupt the flow of a document and prevent transfer of ideas from writer to reader. The problem lies in maintaining awareness of navigational paths, whilst understanding the information in course. As a result, errors may be concealed which with safety related material (notably safety cases), can compromise the integrity of a system. We note that recent work on web-based technologies indicates the need to base document structures on conceptual models that take into account why and by whom they will be used (Smith *et al.*, 1997).

In principle (and despite the inability to describe properties of nodes), cross-referencing is capable of supporting traceability across all the dimensions discussed in Chapter One. Inevitably, restrictions on type mean lower-order approaches struggle to go beyond simple horizontal traceability, or at best, vertical traceability using bipartite nodes (without that is, recourse to overloading and the information loss that occurs when disjoint node types are treated as a single supertype). However, the multiple node

[6] Exponents of this perspective might include requirements engineers and designers.
[7] This perspective is appropriate to requirements review and safety assessor roles.

and relationship types of semantic networks *do* allow for representation of complex vertical traceability paths, as well as (potentially) supporting revision and variant traceability.

2.2.2 Conceptual Data Modelling

This subsection provides an introduction to conceptual data modelling and the support it provides for traceability.

2.2.2.1 Foundations

Relative to cross-referencing techniques, conceptual data models offer practitioners a greater range of 'tools' (or concepts) for developing an effective traceability approach. Structural modelling constructs include entity types (or classes), relationships, attributes and domains, whilst many data models also support the established abstraction principles of classification and aggregation; note that in moving from a cross-reference based to a data-modelling approach, we are effectively replacing nodes with entities and arcs with relationships. Most conceptual data models further include means for stating constraints and manipulating the data sets of populated models. Indeed strictly, a data model is defined by this trio of components - structural aspects, means to express constraints and manipulative operators (Date, 1995). Recall that these form the basis of criteria used to evaluate traceability techniques discussed in this chapter and as such, biasing the evaluation in this way may appear somewhat unjust. However, the literature suggests that data modelling and traceability have now become inexorably linked in that data modelling features map readily to the requirements for effective traceability tools (Riddle & Saeed, 1999b). In the following paragraphs, we briefly introduce key structural constructs, constraints and operators.

2.2.2.1.1 Structural Constructs

- **Entities**

Entities capture real-world concepts, whether they be physical (e.g., a fuel tank), or abstract (e.g., a requirement for a fuel tank). All entities with similar properties are assigned to a particular entity type or class (in object-based terminology). Note, entity types, classes and indeed 'relations' (as described in *the* original data model by Codd, 1970) are analogous to mathematical sets.

- **Attributes and Domains**

Entities (and relationships) may be described in terms of their characteristic features, variously referred to in the literature as attributes or properties. For instance, possible characteristics of requirements could include a unique identifier, author and specification. Individual values for these attributes are termed scalars, the smallest semantic unit of data (Date, 1995), while a named set of scalar values is termed a *domain* (also known as a *value-set*). Most of the models in the paragraphs that follow include primitive domains for integer, string , boolean, etc. From these, we may wish to define more specific value-sets; e.g. the domain of integrity levels according to ARP 4754 is precisely {a, b, c, d, e}. Thus, domains are simply pools of values from which attribute values are drawn.

- **Relationships**

The data modelling literature lacks a clear consensus on relationships, what they are and how best to represent them. Peckham & Maryanski (1988) contend they can be modelled as entities, attributes, independent connections or even as functions. A relationship is modelled as an entity if it is a distinct concept whose properties describe the actual association, rather than one of the entities being related - e.g., an Interface type between instances of a Module entity. Alternatively, relationships may be represented as attributes if the attribute of one entity points to or is derived from another; e.g., a Module entity with an attribute condition relating to the Condition type. Relationships can also be expressed as simple connections described using a verb phrase or 'claim', e.g., a *realised_by* relationship between Requirement and Design entities. Similarly, connections may be labelled with rolenames indicating the purpose of each entity participating in a relationship. Rolenames are especially useful in clarifying reflexive relationships, or in situations where two entities participate in multiple relationships. Connections can also be expressed as entities if we have cause to describe them using attributes, or else wish to relate them to other connections; e.g., where a Requirement is *realised_by* a Module and where this claim is itself related to a TestCase entity via a *validated_by* connection. Finally, and though less common, we note that some textual modelling languages specify relationships through function definitions.

- **Classification and Aggregation**

Classification and aggregation are both abstractions originating from research in Cognitive Psychology, with Smith & Smith (1977) being the first to apply them to conceptual data modelling. Classification has two attendant viewpoints, namely generalisation and specialisation. Generalisation describes the factoring of common features among related entities to form a generic high level type, while specialisation (often seen as the basis of reuse) relates to the capture of features not already distinguished in existing types; e.g., Systems and Components may both be classified as specialisations of a generic Module entity. The generalised type is often termed a supertype or superclass and the specialised type or class, its subtype or subclass. Given that entity types and subtypes can be said to correspond to sets and subsets, then generalisation can be said to equate with the inclusion relationship. Similarly, multiple generalisation (where a subtype incorporates features from $n > 1$ supertypes) may be thought of as the intersection of two sets that are not subsets of the same superset.

Aggregation is simply a special and stronger (in the sense of coupling) form of relationship. Such relationships are transitive, bi-directional, asymmetric and possibly reflexive and are used to show that one kind of entity (the whole) is composed-of (i.e., contains), one or more other entities (the parts); e.g., in the context of ARP 4754, an aircraft can be said to comprise several system modules, each made-up of many item modules that in turn contain multiple hardware and software modules. In other words, aggregation expresses the semantics of '*has-part/part-of*' or '*has-component/component-of*' associations. It is also worth noting that while seldom treated as such in the literature, relationships between entity types and their attributes are merely a particular form of aggregation.

2.2.2.1.2 Constraints

Most conceptual data modelling techniques support means for expressing constraints over model constructs (a feature largely absent from cross-referencing approaches). Notwithstanding domains (discussed previously), the most basic form of constraints are those reflecting 'real-world' restrictions on relationships between entities. Such constraints are said to specify *cardinality* and *participation*. Cardinality describes the number of possible relationships for each participating entity; e.g., a single requirement statement may produce (and therefore relate to) several design artifacts. This is usually expressed as a ratio, in this case one-to-many. A more precise constraint may limit entities to some lower or upper bound; e.g., 'good practice' may restrict the number of derived requirements spawned by a source requirement to thirty[8]. Conversely, participation constraints describe whether the existence of some entity depends on it being related to another entity through a relationship. Such participation is referred to as either total or partial, or more commonly, mandatory or optional.

The other type of restriction of interest to traceability practitioners can be broadly categorised as integrity constraints (or static dependencies) which typically verify consistency and completeness of a data set. Consistency checks are necessary, for example, to maintain uniqueness among elements of sets (such as requirement identifiers), or to ensure referential integrity where models are related via a common entity (*cf.* Klein, 1993a; and Pearson *et al.*, 1998). Conversely, completeness checks are necessary to verify 'required data'; e.g., in the structure for recording failure behaviours by Pearson *et al.* (ibid.), a constraint ensures that for each Failure, there is at least one Error leading to that Failure, and at least one Fault stated as a consequence. A proviso of integrity checks for completeness is that they should not inhibit partial population since the nature of the aerospace domain for example, means engineers often have to work with incomplete information. Support for specification of integrity constraints is widespread (though by no means universal) among conceptual data models. The most leverage comes from those enabling formal definition of invariants using predicate logic, set and boolean constructs.

2.2.2.1.3 Operators

The final issue of concern to traceability practitioners and again a deficiency of cross-reference based approaches, is support for manipulating the data set of a populated model; i.e., the ability to produce 'new' information from existing elements. The first form of manipulation relates to means of specifying queries over a data set, to select and retrieve a subset of elements according to specified criteria using either standard or user defined query expressions. Another form of manipulation describes means of specifying expressions projecting views on the data model and which typically evaluate to the complete data set for a subset of elements reflecting (for instance) the information needs of particular stakeholder groups. In both cases, manipulation merely implies packaging (or re-packaging) of existing information. A further basis for manipulation (and a more authentic 'take' on newness) relates to the use of deductive logic to infer new propositions; i.e., rules operating over a subset of elements within a model (or group of models) that derive information populating other elements. It should be noted that in each case, the ability to traverse complex hierarchical structures is of paramount importance. Moreover,

[8] More may suggest the original requirement is either vague or trying to state too much.

while most conceptual data models include some basic operators, they tend to be less well developed than means of specifying constraints and structural features.

2.2.2.2 Representative Conceptual Data Models

Having introduced the foundations of conceptual data modelling approaches, we now consider a number of actual models embracing some or all of the constructs discussed (i.e., entities, relationships, constraints, etc.). The ordering is arbitrary, although we begin with the Relational Model since it is widely regarded as being the very first data model, and conclude with O-Telos and UML/OCL which together provide a basis for developing the MATrA framework.

It will be shown that conceptual data models may be represented using a graphical and/or a lexical formalism; graphical representations are effectively higher-order graph-theoretic approaches (i.e., multiple-overlaid graphs capable of capturing $n > 1$ node and relationship types), but with a range of additional capabilities. Both employ a finite set of pre-defined symbols (graphical icons and words respectively), with rules on how they may be composed.

2.2.2.2.1 Relational Data Model

Based on set theory and predicate logic, the relational model (Codd, 1970) supports data structuring, integrity constraints and manipulation operators. The data are structured as tables of records (one table per entity type), with each row or tuple (horizontal subset) corresponding to an instance of a record and each column (vertical subset), an attribute (whose value is drawn from a domain) describing a particular facet of the tuples. However, neither classification nor aggregation (other than entities being composed of attributes) are a feature.

The relational model enforces constraints on data integrity through *keys*. Specifically, the primary key is the (minimum) combination of columns (attributes) within a table necessary to ensure uniqueness of each tuple. Mappings between tables are handled through foreign keys, such that the value of a set of attributes in one table matches those of the primary key in another. The latter is a major limitation of the model; handling logical relations implicitly through shared values means associations can neither be named nor given attributes. It also means the semantics of relationships are embodied in query operations and that users of tools implementing the model must know which attributes define inter-relational connections in order to extract instances of such mappings.

Further, the leanness that comes from expressing data in 'third normal form' (a desirable model property that removes repetition and hence scope for inconsistencies) results in fragmentation of the tables. This is especially true where the multiplicity of association is M..N, or when relating objects of the same type (e.g., to support horizontal traceability). As a result, there is likely to be some divergence between the entities and relations as they exist at the conceptual level and the collection of tables representing them. However, despite these limitations, manipulative aspects of the model are strong, supported as they are through a relational algebra which defines a range of operators over the data. These comprise traditional set operations for union, intersect, difference and Cartesian product, as well

as unique relational operations for projection, join and divide.

2.2.2.2.2 Entity-Relationship Model

As its name suggests, founding constructs of the Entity-Relationship (E-R) model (Chen, 1976) are entity and relationship types. The former are denoted as rectangles and the latter as rhombi (both name bearing) on relationship arcs connecting entities. Attributes are represented as annotations on both entities and relationships, although the model lacks a convention for denoting either unique identifiers or domains. Existence dependencies (termed weak entities) are enclosed within a double rectangle, but in Chen's original work at least, neither classification nor aggregation (save for entities and their attributes) is supported. Cardinalities of the form one-to-one, one-to-many and many-to-many can be specified, while optional and mandatory relationships are denoted using single and double relationship lines respectively. On the issue of integrity constraints, the E-R model includes a set of *in-built* rules corresponding to those for foreign keys in the relational model; in-built because a pure relational system requires formulation of explicit foreign key rules, whereas E-R demands only that users state the kind of relationship involved. Finally, in terms of operators, the model basically provides a subset of those in Codd's work (subset in the sense that there is no explicit join, for example). However, this aspect is generally less clearly defined than structural aspects.

A number of enhanced or extended E-R models (EE-R) have emerged, including those by Czejdo *et al.* (1992) and Gogolla (1994), while Gogolla & Hohenstein (1991) and Parent *et al.* (1989) are among those seeking to give the model a formal semantics. Additional concepts proposed by EE-R models include classification (normally denoted by a rectangle within a rectangle), as well as the notion of table types - preliminary text listings of attributes for each entity. Table types may be optimised through normalisation and thus map intuitively onto the relational model (with some loss of subtypes and weak entities). Figure 2.8A shows a simple example of the ER approach illustrating a subset of the principles found in Chen's original model. Elements from this example will be used to demonstrate all the techniques in the subsections that follow.

2.2.2.2.3 Object-Role Modelling (ORM)

Object-Role Modelling (Halpin, 1998) also known as the Natural language Information Analysis Method (NIAM) is a graphical modelling technique in which 'facts' or *predicates* are described as combinations of objects (entities), attributes and roles (relationships). Objects are represented using ellipse icons and attributes as circles (both name bearing); object identifiers (termed labels in ORM) are shown as dashed circles, while a plus sign (+) within an attribute circle indicates a calculable sequence number (typically system generated). Roles are analogous to relational tables, or columns within tables to be precise; i.e., they are the foreign keys to the entities being related. They are represented by adjacent (name bearing) rectangles and connect objects to objects and objects to attributes via solid lines (no separate notation exists for aggregation), allowing the relationship of an attribute to its object to be precisely defined. Finally, classification is represented using a 'heavy' arrow pointing from the supertype.

ORM provides a number of symbols for capturing constraints. For instance, domain constraints can be listed and attached to attributes in braces (if values are ordered, the range may be declared by separating first and last values with ".."; e.g. $\{a_1 .. a_n\}$). Cardinality meanwhile is denoted using double-headed arrows; with one-to-many relationships the arrow is on the 'many' side, whereas for one-to-one relationships, it appears on both sides. If the relationship is many-to-many, arrows span both halves of the role rectangle (i.e., both halves are required to identify each occurrence in the relationship). A circled 'U' symbol denotes instances where two or more attributes or relationships are required to establish uniqueness, while mandatory role (participation) constraints are designated by placing a solid circle adjacent to the appropriate object or attribute. Many further symbols exist for the specification of additional constraint types, including frequency constraints (imposed over roles, meaning instances must 'play' a role *n* times) and ring constraints (indicating that binary relations formed by the role population must be irreflexive, intransitive, acyclic, asymmetric, antisymmetric, or symmetric).

ORM has evolved through several iterations, including a number of extensions supporting query operators. Of note are RIDL (Reference and IDea Language), a hybrid declarative and procedural language and ConQuer (Conceptual Query) which enables ORM models to be queried without knowledge of the underlying schema (unlike the relational model).

It can be seen that ORM is a highly expressive language, although the corollary is that diagrams can often appear cluttered. Figure 2.8B shows a simple example illustrating a subset of the principles discussed.

2.2.2.2.4 GEM

The General Entity Manipulator (Zaniolo, 1983) is a textual modelling language that extends Codd's relational model. GEM is based on the elements entity and attribute; entities are made up of attributes which may be atomic, set-valued (i.e., elements from a domain), a generalisation list (means for classification allowing definition of sub-entities), or a reference relating to another entity (providing support for aggregation). GEM has some similarities with object-based approaches in the sense that entities can conceptually *contain* other entities (as opposed to having foreign keys that are pointers to those objects). The dot notation is used as a means of referring to the 'join' paths necessary to access contained entities. Participation of reference attributes is mandatory (i.e., a value must be supplied) unless explicitly defined as '`null allowed`'. GEM also includes the notion of alternative attributes allowing for example, instances of a Module type to populate either a weight attribute or a language attribute depending on whether they represent a physical or logical entity.

Like the relational model, designated key attributes enforce uniqueness, while domain rules restrict set-valued attributes. Essentially, these along with the treatment of null values constitute the extent of support for constraints in GEM. However, a simple but powerful sub-language (based on QUEL) provides a range of operators for specifying queries and updates over the data model. Again, figure 2.8C presents a basic example illustrating a subset of GEM constructs.

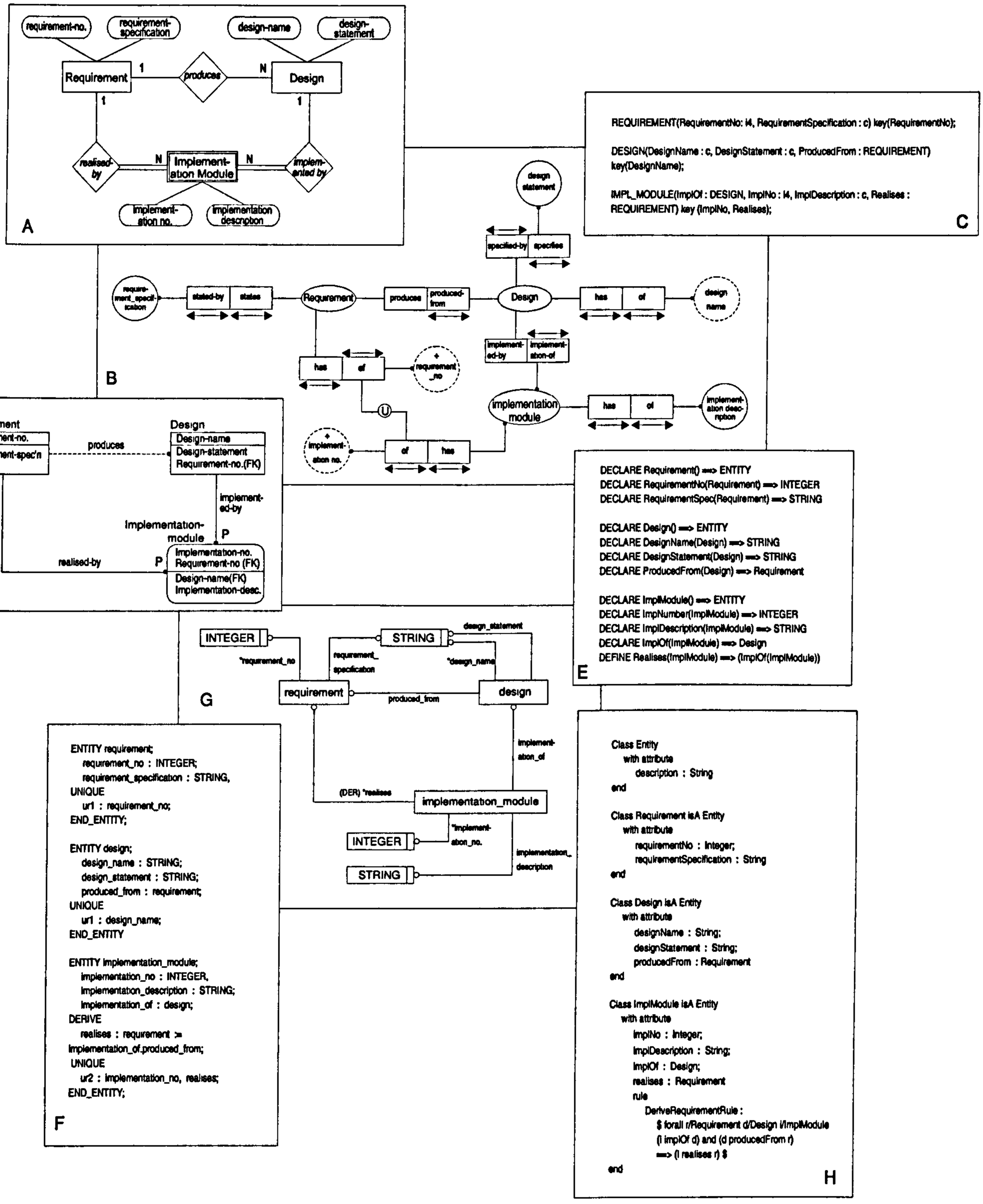


Figure 2.8 - 'Examples of Conceptual Data Modelling Techniques - A (ER Model); B (ORM); C (GEM); D (IDEF1X); E (DAPLEX); F/G (EXPRESS); H (O-Telos)'

2.2.2.2.5 IDEF1X

IDEF1X (FIPSP, 1993) is a graphical, quasi-relational modelling approach developed by the United States Air Force. Basic constructs are the entity, attribute and relationship; entities are denoted by round-cornered or square-cornered rectangles (with names appearing above). The former indicate dependent entities whose unique identifier includes at least one relationship to another entity, whereas the latter signify independent entities whose identifiers are not derived from other entities. In both cases a dividing line separates identifier attributes (above the divide) and non-identifier attributes.

Relationship lines (bearing an appropriate name) associate entities. In addition, the foreign key (fk) 'implementing' that line features as an attribute of the corresponding entity. Contrary to most modelling notations, different line styles and symbols are used to describe different combinations of participation and cardinality. For instance, a dashed line between two entities A and B, with a solid circle adjacent to entity B has the semantics 'one to zero or more'. Conversely, a solid line between two entities A and B, with a solid circle and a 'P' symbol adjacent to entity B (where B is dependent) has the semantics 'one to one or many dependent'. All told, IDEF1X specifies no less than twenty four symbol combinations and we therefore refer readers to (FIPSP, 1993) for further details.

IDEF1X also supports supertype (generic entity) and subtype (category entity) classification through the notion of 'categorisation relationships'. However, neither aggregation (except through attributes), nor operators are a feature. Moreover, semantic anomalies mean certain situations may be represented by more than one set of symbols, while the same symbol can mean different things according to context. This both reduces readability and makes the notation difficult to learn. It is also worth noting that IDEF1X effectively imposes third normal form and therefore assumes all attendant dis-benefits of the Relational Model. Again, figure 2.8D shows a simple example of the approach illustrating a subset of these principles.

2.2.2.2.6 DAPLEX

DAPLEX forms the data definition component of the Functional Data Model (Shipman, 1981). Although arguably the best known example, it is nevertheless just one of several attempts to construct a modelling approach based on functions rather than relations. In general, it can be said of such models that the basic navigational ('path-following') style is similar to that of object-based approaches in terms of addressing objects that are functionally related to other objects, that are functionally related to other objects and so on (Date, 1995).

The most striking features of DAPLEX are its simplicity and syntactic leanness. Whereas most conceptual data models feature a range of modelling constructs, DAPLEX relies on just two, the function and the entity (i.e., no relationships, attributes or value-sets). A function declaration can take one or more parameters and return a set of entities of a given type. Entities are specified using functions that take no parameters, whilst attributes are defined as functions taking the entity to which they belong as a parameter. Relationships are also represented as functions. A number of built-in types are provided including entity, and simple types such as integer and string. No explicit means are provided for

representing either classification or aggregation, although users can define their own functions for such purposes.

Constraints are specified using the model's functional programming language, though even basic restrictions are far from straightforward to impose. Finally, a powerful query sub-language enables manipulation of the data-model using English-like statements and expressions. Figure 2.8E presents a simple example illustrating the main principles of DAPLEX.

2.2.2.2.7 EXPRESS/EXPRESS-G

EXPRESS (Schenk & Wilson, 1994) is a structured textual language based on an extended entity-relationship formalism. Its main constructs are entities and attributes, the latter specifying a data type (either user defined or chosen from one of the in-built data types such as integer, string and boolean, etc.), a cardinality and also a possible value-set; relationships between entities are subsumed in the domains of attributes. We note also that the main abstraction concepts of classification and aggregation are both supported. Attributes and derived attributes can be designated unique, whilst entities, attributes and relationships may be constrained using rules written in a procedural language. Finally, the query language EQL defines a number of operators for analysing EXPRESS data structures.

EXPRESS-G meanwhile provides a graphical means of representing models specified in the language's textual form, although only a subset of constructs are supported, including entity, relationship and cardinality. Rectangular boxes represent entities, whilst their attributes are shown as a labelled arcs branching off and connected to a domain type - either in-built (denoted by a solid rectangular solid box with a double vertical line at the end) or user defined (denoted by a dashed rectangular box); dashed and solid arcs indicate whether an attribute is optional or mandatory. The destination of relationships between entities, or between entities and their domain types is conveyed as a circle at the end of an arc, while the convention for inheritance uses bold arcs[9]. Asterisks denote a constraint over an entity or attribute (although the constraints themselves are not shown), whilst the characters `'DER'` enclosed in parentheses indicate derived attributes.

We return to EXPRESS in Chapter Three (subsection 3.2.2) when considering work by ESPRIT project SEDRES (Johnson, 1997) and also in Chapter Seven (7.4.14) when discussing future work. In the meantime, figures 2.8F and 2.8G respectively show a subset of EXPRESS and EXPRESS-G conventions.

2.2.2.2.8 O-Telos

O-Telos (Jarke *et al.*, 1995) is of particular interest in the context of this thesis as object management features of its implementation in ConceptBase are used throughout to provide a 'flavour' of tool support for the MATrA structures. O-Telos is an extension of Telos (Mylopoulos *et al.*, 1990) and includes the key structural mechanisms of specialisation, aggregation and association, as well as means to specify

[9] It is debatable whether the thickness of a line should carry semantic force, although the same criticism also applies to ORM (discussed in subsection 2.2.2.2.3) and also to the graphical form of O-Telos (to be considered in 2.2.2.2.8).

constraints and deductive rules. Thus, O-Telos constitutes what its authors term a deductive object base (DOB).

A DOB is a triple, (OB, R, IC), where OB is the extensional object base and R and IC are deductive rules and integrity constraints respectively. Given the set of object identifiers *ID* and the set of labels *LAB*, an extensional object base is formally defined as a finite subset, $OB \subseteq \{P(oid, x, lab, y) \mid oid, x, y \in ID \wedge lab \in LAB\}$; elements (propositions) $P(oid, x, lab, y)$ of the object base are referred to as 'OB objects', where *oid* defines the object identifier, *x* is the object source, *lab* the name, and *y* the destination.

An O-Telos object base distinguishes four kinds of objects:-

- *Individuals* - a real world object is represented as P(oid, oid, lab, oid), where object identifier, source and destination have the same oid[10];
- *Instances* - a relationship between an object P(oid_o, oid_o, obj_name, oid_o) which is an instance of a class P(oid_c, oid_c, class_name, oid_c) is represented by P(oid_rel, oid_o, in, oid_c) - i.e. the relationship is an object with oid_o as its source, in as its label, and oid_c as its destination;
- *Specialisations* - specialisation of a class P(oid_c1, oid_c1, class_name, oid_c1) by a class P(oid_c2, oid_c2, class_name, oid_c2) is represented by an object P(oid_rel, oid_c2, isA, oid_c1);
- *Attributes* - P(oid, x, lab, y) states that object x has a relationship lab to an object y.

O-Telos supports an infinite number of modelling levels. At the lowest level, real-world objects are modelled as individuals or *Tokens*. In turn, Tokens instantiate *SimpleClasses* which are likewise instances of *MetaClasses* that are themselves instances of *MetametaClasses*, and so on[11]. MATrA is defined in ConceptBase using the Token, SimpleClass and MetaClass levels.

Both textual and graphical representations are supported in O-Telos[12]. The textual form featured in this thesis employs a frame syntax which uses object-labels for identification; all objects with a particular object as their source are grouped around that object. For each attribute, the frame description includes labels of attribute classes. Meanwhile, the corresponding graphical notation resembles a semantic network, with *Individuals* represented as nodes, *Instances* as dashed arcs, *Specialisation* using bold arcs and *Attributes* as 'solid' labelled arcs.

O-Telos also provides an assertion language to express DOB integrity constraints and rules. These are defined as instances of the pre-defined constraint and rule classes and included as attributes of the class to which they are attached. Constraints take the form <quantification> <formula> and rules, <quantification> <condition> ==> <result>, where quantification involves evaluation of universal and existential operators over O-Telos classes, formula and condition are logical combinations of literals describing relationships among O-Telos objects and result is a literal describing the logical consequence when a condition

---

[10] The object model of O-Telos includes around thirty in-built constraints that maintain integrity of an object base and ensure (among other things), that each object has a unique identification and that each referenced object exists.
[11] The uppermost layer of any object base (irrespective of the number of levels) is pre-defined by the objects Object and Class.
[12] In ConceptBase, the graphical notation may only be used to browse elements.

holds. Constraints are mainly used in this thesis to model value-sets; e.g., a class AssuranceLevel of type integer with values in the range 1 to 4 could include the constraint: AssLev1to4: $ forall a/AssuranceLevel (a >= 1) and (a <=4).

Finally, O-Telos defines operators for updating and querying an object base. Specifically, Tell and Untell operations allow for adding and deleting of objects respectively, while Ask permits their retrieval. Objects retrieved using Ask are represented as instances of the QueryClass and as a specialisation of one or more O-Telos classes. Constraints can be used to restrict possible answers by specifying particular attributes and attribute values.

Again, figure 2.8H features a simple example incorporating a subset of O-Telos constructs expressed in the textual frame syntax. An illustration of the graphical representation appears in Chapter Three (subsection 3.2.1).

2.2.2.2.9 Unified Modelling Language (UML) & Object Constraint Language (OCL)

We conclude our discussion on data modelling approaches by considering the Unified Modelling and Object Constraint Languages. The level of detail is necessarily greater than for previous techniques as they provide a foundation for the modelling of MATrA structures in Chapters Four and Five.

- **Unified Modelling Language**

The Unified Modelling Language (Rational Software Corporation, 1997a; Muller, 1997) adapts and extends modelling techniques developed by Booch (1994), Rumbaugh *et al.* (1991) and Jacobson *et al.* (1993). UML defines nine different types of diagram, each one capturing a different system viewpoint. However, we concentrate exclusively on Class Diagrams as these are used to represent all MATrA structures.

The main elements of Class Diagrams are class and relationship icons. Individual classes are represented as solid outline rectangles, with a mandatory compartment for the name, plus optional compartments in which to list attributes and operations (see figure 2.9). Note that operations are primarily used in software development to describe parameters of member functions and are therefore not of concern to us in modelling the traceability structures.

The simplest form of relationship depicted on Class Diagrams represents a dependency between (generally two different) classes and is denoted by a connecting line. Such associations may be labelled with either a passive or active verb (e.g., produces in figure 2.9), with the direction it should be read indicated using a small arrowhead. Alternatively, both ends can be labelled with rolenames that describe how each class 'sees' the other (e.g., architecture and build_element from the Design and ImplementationModule classes in figure 2.9). Reflexive associations linking classes of the same type can also be defined; e.g., an instance of Stakeholder with rolename responsibility_principal may be associated with another instance with rolename responsibility_holder (again, see figure 2.9). UML further supports

multiplicity adornments for '1' (one and only one), '0..1' (zero or one), '0.. *' (from zero to any integer), '1..*' (from one to any integer) and 'M..N' (from M to N integers)[13].

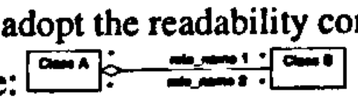
Dependency associations can themselves be represented as classes (complete with attributes, operations and constraints) and so participate in relationships with other classes (including other dependency associations). We use this particular approach to represent dependencies between MATrA structures (and elements) since it also provides a useful placeholder for decision rationale. In modelling dependencies in this way we chose to use aggregation, the semantics of which are that the claim being expressed by a dependency is 'composed-of' the adjoining classes; see for example Validates and RealisedBy in figure 2.9[14].

UML denotes aggregation associations using a small, hollow diamond situated next to the aggregate class (as depicted by the above-mentioned Validates and RealisedBy dependencies and also the reflexive association on ImplementationModule). A variation of this formalism is used where attributes must participate in relationships with other classes. This is termed composition and denoted through a small, black diamond adjacent to the aggregate (as shown between Requirement and Stakeholder in figure 2.9). Composition also implies a multiplicity of zero or one on the aggregate side. Note, the nature of concepts modelled in this thesis, i.e., traceability structures composed of elements which in turn are composed of other traceability structures and elements, makes aggregation the dominant association type used throughout.

Finally, UML denotes classification using an arrow pointing from the specialised class towards the general class; e.g., in figure 2.9, Requirement, Design and ImplementationModule are all forms of Artifact. The generalised class is termed a superclass and its specialised counterpart, a subclass such that a subclass inherits all attributes specified in its superclass, together with any relationship dependencies that the superclass has against other classes. A subclass then specialises the superclass through addition of its own attributes and associations. Note, the Artifact class in figure 2.9 is *abstract* meaning it is not instantiated directly, but instead is used to (transparently) manipulate instances of its subclasses.

Figure 2.9 will now be used to provide a context for consideration of OCL. It must be stressed that our interest in the figure is purely as a platform for exhibiting the basic modelling constructs used in developing MATrA (and *not* the content of the schema itself).

---

[13] Where two classes are related by more than one association, we sometimes adopt the readability convention of using a single association annotated with multiple rolenames and multiplicities. For example: 

[14] Note a dashed line can also be used to attach an 'Association Class' to a connecting line denoting a dependency between two classes (for more information, readers are referred to Muller, 1997).

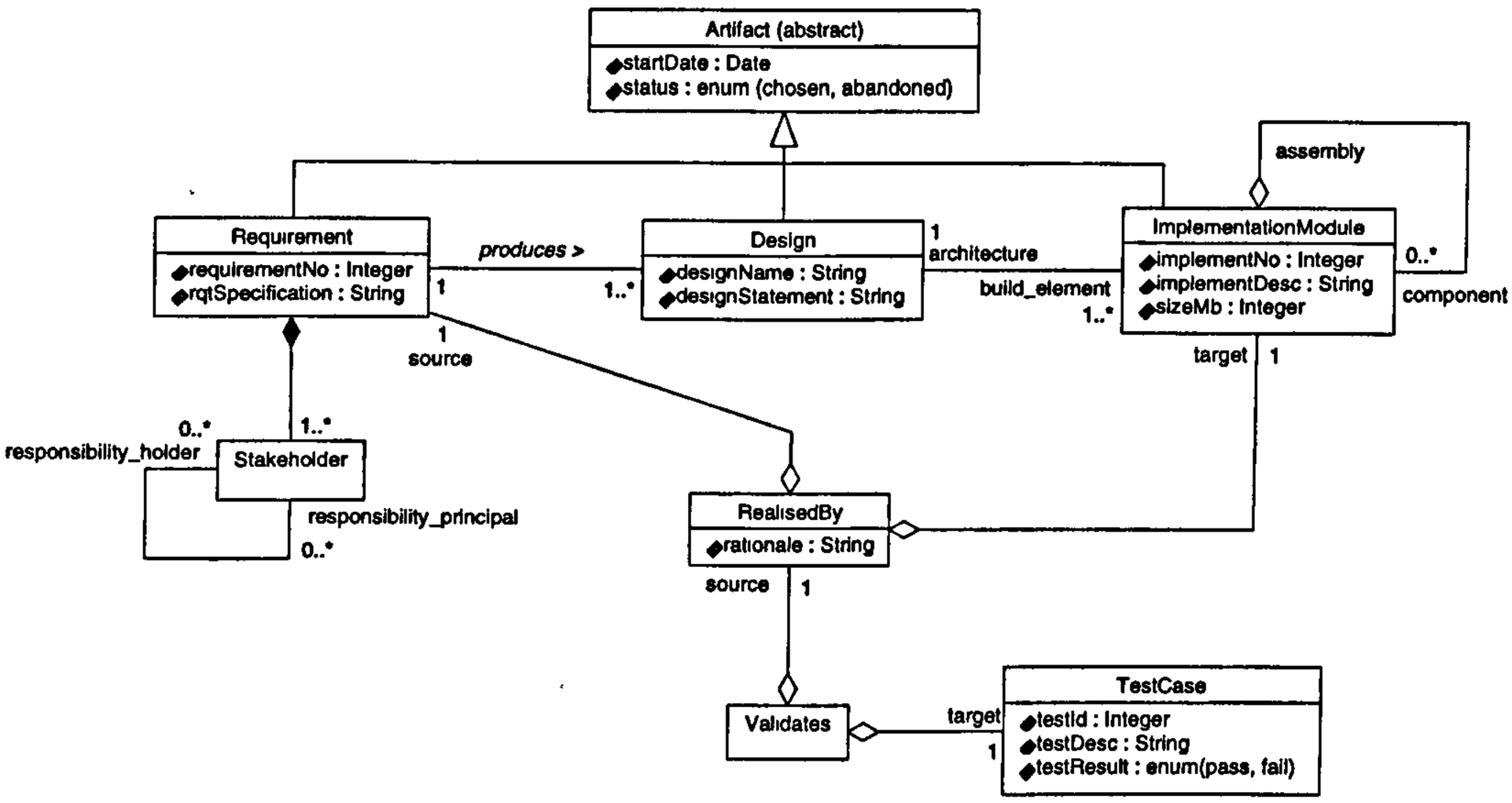


Figure 2.9 - 'Example UML Class Diagram'

- **Object Constraint Language**

Notwithstanding multiplicity, UML itself has no actual syntax for specifying constraints; natural language, pseudo-code and formal expressions can all be used on condition that definitions are enclosed in braces adjacent to the appropriate model elements. However, version 1.1 *prefers* use of the Object Constraint Language (Rational Software Corporation, 1997b; Warmer & Kleppe, 1999) which extends UML in much the same way as Syntropy (Cook & Daniels, 1994) previously extended OMT.

OCL is a precise (and strongly typed) language with a simple, non-symbolic syntax for expressing constraints over elements of UML models. It can be used for a range of different purposes, including specification of pre and post-conditions on operations as well as detailed behavioural constraints such as guards on state transitions. However, as regards means of representing the traceability structures, we are solely concerned with specifying rules and invariants over elements of Class Diagrams.

Before discussing these aspects further, we introduce some basic OCL conventions. As figure 2.9 shows, Class Diagrams express a vocabulary of classes, attributes and associations describing the subject being modelled. OCL uses these in conjunction with its own pre-defined *basic* (integer, real, string and boolean) and *collection* (set, bag and sequence) types to form expressions. OCL types also have pre-defined operations, e.g., those over basic types include real and integer modulus, boolean implication and string concatenation (we consider collection operations later). Several meta-types that apply to all objects are also available, including oclIsKindOf (which evaluates to true if a type *t* is either the direct type or one of the supertypes of an object); oclType (which evaluates to the type of an object); and most importantly of all, allInstances (which gives the set of all instances of a type and its subtypes).

An OCL expression is stated within the context of an instance of a specific type. The name self is used to refer to the contextual instance. The type of contextual instance of an OCL expression is written with

the name of the type underlined as follows[15]:-

```
Requirement self.requirementNo        -- evaluates to the value of the requirementNo attribute
```

Another important concept when stating expressions is the convention for navigating Class Diagrams. This enables us to refer to other objects (and their properties) that are either directly or transitively related to a context class. Navigation is accomplished using the rolename of an opposite (destination) association end, i.e. self.rolename. For example, starting from the context of Design in figure 2.9, we can state:-

```
Design self.build_element             -- navigates to objects of type ImplementationModule
```

Evaluation of such expressions results in the objects on the other side of the rolename association (in this case, of type ImplementationModule). If multiplicity is either '0..1' or '1', the value of the expression is an object, otherwise (as it is here), the result will be a collection or more specifically, a set[16].

If rolenames are not specified on a Class Diagram, navigation can be accomplished using the names of types at association ends. The convention is to refer to them using lower case for the initial character. Note however that if this results in an ambiguity, as for example with a reflexive association, then rolenames are mandatory. Again, from figure 2.9, we can state the following:-

```
Requirement self.design               -- evaluates to objects of type Design
```

As previously indicated, the OCL *collection* type comprises set, bag and sequence subtypes. These support a number of pre-defined operations, among them size (cardinality), isEmpty and notEmpty (for boolean evaluation of a null set), includes and includesAll (for the '∈ 'and '⊂' set operators) and select and reject (for criteria based inclusion and exclusion of elements from operation results), together with the existential and universal qualifiers, exists and forAll ('∃' and '∀'). Note each collection subtype also has its own specialist operations - e.g., those for set include difference, intersection and union.

A collection operation is accessed using an arrow '->', followed by the operation name. For instance:-

```
Requirement
self.design->size                     -- returns the number of Design types of the Requirement self

Requirement
self.design->isEmpty                  -- evaluates to true if the set of Design types of Requirement self is
                                      -- empty

Requirement
self.design.build_element->includesAll(self.realisedBy.target)
                                      -- evaluates to true if the set of ImplementationModule types reachable
                                      -- via Design includes all ImplementationModule types reachable via
                                      -- the RealisedBy class
```

---

[15] An alternative to this notation precedes the contextual instance type with the keyword **context**.
[16] Unless that is, the association carries an '{ordered}' adornment, in which case a sequence results.

```
ImplementationModule
self.realisedBy.validates.target->select (self.realisedBy.validates.target.testResult = #fail)
                                        -- evaluates to TestCase types whose testResult attribute has the
                                        -- value #fail[17]
```

Note the same class can be treated as both an object and as a set, depending on whether the self.object ->set-property or self.object.object-property convention is being applied.

The forAll operation can be used to constrain all elements of a collection. Again we use the arrow syntax with a boolean parameter; the result of evaluation is true iff the expression holds for all elements. For instance, in the context of a Requirement:-

```
Requirement
self.realisedBy.validates.target->forAll (t | t.testResult = #pass)
                                        -- evaluates to true if the testResult of each TestCase is #pass
```

Likewise, the exists operation can be used to determine whether a constraint holds for at least one element of a collection. Again, in the context of a Requirement:-

```
Requirement
self.realisedBy.validates.target->exists (t | t.testResult = #pass)
                                        -- evaluates to true if the testResult of at least one TestCase is #pass
```

As previously stated, the oclIsKindOf operation results in true if a type *t* is either the direct type or one of the supertypes of an object. For instance:-

```
Requirement
self.oclIsKindOf(Artifact)              -- evaluates to true because Requirement is a subtype of Artifact
```

Remember also that evaluation of the oclType and allInstances operations will result in the type of an object, and the set of all instances of a type (and its subtypes) respectively; for example we can combine these operations to state the following expression testing the abstract property of Artifact (i.e., to test that Artifact has no instances):-

```
Artifact
self.allInstances->select (oclType = Artifact)->isEmpty
                                        -- evaluates to true because Artifact is designated abstract
```

The conventions outlined above will now be used to express two simple invariants over elements of the Class Diagram in figure 2.9. An invariant is a boolean expression which either limits the value of an attribute or association role, or else states a relationship between the values of attributes and association roles. The result must evaluate to true for all instances of the associated class at any point in time.

Our first example restricts values for the sizeMb attribute of ImplementationModule to less than 10Mb

[17] The # syntax is used when referring to enumerators of enumerated types.

(i.e., it defines the domain of permissible values). This can be expressed as follows (note use of the keyword invariant):-

```
ImplementationModule invariant
self.allInstances->forall(i | i.sizeMb < 10)
```

In the above, the allInstances operation is used to obtain the set of all instances of self, in this case ImplementationModule; forAll then constrains the appropriate attribute for all elements of that particular collection.

Our second example ensures that Requirement identifiers are unique. Again the forall operation is used, this time over the Cartesian product of all instances of self (i.e., Requirement):-

```
Requirement invariant
self.allInstances->forAll (r1, r2 | not (r1.requirementNo = r2.requirementNo and r1 <> r2))
```

In keeping with the style to be used in Chapters Four and Five, we use the proof by contradiction principle to express this invariant (i.e., negate the condition we wish to hold).

The UML and OCL conventions introduced above are for reader orientation and hence consider only a subset of their respective language features. Nevertheless, they represent the main constructs used in expressing the MATrA traceability structures. For a more exhaustive consideration of UML and OCL, readers are referred to (Rational Software Corporation, 1997a and 1997b) respectively.

2.2.2.2.10 Other Conceptual Data Models

The previous discussion provides an overview of conceptual data modelling approaches spanning over a quarter of a century. Some older examples, e.g., GEM and DAPLEX are of little more than historical interest nowadays, although age is not necessarily an accurate barometer given that the two oldest approaches considered (namely the E-R and Relational models) remain prevalent to this day. Space prevents the inclusion of further examples, however interested readers may refer to works on TAXIS (Nixon *et al.*, 1987), SDM (Hammer & McLeod, 1981), SAM* (Su, 1986) and SHM+ (Brodie, 1984).

2.2.2.3 Traceability Enhancements

From a traceability perspective, the means by which data-modelling techniques build on basic set theoretic concepts can be seen to include structural, integrity and manipulative aspects. Structurally, all of the techniques offer rich graphical and/or lexical representations of the underlying mathematical concepts. The representations themselves are generally more expressive than graphs in the sense of capturing multiple overlaid relations, as well as enabling practitioners to describe domain elements in greater detail (using attributes) and to express stronger (in terms of coupling) set-theoretic relations such as multiple inheritance.

In addition (and to varying degrees), all featured notations further support the expression of constraints, ranging from multiplicity and participation, to entity integrity. Sometimes the mechanisms are in-built

(e.g., referential integrity in the relational model), while more specific user-defined restrictions can often be stated using some form of assertion sub-language (as in O-Telos). Many techniques further provide data manipulation operators, including the relational model with its select, project and join constructs and OCL with its array of built-in functions over set, bag and sequence types. It should be noted that whilst all of the featured techniques are structurally rich (relative to cross-referencing), some, such as the E-R model, require charitable reading to conclude that they are in fact data models; the integrity and operator constituents are often either weak or else not clearly defined in the literature.

Thus a degree of care is necessary when assessing the full extent of support for traceability afforded by data-modelling approaches. Those allowing the definition of sets of artifact and relationship types, with basic support for integrity constraints and some means of manipulation (e.g., the Relational, E-R and IDEF1X models) afford a basis for what is often referred to as 'syntactic traceability' (Pearson & Saeed, 1995). However, formalisms such as O-Telos and UML/OCL that combine rich structural abstraction mechanisms with a predicative sub-language, potentially permit what may be termed 'semantic traceability' (Palmer & Evans, 1994). In other words, they support precise formal definition of complex artifacts, their relationships and constraints imposed over them, as well as rules for reasoning with the data. This is the most sophisticated form of traceability achievable. It is also the most ambitious, requiring that each artifact and dependency is given a formal semantics. With MATrA, we are seeking to provide a foundation towards semantic traceability for the aerospace domain.

2.2.2.4 Traceability Applications

We purposely limit discussion on applications of conceptual data-modelling in this subsection since it constitutes a key aspect of the thesis and is demonstrated extensively throughout Chapters Four to Six.

There are numerous examples of data modelling approaches to traceability in the literature, although the emphasis is very much on presenting structural aspects, with little space devoted to semantic issues. This is perhaps understandable given that establishing the kinds of information and relationships to record is fundamental to any traceability approach and is the foundation on which the other aspects are built. The bias towards structural issues may explain why authors often present their work using arbitrary 'box-and-line' notations (which lack support for both constraints and operators), rather than using recognised data modelling techniques (*cf.* Laubengayer & Spearman, 1994; Ramesh, 1994). However, there *are* many examples of models based on the approaches considered in subsection 2.2.2.2, including Canfora *et al.*, (1995), Eberlein *et al.* (1997), Herzog & Törne (1999), Mason (1996) Oliver, (1994) and Pohl (1996).

Work on data modelling and traceability tends to be situated in the horizontal and/or vertical dimensions, as is the case with these examples. Again, this reflects the more specialised nature of the variant and revision axes. However interested readers are referred to work on data modelling for variants by McKay *et al.* (1996) and on revisions to Rolland (1994b).

2.2.2.5 Evaluation

In evaluating conceptual data-modelling as the basis of a traceability approach, we must consider what practitioners gain, both directly *and* indirectly, from using such techniques.

The main product of data modelling for traceability is a logical representation of project artifacts in terms of entities, relationships and well-formedness constraints. As we demonstrate in Chapters Four and Five, the expressive capabilities of data-modelling techniques allow practitioners to represent artifacts employing text-based, graphical and even formal notations in a way that with appropriate tool support, enables horizontal and vertical traceability between them; we note this normally requires links from the data-models into appropriate tools, thereby removing the need to capture information twice - once in the tool itself and once in the data-models (an issue addressed in Chapter Three). Data-modelling further allows revisions and variants to be structured in a way that supports traceability, while depending on which notation is being used, standard operations may also be produced for projecting different views of the data.

However, this perspective belies the fact that developing a conceptual data model (or set of models) requires deep understanding of the artifacts involved in a project and the life-cycle processes that produce them. As such the modelling task itself is actually a project within a project, comprising a requirements phase to elict user needs, a design phase to develop the models themselves and an implementation phase in which the necessary tool support is produced (see subsection 2.3). Thus, improved understanding of notations used to express the artifacts being modelled, of the processes employing them and of the relationship between notations and process activities can be said to be an indirect benefit of the modelling activity.

It is important the resultant data model(s) are continually re-evaluated throughout a project. Indeed, since inputs and outputs from process activities ultimately map to model entities, any modifaction of 'live' data-models may indicate a growing gap between the perceived process, and that being enacted. This in turn might suggest the need for process re-definition, thereby completing a product/process feedback loop. Therefore, practioners further benefit indirectly from the fact that data models supporting traceability make the process model more visible, enabling greater scope for process monitoring and improvement.

Finally, development of the data model(s) involves close interaction with a cross-section of stakeholder groups. This is necessary to establish not only what artifacts need to be modelled and the required ways of tracing between them, but also who will employ what information. This is especially important as project data is often used by people other than those involved in its capture. Thus, another indirect benefit of the data modelling activity is that it helps establish a control framework for accessing information, as well as determining 'ownership' and responsibilities for its maintenance and management.

2.2.3 Applicability of Techniques

Clearly, while generally inferior to data-modelling approaches, cross-referencing is still of value since the degree of sophistication an organisation requires from traceability will broadly correspond to its level of maturity[18]. At lower levels, a properly maintained if rudimentary cross reference-scheme is infinitely preferable to sophisticated, but neglected data-models where information becomes progressively less useful and there is little incentive to either update or use it.

It is further clear that cross-referencing techniques can *benefit* from tool support, whereas data-modelling *requires* it in order to be practical. However, tools are also essential given our domain of interest, where aerospace practitioners must often capture and analyse vast data sets. We address the issue of tools in the following section.

2.3 Tool Support For Traceability

Before considering tools supporting traceability directly, we briefly mention some other tools that provide limited traceability capabilities as a by-product of their stated purpose. These include the KJ editor (Takeda *et al.*, 1993), the T tool test case generator (Sodhi, 1991) and AGE (Keys, 1991), as well as code analysers such as Microscope (Ambras & O'Day, 1988), MasterScope and CScope (summarised by Devanbu *et al.*, 1991). Traceability is also an inherent feature of some languages used in the development process (*cf.* Bell *et al.*, 1977 and Davis & Vick, 1977; Dubois, 1994) and in the notion of *parasitic* languages described by Hill (1996). Also worthy of mention are tools supporting automatic transformation of specifications into source code; research in this area dates back to (Balzer *et al.*, 1983), whilst other works include Fraser *et al.* (1991), Reubenstein & Waters (1991), Börstler & Janning (1992), Duke & Harrison (1995) and Goguen (1996b).

All remaining tools considered in this section *are* themselves, or are built on-top of, some form of database. We note that imperative programming languages such as C++ and logic programming languages such as Prolog - both potential alternatives to a database approach - are undermined by lack of specialist capabilities for file handling and recovery.

A number of guidelines and heuristics exist for the evaluation of CASE tools generally (*cf.* Anderson, 1989; IEEE, 1992; Mosley, 1992; Sodhi, 1991; Thompson, 1994) and traceability tools in particular (*cf.* Gotel, 1995; Arango *et al.*, 1991; Brown, 1993; Edwards & Bergstein, 1993; Fiksel & Hayes-Roth, 1993; and Kelley 1990). However, our assessment is based on work by Riddle & Saeed (1999b) as it is specific to the aerospace domain. Their 'wish-list' of features for an ideal traceability tool can be summarised as support for:-

- *Elicitation* - i) varied means of extracting data (such as forms/templates); ii) integrity checks (to be applied to new data or triggered by updates); and iii) tolerance of incomplete information.

- *Expression* - i) representation of complex hierarchical structures; ii) specification of dynamic

[18] Maturity as implied by the evaluation frameworks introduced in subsection 1.4.6.2.

dependencies (enabling propagation of updates); and iii) features for extension of the underlying information schemas.

- *Analysis* - i) means of traversing complex hierarchical structures/transitive relations; ii) standard queries (including checks for consistency and completeness); iii) an expressive query definition language; and iv) predefined report formats.

We also address support for the traceability dimensions discussed in Chapter One.

2.3.1 General Purpose Tools

Specialist traceability tools or CASE tools providing explicit traceability support have only recently emerged. Prior to that, practitioners had little alternative but to use general purpose technologies. For cross-reference based schemes, that meant basic text editors (Davis, 1990; Kelley, 1990), UNIX *Nroff* and *Troff* text processing macros (Ni *et al.*, 1994; Yu, 1994), spreadsheets (Dean, 1992) and in particular, hypertext (Conklin, 1987) and hypermedia (Grønbaek & Trigg, 1994) technologies[19].

2.3.1.1 Hypertext

Hypertext in general provides a natural means of *presenting* inter-related information for browsing and on-line document analysis. However, lack of user operations on the underlying structure (database) has traditionally made it unsuitable as a basis for interactive development tools and as such, the Riddle and Saeed *elicitation* criteria are largely inapplicable.

From (Halasz & Schwartz , 1994) we have identified some further general criticisms of hypertext with regard to *expression* and *analysis*, including:- i) weak support for link typing; ii) lack of support for consistency checks; iii) weak support for view-based presentation and lack of support for view-types; iv) lack of support for inferred links; and v) lack of support for queries and reports using selective retrieval[20]. We also note the general absence of mechanisms for revision control (and by implication, revision traceability).

Despite such failings, hypertext *is* adept at representing hierarchical document structures, as well as in handling coarse and fine-grained inter and intra-document relationships. Also (and in contrast to its graph theoretic base), hypertext systems normally provide limited node typing and can therefore support both horizontal *and* vertical traceability using relationships between nodes of the same and different types.

Examples of tools supporting traceability based on hypertext have been proposed by Börstler (1994), Corriveau & Hayashi (1994), Cybulski & Reed (1992), Gardner (1994), Garg & Scacchi (1989, 1990), Hughes *et al.* (1995), Kaindl (1993), Kydd *et al.* (1994), Lee & Yen (1993), Papaioannou &

---

[19] *Hypertext* refers to text only systems and *hypermedia* describes systems supporting multiple-media.
[20] Note work by Pohl & Haumer (1995) - on which the MATrA structure in 4.2 is based - seeks to address issues such as view typing and selective retrieval.

Theodoulidis (1996), Smith (1993), Takahashi *et al.* (1996) and Westfechtel (1989).

It is also worth noting that generic mark-up languages such as HTML and its sibling XML (which both provide annotations for the digital representation of hypertext documents using tags[21]) are now being challenged by domain specific variations. For instance, SML, a mark-up language for safety engineering includes tags for *hazards*, *safeguards*, *failures* and other key safety related terminology. Such languages further improve traceability, in addition to making the analysis process potentially more efficient (Fan & Yih, 1999).

2.3.1.2 General Purpose Database Management Systems

To provide tool support for data-modelling approaches, practitioners have typically employed commercial database management systems (DMS). Of these, relational databases remain the most popular despite innovations in the object-oriented and deductive fields. We base material presented in this subsection on work in DCSC investigating use of relational (Mason, 1996) and deductive object-oriented databases (Riddle & Saeed, 1997; Stephenson, 1997; Mason & Saeed, 1998; and Pearson *et al.*, 1998) as potential platforms for traceability tools in the aerospace domain. Note that Chen *et al.* (1993) provide a general set of criteria against which to evaluate DMS for use in systems engineering.

2.3.1.2.1 Relational Database Management Systems (RDMS)

RDMS are based on implementations of Codd's Relational Model developed in 1970 (and described in subsection 2.2.2.2.1). The most significant development since then has been adoption of SQL (Structured Query Language), a non-procedural approximation of the underlying relational algebra, as the official standard relational query language. Examples of RDMS include Informix, Sybase, DB2, Ingres and Oracle.

Most commercial RDMS support means to develop form-based interfaces that shield users from the underlying SQL syntax. Some systems allow these forms to include derived attributes based on arithmetic operators or aggregates. Constraints preserving domains as well as referential and entity integrity are also normally enabled, as is the definition of triggers[22]; constraints are usually attached to forms in order to validate input at source. Support for partial completion of forms typically depends on the status (i.e., optional/mandatory) defined for individual attributes when creating the underlying schema.

As regards expression, RDMS permit the representation of complex, hierarchical structures. However, 'shoe-horning' them into tables expressed in third normal form leads to fragmentation of the data and often creation of many intermediate tables (requiring query via outer-natural-join to prevent information loss). The notion of dynamic dependencies, enabling propagation of changes caused by updates, are handled through transactions. Essentially, a transaction is a sequence of operations that transforms the

---

[21] Tags are used to structure text into headings, paragraphs and links etc., e.g., <h1> Heading </h1>.
[22] Events initiating triggers are typically updates, deletions, or insertions of tuples, with the actions to be executed on triggering defined as standard SQL statements.

database from one consistent (initial) state to another via a series of potentially inconsistent states[23]. One notable weakness of RDMS expression-wise is that once populated, edits to the underlying schema are often either prohibited, or else difficult and cumbersome to perform.

As previously indicated, SQL provides the basis for defining standard query operations and for projecting virtual tables (or views) over a repository. However, RDMS have no inferencing capabilities and are largely unable to support recursive queries that compute the transitive closure of a relation. As Mason (1996) demonstrated, this is potentially a major weakness in terms of their potential application to the aerospace domain, although the SQL3 standard (Elmasri & Navathe, 1997) *does* now include an explicit recursion feature. Alternatively, SQL statements can be embedded in a host programming language such as C++ or Pascal, with recursion supported by means of loops. Finally, most RDMS systems include a report-generator for specification of pre-defined report formats, with the content again determined using query language operations.

Examples of traceability tools built on RDMS include those described in Buus *et al.* (1997), Cockram *et al.* (1998), Dorfman & Flynn (1984), Flynn & Dorfman (1990), Garcia (1994), Mason (1996), Neely & Hartley (1993), Patel *et al.* (1993) and Watkins & Neal (1994). These works demonstrate horizontal and vertical traceability capabilities, whereas variants can be handled by RDMS using appropriate attributes (Silva & Agusta, 1998); versioning is not normally supported in relational systems.

2.3.1.2.2 Object-Oriented Database Systems (OODS) and Deductive Database Systems (DDS)

Two approaches seeking to address the problems inherent in RDMS are object-oriented databases (OODS) and deductive databases (DDS). OODS date back to the late 1970s, with commercial products first emerging in the late 1980s. They provide rich facilities for representing both structural and behavioural information by combining features from database technology with those of object-oriented programming languages; examples include O2, ObjectStore, GemStone, Ontos and Versant. For a comprehensive review of OODS, readers are referred to McFarland *et al.* (1997).

In contrast, development of precursors to deductive databases can be traced back to the late 1950s and to subsequent advances in logic programming in the 1970s. This was followed by work towards efficient implementation of recursion and reinterpretation of the conventional model-theoretic perspective on databases in proof-theoretic terms (both during the 1980s). Thus, DDS combine database technology with the formal reasoning capabilities of logic programming; examples include LDL and Coral. Interested readers are referred to Minker (1988) for an account of the development of DDS and to Grant & Minker (1992) for an early assessment of the impact of logic programming on databases.

Note, while the potential exists, we are not aware of any work describing traceability tools based

[23] Thus, where the transaction fails to complete, a *rollback* operation must be applied to restore the database to its initial state. As indicated in 2.3, a lack of such facilities undermines potential use of programming languages as a basis for traceability tools.

specifically on either object-oriented or deductive databases. They are therefore not considered further in this thesis.

2.3.1.2.3 Deductive Object-Oriented Database Systems (DOODS)

Both OODS and DDS have inherent weaknesses. For instance the former are seldom based on formal semantic models and lack declarative query languages, whilst the latter have poor data structuring mechanisms and limited facilities for update and I/O operations. Deductive Object-Oriented Database Systems (DOODS) attempt to combine these two paradigms in a manner which utilises their respective strengths to overcome these respective weaknesses, but without compromising the characteristic benefits of either. The resulting systems provide a rich modelling capability combined with a formal mathematical foundation; examples include Coral++ (Srivastava *et al.* 1993), Rock & Roll (Barja *et al.*, 1995) and ConceptBase (Jarke *et al.*, 1995), an implementation of O-Telos (described in subsection 2.2.2.2.8) that provides a target platform for the MATrA structures[24]. Note that since the features of DOODS tend to vary significantly, we concentrate on ConceptBase for the purpose of this evaluation.

An immediate criticism of ConceptBase is its lack of either a form based or template interface, though this is probably due to being developed for research rather than commercial use. However, data can be loaded from pre-edited files and therefore a template of sorts could be provided as a commented text file if required; work in DCSC towards development of a JAVA based interface to ConceptBase for a Requirements-Engineering tool (Sukamaran, 1999) is also noted. In terms of constraints, the tool provides good support for integrity checks which are encoded as attributes of classes (although the restriction of operators to universal and existential quantifiers is a limitation); new and updated instances must conform to these constraints which can enforce various domain, real-world and entity integrity restrictions. Note, new instances of a class need not by default have values associated with the attributes defined, so enabling partial population.

The underlying object model supports definition of complex, hierarchical structures using O-Telos' mechanisms for specialisation, aggregation and association (described in section 2.2.2.2.8), while the tool's axiomatic basis means querying such structures is not problematic. ConceptBase further enables definition of deductive rules (again, as attributes of a particular class) that can be used to derive dynamic dependencies, allowing propagation of changes to related objects. As regards extendability, the underlying schema can be arbitrarily changed provided constraints and dependencies are not violated.

Standard queries can be defined via the special QueryClass construct (as introduced in section 2.2.2.2.8); these become classes within the database which may be selected from a menu and applied at any time. QueryClass can be thought of as generalising the notion of relational views in that its instances are answer objects to the query. This form of 'lazy evaluation' is one of the tools strengths and is often preferable to expressing constraints on the classes themselves which *can* be overly restrictive.

---

[24] In providing a flavour of automation for MATrA structures, we focus on representation of the base classes and hence on object-oriented rather than deductive features of ConceptBase (see subsection 2.4).

Conversely, one area where ConceptBase is particularly weak is its reporting facilities, with no means for defining standard report formats or templates.

It should be noted that application of DOODS has largely been confined to academia, including some work on the development of traceability tools (*cf.* Eberlein *et al.*, 1997 and Pohl, 1996).

2.3.2 Commercial Traceability Tools

This section analyses three commercial traceability tools, namely DOORS (QSS, 1998), RTM (Integrated, 1997) and RDD-100 (Ascent, 1997). We base our appraisal on a combination of 'hands-on' evaluation and discussions with various user groups, including experienced[25], intermediate[26] and beginner[27] levels, together with findings in surveys by INCOSE (1999) and Riddle & Saeed (1999a, 1999b). It should be stressed that as commercial tools, DOORS, RTM and RDD-100 are constantly evolving and therefore any appraisal is likely to become rapidly outdated. We therefore indicate which particular releases were considered, whilst highlighting subsequent developments of note where appropriate.

2.3.2.1 DOORS (Dynamic Object Oriented Requirements System)[28]

DOORS is a dedicated requirements management tool capable of interfacing with the likes of Statemate, Teamwork, Rational ROSE and Word. It also provides a C-like scripting facility - the DOORS eXtension Language (DXL) - which may be used (among other things) to construct custom interfaces with non-supported tools. However, relative to this thesis at least, a more significant means of interfacing with other CASE tools, or to be precise, capturing their project data within the DOORS environment, is the 'DOORS Connect Programme'; we return to this issue below.

In essence, DOORS adopts a document-centric approach; i.e., it presents the information via a word-processor-like interface, with requirements displayed as hierarchically organised 'document' segments. Requirements may be captured in DOORS in several ways; e.g., automatic parsing mechanisms can read information from multiple file formats (including ASCII and RTF) so that structures, attributes and links may be set up without manual input. The parsers operate by analysing text and identifying requirements according to keywords. A manual mark-up facility (using mouse highlighting) is also available, while requirements and links can be further loaded in batch mode directly from file. Finally (notwithstanding the above-mentioned DOORS Connect Programme), there is the template based approach, where DXL scripts generate data entry forms with pre-defined headings for users to populate; templates are supplied for standard format requirements such as Mil-Std-498 (DoD, 1994).

DOORS uses a proprietary object-oriented database which is reflected in the way information is structured. A DOORS 'project' contains a set of 'formal modules', each one typically containing a

---

[25] Aerospace practitioners.
[26] Academic colleagues in the BAE Systems Dependable Computing Systems Centre.
[27] Undergraduate and post-graduate MSc. students (*cf.* Duvall, 1997; Brown, 1999; Casemore, 1998).
[28] Considers release 4.0.

specific requirements sub-group (e.g., aircraft-level, system-level, item-level, etc.); traceability is realised through links ('link modules') both within and between modules. DOORS handles individual requirements as discrete objects (which it allocates unique identifiers) organised under numbered sub-headings. Each object is described by typed attributes, some of which are standard and may be attached automatically (e.g., date of creation/last update, creator, etc.), whilst others are defined by the user (note that links can also have attributes). However, the use of headings and sub-headings naturally encourages a hierarchical structure which though supporting inheritance between levels, is not always appropriate. It should also be noted that the absence of an underlying graphical schema underlines the need for a clear understanding of entities and relationships involved in a project before creating the actual objects and links; that said, extensions (or changes) to the database are easily performed.

As indicated previously, the DOORS Connect Programme is an important feature of the tool allowing users to capture data from other CASE tools inside the DOORS environment. Technically an interface to a particular CASE tool is achieved through a 'surrogate' formal module which shares common (unique) identifiers with the data set of that CASE tool. Surrogate formal modules are populated automatically by directly importing data into the DOORS database. Data is synchronised between DOORS and the CASE tool by updating the surrogate module with changes made to the data set of the CASE tool. As will be seen from Chapter Three, a similar approach is used for development of the MATrA framework described in this thesis.

For simple analysis, the Traceability Explorer offers an on-line-browser tool showing all incoming or outgoing links for a particular module. Meanwhile the 'Traceability Wizard' allows selection of forward and backward traversal paths over links between modules. Custom analysis is achieved using filters or DXL coded queries; filters are constructed by combining filter criteria (such as operations on attributes), the results of which can be saved as views. In addition DOORS provides a 'View Wizard' to guide selection of filter operations, such as the columns to display and sorting operations to conduct over filter results. Views further provide the basis for producing printed reports; a view is used to select the information required which is then included in the report definition. Basic consistency checks (e.g., on attributes) may be conducted by filtering, although more complex checks (e.g., of links) require DXL code (note as a procedural language, recursive querying of hierarchical structures is relatively easy). Several standard DXL queries are provided which may be adapted or extended as needs dictate. In terms of output, DOORS provides a number of report generation templates that comply with software engineering standards (including Mil-Std-499b and ESA PSS-05), while further reports can again be created using DXL. It is also possible to extract a detailed audit trail detailing the 'who, what, when and how' of changes to objects for revision control purposes.

To summarise, DOORS is mainly a tool for managing textual requirements and specifications[29]. Consequently vertical or horizontal traceability to non-textual artifacts comes either through interfaces

[29] The ability to capture information expressed in other tools through the DOORS Connect Programme and to represent textual data from all project phases (not just requirements) - including design and testing - has recently lead to DOORS being marketed as an 'information management tool'.

into other development tools, or else through data stored as surrogate formal modules within DOORS itself. For artifacts stored as DOORS modules (including surrogate modules), vertical and horizontal traceability links may be inserted between any two object classes. DOORS also enables revision traceability through change histories and while no explicit support for variants exists, this may be partially offset through the use of appropriate object attributes.

2.3.2.2 RTM (Requirements & Traceability Management)[30]

RTM like DOORS, is intended to form the requirements management component of a life-cycle wide CASE tool environment. Pre-defined interfaces are provided for a range of development tools (including Teamwork and Statemate), as well as text processing tools (such as MS Word). For tools without pre-defined bridges, RTM provides a C and C++ driven API (Application Programming Interface), enabling users to develop their own custom interfaces to third party tools. In addition, later releases include a mechanism for representing data transferred from CASE tools directly into RTM using concepts similar to the DOORS Connect Programme discussed in 2.3.2.1.

Normally, the first stage in using RTM is to define an information model known as the Class Definition Diagram (essentially an ER schema for the underlying ORACLE relational database). Its purpose is to capture information elements to be used on a project, the relationships between them and the rules governing these relationships. Essentially, a 'class' equates to an entity (in the entity-relationship sense), each one defined as a set of attributes and each attribute specified from a range of types (e.g., alpha-numeric, character, etc.). It should be noted that since changes to the schema once populated are difficult to make, developers are under pressure to get the schema right first time. We also note that (unlike DOORS) the need to construct a Class Definition Diagram means RTM cannot be used 'out-of-the-box'.

There are several ways of entering requirements into RTM; e.g., the Capture tool provides a language parsing mechanism for automatic identification of requirements within a source text (by keywords, unique identifiers, etc.). Users can further identify requirements interactively by highlighting appropriate document sections. Requirements and links can also be entered in batch mode by importing the data from file (such as ASCII text), or failing that, created manually using a form based editor with pre-defined fields taken from the Class Definition Diagram.

For structuring, RTM enables links to be established between any type of class in any direction via two relationship types - genealogical and generic - each representing a different aspect of requirements flowdown. Genealogical flowdown describes the decomposition or refinement of a requirement where one or more subsidiary requirements are derived from an existing higher level requirement (with flow down links inserted automatically). Generic flowdown meanwhile supports the definition of relationships between different information types, e.g., from requirements to acceptance tests. The tool further allows users to identify inconsistencies such as orphan (i.e. unlinked) elements.

---

[30] Considers release 4.0.

RTM provides three basic interfaces for viewing, analysing, and maintaining link and traceability information:- i) the Trace tool displays links between individual items in different classes as a cross-reference matrix ; ii) the Visual Network Tool graphically traces relationships between any linked classes using a tree format; and iii) the DocTool uses scripts expressed in an SQL-like query language to generate reports based on information selected for inclusion. The DocTool also provides an alternative means of generating inconsistency reports.

RTM supports configuration management by establishing separate database objects for each revision of a requirement, with further support for establishing and comparing project base-lines. In addition, the tool enables propagation of links to new revisions of requirements. This is achieved either automatically or by manual intervention, i.e. existing links are broken and must be physically re-established by the user (preventing situations where the revision is linked, for instance to an irrelevant test). Alternatively, all links are copied to the new requirements and deleted from the old revision.

To summarise, RTM is a tool for textual requirements management and as such, traceability to non-textual artifacts again comes mainly via interfaces with appropriate tools. For artifacts represented within RTM itself, both vertical and horizontal traceability are supported, although recursive queries are potentially problematic owing to the tool's underlying relational architecture (i.e., the depth of recursion involved in a query must be known in advance). As with DOORS, variant traceability is not explicitly enabled, although again, it can be achieved using appropriate attributes. Revision traceability is however supported (the RTM practice of establishing a separate object for each modification being arguably more effective than DOORS' change histories).

2.3.2.3 RDD-100[31]

Whilst DOORS and RTM focus on requirements management, RDD-100 (which is built on the 'Visual Works' object-oriented database) provides an extensive systems engineering tool-set that in principle, reduces the need for tool integration. That said, the ASCII interface provides a basic bridge to a range of CASE tools including Teamwork, Software Through Pictures and Statemate. There is also a bi-directional interface between MS Word and the RDD-100 text editor, RDD Word.

In addition to a standard form based approach, RDD-100 accepts input in a variety of ways. Among them: i) a parser tool for identifying single or compound requirements in source documents based on key words and unique identifiers; ii) manual selection and extraction of requirements text from ASCII format documents; iii) the RDD-100 Command Reader and Report Writer facilities which can capture and create requirements in batch mode; iv) the RDD Word facility which may be used to associate MS Word formatting with entity instances in RDD-100; and v) manual entry using various diagram formats, including Function Block, Data Flow and Behaviour Diagrams. Incomplete information is tolerated provided that integrity checks have not been violated. These are encoded using the consistency

[31] Considers release 4.1.1

checking mechanism and supplement standard, pre-defined constraints for consistency and completeness.

RDD-100 includes a wide range of standard system engineering entity and relationship types. These can be extended with the addition of user defined elements as needs dictate. The types are categorised in a hierarchical manner, with inheritance between different levels. RDD-100 allows users to interrelate elements between hierarchies, as well as supporting reflexive relationships. It should be noted that the linking of elements in RDD-100 is bi-directional in the sense that when a link between two elements is established, an inverse link is automatically inserted. Extensions to the database (i.e., the addition of new element and link types) are best accomplished when the database is un-populated, otherwise the complete data set must first be exported to a schema copy and then re-imported into the extended schema.

RDD-100 provides two main mechanisms for analysing the database, namely Custom Hierarchies and Behaviour Diagrams. Custom Hierarchies provide a graphical or textual view of entities and relationships based on standard pre-defined templates. For more complex analysis, Behaviour Diagrams can be used as a form of visual programming tool, exploiting facilities offered by language constructs such as loops and recursive procedure calls. One of RDD-100's real strengths meanwhile lies in its ability to produce reports, including pre-defined formats for a range of recognised documentation standards (e.g., Mil-Std-498); further, user specified styles can be defined using RDD Word. Again, behaviour diagrams are used to select information and to produce the final printed reports.

RDD-100 also provides users with the ability to track changes to data during the course of a project (using the 'creation date' and 'modification date' attributes). Revision control is accomplished through the Model Configuration Management Facility (MCMF) which as its name suggests, tracks configuration of the system throughout development and enables management not only of item revisions, but also variants.

To summarise, RDD-100 is a systems engineering tool which in addition to various functional, data and behavioural modelling, provides support for requirements traceability. On the dimensions referred to throughout, it is clear the ability to link any user defined or in-built element types (including elements of the same type) enables both horizontal and vertical traceability. RDD-100 also supports revision traceability (although like DOORS this does not extend to the maintenance of separate objects) and variant traceability via the MCMF facility.

2.3.2.4 Additional Commercial Traceability Tools

In addition to the above, a host of other commercial tools now offer support for traceability. These include:- i) *SLATE* (System Level Automation Tool for Engineers), which like RDD-100, is intended more as a systems engineering tool; ii) *Requisite Pro*, a tool aimed at the requirements management market and a direct competitor of RTM and DOORS; iii) *Vital Link*, another requirements tool which like DOORS manages traceability via a document-centric interface; iv) *XTie-RT* an entry level

requirements tool with basic traceability facilities; and v) *Cradle*, another systems engineering tool with traceability support (this time based on the Yourdon methodology).

2.3.3 Comment on Tools

In the past, there has been a tendency in developing traceability tools (particularly those managing textual requirements) to simply automate paper based techniques (*cf.* Horrowitz & Williamson, 1986, Lefering, 1993; Queille *et al.*, 1994 and Singh & Han, 1996); the literature suggests this is no longer the case. However, despite advances reported by Dömges & Pohl (1998), INCOSE claim that traceability remains *the* on-going tool related issue among systems engineering practitioners.

It has long been felt that traceability approaches (and therefore tools) should be capable of reasoning about the artifacts they link instead of merely creating navigable paths between them (Ramesh & Edwards, 1993). However, in order to do so, models[32] on which the tools are based must also capture the *semantics* of the artifacts they represent; we address this issue in the development of MATrA structures.

White (1993) highlights a lack of tool support for the tracing of behavioural and non-functional requirements such as reliability and fault-tolerance. Save a few exceptions (Boyd, 1993; Haveman & Pearson, 1997; Landes & Studer, 1995; Mylopoulos *et al.*, 1992; Prowell & Poore, 1998; and White, 1994a, 1994b), work on traceability largely excludes these areas (possibly because they are often satisfied by an entire system and therefore cannot be traced to a particular set of design elements). MATrA partly addresses this issue through its range of Workspace notations (subsection 3.3.2) and by primitives in the structure that maintains Workspace consistency[33] (subsection 3.3.5). We also propose topics for further work in this area as described in subsections 7.4.1 and 7.4.4.

Another problem is that again, apart from a few exceptions (*cf.* Ni *et al.*, 1994; Yu, 1994; Pearson & Saeed, 1996; Silva, 1998; Tran *et al.*, 1997), work on tool support for traceability seldom considers the *method* by which the tools will be used. According to Jayaratna (1994), a method generally contains guidance on steps to be taken, how the steps are to be performed and why the steps must be followed in a specified order. Though not explicitly addressed by this thesis, MATrA raises a number of method related issues and is identified as an area for future work (see subsection 7.4.6).

Finally, and especially significant as regards this particular piece of research, is the problem of CASE tool fragmentation where separate applications (often with overlapping capabilities) are used for different development and assessment activities. A lack of tool integration (to be discussed further in Chapter Three) makes it difficult to establish traceability between, and maintain consistency across, artifacts produced by these activities; this thesis seeks to address both issues.

---

[32] The need to define artifacts (nodes) in detail implies a data-modelling rather than a cross-referencing approach.
[33] These concepts were introduced by the thesis argument in subsection 1.3 and are discussed in more depth in the subsections identified.

2.4 Techniques and Tools for MATrA

From the investigation of tools and techniques described above it was possible to establish an appropriate technical basis for MATrA. Cross-Referencing was immediately discounted as we wish to represent artifacts (i.e., nodes) as more than atomic elements.

Regarding data modelling, UML/OCL, EXPRESS and O-Telos are the only formalisms featured in this chapter which broadly support the range of foundations outlined in 2.2.2.1. As indicated, the UML/OCL combination was our eventual choice since it is widely used by BAE SYSTEMS and throughout the aerospace sector generally. This obviously made it easier to communicate ideas to practitioners than if we were using an unfamiliar language. However, for reasons outlined in a future work item (subsection 7.4.14), there are strong reasons to consider re-expressing MATrA in EXPRESS at a later date.

As previously indicated, we chose the ConceptBase implementation of O-Telos to provide a flavour of tool support. This was motivated by the fact that O-Telos supports both object-oriented and axiomatic constructs and hence is (relatively) close in spirit to the combination of UML and OCL. That said, we largely elect to concentrate on implementing structural aspects of MATrA, while noting that expressing the constraints and rules using O-Telos may be difficult as the range of set and boolean operators available in OCL is far greater. Therefore subsection 7.4.13 commits to investigate various commercial tools, of which DOORS (with its procedural extension language that can potentially replicate all necessary operators) is a leading candidate.

2.5 Chapter Summary

Following on from Chapter One which provided a *user* view on the need for traceability, this chapter has taken an *applied* perspective on how it can be realised using different techniques and tools.

Traceability techniques were classified as based on either a cross-reference or conceptual data modelling approach. We further differentiated between lower and higher-order cross-referencing, and thence higher-order multiple relation and higher-order multiple artifact techniques. Various means of automation were also considered, including hypertext, general purpose database and commercial traceability tools.

The chapter concluded with a brief summary of techniques and tools used to develop the MATrA framework which we consider in the following chapter.

Chapter 3 MATrA: Foundations and Fundamentals

3.1 Introduction

This chapter considers the main works that have influenced MATrA (*foundations*), together with the nature of their influence and/or perceived weaknesses we address in our thesis. It goes on to introduce the basic principles of MATrA (*fundamentals*), their purpose and composition.

3.2 Foundations of MATrA

In this subsection we consider three key works from current literature that have influenced the development of MATrA.

3.2.1 Novel Approaches to Theories Underlying Requirements Engineering (NATURE)

Our thesis argument in Chapter One (subsection 1.3) posited the notion of a traceability *Workspace* as a mechanism to support traceability across data from the various tools used by aerospace practitioners. A key constituent of this Workspace is a set of meta-models capturing elements of notations supported by these tools. The origins of our approach to representing such meta-models stems from work by ESPRIT project NATURE (summarised in [Pohl, 1996]), a three year programme with the aim to develop a framework, tool environment and models for process-centred requirements engineering.

The NATURE framework supports functional, data and behavioural modelling through the following quasi-standard techniques:- Structured Analysis, Entity Relationship Models and OMT (including object and dynamic models). They further provide a hypertext model for recording informal representations and an argumentation structure (based on the IBIS model - Kunz & Rittel [1970]) for asserting rationale.

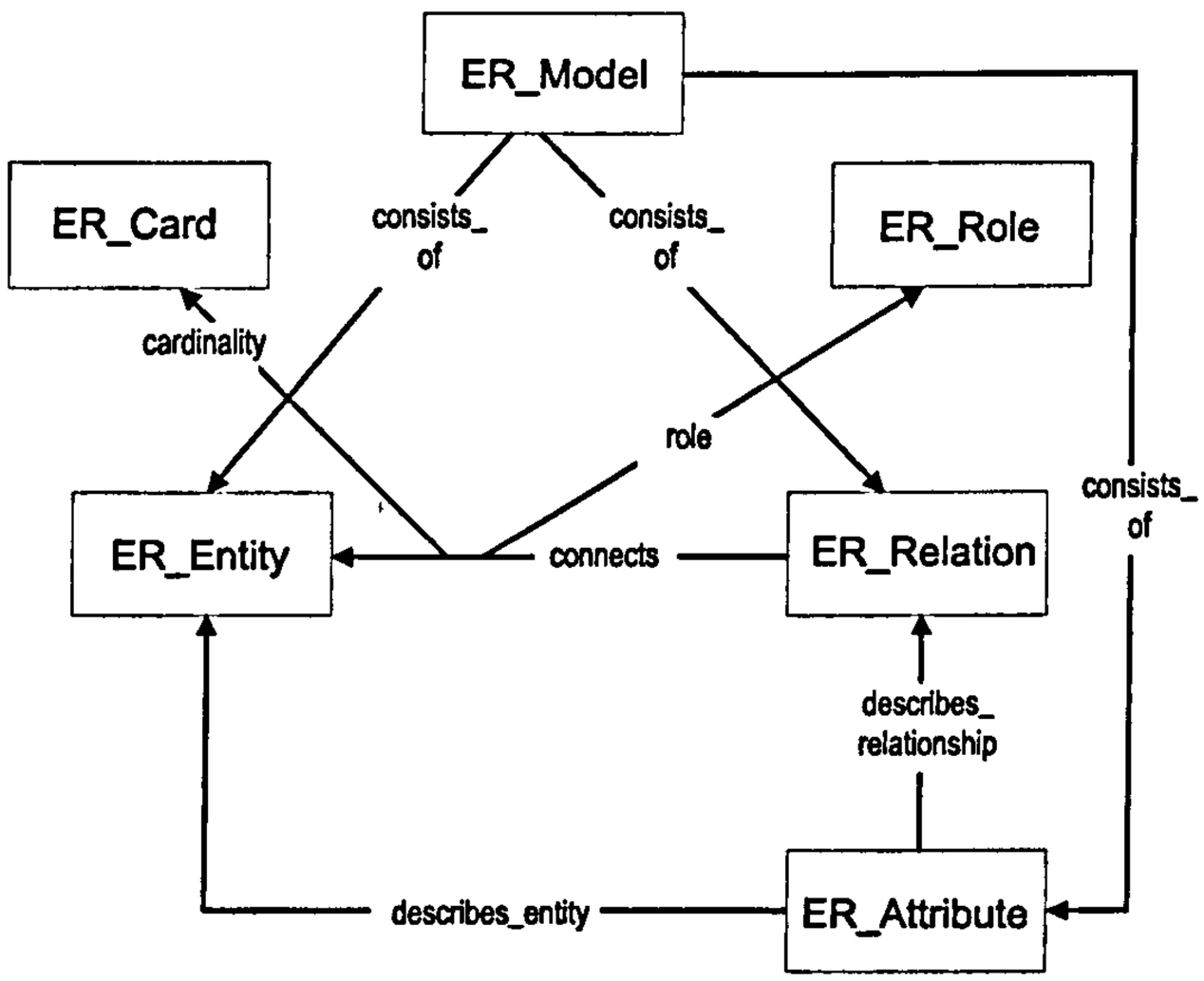


Figure 3.1 - 'Project NATURE Entity-Relationship Meta-model'

NATURE partners capture elements of these techniques in the form of conceptual meta-models (i.e., they adopt a *data-modelling* approach) expressed using the O-Telos knowledge representation language (Pohl, 1996); to provide tool support, they implemented these models in the ConceptBase object management system. Figure 3.1 demonstrates an example of one such meta-model (expressed in the graphical O-Telos language) which captures information elements for Entity Relationship diagrams (ER_Model), specifically entity (ER_Entity), relationship (ER_Relation), attribute (ER_Attribute), cardinality (ER_Card) and role (ER_Role).

NATURE records associations between models structured in this way using a 'dependency' class with attributes 'to' and 'from'. Dependencies are typed (and organised as a taxonomy - the Dependency Model) in order to restrict instantiation of these attributes; examples of dependencies include 'elaborates', 'based-on' and 'formalises' (of taxonomy type *evolutionary dependency*) and 'compares', 'contradicts' and 'conflicts' (of taxonomy type *content dependency*). Though drawn from a survey of requirements engineering literature, many of the associations identified (including those above) have potential for wider application in linking 'down-stream' artifacts.

3.2.1.1 NATURE Influence

MATrA is perhaps closest in spirit to the work by project NATURE. We have been particularly influenced by their use of a conceptual modelling language to structure object-based representations of various requirements notations. Accordingly, in this thesis we use a similar approach to develop meta-models covering a representative subset of notations employed by aerospace practitioners (introduced in 3.3.2), including examples used for design and implementation, for developing heterogeneous systems, for stating real-time and non-functional properties, for safety analysis, and for product management, etc. Moreover, like NATURE meta-models, those in MATrA instantiate elements of a common meta-level structure (subsection 3.3.3) such that each *model* (ER_Model in the above) is composed of *elements* (ER_Entity, ER_Relation, ER_Attribute, etc.); this is similar to the approach employed by Pearson & Saeed (1996).

We have also been influenced by the NATURE way of creating associations between meta-model representations (subsection 3.3.6.3.2). Indeed, this thesis largely concentrates on meta-modelling aspects; whilst the case studies in Chapter Six demonstrate example associations between elements of these models, the approach used is essentially as described above. Moreover, the featured associations are fairly arbitrary and a detailed investigation (including a literature survey, together with practitioner consultation) will be required to establish a set of domain specific associations. We return to this issue in the concluding chapter (subsection 7.4.3).

Finally, whilst NATURE regard their framework as autonomous (each model has a graphical interface providing an appropriate 'look-and-feel' for the notation represented), aerospace practitioners are unlikely to willingly relinquish existing tools for bespoke alternatives. Therefore MATrA aims to integrate with, rather than replace such tools; this is the basis of our SEDRES influence.

3.2.2 System Engineering Data Representation and Exchange Standardisation (SEDRES)

In order to populate Workspace meta-models, a mechanism is required to transfer data from the models underlying various CASE tools used by practitioners. As previously indicated, our thesis focuses on a framework to support traceability of this data once 'inside' MATrA, with the transfer process itself treated as a 'black-box'. However, in doing so it is necessary to show feasibility of such a process based on reputable research from the public domain. For this we turn to work by partners of ESPRIT project SEDRES (Johnson, 1997) and its follow-on SEDRES-2 (Johnson, 2000).

The objective of SEDRES has been to produce a usable and standardised data exchange capability for systems engineering tools, based on STEP (Standard for the Exchange of Product Data - ISO 10303), a framework for the unambiguous representation and exchange of computer-interpretable product data. Johnson (1997) summarises the design benefits of data exchange as follows:- i) support for the movement of data between tools; ii) the possibility of tool-independent data-storage (as opposed to proprietary formats); iii) support for verification and analysis of the emerging design across tool boundaries (something that is currently both difficult and labour intensive); and iv) greater scope for the way in which a design can be viewed (e.g., using data from one or more tools).

To realise these benefits, SEDRES developed a comprehensive information model capturing primitives relevant to systems engineering. The model provides, in conjunction with STEP framework services, what Herzog and Törne (1999) describe as an 'infrastructure' for data exchange. We now briefly describe the SEDRES concepts underlying this infrastructure using a simple scenario (from Harris & Candy [1999]) involving the transfer of information between two tools.

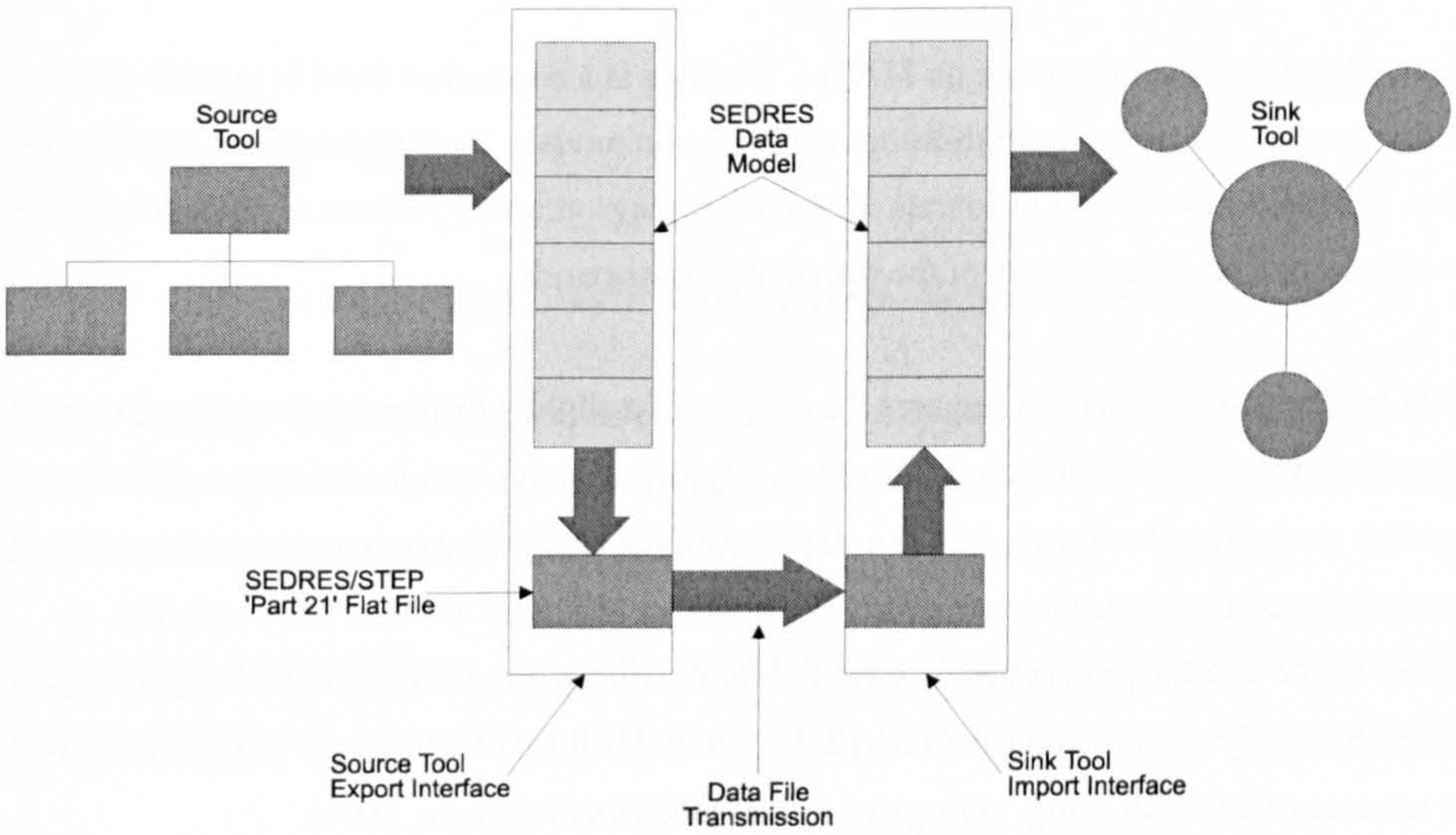


Figure 3.2 - 'SEDRES Data Exchange Concept'

From figure 3.2, it can be seen that SEDRES' export interface maps data from the internal data model of a source tool, onto the SEDRES model - its boundary of influence on MATrA - and thence into a flat ASCII file (or "Part 21" in STEP terminology) for transmission to a receiving or 'sink' tool. The import

interface of the receiving tool then maps this file onto the SEDRES model and thence onto its own internal representation. For further consideration of these concepts, readers are referred to Johnson (1998) and Johnson *et al.* (1999).

The SEDRES data model is represented in EXPRESS (the standard language for STEP) and divides into several loosely coupled Units of Functionality (UoF). These include the following (readers are referred to Herzog & Scerri (1998) for the details on each):-

- The *Requirements* UoF contains entities for representing requirements, the system under specification and allocation of requirements onto systems, functions, behaviour specifications, etc.
- The *Functional Architecture* UoF contains entities for representing composite and leaf functions. These can be assigned to physical elements realising the specified functionality. Support for recording how and with which external functions a system interacts is also provided.
- The *Physical Architecture* UoF contains entities for the specification of physical system objects, including physical component and data link definitions, physical context definition and physical ports (defining the component interfaces).
- The *Configuration Management* UoF contains entities supporting version and variant management. A mechanism for object-grouping (or 'packaging') is also provided.

3.2.2.1 SEDRES Influence

The Functional and Physical Units of Functionality provided a steer in developing a model to verify consistency across the MATrA Workspace (subsection 3.3.5), while the Configuration Management UoF has influenced our means of managing versions (described in subsection 5.5).

However, SEDRES' main influence on MATrA has been at a conceptual level in providing evidence of the ability to map data from CASE tools onto information models. In confirming that this *is* indeed possible, SEDRES has enabled us to treat all such mappings at a very abstract level (subsection 3.3.4) and to concentrate on other aspects of the traceability framework.

It should be stressed that MATrA requires the support of a slightly different form of 'tool-to-model' mapping to that shown in figure 3.2. Rather than mapping a source tool model onto a generic information model (as illustrated), MATrA depends on the ability to map a source tool model onto a corresponding notation dependent structure. We note that SEDRES also has this capability, as evidenced by the fact the project has produced several working implementations of import/export interfaces. Similarly, recall from subsection 2.3.2.1 that this form of one-to-one mapping is possible in recent releases of DOORS using 'surrogate' formal modules (Telelogic, 2001).

3.2.3 Design Rationale Capture System (DRCS)

The origins of our approach to maintaining consistency across the MATrA Workspace stem from the Design Rationale Capture System - DRCS a (higher-order cross-referencing) technique for expressing

argumentation over an emerging design (Klein, 1993a). We have been particularly influenced, not by means to record the arguments themselves, but by the way in which they are placed in context. Recall from 1.4.6.1 that early models of this type were criticised for being detached from their subject matter; i.e., they merely structured elements of an argument (claims, issues, positions, etc.) and not the artifacts over which they were being expressed. What sets Klein's approach apart is the use of a top-down representation of fundamental system elements as a basis for expressing decision rationale.

DRCS is constructed from a decision rationale language which provides a vocabulary of assertions about a system and its components. The vocabulary includes a pre-defined set of entities, and claims relating them. Klein divides DRCS into a number of self-contained information structures (connected through common entities), each focusing on a particular aspect of development information.

The *Artifact Synthesis* structure (figure 3.3) records the physical system architecture. Basic entities include modules, attributes, interfaces and connections. Modules can have sub-modules or specialisations, while attributes can have values expressed over them. The DRCS vocabulary represents these features using claims such as *has-attribute*, *has-interface*, *has-value*, etc.

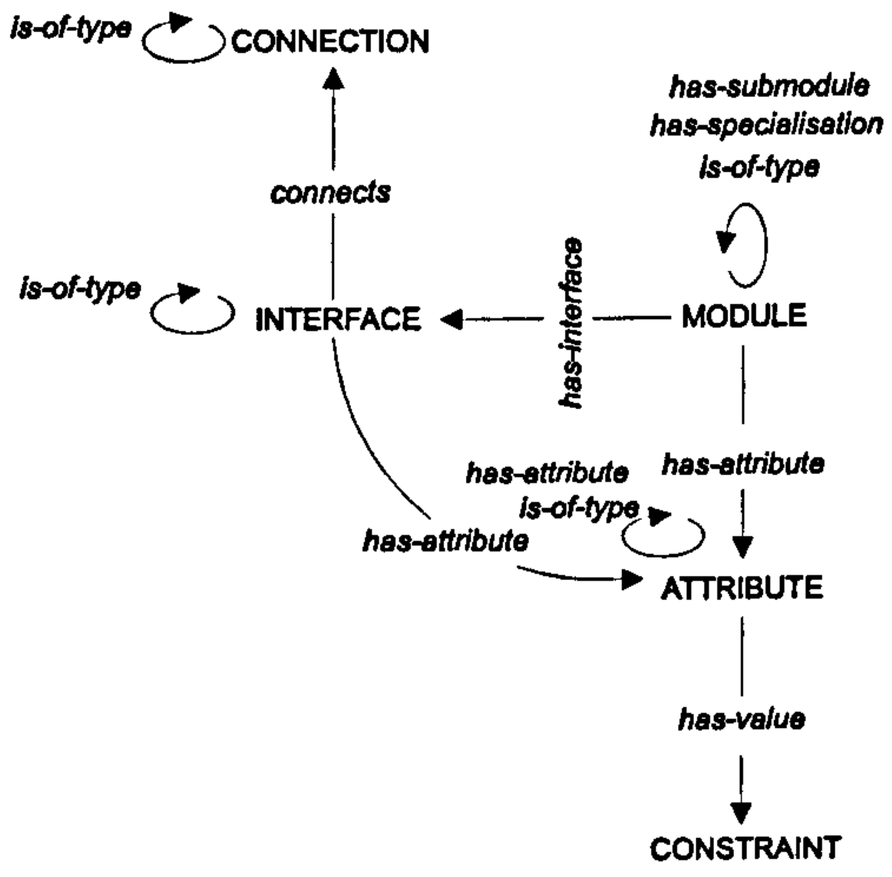


Figure 3.3 - 'DRCS Artifact Synthesis Structure'

The rationale language (figure 3.4) embodies a set of question-spaces proposed by Lee (1991). It includes the following structures for expressing various aspects of rationale over *Artifact Synthesis* components (abstracted into the claim entity in the figure):-

- The *Evaluation* structure (figure 3.4A) links requirement specifications to the versions that achieve them over *achieves* and *best-achieves* associations[1]. Both can have absolute or relative priorities.

- The *Version* structure (figure 3.4B) captures alternatives for a decision-problem, with the chosen option represented by an *is-best-option-for* claim. Versions have a status (abandoned, suspended, or conflict), and again can be assigned an absolute or relative priority.

[1] Note requirement usually represents 'attribute-*has-value*-constraint' relationships from the *Artifact Synthesis* (see figure 3.3).

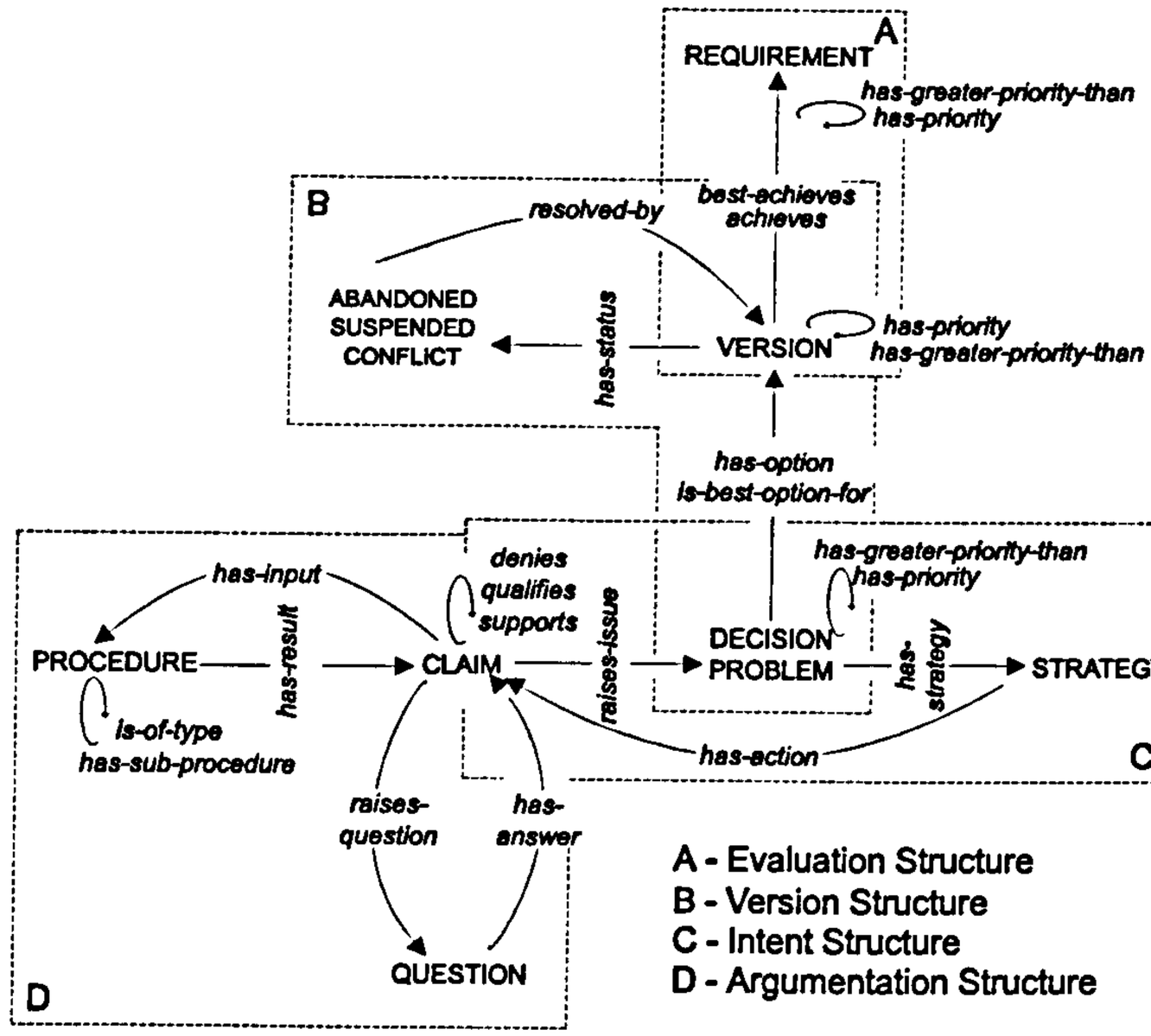


Figure 3.4 - 'Rationale Components of DRCS'

- The *Intent* structure (figure 3.4C) relates a decision-problem to both the claim that raised the issue and a strategy to resolve it over *raises-issue* and *has-strategy* relations respectively. Like requirements, decision-problems can have absolute or relative priorities.

- The *Argumentation* structure (figure 3.4D) records beliefs pro and contra to a claim. Questions can be raised about the validity of a claim and answers asserted in response, while *has-result* and *has-input* may be used to link claims to the procedures that derive them and to inputs to those procedures.

3.2.3.1 DRCS Influence

The main DRCS influence has been on development of a model to verify consistency across the MATrA Workspace (subsection 3.3.5) which we base on the Artifact Synthesis structure. However, extensions are necessary as it lacks elements to record functional architecture and behaviour. The literature provides a sound basis for developing these extensions; in particular, works by Pyle *et al.* (1993), Oliver (1994) and Wilson & McDermid (1995) as well as the SEDRES model discussed previously.

Klein's rationale language component highlights an important trade-off between expressive power and usability. Put simply, discussions with practitioners indicate that these structures are too complex for use on real projects. Therefore as part of this work, a single optimised structure composed of fewer elements and capable of use in conjunction with almost any MATrA element has been produced (Appendix B, Part Two).

With the above influences in mind, remaining sections of this chapter set out the fundamental elements of MATrA.

3.3 Fundamentals of MATrA

This subsection introduces the fundamental principles *or* 'building-blocks' of MATrA. Where appropriate, we highlight our scope of interest.

MATrA is an object-based approach to tracing artifacts for the development and assessment of aviation electronics (avionics) systems. It is based on a set of interconnected 'traceability structures' specified using the Class Diagram view of UML, with integrity constraints over these structures expressed in the Object-Constraint Language (OCL). To provide a flavour of tool support, a subset of elements for each structure are embedded in the ConceptBase object management system which implements the O-Telos modelling Language. Alternative representations and tool support are considered in Chapter Seven.

3.3.1 MATrA Fundamentals Overview

MATrA consists of five main principles. For reader orientation, these are introduced below with the details to follow in subsections 3.3.2 through 3.3.6:-

1. A Workspace of *notation dependent structures* (meta-models) representing project data transferred from CASE tools (see 3.3.2).
2. A *Meta-class model* to maintain consistency of definition across Workspace meta-models by providing a common underlying representation (see 3.3.3).
3. A *tool2matra* (tool-to-MATrA) mapping function to provide data transfer from bespoke and commercial CASE tools to the Workspace (see 3.3.4).
4. The *Product Data Synthesis* (PDS), a notation independent structure representing fundamental elements of the emerging system (e.g., components, functions, behaviour, etc.), together with associations describing their composition; it maintains Workspace consistency by preventing 'bad' data from CASE tools entering via *tool2matra* (i.e., preventing data being mapped to a notation dependent structure) unless the PDS contains corresponding data elements, and by preventing violations once the data is 'inside' (see 3.3.5).
5. A *Framework Model* that gathers together MATrA elements to allow common behaviour to be managed more easily. In addition, means to create relations among notation dependent structures, and between these and the PDS are introduced (see 3.3.6).

Note, Workspace and PDS structures are intended for use by avionics engineers, rather than by method engineers who design the procedures that avionics engineers follow[2]. Thus, in confining our scope to modelling and implementation of the structures themselves, we do so in the knowledge that graphical interfaces are necessary to 'hide' these definitions and so render MATrA practical. As evidence of the feasibility of creating these interfaces, we again highlight work within the department (Sukamaran, 1999) and also by the NATURE project which implemented graphical interfaces to various information structures (expressed in O-Telos) using a combination of C++ and the Andrew tool-kit (Pohl, 1996).

---

[2] In this thesis, the term method engineer refers to persons who construct dedicated methods for engineering avionics systems. Avionics engineers then apply these methods to produce avionics systems.

3.3.2 Notation Dependent Traceability Structures (Meta-models)

As previously stated, practitioners use a range of notations to model avionics systems (often in conjunction with a process as part of a technique or methodology). These notations fall into two broad categories: those with a well-defined syntax and semantics (such as Circuit Diagrams and Ada) and those that are less rigorously defined but which offer flexibility as a result (for example Use Cases and Scenarios). Practitioners also require the ability to conduct safety assessment over these models using established techniques for hazard analysis (e.g., Fault Tree and Failure Modes and Effects Analyses). In addition, the scale and complexity of avionics projects normally dictates use of further notations and techniques to aid product management (for instance, Gantt Charts and the Programme Evaluation & Review Technique).

To maintain a tractable scope, we only feature a small subset of notations used throughout the industry drawn from the requirements, design, implementation, safety assessment and product management domains. Selection has been guided not only by their relevance to avionics engineering (determined from the literature, standards and discussions with practitioners), but also by a desire to demonstrate different representation formats (textual, graphical, tabular and program code) and hence tackle the respective modelling challenges presented by each. Featured notations are therefore as follows:-

- *Natural Language Structure* - means to represent informal artifacts (typically constituent parts of other notation dependent structures) at variable and user determined granularities (section 4.2);
- *User Centred Requirements Structure* - means to model functional requirements from a user perspective as Use Case Models, and to describe them using Scenarios and Message Sequence Charts (section 4.3);
- *Real-Time Network Specification Language (RTN-SL) Structure* - means to model architectural designs where concurrent processing components exchange information and synchronise through shared data in the connections (section 4.4);
- *SPARK Ada Structure* - means to model artifacts expressed using the SPARK Ada software implementation language (section 4.5);
- *Fault Tree Analysis (FTA) Structure* - means to model the results of FTA, a deductive safety analysis technique that identifies causes of some hazardous event and allows calculation of a probability of occurrence for that event (section 5.2);
- *Failure Mode and Effects Analysis (FMEA) Structure* - means to capture the results of FMEA, an inductive safety analysis technique that considers the failure of components of a system and tracks their effects to determine the ultimate consequences (section 5.3);
- *Programme Evaluation and Review Technique (PERT) Structure* - means to manage the planning and control of projects which represents relationships between the timing of events and activities as a network (section 5.4).

When developing these structures, we must first establish the concepts to be modelled. Note that most MATrA structures either represent domain specific 'dialects' of less rigorously defined notations, or else rigorously defined notations whose arrangement has been enhanced to reflect domain usage. In both cases the models proposed and the concepts they contain are assumed to correspond to those underlying existing bespoke tools. For well-defined notations without domain enhancements, we make assumptions about the concepts and elements underlying hypothetical COTS tool.

Having identified the relevant concepts for a given notation, a meta-model is created using the Class Diagram view of UML. We then add OCL constraints defining well-formedness and PDS consistency; note with the former, we are guided by the literature for well-defined notations and by our own analysis of constituent elements for flexible notations. PDS checks verify integrity of the *tool2matra* transfer function by stating appropriate invariants for Workspace elements that must hold following its invocation. However, their main purpose is to determine whether consistency is preserved (between the Product Data Synthesis and the traceability Workspace) following changes to the PDS. Finally, we provide a flavour of tool support by encoding base class elements for each structure in the ConceptBase implementation of O-Telos. For reader orientation, subsection 3.3.7 has a worked example developed using the above approach which follows the format used with our featured meta-models in Chapters Four and Five.

3.3.3 MATrA Systems Engineering Notation Meta-class Model

The Systems Engineering Notation Meta-class model (SENM) provides a common basis for describing (and readily extending) notations and techniques supported within the MATrA Workspace. It does so through meta-level class definitions whose instances define the structures and elements of notations featured in 3.3.2. Given that we are defining meta-level classes - i.e., classes whose instances are classes - we use the UML «MetaClass» stereotype.

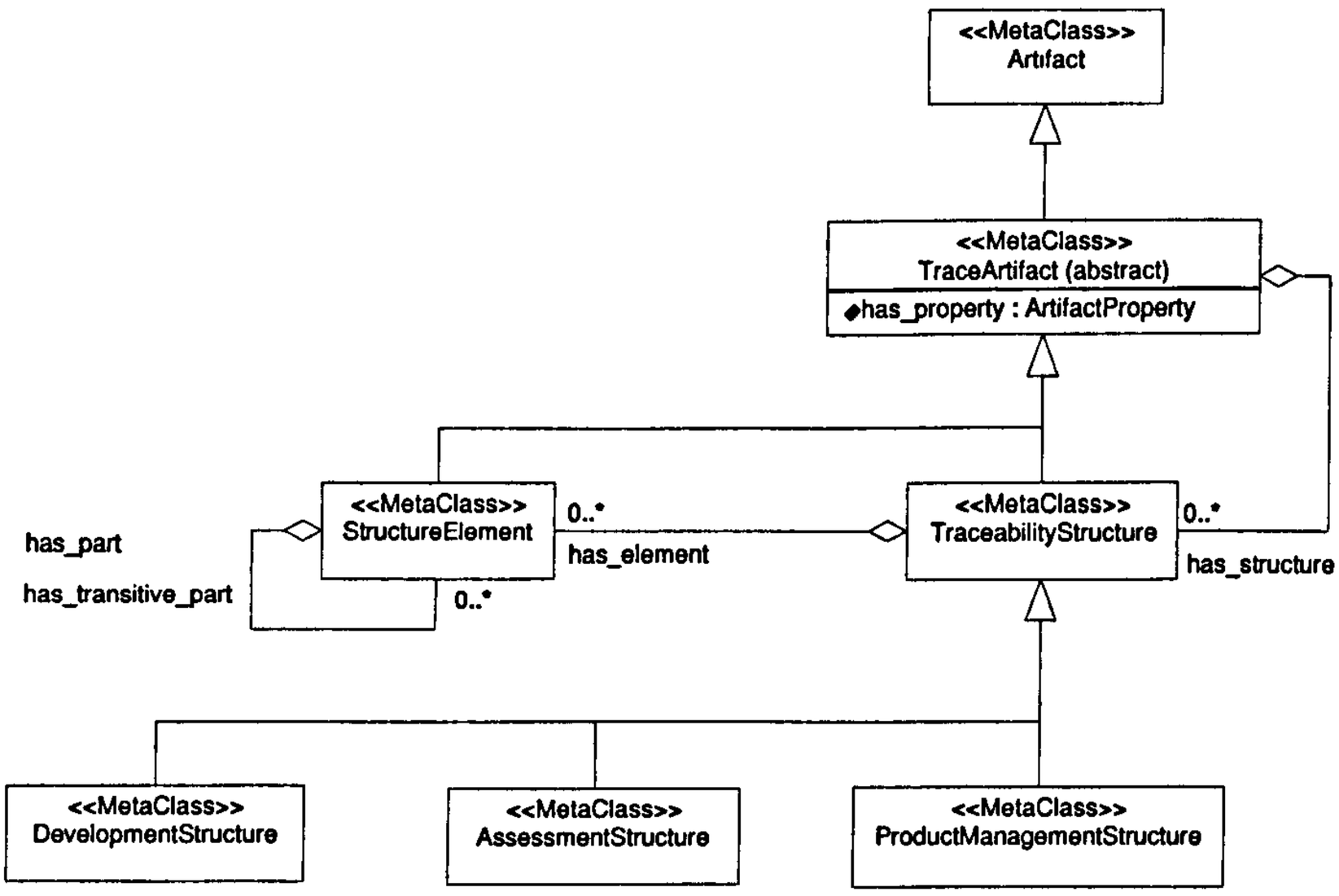


Figure 3.5 - 'MATrA Systems Engineering Notation Meta-class Model'

The model itself (figure 3.5) consists of seven classes organised in a specialisation hierarchy; at its root is the artifact (Artifact) class, whose sole instance is the (abstract) AerospaceEngineeringObject class (see subsection 3.3.6.3.1) which serves to generalise all Workspace structures and elements for ease of manipulation.

Artifact is specialised by trace artifact (TraceArtifact), an abstract class containing the has_property attribute of type artifact property (ArtifactProperty). ArtifactProperty subsumes all predefined types as instances, e.g., String, Integer, Boolean, etc., together with user defined types such as Voltage. Note, we could simply state the latter as an instance of ArtifactProperty and specialisation of Real. However, it is often necessary to compose attribute definitions from other ArtifactProperty types. For example, Voltage could be stated in terms of a voltage attribute of type Real and a unit attribute of type String (with default "V"). Thus the actual definition of ArtifactProperty (see table 3.1) is as an instance of MetaClass with attribute described_by (stated using a reflexive composition association) of type ArtifactProperty.

TraceArtifact is specialised by the traceability structure (TraceabilityStructure) and structure element (StructureElement) classes. These provide the basis for representing all MATrA notation dependent structures such that each traceability structure (or sub-type) is defined as an aggregation of structure elements (over rolename has_element). In addition, TraceArtifact propagates its aggregation association (has_structure) with TraceabilityStructure to both subtypes (so for example decomposition of a DFD Function StructureElement may be represented using a separate model). StructureElement also bears two reflexive aggregation associations (has_part and has_transitive_part), as most of its instances are actually composed of other elements.

TraceabilityStructure is further specialised to differentiate between structures for development (DevelopmentStructure), assessment (AssessmentStructure) and product management (ProductManagementStructure). The ability to distinguish these different 'viewpoints' is convenient for manipulation purposes, in particular for constraining the source and target of associations between traceability structures and elements.

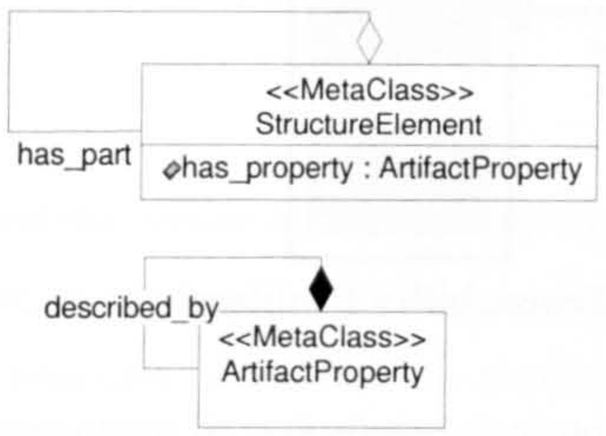
O-Telos implementation of the SENM base classes from figure 3.5 is as follows:-

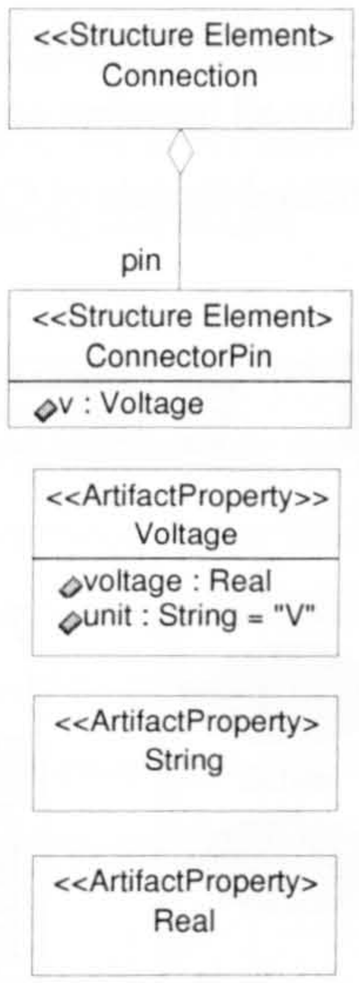
```
Artifact in MetaClass end

ArtifactProperty in MetaClass with
attribute
described_by : ArtifactProperty
end

TraceArtifact in MetaClass isA Artifact
with attribute
    has_property : ArtifactProperty;
    has_structure : TraceabilityStructure
constraint
abstract_TA: $forall t/Token
s/SimpleClass (t in s) ==> not (t in
TraceArtifact)$
end

StructureElement in MetaClass isA
TraceArtifact with attribute
    has_part : StructureElement;
    has_transitive_part :
    StructureElement
end

TraceabilityStructure in MetaClass isA
TraceArtifact with attribute
    has_element : StructureElement
end

DevelopmentStructure in MetaClass isA
TraceabilityStructure
end

AssessmentStructure in MetaClass isA
TraceabilityStructure
end

ProductManagementStructure in MetaClass
isA TraceabilityStructure
end
```

Notice O-Telos' uniform treatment of aggregation relationships and attributes which are both represented using the `with attribute` convention. It is also worth commenting on the information loss from UML to O-Telos, in particular as regards multiplicity. This can however be stated by specifying appropriate constraints (not shown) as described in 2.2.2.2.8.

Table 3.1 clarifies the relationship between UML and O-Telos modelling levels and conventions. It does so by demonstrating specification and instantiation of ConnectorPin and Connection (StructureElement) types for a Circuit Diagram meta-model, to be featured in subsection 3.3.7.

UML		**O-Telos**	

«MetaClass» Level		**Meta Class Level**	`StructureElement in MetaClass with attribute`
			`has_property : ArtifactProperty`
			`has_part : StructureElement`
			`end`
			
			`ArtifactProperty in MetaClass with attribute`
			`described_by : ArtifactProperty`
			`end`

Class Level		**Simple Class Level**	`Connection in StructureElement, SimpleClass with`
			`has_part`
			`pin : ConnectorPin`
			`end`
			
			`ConnectorPin in StructureElement, SimpleClass with`
			`has_property`
			`v : Voltage`
			`end`
			
			`Voltage in ArtifactProperty, SimpleClass with`
			`described_by`
			`voltage : Real`
			`unit : String = "V"`
			`end`
			
			`String in ArtifactProperty`
			`end`
			
			`Real in Artifact Property`
			`end`

Object Level	Not Considered in this Thesis - All Instantiations in O-Telos	**Token Level**	`ExampleConnection in Connection, Token with`
			`pin`
			`pin1 : ExamplePin1`
			`end`
			
			`ExamplePin1 in ConnectorPin, Token with`
			`v`
			`Pin1V : Pin1Voltage`
			`end`
			
			`Pin1Voltage in Voltage, Token with voltage`
			`_Voltage : 100`
			`end`

Table 3.1 - 'Comparison of MATrA Modelling Conventions : UML and O-Telos'

3.3.4 '*tool2matra*' Mapping Function

The difficulty faced by aerospace practitioners in establishing traceability linkages between data stored across disparate CASE tools was indicated at the outset (subsection 1.3); this point is emphasised by figure 3.6. One solution is to transfer data from the tools to a Workspace of notation dependent structures (introduced in 3.3.2) capable of receiving this data. By expressing these structures in a uniform format (i.e., in a common language), links (expressed in the same language as the structures) can be inserted that capture dependencies among data in CASE tools, within the Workspace.

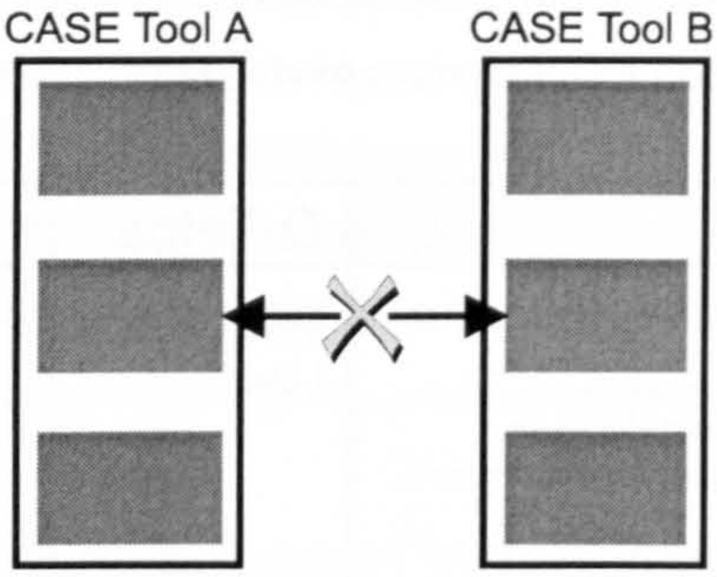


Figure 3.6 - 'Inter-Tool Traceability Problem'

The potential volume of data generated by aerospace projects means that all mappings across the CASE tool/MATrA interface should (as far as possible) be achieved with limited human intervention. In this research we treat the mapping process as a 'black-box', such that all transfers are considered in terms of an undefined function, *tool2matra*, that maps data from the internal models of CASE tools onto notation dependent structures as figure 3.7 illustrates.

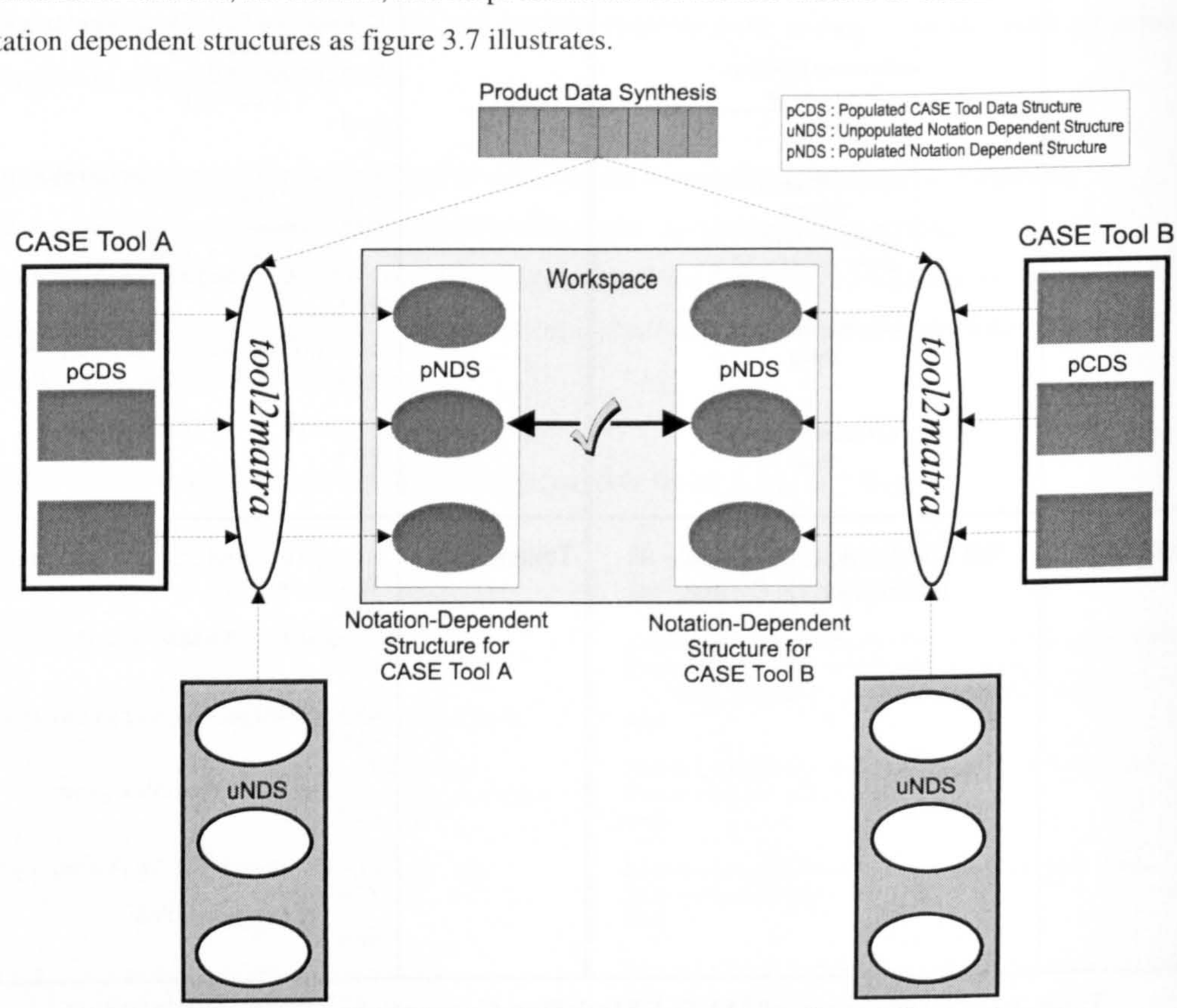


Figure 3.7 - 'Realising Inter-Tool Traceability using *tool2matra*'

The function takes as its input parameters, a populated CASE tool data structure (pCDS) with a corresponding unpopulated notation dependent structure (uNDS) and the Product Data Synthesis (PDS), and returns a populated notation dependent structure (pNDS). The interface to this function may be defined as follows:-

pNDS *tool2Matra* (pCDS, uNDS, PDS)

The resulting Workspace provides an integrated environment allowing traceability linkages to be established between otherwise disjoint data (as shown in figure 3.7); by 'dropping' from CASE tool level into the Workspace, engineers can move around the complete data set wherever traceability links exist - but especially *between* notations. For instance, from a use case in a Use Case Model tool, to an Activity in RTN-SL, to a SPARK Ada package specification - a combination unlikely to be supported at tool level.

It should be stressed that where a 'clean' mapping of elements to the Workspace is not achieved, *tool2Matra* will create an error-log. The reasons for failure are likely to be attributable to bad data detected by PDS cross-checks and due to:- i) misnomer errors on the part of developers when referring to legitimate elements of the target system (caused for example by typos); ii) developers referring to elements of the target system that do not and should not exist; or iii) developers referring to legitimate system elements that have not as yet been added to the Product Data Synthesis. We consider the PDS in more depth in the following subsection.

3.3.5 Product Data Synthesis (PDS)

As subsection 3.3.4 has demonstrated, the Product Data Synthesis plays an important role in MATrA by preventing bad data from entering the Workspace during *tool2matra* mapping. However, it is also required to maintain consistency once data are inside the Workspace, notably following updates to the PDS itself. This is ensured by rules that maintain the integrity of links associating elements of the PDS with corresponding Workspace elements. The links are introduced in subsection 3.3.6.4.4, while constraints on their instances are specified in Chapters Four and Five.

Product Data Synthesis is a notation independent structure populated by engineers with appropriate design authority (see also 7.4.6). It represents fundamental elements of the emerging system and associations between these elements. By fundamental elements we mean generic types for modelling architecture and behaviour, while the associations enable meaningful combination of these elements.

It can be see from figure 3.8 that core PDS constituents are referred to as build elements (BuildElement) and build associations (BuildAssociation)[3], both of which are abstract. Each build association subtype has single source and target build elements. Correct usage (i.e., legitimate combination) of the various element and association subtypes is maintained through appropriate constraints (see 3.3.5.2).

[3] Representing Build Associations as classes allows rationale to be expressed over the claims made by these associations using the structure in Appendix B (Part 2).

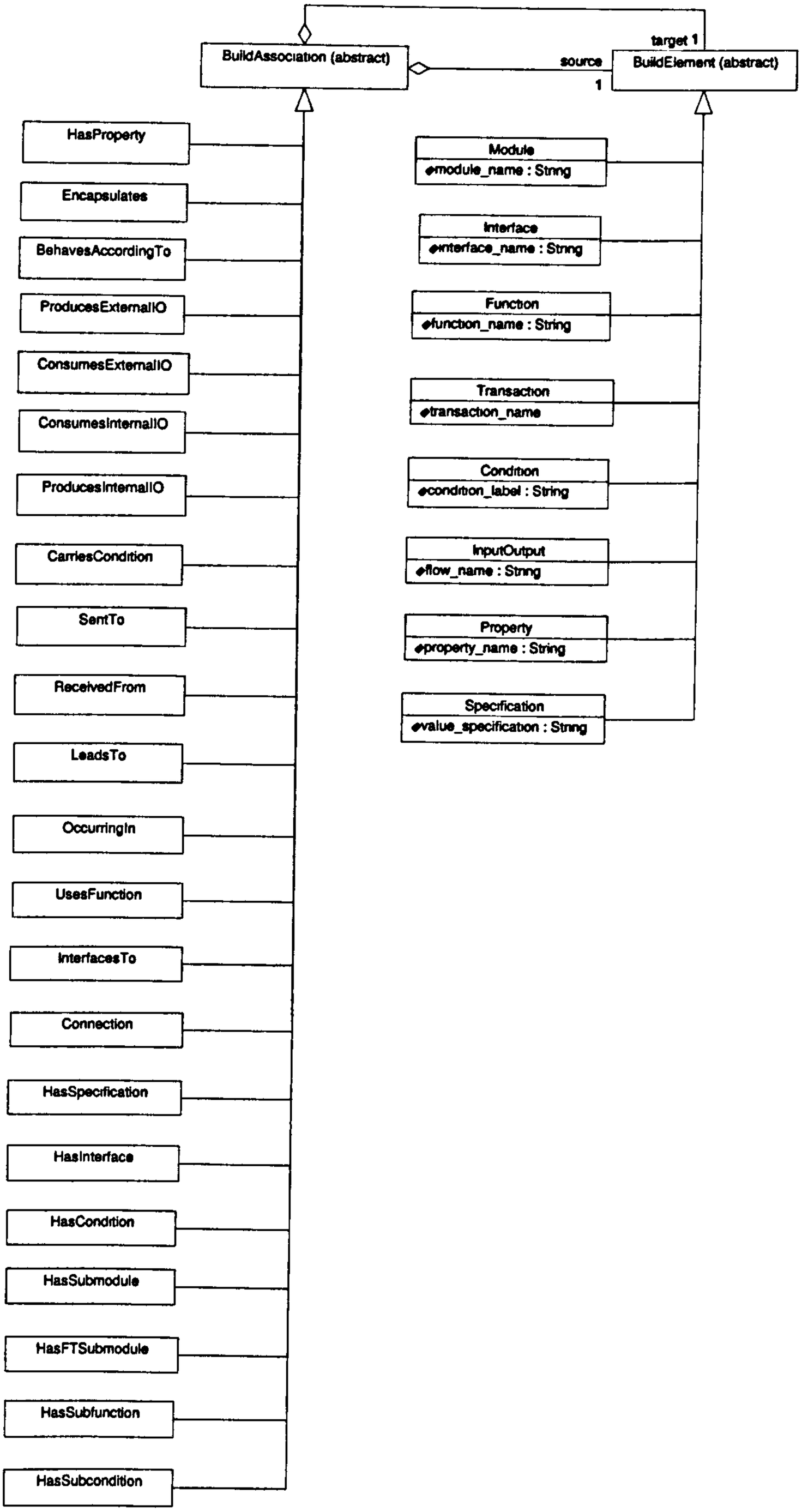


Figure 3.8 - 'Product Data Synthesis Elements'

3.3.5.1 Build Elements

BuildElement is specialised by classes representing modules (Module), interfaces (Interface), functions, (Function), transactions (Transaction), conditions (Condition), input/output (InputOutput), properties

(Property) and specifications (Specification). Module (with attribute module_name of type String) describes a system or 'component' of a system - be it hardware, software or human; modules or functions may be connected via an Interface (with attribute interface_name of type String). The functional architecture of a module is described using the Function element (with attribute function_name of type String); a Transaction (with attribute transaction_name of type String) is a combination of functions that perform some task or unit of work. Flows (energy, material or signals) within and between modules are described using the InputOutput element (with attribute flow_name of type String). Meanwhile, Condition (with attribute condition_label of type String) expresses some "state of affairs" and is a generalisation of state and event[4]. All of the above can be described by the Property element (with attribute property_name of type String), which in turn has a Specification (with attribute value_specification of type String).

3.3.5.2 Build Associations

In the interests of readability, we present build associations permitted between the above build elements in the form of a table (table 3.2).

BuildAssociation	Source	Target
HasProperty	Module	Property
	Function	Property
	Interface	Property
	Transaction	Property
	Condition	Property
	InputOutput	Property
Encapsulates	Module	Function
BehavesAccordingTo	Module	Transaction
ProducesExternalIO	Function	InputOutput
	Module	InputOutput
ConsumesExternalIO	Function	InputOutput
	Module	InputOutput
ConsumesInternalIO	Function	InputOutput
ProducesInternalIO	Function	InputOutput
CarriesCondition	InputOutput	Condition
SentTo	InputOutput	Interface
ReceivedFrom	InputOutput	Interface
LeadsTo	Condition	Condition
OccurringIn	Condition	Condition
UsesFunction	Transaction	Function
InterfacesTo	Module	Module
	Function	Function

[4] The notion of Condition as an abstraction of state and event is taken from Wilson & McDermid (1995)

BuildAssociation	Source	Target
Connection	Interface	Interface
HasSpecification	Property	Specification
HasInterface	Module	Interface
	Function	Interface
HasCondition	Module	Condition
	Function	Condition
	Interface	Condition
	Transaction	Condition
HasSubmodule	Module	Module
HasFTSubmodule	Module	Module
HasSubfunction	Function	Function
HasSubcondition	Condition	Condition

Table 3.2 - 'Product Data Synthesis Build Associations'

Note: we are not claiming this set of build elements and associations is exhaustive, but rather sufficient to demonstrate verification of Workspace elements for the notations featured in Chapters Four and Five.

Most build associations in table 3.2 are self explanatory and based on existing systems engineering literature. HasProperty for example corresponds to the 'has-attribute' association in Klein's work (figure 3.3), but with additional source types to accommodate extensions for behavioural entities; the same is true of HasInterface (whose source types reflect the ability to capture functional as well as physical architectures). Similarly, HasSpecification corresponds to 'has-value', while the notion of module decomposition using 'has-submodule' (HasSubmodule) is extended to fault-tolerant architectures (HasFTSubmodule[5]), functions (HasSubfunction) and conditions (HasSubcondition).

The remaining associations capture behaviour and are mainly derived from work by Oliver (1994). In particular Encapsulates relates modules to functions, BehavesAccordingTo, modules to transactions and UsesFunction transactions to functions. HasCondition meanwhile captures states and events of module, function, interface and transaction entities. Events provide stimuli that are carried in input-output flows (represented by CarriesCondition[6]) and which trigger state changes, denoted using OccurringIn and LeadsTo associations.

Flows within and between systems are recorded through ProducesInternalIO/ConsumesInternalIO and ProducesExternalIO/ConsumesExternalIO[7] respectively; these may be exchanged via interfaces using SentTo and ReceivedFrom. Where two interfaces join to one another, the Connection class is used; if the connection itself is an entity and needs to be modelled as such, then it too is classed as an interface. If

---

[5] This BuildAssociation is based on work by Pearson *et al.* (1998).
[6] This is also compatible with Pyle *et al.* (1993).
[7] The fact that modules can also consume and produce InputOutput enables external entities to be treated as black boxes.

no interface is explicitly stated between two interacting modules or two functions, an InterfacesTo association is employed.

Constraints restricting the source and target of these associations follow a similar pattern. This can be parameterised in the Object Constraint Language[8] as follows:-

```
{BuildAssociation Subtype t} invariant
self.allInstances->forall(t |
(t.source.oclType = {Type S} or t.source.oclType ... ) and (t.target.oclType = {Type T} or t. target.oclType ... ))
```

For instance, the following invariant instantiates these parameters by constraining source and target of Encapsulates associations to Module and Function types respectively:-

```
Encapsulates invariant
self.allInstances->forall(e | e.source.oclType = Module and e.target.oclType = Function)
```

Note: additional rules could be stated over build associations to prevent, for instance, circular dependencies among build elements (e.g., modules containing themselves as sub-modules).

3.3.6 MATrA Framework Model

The Framework Model (figure 3.9) assembles core MATrA elements, many of which are abstract, allowing common behaviour to be managed more easily. Means to create relations between notation dependent structures and to link these to the Product Data Synthesis are also introduced. Elements of the model are described in the subsections that follow.

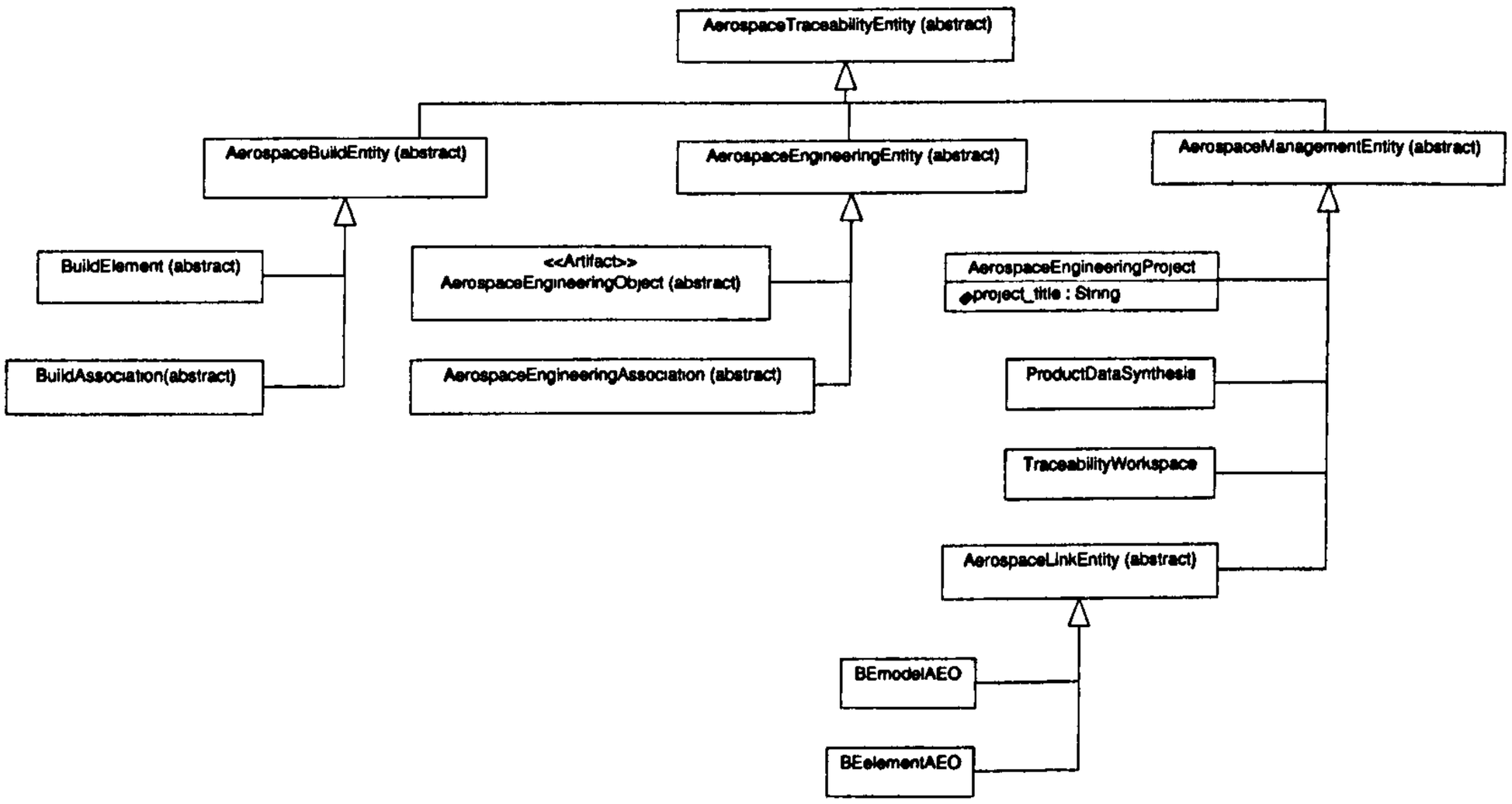


Figure 3.9 - 'MATrA Framework Model Elements'

O-Telos implementation of the base classes in figure 3.9 (along with their associations) appears below:-

[8] Note the { } generalisations are non-standard OCL.

```
AerospaceTraceabilityEntity in
SimpleClass with
constraint
    abstract_ATE: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in
AerospaceTraceabilityEntity)$
end

AerospaceBuildEntity in SimpleClass isA
AerospaceTraceabilityEntity with
constraint
    abstract_ABE: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in
AerospaceBuildEntity)$
end

BuildElement in SimpleClass isA
AerospaceBuildEntity with
constraint
    abstract_BE: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in BuildElement)$
end

BuildAssociation in SimpleClass isA
AerospaceBuildEntity with
attribute
    source : BuildElement;
    target : BuildElement
constraint
    abstract_BA: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in
BuildAssociation)$ end

AerospaceEngineeringEntity in SimpleClass
isA AerospaceTraceabilityEntity with
constraint
abstract_AEE: $ forall t/Token
s/SimpleClass
(t in s) ==> not (t in
AerospaceEngineeringEntity) $ end

AerospaceEngineeringObject in Artifact,
SimpleClass isA
AerospaceEngineeringEntity
with
constraint
abstract_AEO: $ forall t/Token
s/SimpleClass
(t in s) ==> not (t in
AerospaceEngineeringObject) $
end

AerospaceEngineeringAssociation in
SimpleClass isA
AerospaceEngineeringEntity with
attribute
    from_entity :
AerospaceEngineeringEntity;
    to_entity :
AerospaceEngineeringEntity
constraint
    abstract_AEA: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in
AerospaceEngineeringAssociation)$
end

AerospaceManagementEntity in SimpleClass
isA AerospaceTraceabilityEntity with
constraint
    abstract_AME: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in
AerospaceManagementEntity)$
end

AerospaceEngineeringProject in
SimpleClass isA AerospaceManagementEntity
with
attribute
    project_title : String;
    has_pds : ProductDataSynthesis;
    has_workspace :
        TraceabilityWorkspace;
    has_link_entity : AerospaceLinkEntity
end

ProductDataSynthesis in SimpleClass isA
AerospaceManagementEntity with
attribute
    build_entity : AerospaceBuildEntity
end

TraceabilityWorkspace in SimpleClass isA
AerospaceManagementEntity with
attribute
    engineering_entity :
        AerospaceEngineeringEntity
end

AerospaceLinkEntity in SimpleClass isA
AerospaceManagementEntity
with
attribute
    build_element : BuildElement;
    aerospace_engineering_object:
        AerospaceEngineeringObject
constraint
    abstract_ALE: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in
AerospaceLinkEntity)$ end

BEmodelAEO in SimpleClass isA
AerospaceLinkEntity end

BEelementAEO in SimpleClass isA
AerospaceLinkEntity end
```

3.3.6.1 Aerospace Traceability Entity

The root of the Framework is termed aerospace traceability entity (AerospaceTraceabilityEntity) or ATE, an abstract class that generalises every constituent MATrA element. Its presence is motivated by the desire to allow argumentation to be expressed over any of these constituents. This is achieved by placing ATE at the hub of our Argumentation Structure (Appendix B) which optimises the DRCS rationale components from figure 3.4. AerospaceTraceabilityEntity is specialised by aerospace build entity (AerospaceBuildEntity), aerospace engineering entity (AerospaceEngineeringEntity) and aerospace management entity (AerospaceManagementEntity). These are described below.

3.3.6.2 Aerospace Build Entity

AerospaceBuildEntity (ABE) is an abstract class that generalises BuildElement and BuildAssociation from 3.3.5. We use it in modelling the Product Data Synthesis (see subsection 3.3.6.4.2).

3.3.6.3 Aerospace Engineering Entity

AerospaceEngineeringEntity (AEE) is again abstract and is used to model the traceability Workspace (subsection 3.3.6.4.3). It has two subtypes, aerospace engineering object (AerospaceEngineeringObject) and aerospace engineering association (AerospaceEngineeringAssociation) which are described below.

3.3.6.3.1 Aerospace Engineering Object

AerospaceEngineeringObject or AEO (also abstract) instantiates the Artifact meta-class (from 3.3.3). Its subtypes subsume all notation dependent structures and their constituent elements. This is evident from the worked example (3.3.7) and the structures featured in Chapters Four and Five.

3.3.6.3.2 Aerospace Engineering Association

AerospaceEngineeringAssociation (figure 3.10) or AEA is again an abstract class whose subtypes realise traceability between two AEEs (with rolenames from_entity and to_entity), or more specifically, subtypes of the two specialisations of AEE which as indicated in 3.3.6.3 are AerospaceEngineeringObject and AerospaceEngineeringAssociation itself. AEAs can link two AEOs - at either element or model level - or alternatively, an AEO and another AEA (though not two AEAs[9]); the need to connect two associations was highlighted by our featured example in 2.2.2.2.9. As with build associations, correct usage is maintained through constraints (not shown) expressed over AerospaceEngineeringAssociation subtypes.

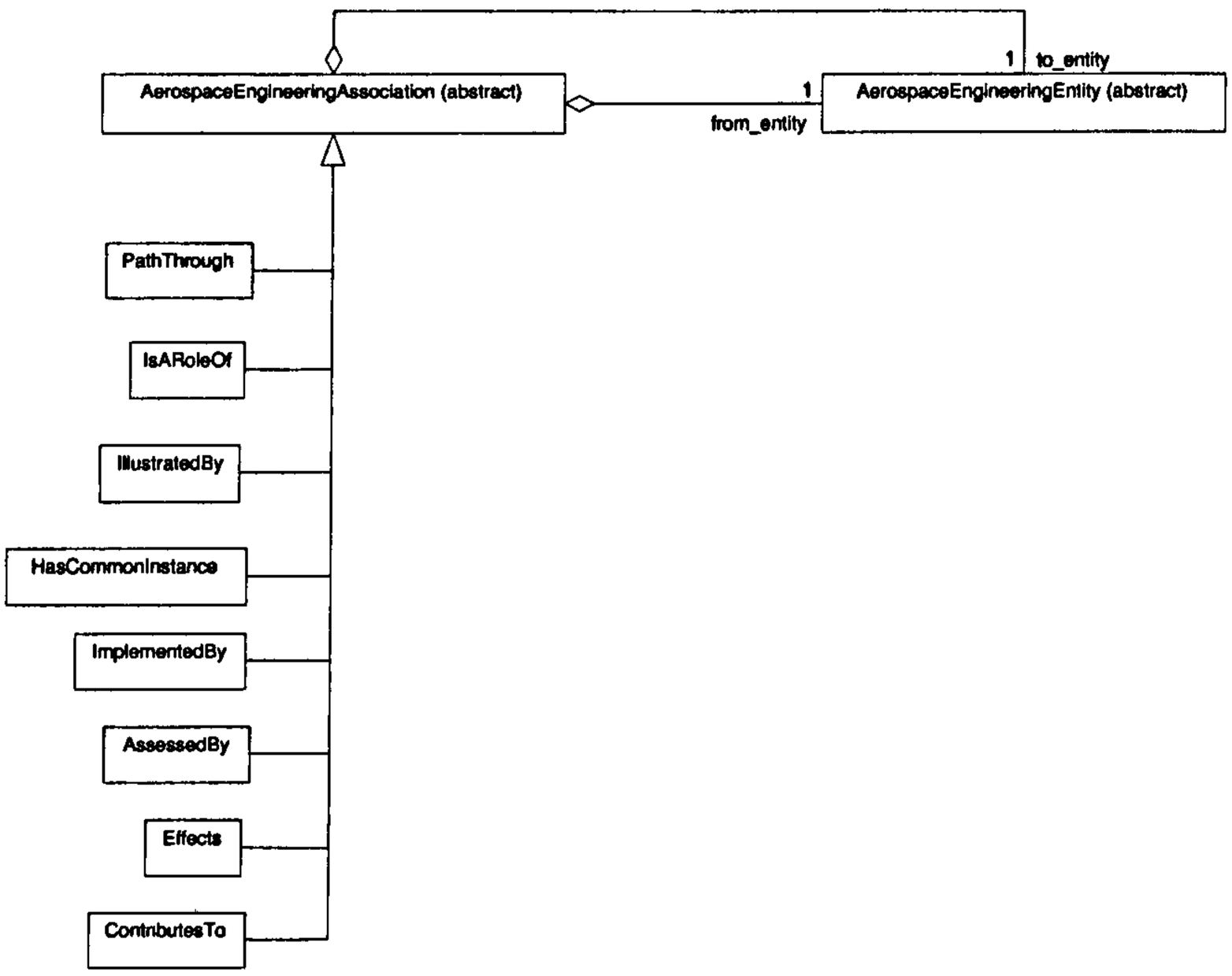


Figure 3.10 - 'Aerospace Engineering Association (and example subtypes)'

[9] This is preserved by a constraint - not shown.

While this thesis concentrates on developing meta-models for notation dependent structures, i.e. the from_entity and to_entity (AEO type) ends of AerospaceEngineeringAssociation subtypes, the case studies in Chapter Six *do* include instances of the examples shown in figure 3.10. We therefore state the O-Telos base classes for these associations to help reader understanding:-

```
Base Classes for AEAs Used in Case Study in Subsection 6.2
PathThrough in SimpleClass isA AerospaceEngineeringAssociation end
IsARoleOf in SimpleClass isA AerospaceEngineeringAssociation end
IllustratedBy in SimpleClass isA AerospaceEngineeringAssociation end
HasCommonInstance in SimpleClass isA AerospaceEngineeringAssociation end

Base Classes for AEAs Used in Case Study in Subsection 6.3
ImplementedBy in SimpleClass isA AerospaceEngineeringAssociation end
AssessedBy in SimpleClass isA AerospaceEngineeringAssociation end
Effects in SimpleClass isA AerospaceEngineeringAssociation end
ContributesTo in SimpleClass isA AerospaceEngineeringAssociation end
```

3.3.6.4 Aerospace Management Entity

AerospaceManagementEntity (AME) is an abstract class, subsuming specialisations for key MATrA elements, namely aerospace engineering project (AerospaceEngineeringProject), Product Data Synthesis (ProductDataSynthesis) and traceability Workspace (TraceabilityWorkspace). In addition, AME includes a further specialisation providing means of linking Workspace and PDS elements through the notion of aerospace link entities (AerospaceLinkEntity). Each of these concepts is described below.

3.3.6.4.1 Aerospace Engineering Project

AerospaceEngineeringProject (AEP) is simply a 'container' for all artifacts relating to a particular project and to that extent, is analogous to a traceability cube (as introduced in subsection 1.4.5). AEP is modelled as an aggregation of a ProductDataSynthesis and a TraceabilityWorkspace, together with linkages between the two described by means of AerospaceLinkEntity subtypes, as indicated in figure 3.11.

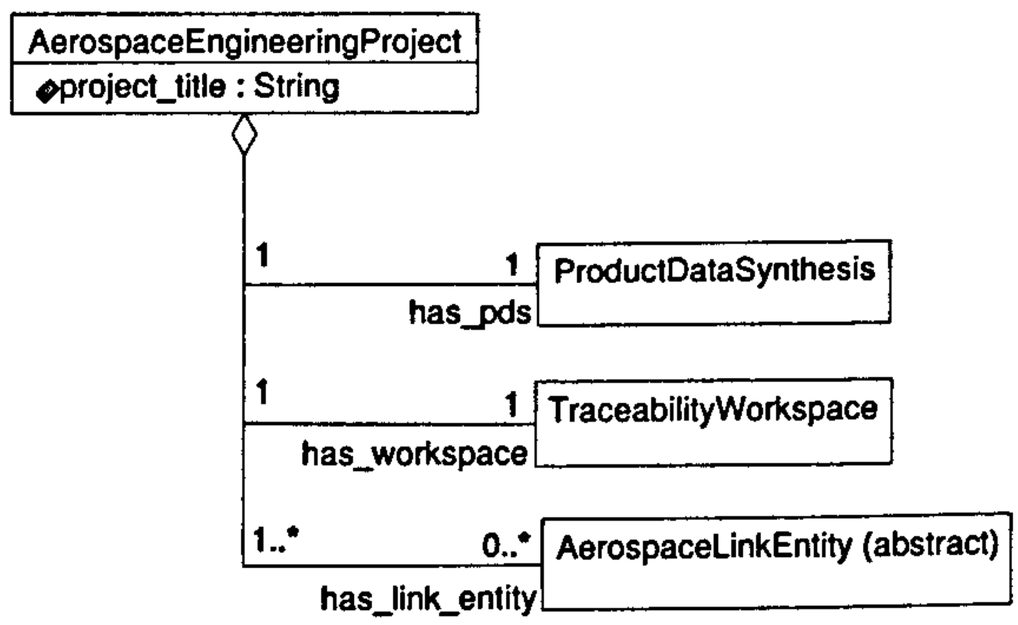


Figure 3.11 - 'Aerospace Engineering Project'

3.3.6.4.2 Product Data Synthesis

ProductDataSynthesis is defined as an aggregation of AerospaceBuildEntity types, as described in subsection 3.3.6.2 (see figure 3.12).

Figure 3.12 - 'Product Data Synthesis'

3.3.6.4.3 Traceability Workspace

Similarly, TraceabilityWorkspace is defined as an aggregation of AerospaceEngineeringEntity types, as described in subsection 3.3.6.3 (see figure 3.13).

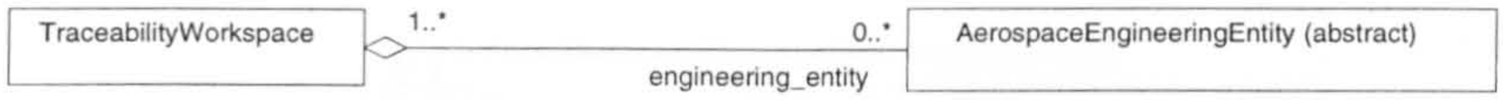


Figure 3.13 - 'Traceability Workspace'

3.3.6.4.4 Aerospace Link Entity

AerospaceLinkEntity (ALE) is an abstract class whose subtypes provide means by which to navigate between the PDS and Workspace. From the Framework Model (figure 3.9), it can be seen that the subtypes in question are BEmodelAEO and BEelementAEO. These represent associations between build elements and meta-models, and between build elements and meta-model elements respectively. Conceptually, this distinction is best illustrated by an example.

In figure 3.14 (A), BuildElement '(BE)X' is linked via a BEmodelAEO association to a Workspace meta-model for which it is the subject[10]. In figure 3.14(B), BuildElement '(BE)Y' is linked over a similar association to another Workspace meta-model in which (BE)X is named as a model element - namely '(ME)X'; (BE)X and (ME)X are therefore related via a BEelementAEO association. Moreover, it can be seen that in the PDS, build element (BE)Y is linked to (BE)X over an (unspecified) BuildAssociation, such as HasSubmodule or HasFunction.

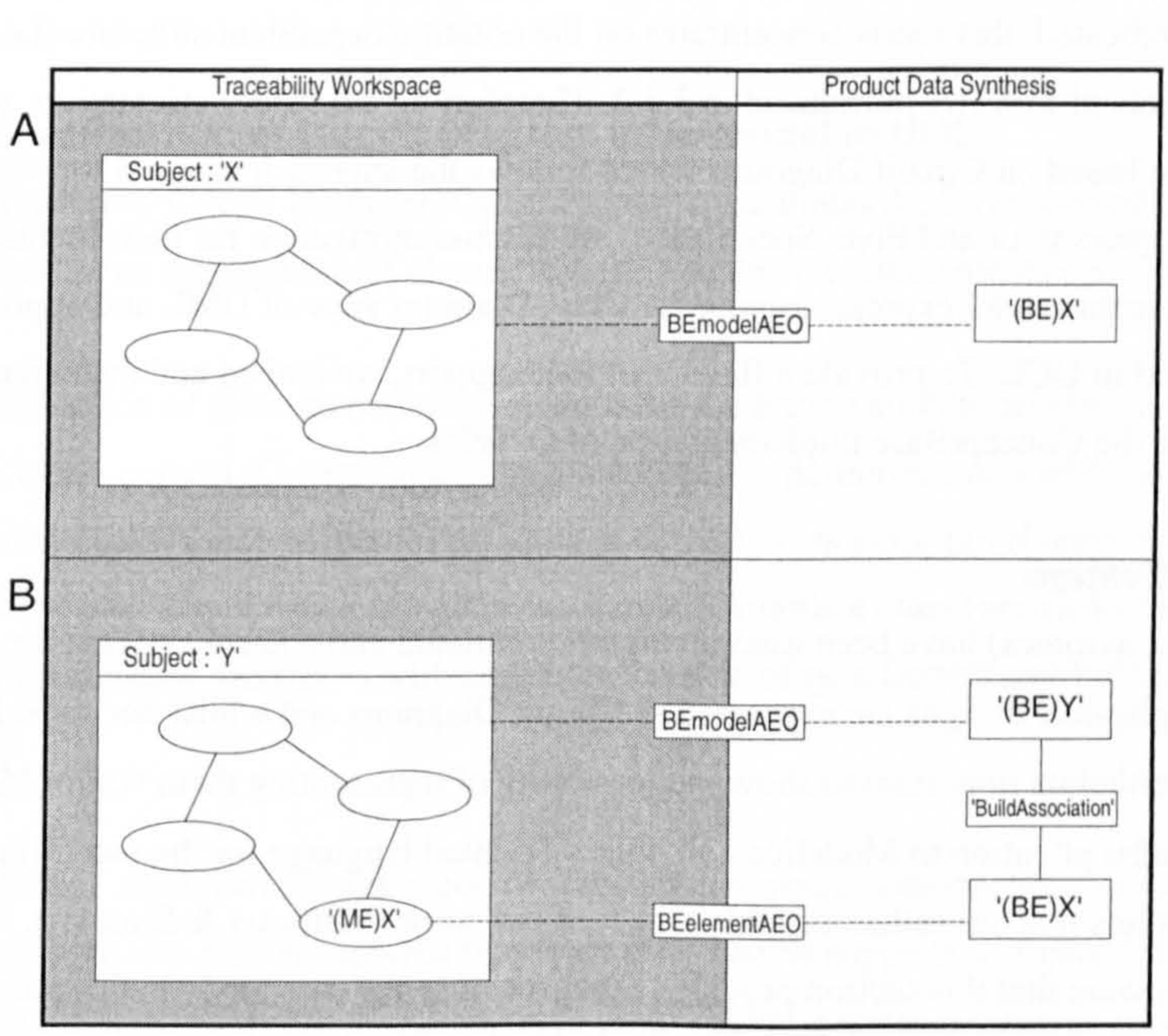


Figure 3.14 - 'Aerospace Link Entity Concept'

[10] It will be seen from Chapters Four and Five that most of the meta-models featured have a subject-module (or similarly named) attribute identifying them with a PDS Module.

Again we choose to simplify the model through a common definition (figure 3.15), with constraints (below) restricting instantiation of the aerospace_engineering_object end to type TraceabilityStructure (or a subtype thereof) for BEmodelAEO associations, and to type StructureElement for BEelementAEO associations.

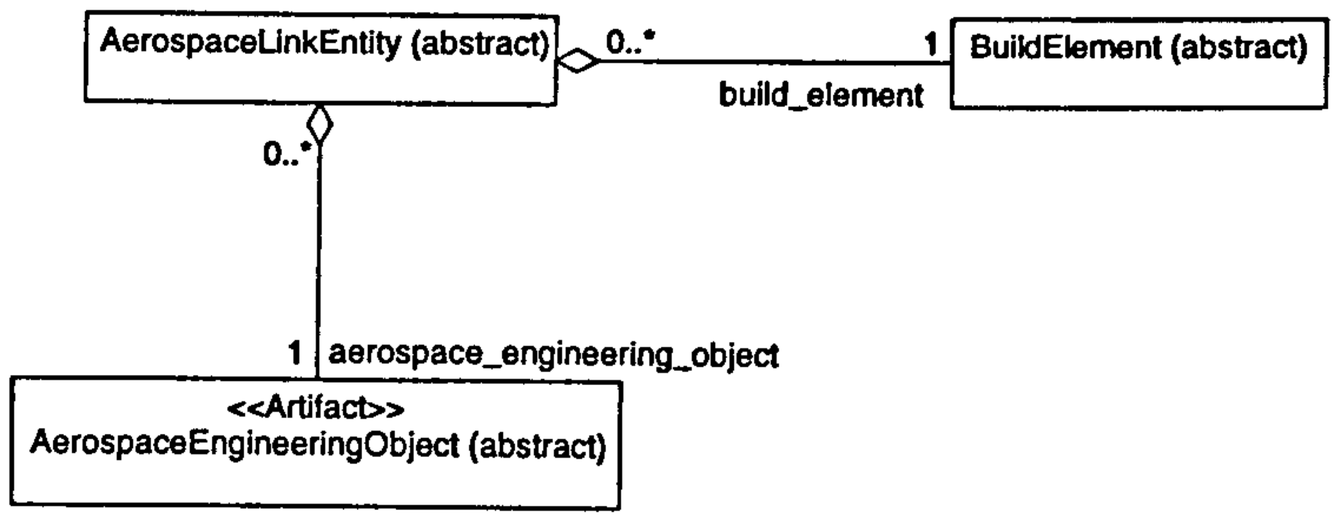


Figure 3.15 - 'Aerospace Link Entity'

BEmodelAEO **invariant**
self.allInstances->forall(b | b.aerospace_engineering_object.oclType.oclType.oclIsKindOf(TraceabilityStructure))

BEelementAEO **invariant**
self.allInstances->forall(b | b.aerospace_engineering_object.oclType.oclType = StructureElement)

3.3.7 Circuit Diagrams: A Meta-model Worked Example

As previously indicated, this thesis concentrates on the notation dependent structure (i.e., meta-modelling) aspects of MATrA introduced in 3.3.2. Therefore to aid reader orientation, we present a worked example based on Circuit Diagrams which follows the approach adopted for our featured notations in Chapters Four and Five. Specifically, we discuss motivation for their inclusion, along with key concepts, a meta-model expressed using the Class Diagram view of UML and appropriate constraints stated in OCL. To provide a flavour of tool support, we embed and instantiate base classes for the model in the ConceptBase implementation of O-Telos.

3.3.7.1 Motivation

Electronics (i.e., avionics) have been used in aircraft command and control systems for over half a century. Their physical designs are expressed as Circuit Diagrams and whilst not considered here in depth, it is nevertheless important to show the feasibility of representing them within MATrA. In doing so, we draw reader attention to Modelica - an object-oriented language for the modelling and simulation of physical systems that has influenced this aspect of our work (Mattsson & Elmqvist, 1998). Readers should also be aware that this section provides background to the case study in Chapter Six (subsection 6.3) which includes a Failure Modes and Effects Analysis of Circuit Diagram components for part of an aircraft braking system.

3.3.7.2 Concepts

Complex electrical circuits may contain a wide range of components. However, our interest is restricted to a small subset necessary to demonstrate the basic wiring schematic in 3.3.7.4, specifically voltage

source, resistor, inductor and capacitor elements[11], together with a ground point. These are connected using a standard pin type interface; for the purpose of this example, we assume each of the above types has two pins (as shown in figure 3.16), p and n, denoting positive and negative - the exception being ground-point, which has a single positive pin. The connection of two pins along a wire forms a node.

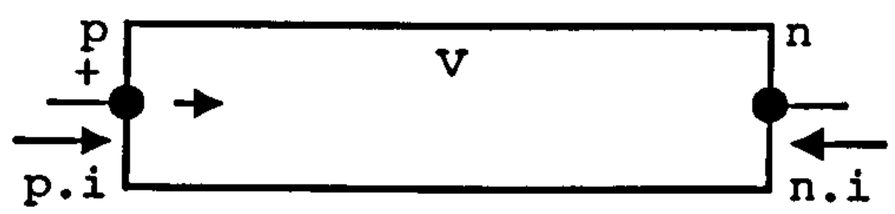


Figure 3.16 - 'Generic Two Pin Electrical Component'

Two basic properties, voltage (v) and current (i) are necessary to define interactions among components connected via wires. These in turn allow calculation of further properties (e.g., the potential difference or 'voltage drop' between the value of v on entering a component at p and leaving at n), along with well-formedness constraints expressing first principles (e.g., Kirchhoff's Current Law requires that the current flowing into a node equals the current flowing out). Therefore besides modelling the basic components, we will also state a number of key invariants.

3.3.7.3 Circuit Diagram Structure (Meta-model)

This section introduces a UML model representing Circuit Diagrams (3.3.7.3.1), together with OCL constraints over elements of the model (3.3.7.3.2) and O-Telos implementation of its base classes (3.3.7.3.3).

3.3.7.3.1 Specification of Circuit Diagram Meta-model in UML

As figure 3.17 illustrates, Circuit Diagram (CircuitDiagram) instantiates the DevelopmentStructure meta-class and is defined as an aggregation of classes representing the circuit elements described above.

We begin our description of these elements by mentioning the basic variables needed to model interaction via a wire - current (Current) and voltage (Voltage)[12] - definitions of which instantiate the ArtifactProperty meta-class. These properties are used in defining connector pin (ConnectorPin), an instantiation of StructureElement which provides our standard interface class (verified against the PDS Interface type for *tool2matra* transfer[13]) with attributes 'i' and 'v' of type Current and Voltage respectively (see figure 3.17).

In turn, ConnectorPin is used towards definition of standard electronic components. For instance, the notion of elements with two pins is captured by the abstract TwoPin superclass (figure 3.18) whose rolenames p and n differentiate positive and negative pins. TwoPin is again defined as an instance of StructureElement with attributes 'pd' - representing potential difference - and 'i' - denoting current into pin

---

[11] We do not explain the detail of these circuit elements here, nor the rules constraining their behaviour; instead, readers are referred to Cogdell (1999).

[12] UML definitions of these classes are omitted from our example, although their O-Telos equivalents are included. Readers can also refer back to Table 3.1 for an indication of how ArtifactProperty types are represented.

[13] In this worked example, we omit the relationship between circuit diagram elements and PDS.

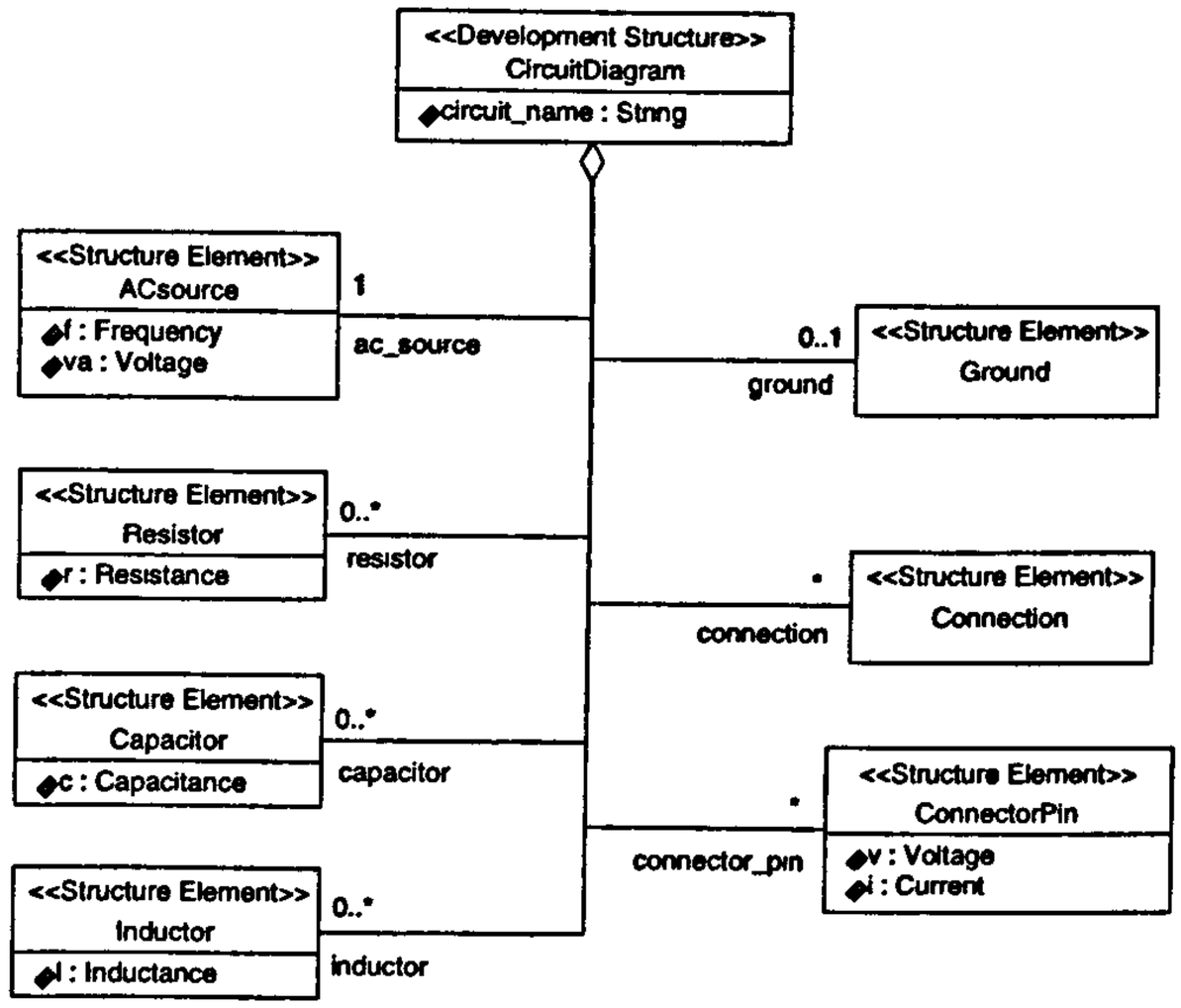


Figure 3.17 - 'Circuit Diagram Structure : Elements'

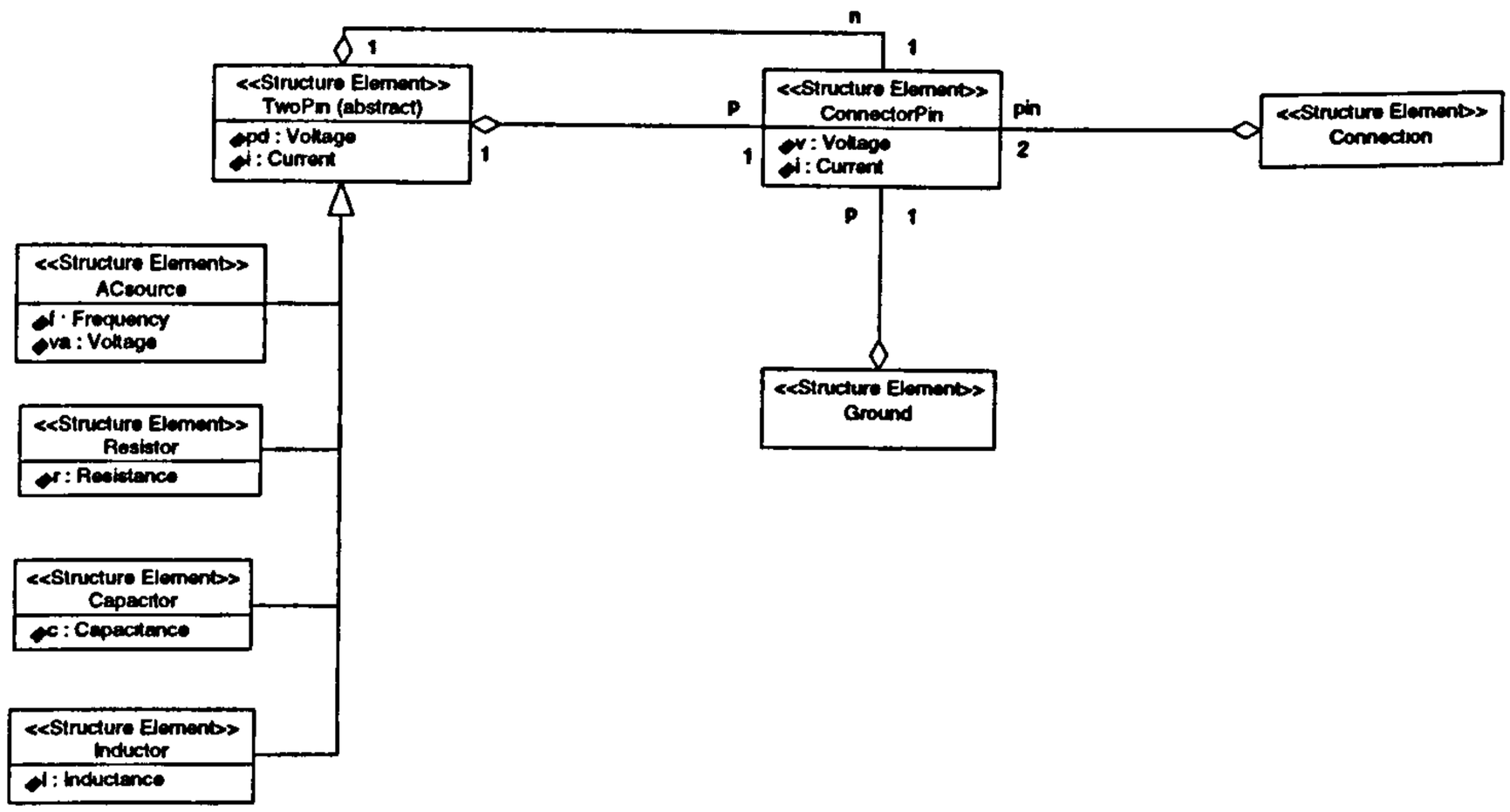


Figure 3.18 - 'Circuit Diagram Structure : Associations'

p, across the component, and out again at pin n (note we state the invariants for these properties in 3.3.7.3.2).

Specialisations of TwoPin may now be defined for specific component types (which map onto Module elements of the PDS) - see figure 3.18. For example, a simple resistor (Resistor) adds an attribute for resistance (r) of type resistance (Resistance). In turn this can be used to express Ohm's law which states that v (potential difference) = i × r (again, see 3.3.7.2.3). Further classes representing AC power source (ACsource), capacitors (Capacitor) and inductors (Inductor) are similarly defined, together with the single pin ground point (Ground) element (all of which instantiate the StructureElement meta-class).

Finally, it is necessary to consider connection of pairs of circuit elements via pins to form nodes. This is

achieved using a Connection class (which also corresponds to Interface in the PDS). Again, invariants are defined in the following subsection to ensure the resulting circuits are well-formed in terms of connecting components with (for instance) compatible voltages.

3.3.7.3.2 OCL Constraints over Circuit Diagram Meta-model

As indicated above, a number of restrictions over elements of the CircuitDiagram meta-model apply. These are expressed as follows:-

Constraints over TwoPin type:-

- Constraint ensuring correct potential difference across a component (i.e., pd equals positive pin voltage minus negative pin voltage).

TwoPin **invariant**
self.allInstances->forall(t | t.pd.voltage = t.p.v.voltage - t.n.v.voltage)

- Constraint ensuring that current flowing into a component at pin p flows out again at pin n (i.e., there is no current loss).

TwoPin **invariant**
self.allInstances->forall(t | t.p.i.current = t.n.i.current)

- Constraint over Resistor ensuring conformance to Ohm's Law (i.e., Potential difference = Current × Resistance):-

Resistor **invariant**
self.allInstances->forall(r | r.pd.voltage = r.r.resistance * r.i.current)

Constraints over Connection type:-

- Constraint to ensure connection of pins with compatible voltages.

Connection **invariant**
self.allInstances->forall(c |
self.pin->forall(p1, p2 |
not (c.pin->includes(p1) and c.pin->includes(p2) and p1.v.voltage <> p2.v.voltage)))

- Constraint expressing Kirchhoff's Current Law (i.e., current into a node equals the current out).

Connection **invariant**
self.allInstances->forall(c |
self.pin->forall(p1, p2 |
not (c.pin->includes(p1) and c.pin->includes(p2) and p1.i.current <> p2.i.current)))

Note, as the complexity of the circuits increases, further and more complex rules and constraints may be defined - for example to identify sneak patterns for use in sneak circuit analysis[14].

[14] Circuit sneaks are caused when current which is expected to flow along a particular path of wires unexpectedly flows in another direction causing systems to malfunction or sub-systems to activate unexpectedly.

3.3.7.3.3 O-Telos Implementation of Circuit Diagram Base Classes

The following O-Telos code implements base class elements for the Circuit Diagram meta-model.

```
Definition of Electrical Measures

Voltage in ArtifactProperty, SimpleClass
with described_by
    voltage : Real;
    unit : String = "V"
end

Resistance in ArtifactProperty,
SimpleClass with described_by
    resistance : Real;
    unit : String = "Ohm"
end

Current in ArtifactProperty, SimpleClass
with described_by
    current : Real;
    unit : String = "A"
end

Capacitance in ArtifactProperty,
SimpleClass with described_by
    capacitance : Real;
    unit : String = "F"
end

Inductance in ArtifactProperty,
SimpleClass with described_by
    inductance : Real;
    unit : String = "L"
end

Frequency in ArtifactProperty,
SimpleClass with described_by
    frequency : Real;
    unit : String = "Hz"
end


Definition of Circuit Primitives

ConnectorPin in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_property
    v : Voltage;
    i : Current
end

Connection in StructureElement,
SimpleClass isA
AerospaceEngineeringObject
with has_part
    pin : ConnectorPin
end

TwoPin in StructureElement, SimpleClass
isA AerospaceEngineeringObject with
has_property
    pd : Voltage;
    i : Current
has_part
    p : ConnectorPin;
    n : ConnectorPin
constraint
    abstract_TwoPin: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in TwoPin)$
end

ACsource in StructureElement, SimpleClass
isA TwoPin with has_property
    f : Frequency;
    va : Voltage
end

Resistor in StructureElement, SimpleClass
isA TwoPin with has_property
    r : Resistance
end

Capacitor in StructureElement,
SimpleClass isA TwoPin with has_property
    c : Capacitance
end

Inductor in StructureElement, SimpleClass
isA TwoPin with has_property
    l : Inductance
end

Ground in StructureElement, SimpleClass
isA AerospaceEngineeringObject with
has_part
    p : ConnectorPin
end


Definition of Circuit Diagram

CircuitDiagram in DevelopmentStructure,
SimpleClass isA
AerospaceEngineeringObject with
has_property
    circuit_name : String
has_element
    ac_source : ACsource;
    resistor : Resistor;
    capacitor : Capacitor;
    inductor : Inductor;
    ground : Ground;
    connection : Connection;
    connector_pin : ConnectorPin
end
```

3.3.7.4 Circuit Diagram Example

We now present an example that instantiates the above model using a simple electrical circuit shown in figure 3.19. The circuit, named "Simple Circuit", comprises six connected components - a voltage source (AC), two resistors (R1 and R2), an inductor (L), a capacitor (C) and a ground point (G).

Note: readers are reminded that in operational circumstances, the O-Telos objects that follow will be created automatically by the *tool2matra* function and 'concealed' from users by an appropriate interface.

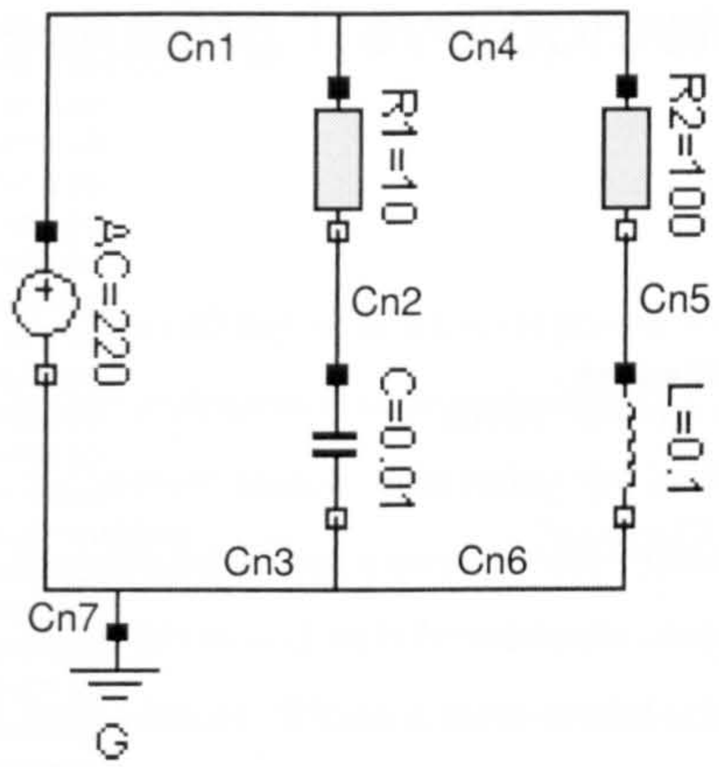


Figure 3.19 - 'Simple Electrical Circuit Diagram (source : Mattsson & Elmqvist, 1998)'

The (partial) O-Telos representation of this Circuit Diagram and its featured components can be stated as follows:-

```
Instantiation of Electrical Measures

ACvoltage in Voltage, Token with
    voltage vlt : 220
end

R1resistance in Resistance, Token with
    resistance rst : 10
end

R2resistance in Resistance, Token with
    resistance rst : 100
end

Ccapacitance in Capacitance, Token with
    capacitance cap : 0.01
end

Linductance in Inductance, Token with
    inductance ind : 0.1
end

Instantiation of Circuit Primitives

ACp in ConnectorPin, Token end

ACn in ConnectorPin, Token end

R1p in ConnectorPin, Token end

R1n in ConnectorPin, Token end

R2p in ConnectorPin, Token end

R2n in ConnectorPin, Token end

Cp in ConnectorPin, Token end

Cn in ConnectorPin, Token end

Lp in ConnectorPin, Token end

Ln in ConnectorPin, Token end

Gp in ConnectorPin, Token end

Cn1 in Connection, Token with
    pin p1 : ACp;
        p2 : R1p
end

Cn2 in Connection, Token with
    pin p1 : R1n;
        p2 : Cp
end

Cn3 in Connection, Token with
    pin p1 : Cn;
        p2 : ACn
end

Cn4 in Connection, Token with
    pin p1 : R1p;
        p2 : R2p
end

Cn5 in Connection, Token with
    pin p1 : R2n;
        p2 : Lp
end

Cn6 in Connection, Token with
    pin p1 : Ln;
        p2 : Cn
end

Cn7 in Connection, Token with
    pin p1 : ACn;
        p2 : Gp
end

AC in ACsource, Token with
    va voltAmplitude : ACvoltage
    p acp : ACp
    n acn : ACn
end

R1 in Resistor, Token with
    r rResistance : R1resistance
    p rp : R1p
    n rn : R1n
end

R2 in Resistor, Token with
    r rResistance : R2resistance
    p rp : R2p
    n rn : R2n
end

C in Capacitor, Token with
    c cCapacitance : Ccapacitance
    p cp : Cp
    n cn : Cn
end
```

```
L in Inductor, Token with
    L lInductance : Linductance
    p lp : Lp
    n ln : Ln
end

G in Ground, Token with
    p gp : Gp
end

Instantiation of Circuit Diagram
SimpleCircuit in CircuitDiagram, Token
with
    circuit_name
    circuitName : "Simple Circuit"
    ac_source
        acSource : AC
    resistor
        resistor1 : R1;
        resistor2 : R2
    capacitor
        capacitor1 : C
    inductor
        inductor1 : L
    ground
        ground1 : G
    connector
        connector1 : ACp;
        connector2 : ACn;
        connector3 : R1p;
        connector4 : R1n;
        connector5 : R2p;
        connector6 : R2n;
        connector7 : Cp;
        connector8 : Cn;
        connector9 : Lp;
        connector10 : Ln;
        connector11 : Gp
    connection
        connection1 : Cn1;
        connection2 : Cn2;
        connection3 : Cn3;
        connection4 : Cn4;
        connection5 : Cn5;
        connection6 : Cn6;
        connection7 : Cn7
end
```

3.3.7.5 Circuit Diagram Example Summary

The above example provides an overview of our approach to representing (in this case graphical) notations used in avionics development. Specifically, it sets out a UML meta-model for Circuit Diagrams, together with some basic OCL constraints and O-Telos implementation of base classes. Given a common representation format such as this, associations (AEAs) can be established to support traceability between various different notations, including those featured in Chapters Four and Five; we demonstrate this aspect in Chapter Six.

3.4 Chapter Summary

Chapter Three described how existing work in the public domain has influenced the development of MATrA. We then provided an overview of key MATrA concepts, including means to represent notations used by aerospace practitioners in a format amenable to traceability (demonstrated by example). This was highlighted as being the main focus of our work and will now be explored in depth through Chapters Four and Five.

Chapter 4 Structuring Development Artifacts

4.1 Introduction

This chapter introduces meta-models (traceability structures) representing well-defined and flexible *development* notations used by avionics engineers that provide input to, and are supported by, the MATrA Workspace. In each case, we present factors motivating the inclusion of a particular notation and a précis of its main concepts. We also introduce a meta-model expressed in UML capturing the main syntactic elements, as well as population and well-formedness constraints stated in OCL and O-Telos implementation of the UML base classes. Where a meta-model is not featured as part of a case study within Chapter Six, then smaller worked examples are provided to demonstrate key aspects. We further relate the models to the traceability dimensions (from Chapter One) as appropriate.

4.2 MATrA Natural Language Structure

4.2.1 Introduction

This section proposes a utility structure allowing the capture and traceability of artifacts expressed using natural language. Its main function in this thesis is to support the design of other structures, the idea being to replace a standard text String type with an MNLS wherever fine-grained traceability is required.

4.2.2 Motivation

Despite a varied range of graphical abstractions and the continued 'push' from academia towards use of formal methods, artifacts expressed in natural language are still commonplace in aerospace systems engineering (especially in the civil market which is not bound by standards such as DefStan 00-55 [MoD, 1997] which calls for a formal mathematical specification[1]). To render these documents traceable (and allow relationships with other representations), MATrA includes the notion of a Natural Language Structure (MNLS). Though an obvious application is the representation of requirements statements (an issue to which we return in our future work section in 7.4.5), the basic MNLS described here is intended as a utility structure. This utility stems from two key features: i) artifacts can be represented at varying granularities; and ii) the granularity levels are user-determined.

4.2.3 Tracing Textual Artifacts: A Natural Language Structure

4.2.3.1 Concepts

Our approach to the representation of natural language artifacts has been influenced by HYDRA, a model for structuring informal artifacts developed as part of project NATURE (Pohl &, Haumer 1995) and based on the hypertext principle of nodes (Conklin, 1987)[2]. Where MNLS differs from HYDRA is that its nodes are 'typed' and can therefore be verified against Product Data Synthesis elements. This in

[1] Subsection 26.1 of Defence Standard 00-55 states that "Formal methods will be the primary means used for the specification and design processes of Safety Related Software, but other methods (for example structured design methods) should be used as appropriate to complement the particular formal method chosen".

[2] HYDRA works over textual descriptions that are marked up and mapped to hypertext nodes which may then be interlinked.

turn means rules may be defined for analysis, as well as raising the possibility of developing specialised models where the content is regulated, as is the case with a structure for specifying Scenarios to be introduced in subsection 4.3.

As with both the Dexter model (Halasz & Schwartz , 1994) and HYDRA, MNLS nodes can be either *composite* or *atomic*. Composite Nodes are used exclusively for structuring and as such contain no user-information; rather they are composed of other nodes (composite and/or atomic). In contrast, atomic nodes are data carrying in the sense that they have some form of information content depending on their type. Those that reference a PDS entry (i.e. are PDS-checked) such as a module, property, function, or condition, etc. contain the name of a corresponding Build Element (which may be '*qualified*' to express 'scope'). Those that don't are designated either as 'non-significant' (in the traceability sense) plain text, or else as null nodes. Strictly, the latter are non-information carrying, but rather a format preserving mechanism to which we return presently.

It is assumed that users enter text into a single atomic node (of type plain-text) via an appropriate interface operating over the structure. It is further assumed that this interface includes operations allowing text fragments to be selected (or 'marked-up') from this single block and then 'split' to create separate nodes[3]. That is, with each split operation, the original node is transformed into three new atomic nodes (grouped by a composite) containing:- i) text *preceding* the selection; ii) the *subject* selection itself; and iii) text *following* the selection. Preceding and following fragments may then be split further to an infinite number of levels, thereby yielding a tree-like structure.

Subject nodes (other than plain text) reference a PDS element and are therefore typed accordingly. Conversely *preceding* and *following* fragments (unless split further) are either plain text, or else null; the latter is used in situations where a subject node has no preceding or following content. For example in the statement 'Fuel System transfer operations are independent from all other ....', Fuel System could be selected as our subject node (a module) even though nothing comes before it; in which case, preceding fragment would be designated null, with the following fragment 'transfer operations ....' as plain text.

One further point; in order to minimise redundancy, we have sought to model the MNLS so that PDS-checked subject nodes exist only once. This assumes that the interface software is able to check whether its underlying object-base already contains an atomic node of the proposed type with the proposed label. For instance, if we were to establish a further structure containing a Fuel System subject (or alternatively to repeat it within the same structure), then the same node created for our previous statement involving this element would simply be reused; i.e., the Fuel System module node would now be part of two structures.

Following definition of the MNLS, we present a brief worked example that provides a 'walk-through' of these concepts at both the physical and logical level.

---

[3] Tools such as DOORS and RTM (sections 2.3.2.1 and 2.3.2.2) allow text to be split in a similar way, normally to separate paragraphs into individual requirements. MNLS seeks to provide a formal basis for artifacts structured using such an approach.

4.2.3.2 Meta-model Definitions

We now introduce the MATrA Natural Language Structure stated in UML (4.2.3.2.1), together with OCL constraints over elements of the model (4.2.3.2.2) and O-Telos implementation of its base classes (4.2.3.2.3).

4.2.3.2.1 MATrA Natural Language Structure Meta-model

Figures 4.1 and 4.2 show elements and associations making up the MNLS meta-model. Its core class, MatraNaturalLanguageStructure instantiates the TraceabilityStructure (rather than DevelopmentStructure) meta-class. This reflects the fact an MNLS may be incorporated into development, assessment or product management artifacts (*cf.* its use to represent pre and post-conditions of the Use Case Model in subsection 4.3 and also the detection column for FMEA tables in 5.3).

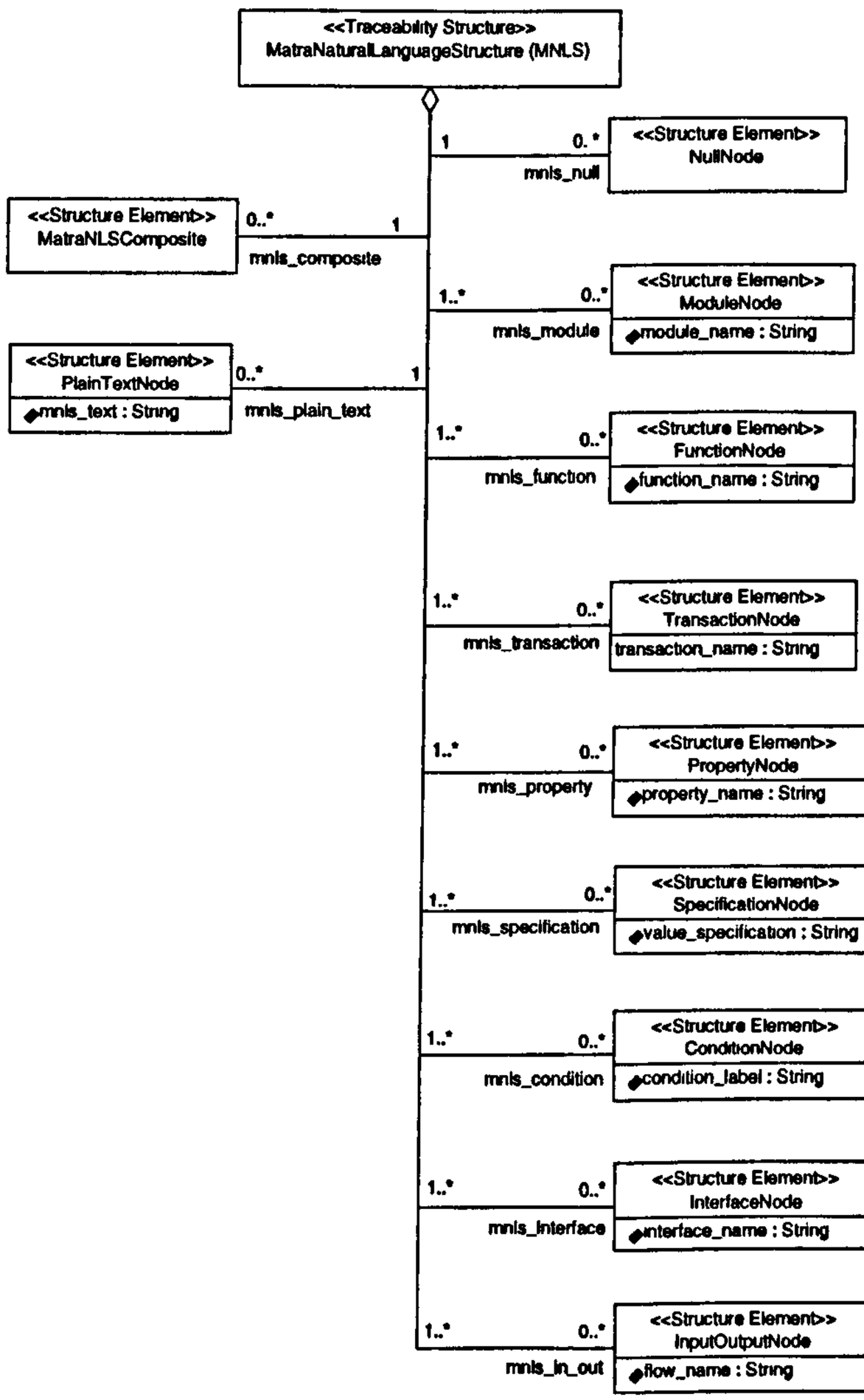


Figure 4.1 - 'MATrA Natural Language Structure : Elements'

A MatraNaturalLanguageStructure is defined as an aggregation of zero-or-more composite nodes (MatraNLSComposite), plain text nodes (PlainTextNode), null nodes (NullNode), module nodes (ModuleNode), function nodes (FunctionNode), transaction nodes (TransactionNode), property nodes

(PropertyNode), specification nodes (SpecificationNode), condition nodes (ConditionNode), interface nodes (InterfaceNode) and input-output nodes (InputOutputNode).

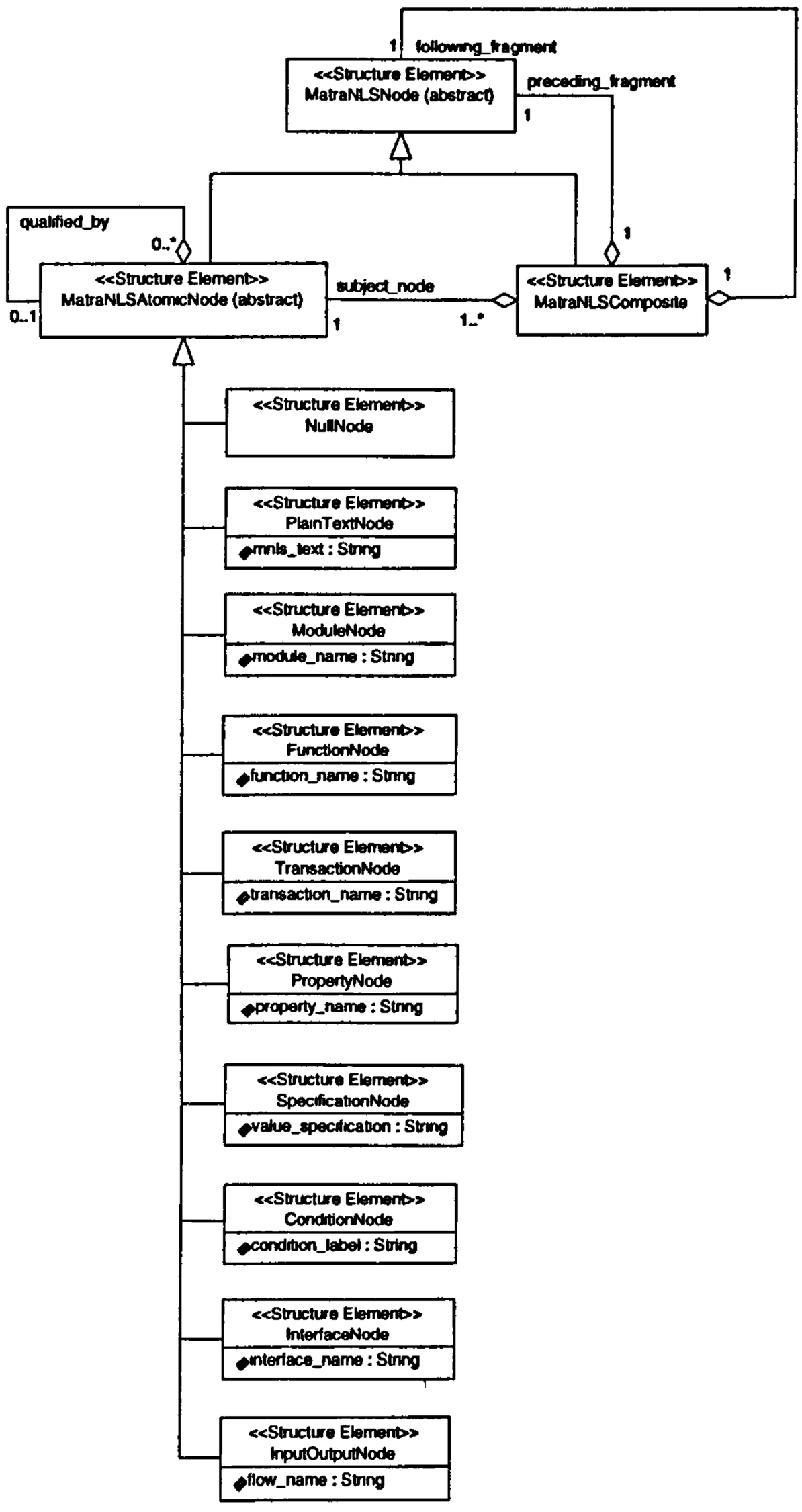


Figure 4.2 - 'MATrA Natural Language Structure : Associations'

Figure 4.2 indicates how these elements (all of which instantiate the StructureElement meta-class) are related. Essentially, NullNode, PlainTextNode, ModuleNode, FunctionNode, TransactionNode, PropertyNode, SpecifcationNode, ConditionNode, InterfaceNode and InputOutputNode are subtypes of the abstract MatraNLSAtomicNode class. All barring NullNode and PlainTextNode have an appropriate property of type String that is cross checked against the Product Data Synthesis (see rule 4.2.3.2.2(1)); PlainTextNode also has a property (mnls_text) which provides a placeholder for non-significant String. To simplify the

modelling, we choose to express the reflexive qualified_by association on MatraNLSAtomicNode and to suppress its use on NullNode using an appropriate constraint (see 4.2.3.2.2(2a))[4]. We do not however do the same for PlainTextNode as this may conceivably have its own qualification (of the same type) to clarify non-significant terms.

MatraNLSAtomicNode is a subtype of the abstract MatraNLSNode, as is MatraNLSComposite; the latter is also defined as an aggregation of MatraNLSAtomicNode type elements over association rolenames preceding_fragment and following_fragment, as well as of subject_node with type MatraNLSAtomicNode (a constraint suppresses use of NullNode as the subject_node - see 4.2.3.2.2(3)). This allows us to model the concepts involved in splitting nodes outlined in 4.2.3.1. Notice that multiplicity on the aggregation side of the subject_node association is one-to-many (again suppressed for the NullNode and PlainTextNode pairing - 4.2.3.2.2(4)), thereby capturing the redundancy minimisation intent also discussed in that section.

4.2.3.2.2 OCL Constraints

We express a small number of possible restrictions over the meta-model from 4.2.3.2.1. These are as follows:-

1. Constraint to ensure that a corresponding BuildElement exists in the PDS for ModuleNode types (similar constraints can be stated for other types of node):-

ModuleNode **invariant**
self.allInstances->forall(m | self.bEelementAEO.build_element->exists(be | m.module_name = be.module_name))

2. The following constraints apply to qualification of Atomic Nodes:-

a) Constraint to prevent qualification of a NullNode.

NullNode **invariant**
self.allInstances->forall(n | n.qualified_by->size = 0)

b) Constraint to force qualification (i.e., scoping) of Property Nodes which may otherwise be ambiguous. Other MatraNLSAtomicNode subtypes can have similar constraints (which may be desirable properties, rather than invariants) though these are not shown.

PropertyNode **invariant**
self.allInstances->forall(p | p.qualified_by->size = 1)

c) Constraint to prevent nonsensical qualification; e.g., a module qualified_by a property (again this is just one possible example of such a constraint - at the very least a comparable constraint inhibiting NullNode qualifiers is required).

ModuleNode **invariant**
self.allInstances->forall(m | not m.qualified_by.oclType = PropertyNode)

---

[4] Whilst this means that NullNode is strictly not a specialisation of MatraNLSAtomicNode, treating it as such removes the need for further type-preserving abstract classes.

d) Constraint to ensure qualifiers are correct; e.g., where a module qualifies a property, then the PDS must contain a BuildElement of type Module defined with that particular Property.

PropertyNode **invariant**
self.allInstances->forall(p |
self.qualified_by->select(oclType = ModuleNode)->not exists(m |
p.qualified_by->includes(m) and
m.bEelementAEO.build_element.hasProperty.target.property_name
->not includes(p.property_name)))

3. Constraint that a MatraNLSComposite subject_node is not of type NullNode, and that preceding_fragment and following_fragment are either of type NullNode or PlainTextNode, or else are a MatraNLSComposite.

MatraNLSComposite **invariant**
self.allInstances->forall(c |
c.subject_node.oclType <> NullNode and
(c.preceding_fragment.oclType = PlainTextNode or c.preceding_fragment.oclType = NullNode or
c.preceding_fragment.oclType = MatraNLSComposite) and
(c.following_fragment.oclType = PlainTextNode or c.following_fragment.oclType = NullNode or
c.following_fragment.oclType = MatraNLSComposite))

4. Constraint further restricting multiplicity to one (rather than 1..* as shown on the Class Diagram) on the aggregate side of MatraNLSComposite for NullNode and PlainTextNode types.

MatraNLSAtomicNode **invariant**
self.allInstances->forall(c | not ((c.oclType = NullNode or
c.oclType = PlainTextNode) and c.matraNLSComposite->size > 1))

5. Constraint to enforce uniqueness of ModuleNode elements; similar constraints (not shown) apply to other PDS-checked node types.

ModuleNode **invariant**
self.allInstances->forall(m1, m2 | not (m1 <> m2 and m1.module_name = m2.module_name))

4.2.3.2.3 O-Telos Implementation of MNLS Base Classes

The following O-Telos code implements base classes for the meta-model in subsection 4.2.3.2.1:-

Definition of MNLS Constituents

```
MatraNLSNode in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
constraint
abstract_Nde: $ forall t/Token
s/SimpleClass
(t in s) ==> not (t in MatraNLSNode) $
end

MatraNLSAtomicNode in StructureElement,
SimpleClass isA MatraNLSNode with
has_part
    qualified_by : MatraNLSAtomicNode
constraint
abstract_Atn: $ forall t/Token
s/SimpleClass
(t in s) ==> not (t in
MatraNLSAtomicNode) $
end

MatraNLSComposite in StructureElement,
SimpleClass isA MatraNLSNode with
has_part
    preceding_fragment : MatraNLSNode;
    subject_node : MatraNLSAtomicNode;
    following_fragment : MatraNLSNode
end

PlainTextNode in StructureElement,
SimpleClass isA MatraNLSAtomicNode with
has_property
    mnls_text : String
end

NullNode in StructureElement, SimpleClass
isA MatraNLSAtomicNode end

ModuleNode in StructureElement,
```

```
SimpleClass isA MatraNLSAtomicNode with
has_property
    module_name : String
end

FunctionNode in StructureElement,
SimpleClass isA MatraNLSAtomicNode with
has_property
    function_name : String
end

TransactionNode in StructureElement,
SimpleClass isA MatraNLSAtomicNode with
has_property
    transaction_name : String
end

PropertyNode in StructureElement,
SimpleClass isA MatraNLSAtomicNode with
has_property
    property_name : String
end

SpecificationNode in StructureElement,
SimpleClass isA MatraNLSAtomicNode with
has_property
    specification : String
end

ConditionNode in StructureElement,
SimpleClass isA MatraNLSAtomicNode with
has_property
    condition_label : String
end

InterfaceNode in StructureElement,
SimpleClass isA MatraNLSAtomicNode with
has_property
    interface_name : String
end

InputOutputNode in StructureElement,
SimpleClass isA MatraNLSAtomicNode with
has_property
    flow_name : String
end
```

Definition of MNLS

```
MatraNaturalLanguageStructure in
TraceabilityStructure, SimpleClass isA
AerospaceEngineeringObject with
has_element
    mnls_composite : MatraNLSComposite;
    mnls_plain_text : PlainTextNode;
    mnls_null : NullNode;
    mnls_module : ModuleNode;
    mnls_function : FunctionNode;
    mnls_transaction : TransactionNode;
    mnls_property : PropertyNode;
    mnls_specification :
SpecificationNode;
    mnls_condition : ConditionNode;
    mnls_interface : InterfaceNode;
    mnls_in_out : InputOutputNode
end
```

4.2.3.3 Worked Example

Extensive application of the MATrA Natural Language Structure is demonstrated by the case studies in sections 6.2 and 6.3. However, to provide an overview of the structure at both a logical (i.e. user) level and a physical level (i.e., the underlying mechanics), we 'walk-through' an example based on a simple requirement statement. Note that in this thesis, MNLS is considered in terms of its integration with other structures, such as Use Case and Failure Modes & Effects Analysis. Whilst the following demonstrates a potential application to requirements specification, our research indicates the need for a dedicated requirements structure with additional features and verification rules. This is acknowledged as an area for future work and discussed in subsection 7.4.5.

Meantime, consider the following statement. It contains several fragments that can be usefully extracted (in the sense of being transformed into separate formal objects) for traceability purposes:-

"Total-Fuel-Capacity shall be >= 195,000 litres of useable fuel'

In this case, we choose to demonstrate non-sequential[5] splitting of nodes such that the engineer first selects the '>= 195,000 litres' text-fragment, which will become a SpecificationNode. This action destroys the initial atomic node creating in its place a composite C_1 comprising three atomic nodes - C_1A_p, C_1A_s and C_1A_f[6]. These contain the text before the marked section ('The Total-Fuel-Capacity shall-be '), the marked section itself (>= 195,000 litres[7]) and the text following the marked section (' of

[5] In the sense that process does not follow a strict left-to-right pattern.
[6] The subscripts $_p$, $_s$ and $_f$ denote preceding, subject and following nodes.
[7] Note, this assumes that Specification may be *written* to and contrasts with the other BuildElement types which simply provide an integrity check for 'incoming' data (i.e to the Traceability Workspace) transferred from CASE tools.

useable fuel.'). A Commentary (of type PlainTextNode - C_1A_fQ) is then attached to C_1A_f qualifying exactly what is meant by the term 'useable fuel'. This is summarised in figure 4.3.

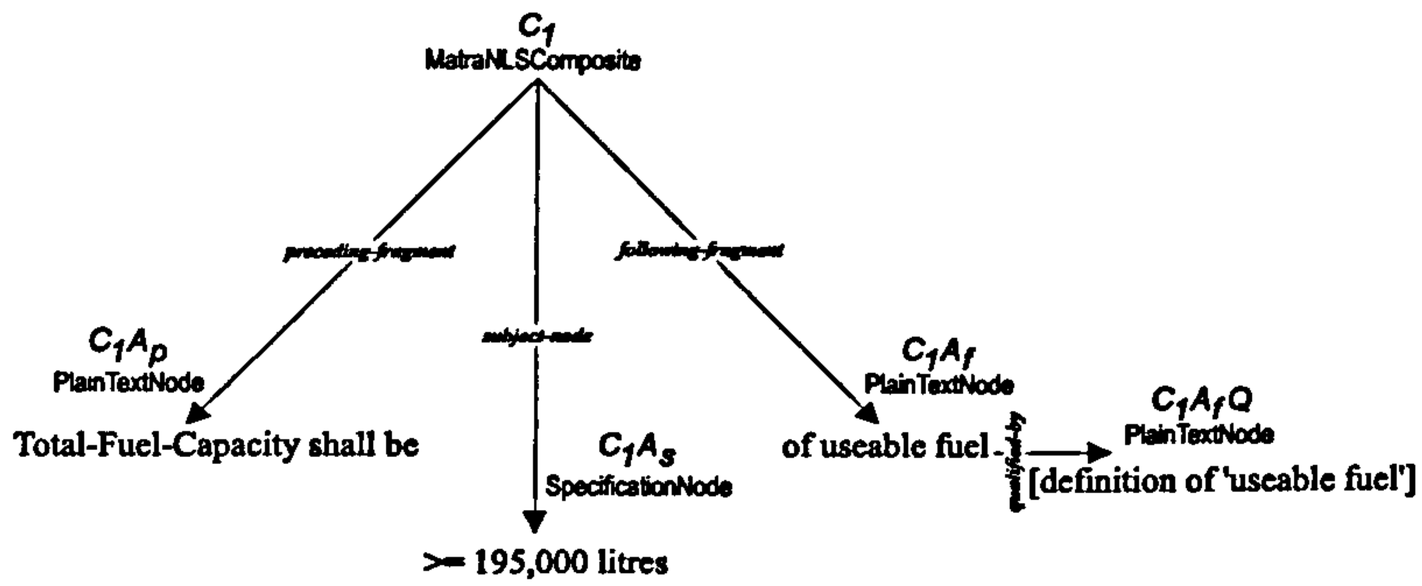


Figure 4.3 - 'MNLS Sample Population : Node Splitting Stage 1'

Next, the engineer selects the property 'Total-Fuel-Capacity', which as previously indicated is now part of C_1A_p. Once again, this node is destroyed and superseded by a composite C_2 made up of atomic nodes C_2A_p, C_2A_s and C_2A_f where C_2A_s (containing the Total-Fuel-Capacity fragment) is demarcated as being of type PropertyNode.

Note that C_2A_p becomes a null node which, as stated previously, occurs wherever the marked selection is located at the beginning (as is the case here) or end of a text fragment, whilst C_2A_f contains the PlainTextNode 'shall-be '. The Total-Fuel-Capacity PropertyNode is also qualified (see C_2A_sQ) by specifying its host module, in this case 'Fuel System'. This is summarised in figure 4.4.

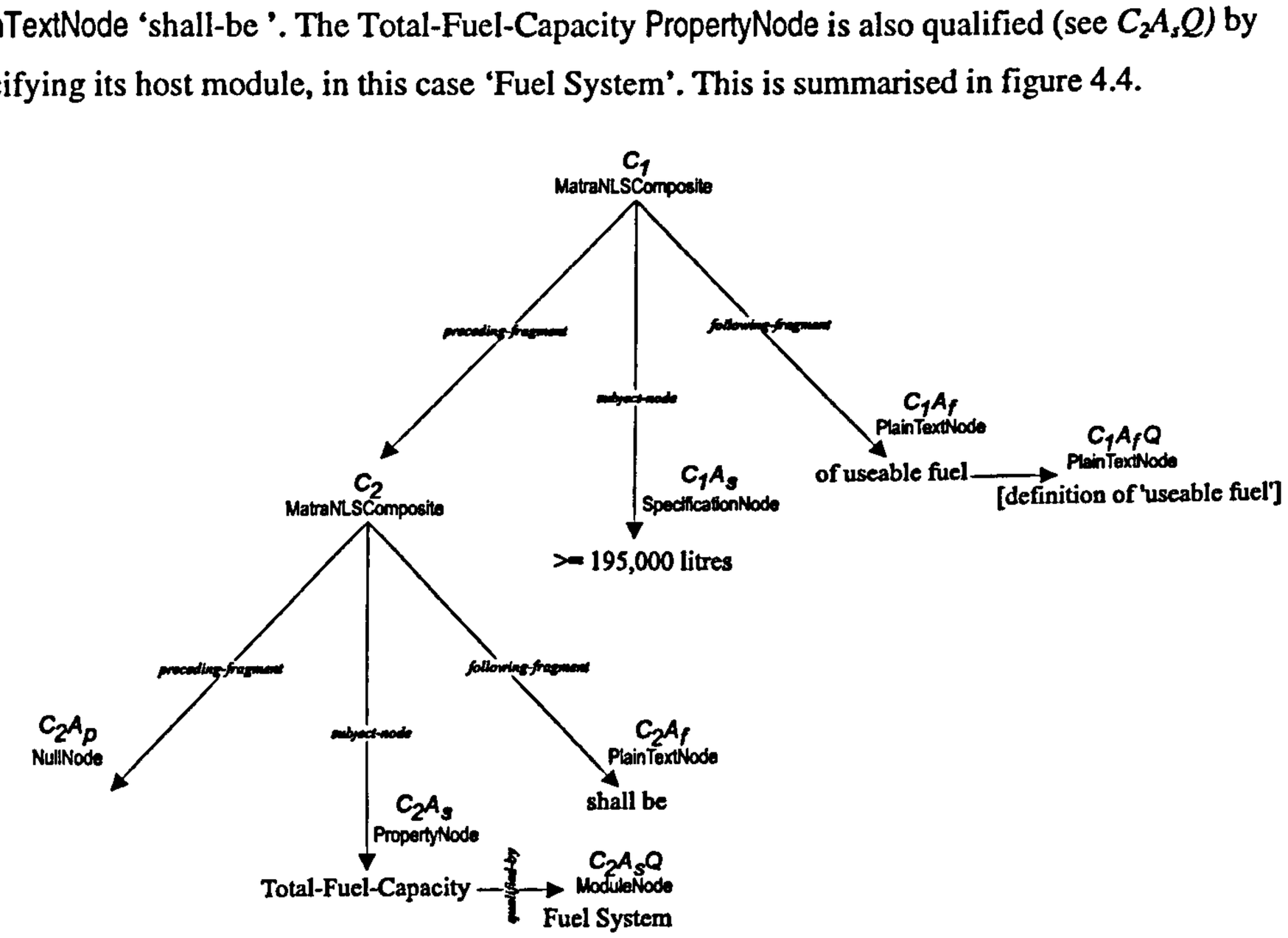


Figure 4.4 - 'MNLS Sample Population : Node Splitting Stage 2'

O-Telos code for the completed MNLS - i.e., following 'Stage 2' (figure 4.4 above) is as follows:-

```
ExampleMNLS in                                    mnlsComposite1 : C1;
MatraNaturalLanguageStructure, Token with         mnlsComposite2 : C2
mnls_composite                                 mnls_plain_text
```

```
    mnlsPlainText2 : C1Af;
    mnlsPlainText3 : C2Af
mnls_null
    mnlsNu111 : C2Ap
mnls_specification
    mnlsSpecification1 : C1As
mnls_property
    mnlsProperty1 : C2As
end

C1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : C2
subject_node
    subjectNode : C1As
following_fragment
    followingFragment : C1Af
end

C1As in SpecificationNode, Token with
specification
    _Specification : ">= 195, 000 litres"
end

C1Af in PlainTextNode, Token with
mnls_text
    mnlsText : " of usable fuel"
qualified_by
    qualifiedBy : C1AfQ
end

C1AfQ in PlainTextNode, Token with
mnls_text
    mnlsText : "[definition of 'usable
fuel']"
end

C2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : C2Ap
subject_node
    subjectNode : C2As
following_fragment
    followingFragment : C2Af
end

C2Ap in NullNode, Token end

C2As in PropertyNode, Token with
property_name
    propertyName : "Total-Fuel-Capacity"
qualified_by
    qualifiedBy : C2AsQ
end

C2AsQ in ModuleNode, Token with
module_name
    moduleName : "Fuel System"
end

C2Af in PlainTextNode, Token with
mnls_text
    mnlsText : " shall be "
end
```

4.2.4 Summary

Our investigation has shown that natural language continues to be a highly important format for representing artifacts used by engineers within the aerospace industry. Accordingly means are required to allow traceability of elements embedded within the text of such artifacts.

This subsection has modified and built-on an existing meta-model (based on the hypertext principle of nodes) produced by partners from project NATURE, allowing its integration within the MATrA framework. Our main modification to the original model was to introduce node typing such that node types correspond to (and may therefore be verified against) build element types from the Product Data Synthesis.

A worked example featuring the MATrA Natural Language Structure was considered at both the logical and physical levels. Further demonstration will appear in the main case studies (Chapter Six), with a full evaluation provided in Chapter Seven.

4.3 User Centred Requirements Structure

4.3.1 Introduction

In this subsection, we introduce an integrated structure comprising meta-models that capture syntactic elements of three complementary requirements elicitation, analysis and documentation notations: Use Case Models, Scenarios and Message Sequence Charts; a formal semantics sufficient to preserve well-formedness and usage restrictions is also provided. We refer to this integrated structure as the User Centred Requirements Structure (UCRS).

4.3.2 Motivation

It is now universally accepted that frailties in the requirements phase of systems engineering projects can prove a major factor in their failure. A corollary of this (as indicated in Chapter One) has been the transition of Requirements Engineering, from a special interest group within the software and systems engineering fraternity, to a major discipline in its own right. Accordingly, a range of formal, semi-formal and informal approaches have sought to address issues involved in achieving the desired output from RE (i.e., a consistent and complete specification capable of forming the basis of the next phase of system development). While developers have in the past succumbed to (often) unsubstantiated claims and biases made in support of some of these approaches, as RE matures, practitioners are more able to distinguish what 'works' - either in terms of aiding specification directly, or else in supporting communication among agents involved in the process - from what palpably does not.

Use Case Models, Scenarios and Message Sequence Charts are all complementary and established notations used in the requirements analysis phase of projects. They allow developers to model from a user perspective the high-level functionality of, and interactions with, a target system. In the aerospace industry for example they have been used for a variety of civil and military applications, from exchanges between the ground crew and Fuel System, to pilot interaction with Mission Planning and Navigation Systems (BAe 1999).

We now provide a brief overview of Use Case Models, Scenarios and Message Sequence Charts before introducing a novel meta-model (the User Centred Requirements Structure) that integrates these approaches in a format amenable to traceability.

4.3.2.1 Use Case Overview

Use cases have been acknowledged by most methodologists in the field as an effective means of support for user centred requirements analysis, i.e. the capture of requirements from a user perspective. Use Case diagrams show abstract interactions between a target system and its environment, as well as capturing the scope of functionality. And because they express such information in terms of the problem domain vocabulary, they are readily understandable to participants with a non-technical background. Use cases have previously been a feature of development methods by Jacobson *et al.* (1993), Rumbaugh *et al.* (1991) and Booch (1994), although their profile has undoubtedly been raised by being a constituent of the Unified Modelling Language.

Use Case diagrams are based around a simple, though deceptively rich notation the main elements of which are *actors* and *use cases*. Actors represent sets of external entities who share some common characteristics in terms of how they interact with the target system. These may be human, or else some form of quasi-autonomous system built from hardware/software components. Actors are denoted on Use Case diagrams using 'stick-men' symbols.

A single use case describes a subset of system functionality which delivers some unit of work to an actor or actors in response to an initial stimulus by one particular actor. Use cases are denoted on diagrams using a simple name bearing ellipse, thereby reinforcing the point that this form of analysis regards the system as a 'black-box' (i.e., functionality is exposed, whilst design specification - if such details are known at this stage - is hidden). Interactions between actor and use case symbols are modelled using arcs. A use case can also be annotated with pre and post conditions.

Jacobson *et al.* (1993) provide two means of combining use cases via the *uses* (also known as *includes*) and *extends* associations. The former embeds new behaviour into a complete base case, while the latter embeds a fragmentary sub-sequence (analogous to a sub-routine) as a necessary part of a larger case enabling the same behaviour to occur in several otherwise disjoint use cases[8]. In essence, these associations can be said to support the principles of aggregation (*uses/includes*) and inheritance (*extends*).

Figure 4.5 depicts a basic use case example for a missile subsystem known as the AGA (Attitude Guidance Autopilot). The diagram is reproduced from Grigg & Henderson (2000) in which use case diagrams provide a front-end to real-time transaction (RTT) models (Haveman *et al.*, 1997). RTTs are an abstraction mechanism enabling the recording and analysis of functional and timing properties in the early stages of development for distributed and reactive real-time systems. Figure 4.5 identifies two use cases/RTTs, the Autopilot and the Attitude Guidance (notice that the former *includes* functionality of the latter), together with three actor entities present within the host missile system, namely Sensor(s), an Information Processing System (IPS) and a Fin Controller.

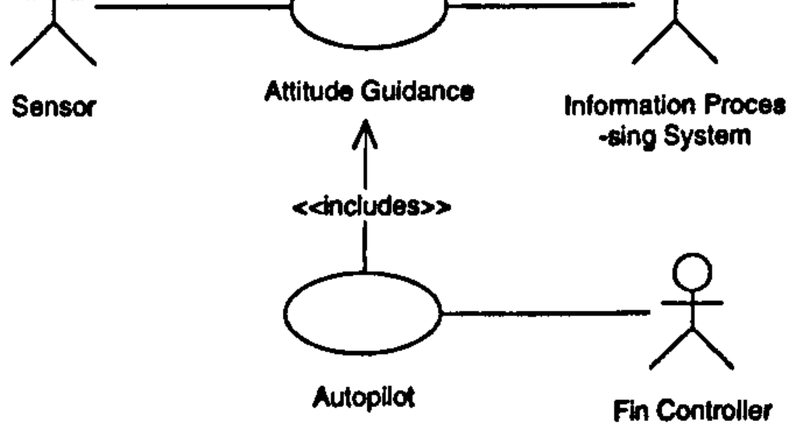


Figure 4.5 - 'Use Case Diagram of the AGA Sub-system'

Although figure 4.5 shows which actors interact with which use cases, it tells us nothing about specific

[8] Note that Rumbaugh (1994) questions whether the extends and uses associations are fundamentally different, suggesting that both may be treated as "special cases" of some unifying association which he terms *adds* between a base case and an additional case in which the multiplicity is (normally) either one for the uses case or optional for the extends case. This is reflected in our treatment of paths through use cases, as described by the Interaction View in 4.3.3.4.1.

usage - i.e., the sequence of individual interactions making up each potential end-to-end transaction between the target system and its environment. Scenarios - natural language descriptions documenting different paths through a use case - provide just such a facility; we consider these in the next subsection.

4.3.2.2 Scenarios Overview

The terms use case and scenario (in the context of projections of future system usage) are often used synonymously[9]. However, according to our interpretation, each scenario represents a separate order-dependent sequence of message events conveying a 'path' through a use case, such that the use case being described is the set of all such scenarios. Put another way, each scenario can be regarded as an instance of a use case in much the same way that UML Object Models instantiate a Class Diagram. Like use cases, scenarios have also featured widely in object-oriented techniques including (Jacobson *et al.*, 1993) and Graham (1996), as well as the Unified Modelling Language.

The overriding advantage of scenarios (at least those where the actors concerned are human) is that users can 'walk' analysts through typical usage situations. Such walkthroughs can take many forms, ranging from simple verbal descriptions, to those involving role play. In doing so scenarios can help validate existing requirements (Sutcliffe *et al.*, 1998), uncover less obvious requirements (including those for exception handling) and surface hidden assumptions (Potts *et al.*, 1994). Further, in an extensive review of their potential application and benefits, Weidenhaupt *et al.* (1998) also identifies scenarios as a means of reducing complexity (by enforcing a usage-oriented decomposition of requirements from an early stage), as well as promoting agreement among stakeholders (by grounding discussions and focusing negotiations during trade-off analysis). The fact they largely abstract away from design and implementation issues and are normally stated in natural language[10] also means there are no barriers to participation in scenario based requirements analysis.

The text of each message event within a scenario typically includes a message sender and message receiver, a verb-phrase indicating a sender's action, together with an indication of the message content; sender and receiver correspond to the actor and target system entities from the Use Case Model. Sometimes, the system acts as both sender and receiver, which normally indicates (at least for the purpose of this discussion) that some internal action (e.g., a verification, calculation or update operation) is performed on data received in a previous exchange.

The following scenario (table 4.1) takes a normal path (i.e., no exceptional events) through the Autopilot use case from figure 4.5; the unit of work it describes is the provision of guidance data by the AGA to the Fin Controller subsystem. The first, third fourth and sixth events describe conventional information exchanges between the target system (AGA) and external actor entities (Sensors, Information Processing System and Fin controller), whereas events two and five are examples of internal system actions (both involving different forms of calculation).

---

[9] Note, different interpretations of the term scenario from other domains have been proposed; e.g., as a means for describing socio-technical systems (Kyng, 1995).

[10] Scenarios have also received formal treatment (*cf.* Hsia et al. 1994; Rolland & Anchor, 1998), as well as being represented using tabular and storyboard techniques (*cf.* Rubin & Goldberg, 1992; Karat & Bennett, 1991)

Provide Guidance Data to Fin Controller - Normal Path

1. The Sensor sends position data to the AGA subsystem;
2. The AGA subsystem calculates the missile attitude;
3. The AGA subsystem sends missile attitude to the Information Processing System;
4. The Information Processing System sends aim point data to AGA subsystem;
5. The AGA subsystem calculates guidance data;
6. The AGA subsystem sends guidance data to the Fin Controller.

Table 4.1 - 'Example Scenario for the Autopilot Use Case'

The text of these simple one-line instructions can be given greater clarity when the scenario is viewed in diagrammatic form using a Message Sequence Chart as described in the next subsection.

4.3.2.3 Message Sequence Chart Overview

Message Sequence Charts (MSCs) are a widely used graphical notation for visualising the temporal nature of interactions between system components or, as is our interest, a target system and its host environment. Like scenarios, they do not seek to express complete behaviour, but rather a single execution trace (i.e., path). Historically, Message Sequence Charts have mainly been applied to the area of telecommunication systems (ITU-T, 1993), although the DCSC is to investigate the possibility of their use with RTTs since both are concerned with specifying end-to-end threads of functionality. Variations on the MSC are a feature of UML and other object-based approaches (e.g., Selic *et al.*).

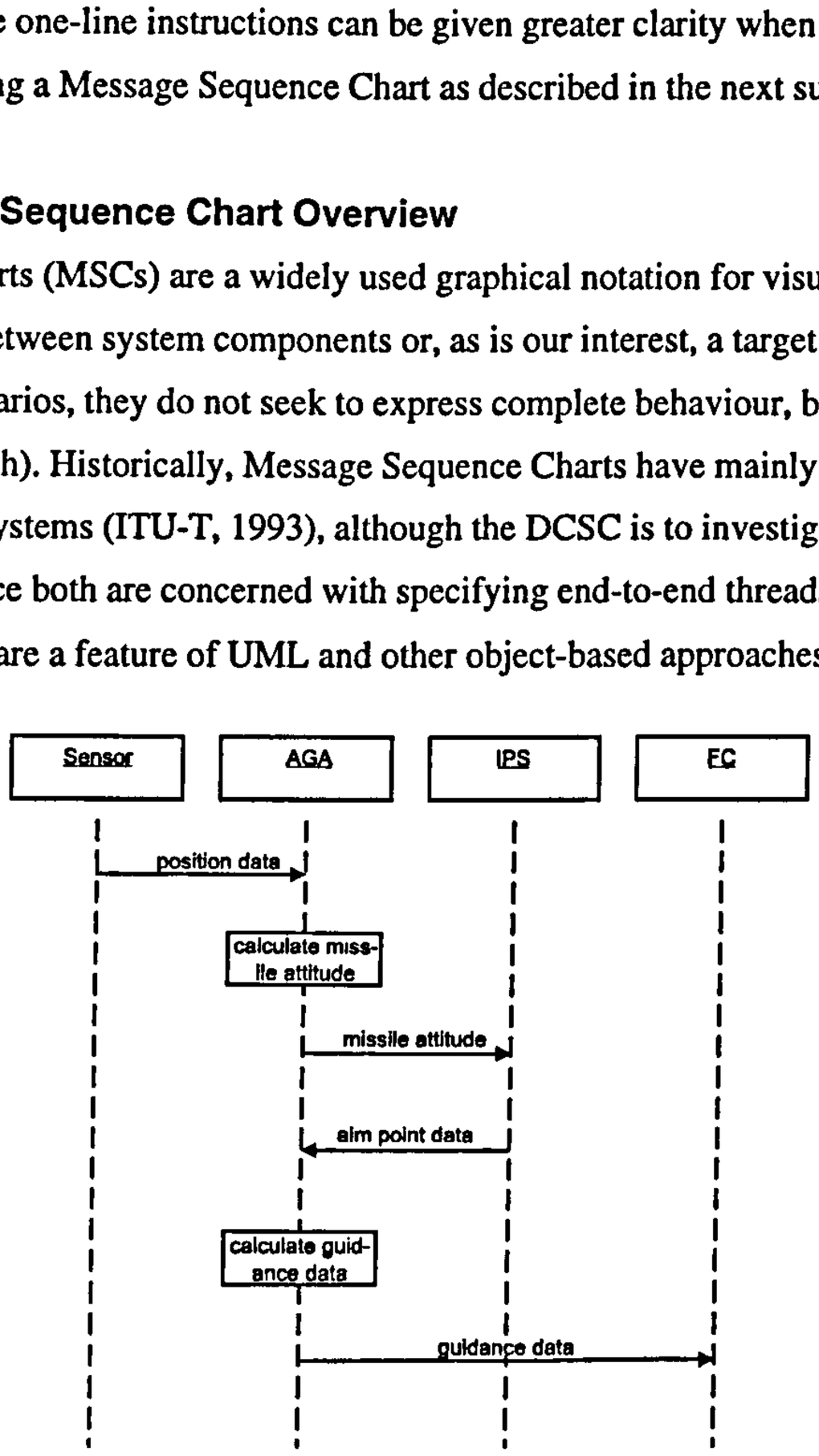


Figure 4.6 - 'Message Sequence Chart for the Provide Guidance Data to Fin Controller Scenario (Normal Path)'

Figure 4.6 presents a visualisation of the scenario in table 4.1 which features the core graphical syntax of all Message Sequence Charts. Vertical axes represent *instances*, i.e., participants of the use case (either actor instances or the target system) as indicated through named rectangles at their head. Conversely, directed horizontal lines indicate messages where each message starts at an *originator* instance and ends at a *target* instance. Some messages are internal to an instance; i.e., they have the same originator and target instance (e.g., "calculation of missile attitude" and "calculation of guidance

data" from figure 4.6). Given our intended usage of MSCs in modelling interactions between a system and its environment, these are exclusively *actions* that are intrinsic to the target system. We note however that software-oriented applications based on object-modelling also use Message Sequence Charts to show the precise interaction of objects within the target system itself.

The instance axis orders events in time downwards. Translated in the context of figure 4.6, this means that "missile attitude" is sent before "aim point data", and so on. However the time axis depicts only sequence in the sense that the scale is non-linear and therefore no semantic importance (e.g., interval) should be implied by the spacing between messages.

The axis/instance and message elements are sufficient to construct most Message Sequence Charts. Nevertheless, extensions to the core syntax make it possible to express additional information such as arrival patterns (e.g., periodic or aperiodic), synchronisation (balking, waiting, asynchronous) and broadcast messages (which originate from a sender instance at the same time point and are received by $n > 1$ instances at potentially different times). These are all features of the UML variant of MSCs known as Sequence Diagrams which can also contain *state marks* placed on the vertical axes in order to provide a bridge to the corresponding Statechart diagrams. Also of note are extensions proposed by Regnell *et al.* (1996) who employ MSCs in conjunction with Episodes (proposed by Potts *et al.* [1994] as a means of grouping the fine-grained events occurring within a use case into coherent parts) such that each MSC represents a single episode and a set of MSCs depicts a scenario.

4.3.3 Tracing User Centred Requirements in MATrA: UCRS - An Integrated Use Case & Interaction Structure

The notations discussed in subsections 4.3.2.1 through 4.3.2.3 provide a sound basis for the elicitation, analysis and documentation of user centred functional requirements in a format amenable to all stakeholders with an interest in this process. We now describe the User Centred Requirements Structure, a novel meta-model that integrates Use Case Models, Scenarios and Message Sequence Charts and in doing so, provides strong traceability between their constituent elements.

4.3.3.1 Concepts

As indicated in Chapter One (subsection 1.3), notations used by avionics engineers fall into two broad categories: those with a well-defined syntax and semantics and those that are less rigorously defined but which offer flexibility as a result. Use Case Models, Scenarios and to a lesser extent Message Sequence Charts are of the latter such that UCRS integrates and extends these notations to serve domain specific needs. The structure has been shaped by discussions with practitioners and examination of actual specifications featuring these notations.

Use Case diagrams in MATrA support all of the concepts outlined in subsection 4.3.2.1, i.e., actors, interactions and use cases, as well as means for combining the latter through includes and extends associations and for their description through pre and post conditions. We do however include the additional notion of a *service* (Regnell *et al.*, 1996); i.e., a demarcated set of functionality encapsulated

within a single package (not in the UML sense)[11].

Discussions with practitioners suggest that user centred requirements for even relatively simple systems (in terms of functionality) can yield a large number of use cases. In MATrA we manage their number through the notion of views. Essentially, a view is a composition of one or more Use Case Models; reuse of actor and use case entities across these models is facilitated by all elements of a model also being elements of the view to which that model belongs. Therefore, the set of elements available to a model is the union of those elements introduced by itself and all models within the same view.

As regards descriptions of use cases, MATrA supports both textual and Message Sequence Chart formats. Perhaps due to their traditional prose representation, textual scenarios lack even a quasi standard. There are however some works proposing alternative representations as well as suggestions on what well-formed events should contain, ranging from structured natural language techniques (e.g. Leite *et al.* 1997) to more mathematical approaches (e.g., Rolland & Achour, 1998). On balance, we favour a natural language representation (for reasons of usability), underpinned with a lightweight formal semantics. This is realised in part through fine-grained modelling, allowing us to identify and validate event primitives against the PDS and also to impose a degree of well-formedness.

The latter is further aided by differentiating between event types, for which we take work by Rolland & Anchor (ibid.) as our steer. They identify two forms of atomic event: i) *message communication* between instances (i.e., actors in the Use Case View) and the target system, which may be further qualified as a *service request*, *service provision*, *information request* or *information provision*; and ii) *internal system actions*, which constitute operations intrinsic to the target system.

In addition, a target system can host Timer sub-modules which they control in terms of *set* and *reset* events. Timers can also *time-out*, although the host plays a passive role in events of this form. For more information on the use of timers and timing events within use case descriptions, readers are referred to work by Regnell *et al.* (1996) which also inspired the UCRS mechanisms for grouping of sequential events and the expression of upper and lower bounds - both of which are necessary to allow iteration within scenarios.

Message Sequence Charts of the UCRS contain the same core elements as textual scenarios. Indeed, other than the fact that MSC communication events differentiate between types of message based on arrival pattern (periodic or aperiodic), synchronisation (simplex, synchronous, balking, etc.) and delay[12], they differ only in terms of presentation[13]. Hence, there are clear optimisation, consistency and traceability benefits to be gained by providing a common underlying representation. This is the approach adopted within MATrA through our Interaction Model.

---

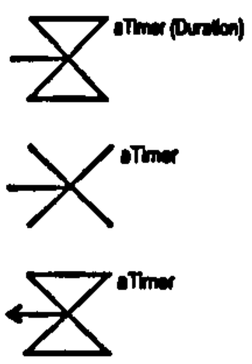
[11] Graphically, services (represented by named rectangles) are the only deviation from traditional use case diagrams. Pre and post conditions simply annotate the conventional use case ellipse symbol.
[12] All of these properties have a corresponding graphical convention.
[13] This was demonstrated through our example in 4.3.2.2 and 4.3.2.3 (albeit using a subset of the concepts outlined above)

Notwithstanding the commonality between textual scenarios and MSCs, the labelling of apparently equivalent communication and action events often differs between the two formats. This is probably explained by a need for the former to adhere to the rules of English grammar, whereas the latter merely annotate symbols. To resolve the issue, we propose that each message and action is able to use an appropriately worded parameter which is displayed in place of the message/action name (note the latter are still required as they provide the basis for PDS verification).

4.3.3.1.1 UCRS Notation

At a logical level, some refinements to the way Scenarios and Message Sequence Charts are presented is necessary. For instance, with the textual representation, each scenario event is preceded by its type: C[SR], C[SP], C[IR], or C[IP] for Communication events (Service Request/Provision and Information Request/Provision respectively), or alternatively, 'A' for Action or 'T' for Timing events. With the MSC equivalent, we place communication event types below their corresponding message arrow.

Our policy of validating event content against the PDS requires us to identify sender, receiver, message, action and other relevant primitives within text strings. Accordingly, these are enclosed within square brackets preceded by a typed subscript; e.g., [$_{sdr}$ *sender*], [$_{rcr}$ *receiver*], [$_{msg}$ *message*], [$_{act}$ *action*], [$_{timer}$ *timer*]; for message elements where a parameter is being used, the actual name (corresponding to its PDS entry) appears in subscript following the parameter label - i.e., [$_{msg}$ *parameter* $_{PDS\ name}$]. Timer events over the (host) instance are also demarcated using [$_{timer\text{-}set}$ *Instance*], [$_{reset}$ *Instance*] and [$_{host\text{-}on\text{-}timeout}$ *Instance*]. With the graphical representation, this information is of course conveyed using symbols (note a *parameter* appears above the message arrow and $_{PDS\ name}$ below); besides those introduced in 4.2.2.3, we add the following to depict timer (set, reset and time-out) events.



Set. The timer is activated.

Reset. The timer is deactivated.

Time-out. The timer expires.

Figure 4.7 - 'MSC Timer Event Types (from Regnell *et al.*, 1996)'

Event groups in textual scenarios are enclosed within a rectangle and preceded by upper and lower bounds. For MSCs, the grouping formalism is displayed using a shaded rectangle. Readers are referred to subsection 6.2 and to Appendix C, Part Two for examples of the notation.

4.3.3.2 User Centred Requirements Structure (Definition)

As previously indicated, User Centred Requirements Structure provides an integrated approach to the representation and traceability of Use Case diagrams, Scenarios and Message Sequence Charts. The structure is essentially a 'container' that draws together elements from Use Case and Interaction Views, where the latter is simply an abstraction of concepts modelled using Scenarios and Message Sequence Charts.

In modelling UCRS, we make a number of assumptions. Specifically, that the structure has bespoke tool support and that instances ported to the traceability Workspace include a Use Case View. We assume this contains at least one Use Case Model featuring a minimum definition of one use case, one actor and one interaction. If present, we further assume the Interaction View contains at least one Interaction Model and that this model is minimally defined by a single scenario with at least one communication event in which a message is exchanged between two instances (sender and receiver, where the target system is receiver). This may populate either a textual or MSC viewpoint, with provision made in the form of rules (see subsection 4.3.3.4.2) to derive one from the other, though user intervention is required to construct legitimate prose event statements around core elements from a sequence chart.

A detailed explanation of the Use Case and Interaction Views appears in subsections 4.3.3.3 and 4.3.3.4 respectively. However, as a precursor to this we describe a meta-model (4.3.3.2.1), OCL constraints (4.3.3.2.2) and O-Telos implementation of base-classes (4.3.3.2.3) for the User Centred Requirements Structure itself.

4.3.3.2.1 User Centred Requirements Structure Meta-model

The User Centred Requirements Structure (figure 4.8) is as an aggregation of a Use Case View (UseCaseView) and Interaction View (InteractionView). Its core class (UserCentredRequirementsStructure) - an instance of the DevelopmentStructure metaclass - can be compared with a banner comment or header in programming language terminology. As with most such classes in the MATrA Workspace, it contains a small number of attributes for configuration management - in this case date (ucrs_date) and subject module (subject_module) which is verified against the Product Data Synthesis (see subsection 4.3.3.2.2). UserCentredRequirementsStructure also provides means to record comments through aggregation to a MatraNaturalLanguageStructure, thereby allowing primitives embedded within comment strings to be linked to other models or model elements.

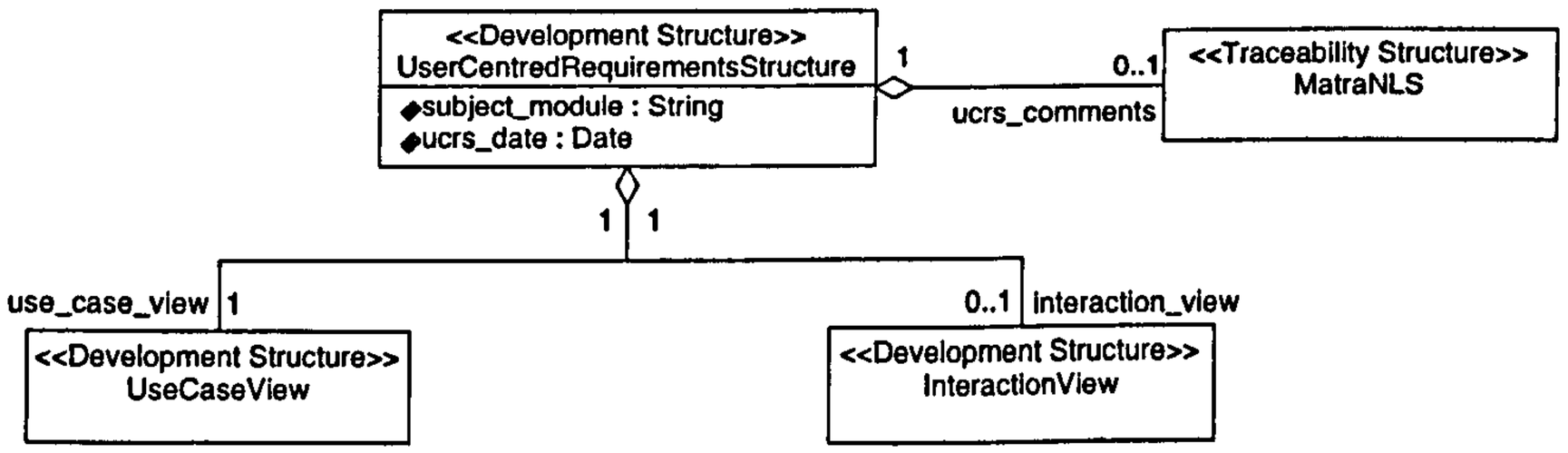


Figure 4.8 - 'User Centred Requirements Structure (UCRS)'

4.3.3.2.2 OCL Constraints over the User Centred Requirements Structure

The following constraint is applied to UCRS in order to verify its subject_module property exists in the Product Data Synthesis (navigation is via the BEmodelAEO AerospaceLinkEntity):-

UserCentredRequirementsStructure **invariant**
self.allInstances->forall(u | self.bEmodelAEO.build_element->exists (be | u.subject_module = be.module_name))

4.3.3.2.3 O-Telos Base Classes for User Centred Requirements Meta-model

O-Telos implementation of the base classes featured in figure 4.8 (4.3.3.2.1) is as follows:-

Definition of User Centred Requirements Structure

```
UserCentredRequirementsStructure in DevelopmentStructure, SimpleClass isA
AerospaceEngineeringObject with has_property
    subject_module : String;
    ucrs_date : Date
has_structure
    ucrs_comments : MatraNaturalLanguageStructure;
    use_case_view : UseCaseView;
    interaction_view : InteractionView
end
```

In the following sections, we introduce the constituents of User Centred Requirements Structure:-

- Use Case View (4.3.3.3) and
- Interaction View (4.3.3.4)

4.3.3.3 Use Case View

Use Case View captures the elements necessary to construct Use Case Models. Again, we represent these in terms of a meta-model (4.3.3.3.1), OCL constraints (4.3.3.3.2) and O-Telos implementation of base-classes (4.3.3.3.3).

4.3.3.3.1 Use Case View Meta-model

Elements of Use Case View (UseCaseView), with its date (ucv_date) attribute and MNLS comment facility are depicted in figure 4.9. Its core class instantiates DevelopmentStructure and is defined as an aggregation of the use case diagram elements described in subsection 4.3.2.1 - namely use case (UseCase) and actor (Actor) entities, together with interaction (Interaction), includes (Includes) and extends (Extends) associations - all of which instantiate the StructureElement meta-class. Means to record pre and post conditions using MATrA Natural Language Structures are also a feature (enabling PDS verification of embedded ConditionNode primitives as appropriate).

Use cases and actors have (unique) name attributes (use_case_name and actor_name respectively) to enable meaningful identification, and for verifying instances of these classes against the Product Data Synthesis. UseCase also contains a boolean attribute (sub_case) to indicate whether instances must combine with others in order to deliver a 'unit of work'. In addition, the Extends class bears a condition rubric (extends_condition) which states the circumstances under which one use case may legitimately extend another. It is also worth noting that the cardinality of association between Actor and UseCaseView is one-to-many on both sides. The underlying rationale is that an actor can conceivably be an external entity to several aircraft systems and hence potentially contribute to many different views.

Remaining UseCaseView constituents are Service (described in terms of one or more use cases through an aggregation association over the service_use_case rolename) and Use Case Model (UseCaseModel). The former is an instance of StructureElement, whilst the latter instantiates DevelopmentStructure and is again analogous to a program banner.

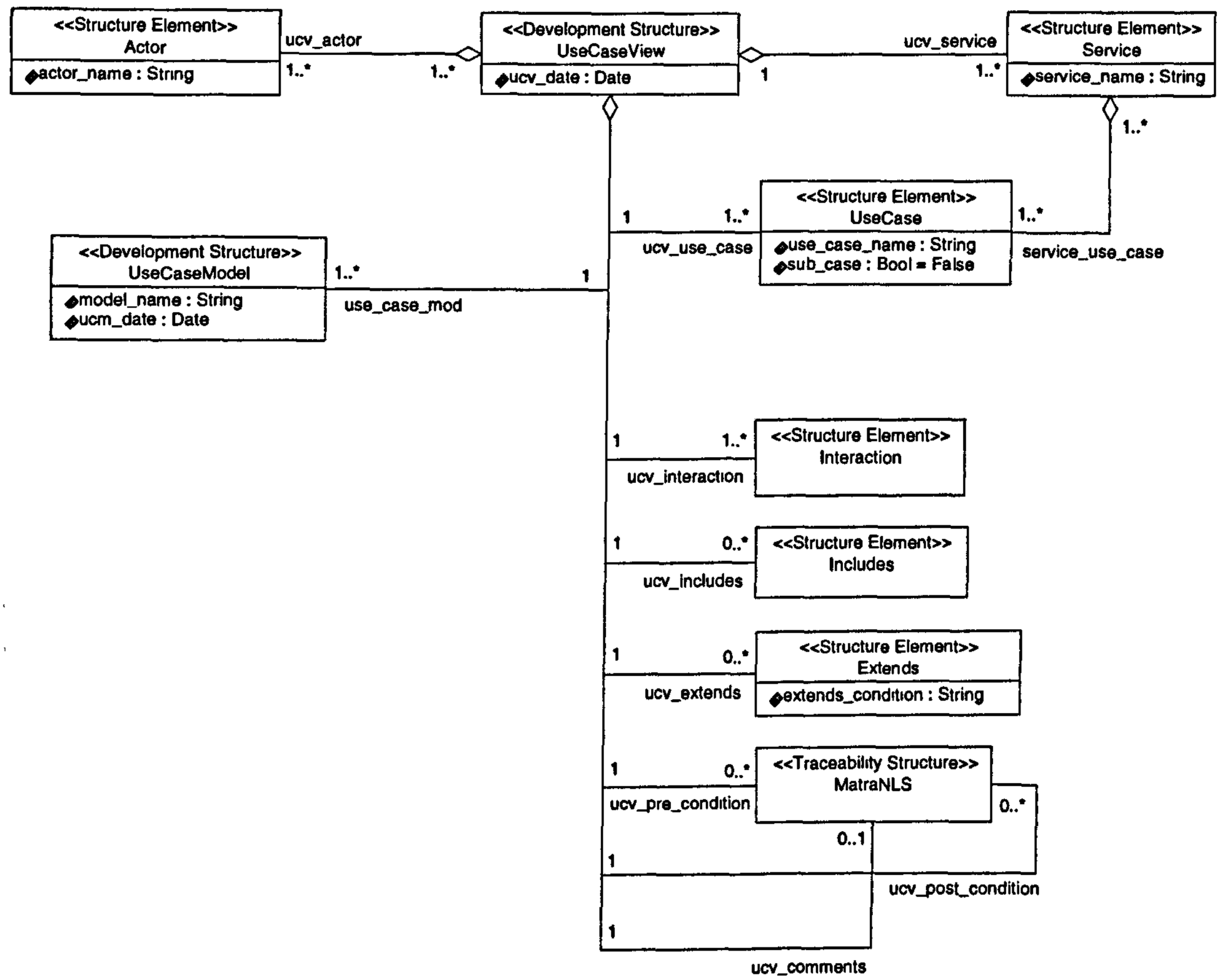


Figure 4.9 - 'UCRS - Use Case View : Elements'

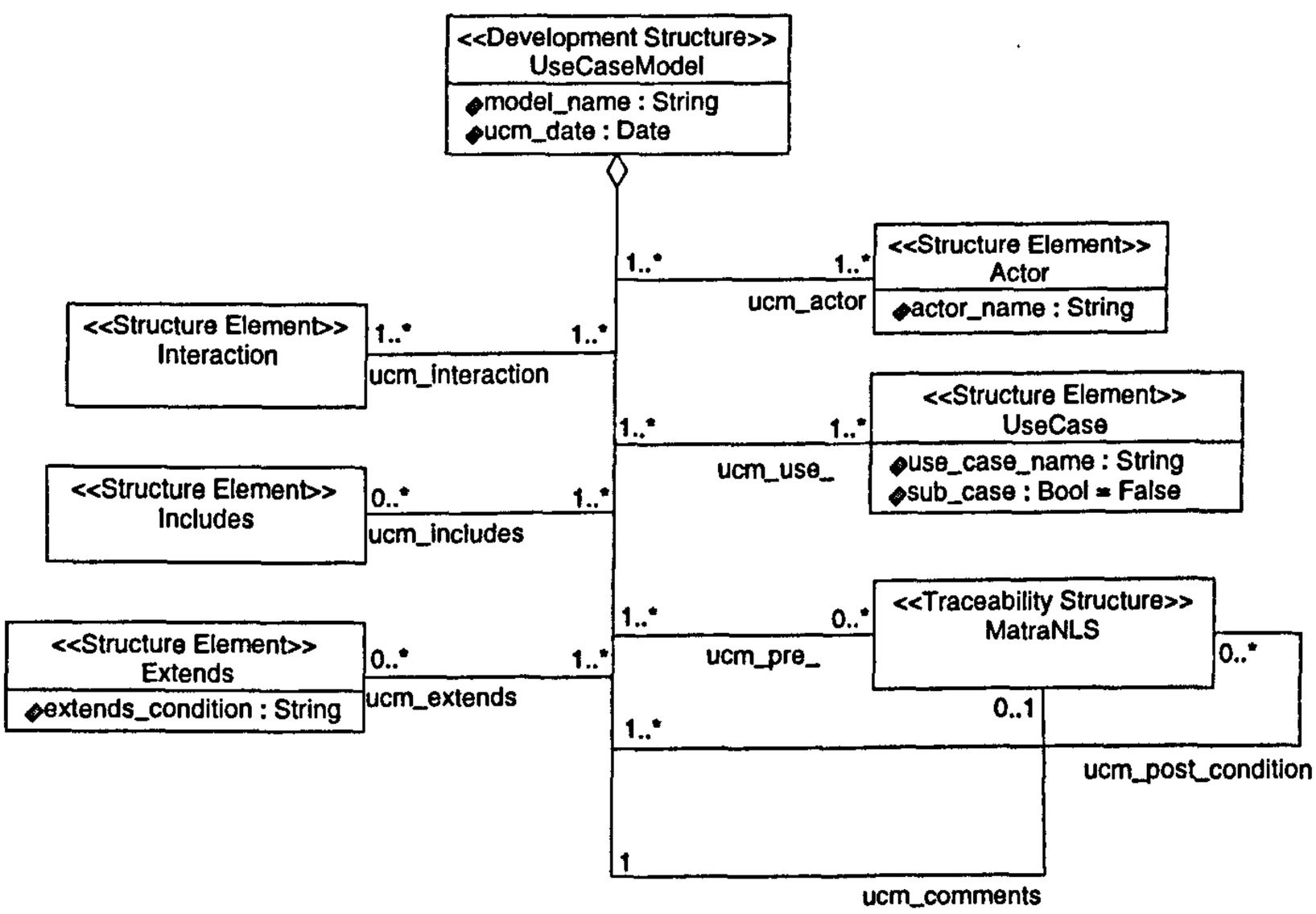


Figure 4.10 - 'UCRS - Use Case Model : Elements'

A UseCaseModel (figure 4.10) is an aggregation of the diagramming elements described when introducing UseCaseView; recall that in order to foster reuse, all such elements (UseCase, Actor, Includes, Extends, etc.) simultaneously belong both to a model and the view to which that model belongs (associations which can be derived using deductive rules - see ii.8 in 4.3.3.3.2 for instance). Accordingly, all elements carry a one-to-many association on the UseCaseModel side.

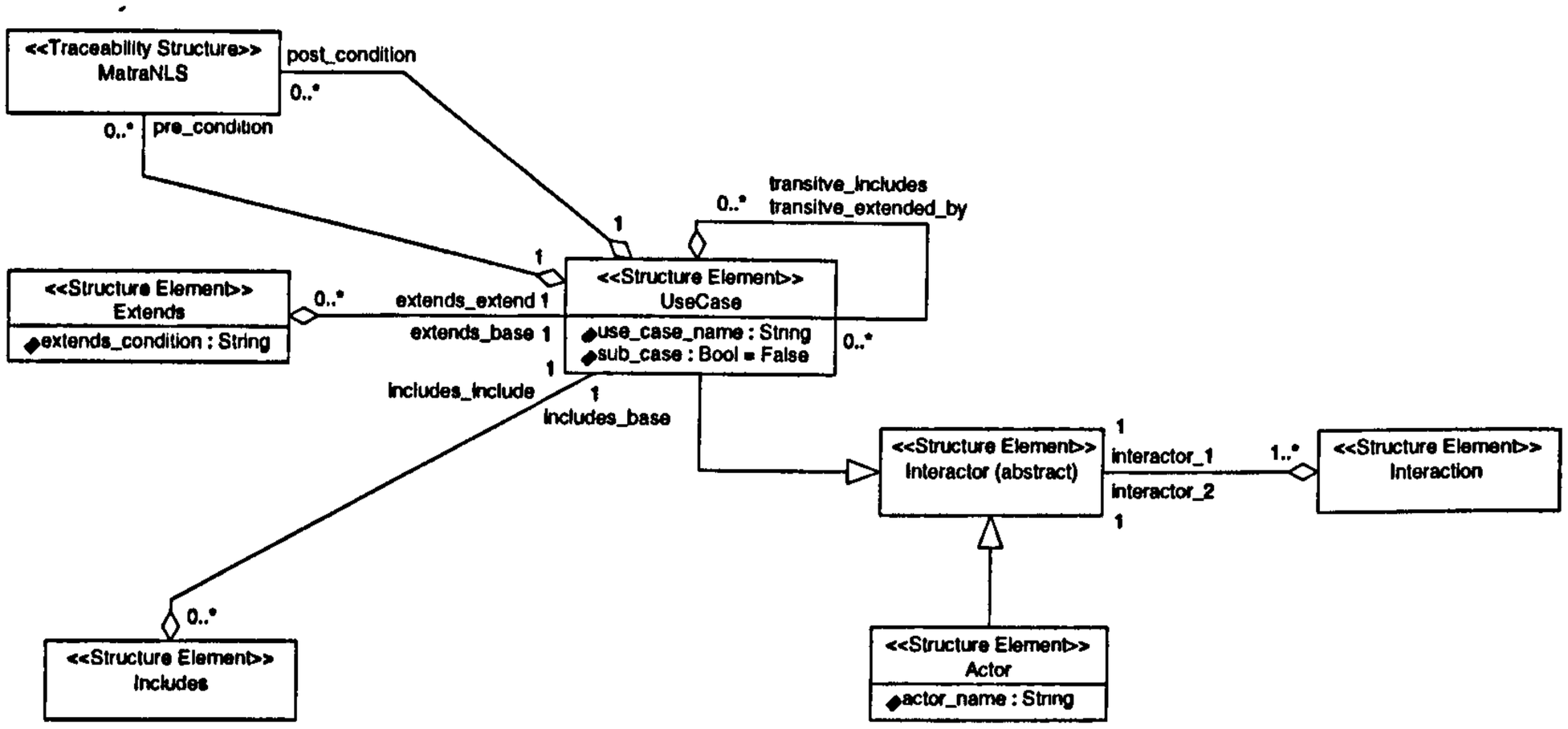


Figure 4.11 - 'UCRS - Use Case Model : Associations'

Associations between UseCaseModel elements are illustrated in figure 4.11. Of particular interest are the transitive_includes and transitive_extended_by associations on the UseCase class. As the names suggest, their purpose is to capture the transitive closure of Includes and Extends. It is also worth explaining the association ends on these two classes; 'base' ends (includes_base and extends_base) signify the including and extending use cases such that where 'a' includes 'b' and 'a' extends 'b', 'a' is the base in both, and 'b' is the element being either included or extended. The other significant aspect of this particular model is the introduction of an (abstract) Interactor class; since both actors and use cases send and receive messages, it is convenient to generalise this behaviour.

4.3.3.3.2 OCL Constraints over Use Case View Meta-model

We have defined a number of constraints and rules over elements of UseCaseView which are grouped on the basis of consistency and well-formedness. A selection of these are included below (readers are referred to Appendix A, Part One for the remainder).

I. Consistency

1. Constraint to ensure that use cases are declared as Transactions of the subject_module in the Product Data Synthesis.

UseCase **Invariant**
self.allInstances->forall(u |
self.useCaseView.userCentredRequirementsStructure.bEmodelAEO.build_element->exists (be |
self.bEelementAEO.build_element->exists (t |
u.useCaseView.userCentredRequirementsStructure.subject_module = be.module_name and
u.bEelementAEO.build_element->includes(t) and

```
u.use_case_name = t.transaction_name and
be.behavesAccordingTo.target->includes(t))))
```

2. Constraint to ensure the target sytsem is not among Actor elements (i.e., all actors are differrent from the subject_module).

```
Actor invariant
self.allInstances->forall(a |
a.actor_name <> a.useCaseView.userCentredRequirementsStructure.subject_module)
```

3. Constraint to ensure actors exist in the PDS as modules interfaced with by the subject_module.

```
Actor invariant
self.allInstances->forall(a |
self.useCaseView.userCentredRequirementsStructure.bEmodelAEO.build_element->exists(be |
self.bEelementAEO.build_element->exists(m |
a.useCaseView.userCentredRequirementsStructure.subject_module = be.module_name and
a.bEelementAEO.build_element->includes(m) and
a.actor_name = m.module_name and
(be.interfacesTo.target->includes(m) or m.interfacesTo.target->includes(b)) )))
```

ii. Well-Formedness

1. Constraint to ensure each interaction involves an Actor and a UseCase.

```
Interaction invariant
self.allInstances->forall(i |
(i.interactor_1.oclType = Actor and i.interactor_2.oclType = UseCase) or
(i.interactor_1.oclType = UseCase and i.interactor_2.oclType = Actor))
```

2. Constraint to prevent 'dangling' use cases (i.e., those not attached to an interaction) - a similar constraint is defined for actors (see Appendix, A Part 1).

```
UseCase invariant
self.allInstances->forall(u |
self.useCaseView.ucv_interaction->exists(i |
i.interactor_1= u or i.interactor_2 = u))
```

3. Constraint to prevent a UseCase from including itself (a similar constraint is defined for «extends» - see Appendix A, Part 1).

```
Includes invariant
self.allInstances->forall(i | i.includes_base <> i.includes_include)
```

4. Constraint to ensure that at most one «includes» association exists between two use cases (see also Appendix A, Part 1 for a similar constraint over «extends»).

```
Includes invariant
self.allInstances->forall(i1, i2 |
not (i1 <> i2 and i1.includes_base = i2.includes_base and i1.includes_ include = i2.includes_ include))
```

5. Constraint ensuring two use cases cannot include each other; i.e. not 'use case a' «includes» 'b' and 'use case b' «includes» 'a' (again, see Appendix A, Part 1 for similar constraint over «extends»).

Includes **invariant**
self.allInstances->forall(i1, i2 |
not (i1.includes_include = i2.includes_ base and i1. includes_base = i2.includes_include))

6. Constraint to prevent cycles within «includes» associations (see Appendix A, Part 1 for a similar constraint over «extends»).

First, we must define a rule to determine the transitive closure for «includes» associations.

UseCase
self.allInstances->forall(u1, u2 |
self.includes->exists(i1 |
i1.includes_base = u1 and i1.includes_include = u2) or
self.allInstances->exists(u3 |
self.includes->exists (i2 |
i2.includes_base = u1 and i2.includes_include = u3 and u3.transitive_includes->includes(u2))))
implies
u1.transitive_includes->includes(u2)

This rule allows us to specify the following constraint.

UseCase **invariant**
self.allInstances->forall(u | not (u.transitive_includes->includes(u)))

7. Constraint to ensure use cases for two services are not identical.

Service **invariant**
self.allInstances->forall(s1, s2 |
not (s1 <> s2 and
s1.service_use_case->symmetricDifference(s2.service_use_case)->isEmpty))

8. Rule to ensure that all uses cases associated with a particular model are also also associated with the UseCaseView to which that model belongs (similar rules may be found in Appendix A, Part 1 for actors, interactions, etc.)

UseCaseView
self.allInstances->forall(v |
self.use_case_model.ucm_use_case->forall(u |
v.use_case_model.ucm_use_case->includes(u)))
implies
v.ucv_use_case->includes(u)

9. Rule to ensure a UseCase appearing in more than one model reuses the original interaction details (see Appendix A, Part 1 for similar rules over other use case elements).

UseCaseModel
self.allInstances->forall(m |
self.useCaseView.ucv_interaction->forall (i |
self.ucm_use_case->exists(u |
m.ucm_use_case->includes(u) and

m.useCaseView.ucv_interaction->includes(i) and
(i.interactor_1 = u or i.interactor_2 = u))))
implies
m.ucm_interaction->includes(i) and
m.ucm_actor->includes(i.interactor_1->select(oclType = Actor)->union(i.interactor_2->select(oclType = Actor)))

4.3.3.3.3 O-Telos Base Classes for Use Case View Meta-model

We implement base classes for UseCaseView and UseCaseModel (shown in figures 4.9, 4.10 and 4.11) as follows:-

```
Definition of Use Case Model Constituents

Interactor in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
constraint
abstract_Int: $ forall t/Token
s/SimpleClass
(t in s) ==> not (t in Interactor) $
end

Actor in StructureElement, SimpleClass
isA Interactor with has_property
    actor_name : String
end

UseCase in StructureElement, SimpleClass
isA Interactor with
has_property
    use_case_name : String;
    sub_case :Bool
has_structure
    pre_condition :
    MatraNaturalLanguageStructure;
    post_condition :
    MatraNaturalLanguageStructure
has_transitive_part
    transitive_includes : UseCase;
    transitive_extended_by : UseCase
end

Interaction in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with has_part
    interactor_1 : Interactor;
    interactor_2 : Interactor
end

Includes in StructureElement, SimpleClass
isA AerospaceEngineeringObject with
has_part
    includes_base : UseCase;
    includes_include : UseCase
end

Extends in StructureElement, SimpleClass
isA AerospaceEngineeringObject with
has_property
    extends_condition : String
has_part
    extends_base : UseCase;
    extends_extend : UseCase
end

Definition of Use Case Model

UseCaseModel in DevelopmentStructure,
SimpleClass isA
AerospaceEngineeringObject
with
has_property
    model_name : String;
    ucm_date: Date
has_structure
    ucm_comments :
        MatraNaturalLanguageStructure;
    ucm_pre_condition :
        MatraNaturalLanguageStructure;
    ucm_post_condition :
        MatraNaturalLanguageStructure
has_element
    ucm_use_case : UseCase;
    ucm_actor : Actor;
    ucm_interaction : Interaction;
    ucm_includes : Includes;
    ucm_extends : Extends
end

Definition of (additional) Use Case View
Constituent

Service in StructureElement, SimpleClass
isA AerospaceEngineeringObject with
has_property
    service_name : String
has_part
    service_use_case : UseCase
end

Definition of Use Case View

UseCaseView in DevelopmentStructure,
SimpleClass isA
AerospaceEngineeringObject with
has_property
    ucv_date : Date
has_structure
    ucv_comments :
        MatraNaturalLanguageStructure;
    ucv_pre_condition :
        MatraNaturalLanguageStructure;
    ucv_post_condition :
        MatraNaturalLanguageStructure;
    use_case_model : UseCaseModel
has_element
    ucv_actor : Actor;
    ucv_use_case : UseCase;
    ucv_interaction : Interaction;
    ucv_includes : Includes;
    ucv_extends : Extends;
    ucv_service : Service
end
```

4.3.3.4 Interaction View

The Interaction View captures elements necessary to describe paths of events through use cases (from

the Use Case View) represented either in textual or Message Sequence Chart form. Once again, these elements are represented by a meta-model (4.3.3.4.1), OCL constraints (4.3.3.4.2) and O-Telos implementation of the base-classes (4.3.3.4.3).

4.3.3.4.1 Interaction View Meta-model

Interaction View (InteractionView) - an instantiation of the DevelopmentStructure meta-class, with date attribute (inv_date) and MNLS commenting facility - is essentially an aggregation of Interaction Models (InteractionModel).

Each InteractionModel (likewise an instance of DevelopmentStructure composed of StructureElement types) describes a use case from the Use Case View (as indicated by the describes_use_case attribute which is verified using a constraint - see i.1 in subsection 4.3.3.4.2). These descriptions take the form of scenarios (Scenario) whose varied involvement within an Interaction Model is evident from the rolenames inm_scenario, inm_included_scenario and inm_extension_scenario. Respectively, these denote paths through the use case being described, and paths through other use cases that are included in, or which extend the use case being described (via «includes» and «extends» associations). We also provide means of representing the different event types introduced in 4.3.3.1 - i.e., communication (CommunicationEvent), internal action (InternalActionEvent) and timing (TimingEvent) - see figure 4.12.

The remaining InteractionModel elements reflect our intent to provide a common underlying representation for textual Scenarios and Message Sequence Charts. These include constituent elements of events such as instance (Instance), message (Message), action (Action) and timer (Timer), as well message description (MessageDescription) and action description (ActionDescription) parameters alluded to in 4.3.3.1. Note that for optimisation reasons, all such elements have a multiplicity of one-to-many on the InteractionModel side.

In addition, we include constructs for describing dual perspectives on the different event types based around these elements. That is textual and MSC representations of communication events (TsnCommunication and MscCommunication), internal action events (TsnAction and MscAction) and timing events (TsnTiming and MscTiming), as well as means to form dual scenario viewpoints (TsnScenarioViewpoint and MscScenarioViewpoint) from these representations. We now consider elements and associations of the InteractionModel in more detail.

From figure 4.13, it can be seen that Scenario contains the String attribute scenario_title and Boolean attribute is_exception. The latter merely identifies use case paths which, for whatever reason (be it user intervention or a system malfunction) fail to deliver their intended 'unit of work'. Reflexive aggregation associations on Scenario further describe relationships formed through «includes» and «extends», either directly (includes_scenario and extended_by_scenario) or transitively (transitive_includes_scenario and (transitive_extended_by_scenario).

Scenarios are aggregated to events over scenario_event, included_event and extension_event rolenames.

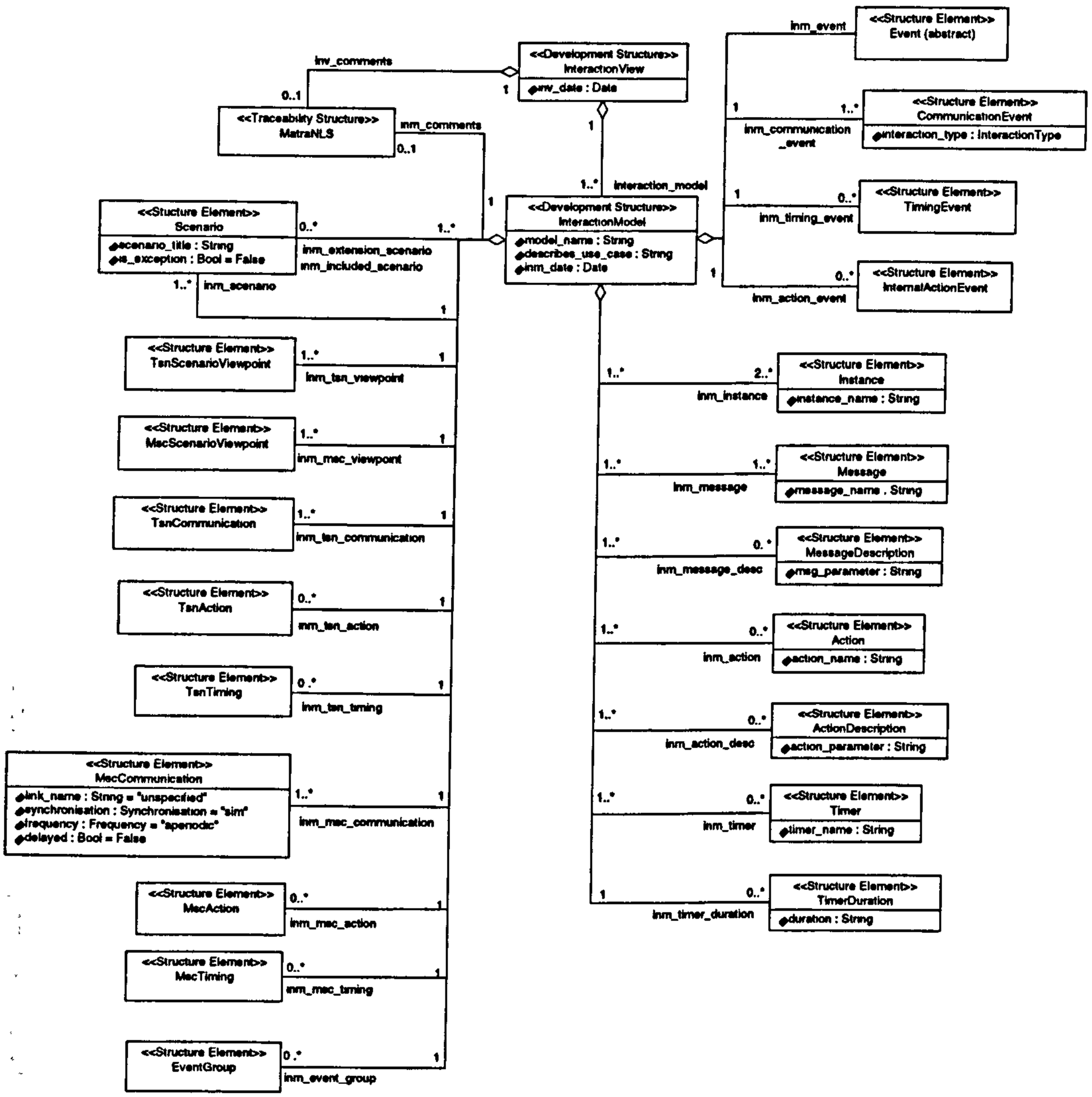


Figure 4.12 - 'UCRS - Interaction View : Elements'

These respectively denote events defining a scenario, and events that define other scenarios related to it by «includes» or «extends» associations (the latter pairing being optional). Note also the one-to-many aggregate side multiplicity indicating that each event may belong to several scenarios.

As previously indicated, each scenario is composed from CommunicationEvent, InternalActionEvent and TimingEvent types. It is convenient to generalise these as specialisations of an abstract Event class in order that associations such as follows_from and transitve_follows_from (identifying preceding events and the transitive closure of preceding events, both of which are used to maintain sequence) may be defined once and inherited by its subtypes.

Due to their (potential) many-to-many relationship with scenarios, each event may have several sequence numbers (SequenceNumber). If we take as an example, an event that closes a scenario - by for

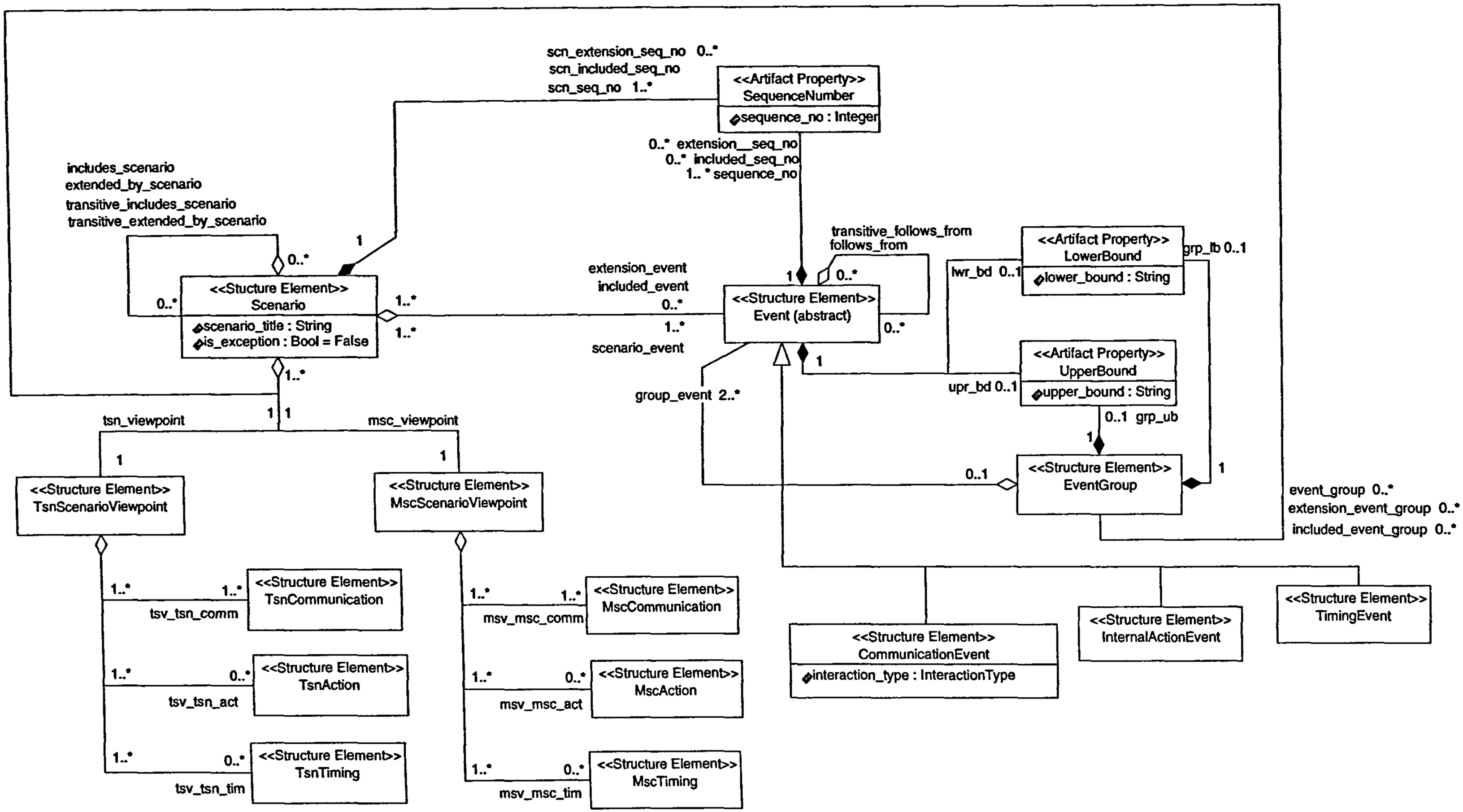


Figure 4.13 - 'UCRS - Interaction Model : Associations'

example displaying a message to a (receiver) instance; in the normal path, this event may have a sequence number of say '10'. However, with exceptions, for example where an Instance chooses to abort an operation, several intermediate events that precede it are potentially omitted, thereby lowering the sequence number of that event within those particular scenarios. An event may exhibit further sequence numbers arising from «includes» or «extends» participation in a scenario. To accommodate these eventualities, Event employs three rolenames in its associations with SequenceNumber, namely sequence_no, included_seq_no and extension_seq_no.

Note that the composition convention is used to express Event-to-SequenceNumber aggregation. But for our efforts to minimise event redundancy, the latter would be simply an attribute of the former. However to realise multiple sequence numbers and allow their association with Scenarios, SequenceNumber is promoted to a class (an instantiation of ArtifactProperty). We should explain that sequence numbers are related to scenarios in order to establish correct usage; while an event may have several sequence numbers, each sequence number may belong to only one scenario. Correct coupling of sequence numbers to scenarios is maintained using appropriate constraints (for which readers are referred to Appendix A, Part Two).

Scenarios may also contain sequential combinations of (two or more) events known as event groups (EventGroup). Aggregation is defined over event_group, included_event_group and extension_event_group rolenames. Again these respectively denote event groups that define a scenario and those that define other scenarios related to it by «includes» or «extends» associations.

In order to permit iteration, lower and upper bounds (LowerBound and UpperBound) may be stated for both events and event groups. Note both are modelled as classes (instantiations of ArtifactProperty) to permit shared use (again through composition) of a single definition. Having introduced these basic building blocks, we are in a position to describe in more detail the elements and associations of scenarios and events.

Each scenario has a textual viewpoint (TsnViewpoint) and an MSC viewpoint (MscViewpoint) constructed from TsnCommunication, TsnAction and TsnTiming perspectives and MscCommunication, MscAction and MscTiming perspectives respectively (note the multiplicity allowing each perspective to be part of one or more viewpoints). We now describe the composition of each event type, thereby relating event perspectives to the constituent elements they share. However, before doing so, we introduce means to model the textual perspective on each which is essentially a specialisation of the MNLS from section 4.2 known as the Scenario Event Natural Language Structure (SENLS).

It can be seen from figure 4.14 that SENLS introduces specialisations of MatraNLSAtomicNode for key primitives of the Communication, Internal Action and Timing event types. Specifically, Message, Action, TimerDuration, Timer and Instance. Several rolenames reflect the diverse usage of Instance as a message sender or receiver (tsn_sender_node and tsn_receiver_node), a sender and receiver in the context of

internal actions (tsn_sdr_rcr_node) and finally in timer set, reset and time-out events (tsn_timer_set_node, tsn_timer_reset_node and tsn_host_on_timeout_node); constraints (see exclusive-or conditions in figure 4.14 and also the restrictions in Appendix A, Part 2) ensure correct combination of these primitives. Note that each primitive (other than TimerDuration which is event specific) potentially belongs to many SENLSs and is verified against the Product Data Synthesis (e.g., instances correspond to Modules, messages to InputOutput and actions to Functions - readers are referred to 4.3.3.4.2 for these rule definitions, in particular i(3), i(4) and i(5)). We now consider definition of CommunicationEvent types.

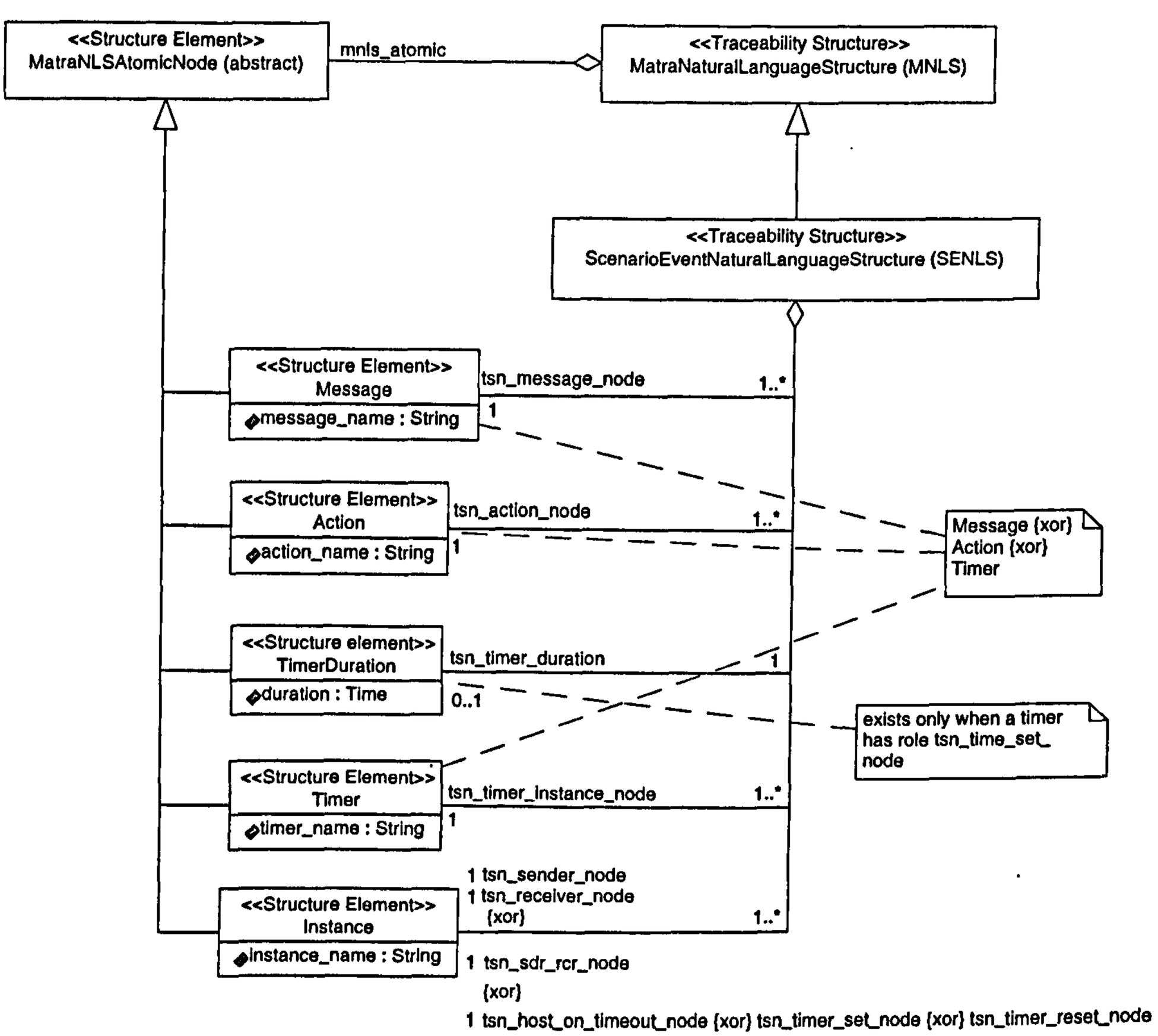


Figure 4.14 -'Scenario Event Natural Language Structure (SENLS) : Elements'

CommunicationEvent (figure 4.15) includes the property interaction_type (of type InteractionType, an instantiation of ArtifactProperty and specialisation of String restricted to IR, IP, SR and SP denoting the interactions discussed in 4.3.3.1). Textual and Message Sequence Chart perspectives are represented by TsnCommunication and MscCommunication respectively; recall that whichever is populated, the other can be derived through an implementation of the rules in 4.3.3.4.2, i.6 (and Appendix A, Part 2). However readers are reminded of the need for user intervention in deriving prose representations of sequence chart events in order to produce meaningful and legitimate statements.

TsnCommunication is described by a Scenario Event Natural Language Structure, comprising sender and receiver Instance (over tsn_sender_node and tsn_receiver_node rolenames) and Message nodes. In the context of textual representations, each message may be assigned a message description (MessageDescription) parameter (as discussed in 4.3.3.1) using the tsn_msg_parameter rolename[14].

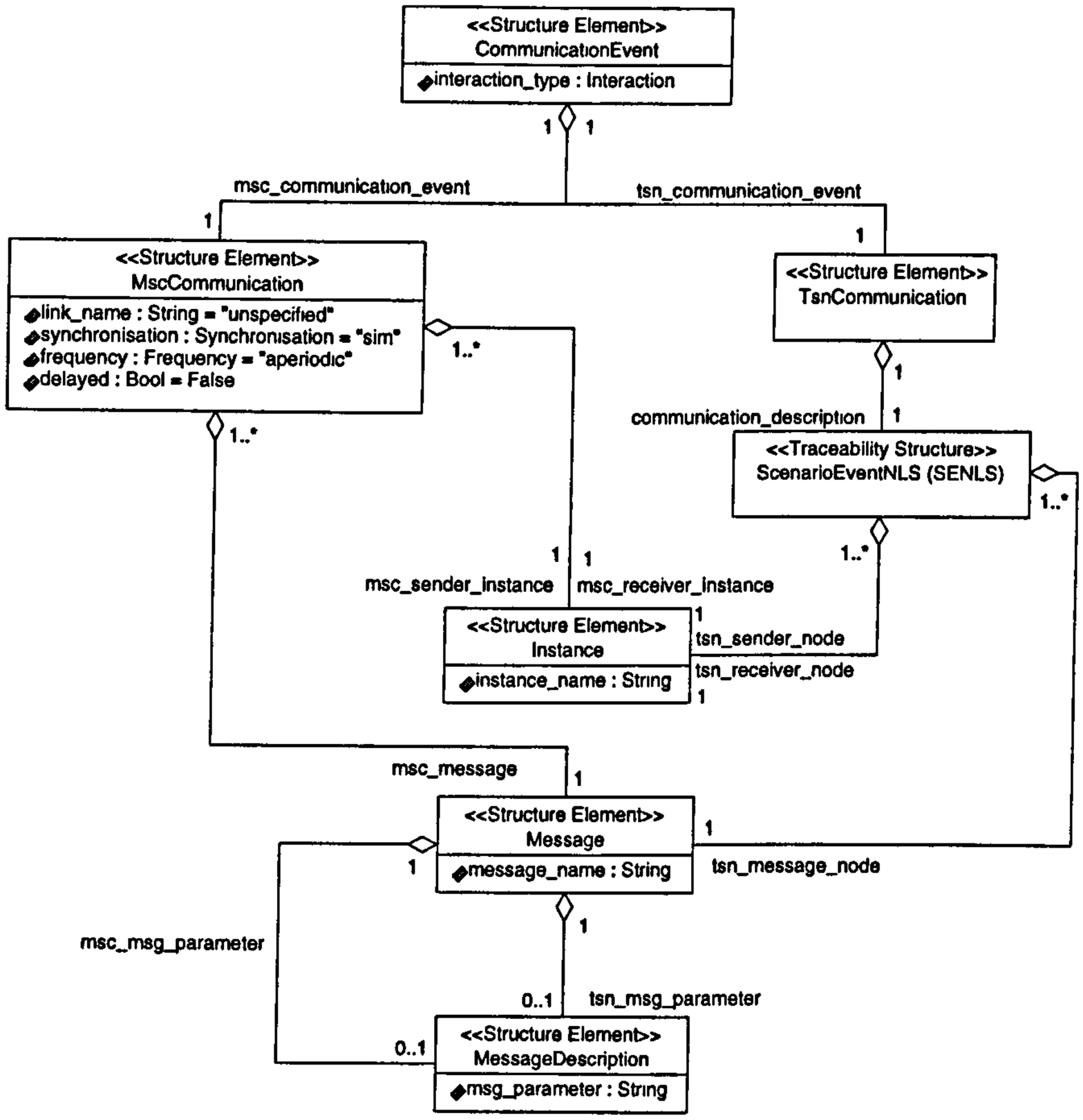


Figure 4.15 - 'Interaction Model - Communication Event : Elements and Associations'

MscCommunication has the attributes link name (link_name), synchronisation, frequency and delayed. Link name is of type String and allows nomination of a connection between the sender and receiver instances (which is checked against the PDS). However, given that UCRS is intended for use primarily during the requirements phase of a project, such information may be as yet undetermined; hence the default link name is 'unspecified'. Meanwhile, the frequency and synchronisation attributes (whose eponymous types are both instantiations of ArtifactProperty and specialisations of String) capture arrival patterns (with default 'aperiodic') and synchronisation patterns (default 'simplex') respectively[15]. Finally, the Boolean delayed attribute (default false) denotes a non-negligible pause in message transmission (relative to the overall dynamics of the target system).

MscCommunication is aggregated to Instance (over msc_sender_instance and msc_receiver_instance) and

---

[14] Note, for added flexibility we could have allowed the textual perspective of Message to have several different parameters - potentially one for each SENLS it appears in. However, that would risk obscuring the original message and intended usage.
[15] All case study examples featuring these properties (see section 6.2) are confined to default values.

Message elements - the same SENLS elements that describe TsnCommunication. As with textual descriptions, sequence diagram messages may also feature a MessageDescription parameter assigned using the msc_msg_paramater rolename.

As figure 4.16 indicates, InternalActionEvent is modelled in similar fashion to CommunicationEvent with textual and Message Sequence Chart perspectives represented by TsnAction and MscAction respectively. TsnAction is also described by a Scenario Event Natural Language Structure, comprising a sender/receiver Instance (over rolename tsn_sdr_rcr_node) and Action node. In the context of textual representations, actions may be assigned an action description (ActionDescription) parameter using the tsn_act_paramater rolename.

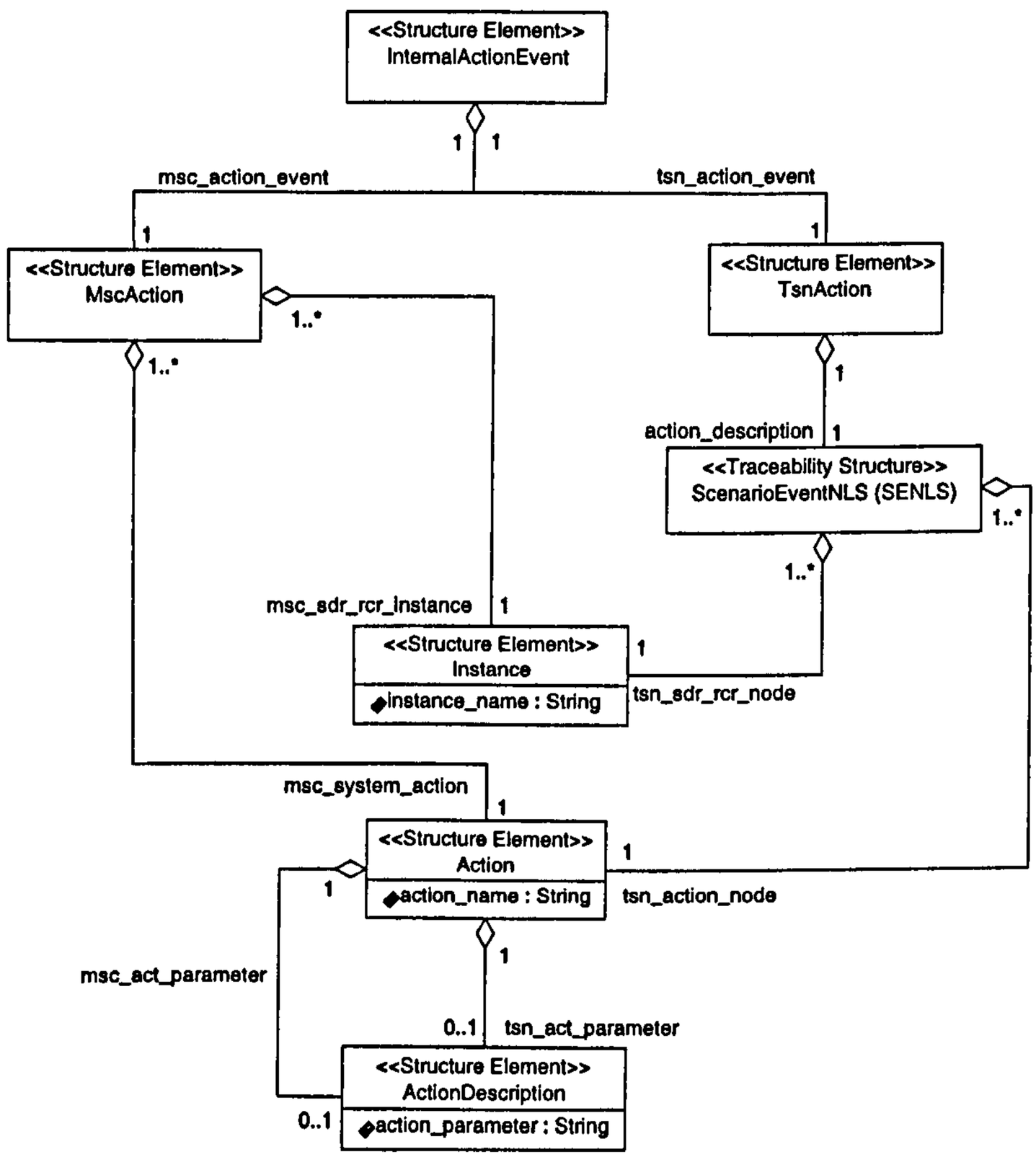


Figure 4.16 - 'Interaction Model - Internal Action Event : Elements and Associations'

MscAction is aggregated to the Instance (over msc_sdr_rcr_node) and Action elements of SENLS that describe TsnAction. Again, sequence diagram actions may be given an ActionDescription parameter through the msc_act_paramater rolename.

It can be seen from figure 4.17 that TimingEvent also follows the pattern of CommunicationEvent and InternalActionEvent such that textual perspectives are represented by TsnTiming and sequence chart perspectives by MscTiming. TsnTiming is likewise described as an SENLS, this time composed of an

Instance element over tsn_timer_set_node, tsn_timer_reset_node and tsn_host_on_timeout_node rolenames, denoting an initiator of timer set and reset events acting on some Timer element, with passive involvement in time-out events.

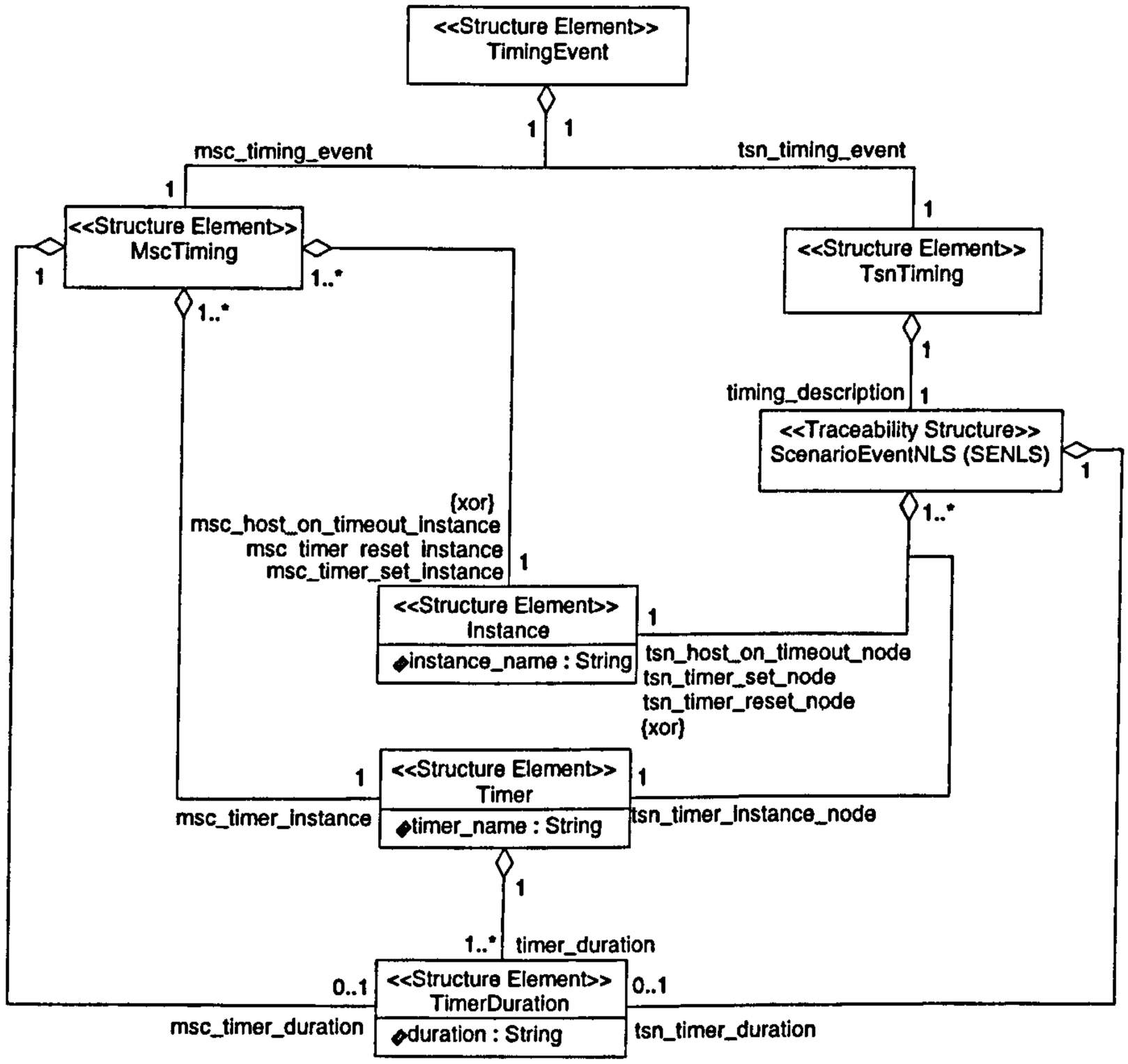


Figure 4.17 - 'Interaction Model - Timing Event : Elements and Associations'

It should be noted that TimerDuration, an aggregation component of Timer serves a different purpose to the message and action descriptions in CommunicationEvent and InternalActionEvent. Rather than providing an optional and alternative means of presentation for the aggregate class (i.e., Message or Action), TimerDuration is a necessary element of timer set events (and only timer set events) which states the timing interval. Note also that each Timer potentially appears in several timer set events and as such has several durations. However, each duration is event specific and so belongs to the textual and sequence chart perspectives of only one timer set event.

As with our previous event models, MscTiming is aggregated to the Instance (over msc_timer_set_node, msc_timer_reset_node and msc_host_on_timeout_node rolenames) and Timer elements of SENLS that describe TsnTiming, as it is to TimerDuration.

4.3.3.4.2 OCL Constraints over Interaction View Meta-model

Again, a number of constraints and rules over elements of the Interaction View have been defined. As with Use Case View, these are grouped on the basis of consistency and well-formedness. A selection of

these are included below (while readers referred to Appendix A, Part Two for the remainder).

I. Consistency

1. Constraint to ensure a UseCase described in an InteractionModel exists in the UseCaseView.

```
InteractionModel invariant
self.allInstances->forall(i |
self.interactionView.userCentredRequirementsStructure.useCaseView.ucv_use_case->exists(u |
i.describes_use_case = u.use_case_name))
```

2. Constraint over Communication Events (textual perspective); ensures there exists an Interaction in UseCaseView with the use case nominated in InteractionModel.describes_use_case as one of its interactors, such that sender and receiver in the event specification equate (not necessarily respectively) to the other end of this interaction and the subject_module attribute of UserCentredRequirementsStructure.

```
CommunicationEvent invariant
self.allInstances->forall(c |
self.interactionModel.interactionView.userCentredRequirementsStructure.useCaseView.ucv_use_case->exists(u |
self.interactionModel.interactionView.userCentredRequirementsStructure.useCaseView.ucv_interaction->exists(i |
c.interactionModel.describes_use_case = u.use_case_name and
(i.interactor_2 = u and
((c.tsn_communication_event.tsn_sender_node.instance_name = i.interactor_1.actor_name and
c.tsn_communication_event.tsn_receiver_node.instance_name =
c.interactionModel.interactionView.userCentredRequirementsStructure.subject_module) or
(c.tsn_communication_event.tsn_receiver_node.instance_name = i.interactor_1.actor_name and
c.tsn_communication_event.tsn_sender_node.instance_name =
c.interactionModel.interactionView.userCentredRequirementsStructure.subject_module)))
or
(i.interactor_1 = u and
((c.tsn_communication_event.tsn_sender_node.instance_name = i.interactor_2.actor_name and
c.tsn_communication_event.tsn_receiver_node.instance_name =
c.interactionModel.interactionView.userCentredRequirementsStructure.subject_module) or
(c.tsn_communication_event.tsn_receiver_node.instance_name = i.interactor_2.actor_name and
c.tsn_communication_event.tsn_sender_node.instance_name =
c.interactionModel.interactionView.userCentredRequirementsStructure.subject_module))) )))
```

3. Constraint (over textual perspective) to ensure PDS consistency of Communication Events. That is, the corresponding PDS sender module produces an external flow (corresponding to the event message) which is consumed by a function of the corresponding PDS receiver module; both sender and receiver modules interface with one another. Depending on how advanced the development is, this may be through some as yet unspecified means (using InterfacesTo), or via a mutual interface (using Interface), or else via their own respective interfaces adjoined by a Connection.

```
CommunicationEvent invariant
self.allInstances->forall(c |
self.tsn_communication_event.communication_description.tsn_sender_node.
bEelementAEO.build_element->exists(be1 |
self.tsn_communication_event.communication_description.tsn_receiver_node.
bEelementAEO.build_element->exists(be2 |
self.tsn_communication_event.communication_description.tsn_message_node.
```

```
bEelementAEO.build_element->exists(f |
c.tsn_communication_event.communication_description.tsn_sender_node.
bEelementAEO.build_element->includes(be1) and
c.tsn_communication_event.communication_description.tsn_receiver_node.
bEelementAEO.build_element->includes(be2) and
c.tsn_communication_event.communication_description.tsn_message_node.
bEelementAEO.build_element->includes(f) and
be1.module_name = c.tsn_communication_event.communication_description.tsn_sender_node.instance_name
and
be2.module_name = c.tsn_communication_event.communication_description.tsn_receiver_node.instance_name
and
f.flow_name = c.tsn_communication_event.communication_description.tsn_message_node.message_name and
be1.encapsulates.target.producesExternalIO.target->includes(f) and
be2.encapsulates.target.consumesExternalIO.target->includes(f) and
(f.sentTo.target.connection.target.receivedFrom.source->includes(f) or
f.sentTo.target.receivedFrom.source->includes(f)or
be1.interfacesTo.target->includes(be2) or be2.interfacesTo.target->includes(be1) ))))
```

4. Constraint (again expressed over the textual perspective) to ensure that actions are declared as functions in the PDS. Furthermore, each function describes the behaviour of a transaction corresponding to the use case nominated in InteractionModel.describes_use_case.

```
InternalActionEvent invariant
self.allInstances->forall(a |
self.tsn_action_event.action_description.tsn_sdr_rcr_node.bEelementAEO.build_element->exists(be |
self.tsn_action_event.action_description.tsn_action_node.bEelementAEO.build_element->exists(f |
self.tsn_action_event.action_description.tsn_sdr_rcr_node.bEelementAEO.build_element.
behavesAccordingTo.target->exists(t |
a.tsn_action_event.action_description.tsn_sdr_rcr_node.instance_name = be.module_name and
a.tsn_action_event.action_description.tsn_action_node.action_name = f.function_name and
a.interactionModel.describes_use_case = t.transaction_name and
be.behavesAccordingTo.target->includes(t) and
t.usesFunction.target->includes(f) ))))
```

5. Constraint (also expressed over textual perspective) to ensure timers are defined as sub-modules of the target system in the PDS.

```
TimingEvent invariant
self.allInstances->forall(t |
self.tsn_timing_event.timing_description.instance.bEelementAEO.build_element->exists(be1 |
self.tsn_timing_event.timing_description.tsn_timer_instance_node.bEelementAEO.build_element->exists(be2 |
t.tsn_timing_event.timing_description.instance.instance_name = be1.module_name and
t.tsn_timing_event.timing_description.tsn_timer_instance_node.timer_name = be2.module_name and
be1.hasSubmodule.target->includes(be2) )))
```

6. Rules to derive Message Sequence Chart event perspectives from textual representations.

```
CommunicationEvent
self.allInstances->forall(c |
self.msc_communication_event->exists(m |
c.tsn_communication_event->notEmpty
and
c.msc_communication_event->includes(m)))
implies
m.msc_sender_instance->includes
```

```
(c.tsn_communication_event.communication_description.tsn_sender_node) and
m.msc_receiver_instance->includes
(c.tsn_communication_event.communication_description.tsn_receiver_node) and
m.msc_message->includes(c.tsn_communication_event.comunication_description.tsn_message_node)

InternalActionEvent
self.allInstances->forall(a |
self.msc_action_event->exists(m |
a.tsn_action_event->notEmpty
and
a.msc_action_event->includes(m)))
implies
m.msc_sdr_rcr_instance->includes
(a.tsn_action_event.action_description.tsn_sdr_rcr_node) and
m.msc_system_action->includes
(a.tsn_action_event.action_description.tsn_action_node)

TimingEvent
self.allInstances->forall(t |
self.msc_timing_event->exists(m |
t.tsn_timing_event->notEmpty
and
t.msc_timing_event->includes(m)))
implies
m.msc_host_on_timeout_instance->union(m.msc_timer_set_instance->union(m.msc_timer_reset_instance))
->includes
(t.tsn_timing_event.timing_description.tsn_host_on_timeout_node->union
(t.tsn_timing_event.timing_description.tsn_timer_set_node->union
(t.tsn_timing_event.timing_description.tsn_timer_reset_node))) and
m.msc_timer_instance->includes(t.tsn_timing_event.timing_description.tsn_timer_instance_node) and
m.msc_timer_duration->includes(t.tsn_timing_event.timing_description.tsn_timer_duration)
```

ii. Well-Formedness

1. Constraint enforcing uniqueness of Instance primitives throughout an InteractionView (Appendix A, Part 2 includes similar constraints over Message, Action and Timer).

```
InteractionView Invariant
self.allInstances->forall(v |
self.interaction_model.inm_instance->forall(i1, i2 |
not(
v.interaction_model.inm_instance->includes(i1) and v.interaction_model.inm_instance->includes(i2) and i1 <> i2
and
i1.instance_name = i2.instance_name)))
```

2. Constraint ensuring that each InteractionModel within an InteractionView describes a different UseCase.

```
InteractionView Invariant
self.allInstances->forall(v |
self.interaction_model>forall(m1, m2 |
not (v.interaction_model->includes(m1) and v.interaction_model->includes(m2) and
m1 <> m2 and m1.describes_use_case = m2.describes_use_case)))
```

3. Constraint ensuring that 'included scenarios' are paths through different use cases (Appendix A, Part 2 includes a similar constraint for 'extended-by scenarios').

InteractionModel **invariant**
self.allInstances->forall(m1, m2 |
self.inm_scenario->forall(s1, s2 |
not (m1.inm_scenario->includes(s1) and m2.inm_scenario->includes(s2) and
s1.includes_scenario->includes(s2) and
m1 = m2)))

4. Constraint to ensure that for two Interaction Models (m1, m2), where the UseCaseView contains an «includes» association in which the use case described in m1 is the base of this association and the use case described in m2 is the included part, then at least one Scenario forming m2 should appear among the included scenarios of any Scenario in m1. Readers are referred to Appendix A, Part 2 for a similar constraint over «extends» associations.

InteractionModel **invariant**
self.allInstances->forall(m1, m2 |
self.interactionView.userCentredRequirementsStructure.useCaseView.ucv_includes->
not exists(i |
m1.describes_use case = i.includes_base.use_case_name and
m2.describes_use_case = i.includes_include.use_case_name and
(m2.inm_scenario->intersection(m1.inm_scenario.includes_scenario)->isEmpty)))

5. 'Style rule' that the first message in a Scenario is a Communication Event. This can be enforced by restricting sequence numbers.

Event
self.allInstances->forall(e |
self.sequence_no->forall(s |
self.included_seq_no->forall(i |
self.extension_seq_no->forall(x |
not((
(e.sequence_no-> includes(s) and s.sequence_no = 1) or
(e.included_seq_no->includes(i) and i.sequence_no = 1) or
(e.extension_seq_no->includes(x) and x.sequence_no = 1)) and e.oclType <> CommunicationEvent)))))

6. 'Style rule' that the first message in a Scenario must be from an (actor) Instance to the target system and must not be an included or extension event; note the rule applies only to scenarios of use cases not designated as a sub-case.

Scenario
self.allInstances->forall(s |
self.scenario_event->union(self.included_event->union(self.extension_event))
->forall(c |
self.interactionModel.interactionView.userCentredRequirementsStructure.useCaseView.ucv_use_case
->forall(u |
self.scenario_event.sequence_no->union(self.included_event.included_seq_no->union
(self.extension_event.extension_seq_no))->intersection
self.scn_seq_no->union(self.scn_included_seq_no->union(self.scn_extension_seq_no))->forall(n |
not(
s.interactionModel.interactionView.userCentredRequirementsStructure.useCaseView.ucv_use_case
->includes(u) and
u.use_case_name = s.interactionModel.describes_use_case and
u.sub_case = False and
((s.included_event->includes(c) and c.included_seq_no->intersection(s.scn_included_seq_no)->includes(n) and

```
n.sequence_no = 1) or
(s.extension_event->includes(c) and c.extension_seq_no->intersection(s.scn_extension_seq_no)->includes(n)
and n.sequence_no = 1) or
(s.scenario_event->includes(c) and c.sequence_no->intersection(s.scn_seq_no)->includes(n) and
n.sequence_no = 1
and c.tsn_communication_event.communication_description.tsn_sender_node.instance_name =
c.interactionModel.interactionView.userCentredRequirementsStructure.subject_module)) ) ))))
```

4.3.3.4.3 O-Telos Base Classes for Interaction View Meta-model

We implement base classes for the Interaction View (shown in figures 4.12 through 4.17) as follows:-

```
Definition of Interaction Model
Constituents

Scenario in StructureElement, SimpleClass
isA AerospaceEngineeringObject with
has_property
    scenario_title : String;
    is_exception : Bool;
    scn_seq_no : SequenceNumber;
    scn_included_seq_no : SequenceNumber;
    scn_extension_seq_no : SequenceNumber
has_part
    scenario_event : Event;
    included_event : Event;
    extension_event : Event;
    includes_scenario : Scenario;
    extended_by_scenario : Scenario;
    event_group : EventGroup;
    included_event_group : EventGroup;
    extension_event_group : EventGroup;
    tsn_viewpoint : TsnScenarioViewpoint;
    msc_viewpoint : MscScenarioViewpoint
has_transitive_part
    transitive_includes_scenario :
    Scenario;
    transitive_extended_by_scenario :
    Scenario
end

TsnScenarioViewpoint in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with has_part
    tsv_tsn_comm : TsnCommunication;
    tsv_tsn_act : TsnAction;
    tsv_tsn_tim : TsnTiming
end

MscScenarioViewpoint in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with has_part
    msv_msc_comm : MscCommunication;
    msv_msc_act : MscAction;
    msv_msc_tim : MscTiming
end

Event in StructureElement, SimpleClass
isA AerospaceEngineeringObject with
has_property
    sequence_no : SequenceNumber;
    included_seq_no : SequenceNumber;
    extension_seq_no : SequenceNumber;
    lwr_bd : LowerBound;
    upr_bd : UpperBound
has_part
    follows_from : Event
has_transitive_part
    transitive_follows_from : Event
constraint
    abstract_Evt: $forall t/Token
    s/SimpleClass
    (t in s) ==> not (t in Event)
end

CommunicationEvent in StructureElement,
SimpleClass isA Event with
has_property
    interaction_type : InteractionType
has_part
    tsn_communication_event :
        TsnCommunication;
    msc_communication_event :
        MscCommunication
end

TsnCommunication in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_structure
    communication_description :
ScenarioEventNaturalLanguageStructure
end

MscCommunication in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_property
    link_name : String;
    synchronisation : Synchronisation;
    frequency : Frequency;
    delayed : Bool
has_part
    msc_sender_instance : Instance;
    msc_receiver_instance : Instance;
    msc_message : Message
end

MessageDescription in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_property
    msg_parameter : String
end

InternalActionEvent in StructureElement,
SimpleClass isA Event with
has_part
    tsn_action_event : TsnAction;
    msc_action_event : MscAction
end

TsnAction in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_structure
    action_description :
ScenarioEventNaturalLanguageStructure
end

MscAction in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with has_part
    msc_sdr_rcr_instance : Instance;
    msc_system_action : Action
end

ActionDescription in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_property
    action_parameter : String
```

```
end

TimingEvent in StructureElement,
SimpleClass isA Event with
has_part
    tsn_timing_event : TsnTiming;
    msc_timing_event : MscTiming
end

TsnTiming in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_structure
    timing_description :
ScenarioEventNaturalLanguageStructure
end

MscTiming in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with has_part
    msc_timer_set_instance : Instance;
    msc_timer_reset_instance : Instance;
    msc_host_on_timeout_instance :
        Instance;
    msc_timer_instance : Timer;
    msc_timer_duration : TimerDuration
end

EventGroup in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_property
    grp_lb : LowerBound;
    grp_ub : UpperBound
has_part
    group_event : Event
end

SequenceNumber in ArtifactProperty,
SimpleClass with
described_by
    sequence_no : Integer
end

LowerBound in ArtifactProperty,
SimpleClass with described_by
    lower_bound : String
end

UpperBound in ArtifactProperty,
SimpleClass with described_by
    upper_bound : String
end

InteractionType in ArtifactProperty,
SimpleClass isA String with
constraint
    enum_Int: $forall i/InteractionType
    (i = "SR") or (i = "SP") or ( i=
    "IR") or (i = "IP")$
end

Synchronisation in ArtifactProperty,
SimpleClass isA String with
constraint
    enum_Syn: $forall s/Synchronisation
(s = "sim") or (s = "syn") or (s = "bal")
or  (s = "tim") or (s = "asy")$
end

Frequency in ArtifactProperty,
SimpleClass isA String with
constraint
    enum_Frq: $forall f/Frequency(f =
    "periodic") or (f = "aperiodic")$
end
```

Definition of Interaction Model

```
InteractionModel in DevelopmentStructure,
SimpleClass isA
AerospaceEngineeringObject with
has_property
    model_name : String;
    describes_use_case : String;
    inm_date : Date
has_structure
    inm_comments :
MatraNaturalLanguageStructure
has_element
    inm_scenario : Scenario;
    inm_included_scenario : Scenario;
    inm_extension_scenario : Scenario;
    inm_event : Event;
    inm_communication_event :
        CommunicationEvent;
    inm_action_event :
        InternalActionEvent;
    inm_timing_event : TimingEvent;
    inm_tsn_viewpoint :
        TsnScenarioViewpoint;
    inm_msc_viewpoint :
        MscScenarioViewpoint;
    inm_tsn_communication :
        TsnCommunication;
    inm_tsn_action : TsnAction;
    inm_tsn_timing : TsnTiming;
    inm_msc_communication :
        MscCommunication;
    inm_msc_action : MscAction;
    inm_msc_timing : MscTiming;
    inm_event_group : EventGroup;
    inm_instance : Instance;
    inm_message : Message;
    inm_message_desc :
        MessageDescription;
    inm_action : Action;
    inm_action_desc : ActionDescription;
    inm_timer : Timer;
    inm_timer_duration : TimerDuration
end
```

Definition of Interaction View

```
InteractionView in DevelopmentStructure,
SimpleClass isA
AerospaceEngineeringObject with
has_property
    inv_date : Date
has_structure
    inv_comments :
MatraNaturalLanguageStructure;
    interaction_model : InteractionModel
end
```

Definition of SENLS Constituents

```
Message in StructureElement, SimpleClass
isA MatraNLSAtomicNode with has_property
    message_name : String
has_part
    tsn_msg_parameter :
MessageDescription;
    msc_msg_parameter :
MessageDescription
end
```

-- Message Description specified as part of Interaction Model

```
Action in StructureElement, SimpleClass
isA MatraNLSAtomicNode with has_property
    action_name : String
has_part
    tsn_act_parameter :
        ActionDescription;
    msc_act_parameter : ActionDescription
end
```

```
-- Action Description specified as part
of Interaction Model

TimerDuration in StructureElement,
SimpleClass isA MatraNLSAtomicNode with
has_property
    duration : String
end

Timer in StructureElement, SimpleClass
isA MatraNLSAtomicNode with has_property
    timer_name : String
has_part
    timer_duration : TimerDuration
end

Instance in StructureElement, SimpleClass
isA MatraNLSAtomicNode with has_property
    instance_name : String
end

Definition of SENLS

ScenarioEventNaturalLanguageStructure in
TraceabilityStructure, SimpleClass isA
MatraNaturalLanguageStructure with
has_element
    tsn_message_node : Message;
    tsn_action_node : Action;
    tsn_timer_duration : TimerDuration;
    tsn_timer_instance_node : Timer;
    tsn_sender_node : Instance;
    tsn_receiver_node : Instance;
    tsn_sdr_rcr_node : Instance;
    tsn_host_on_timeout_node : Instance;
    tsn_timer_set_node : Instance;
    tsn_timer_reset_node : Instance
end
```

4.3.4 Relationship to the Traceability Dimensions

While the focus of this thesis is on developing meta-models for well-defined and flexible notations, we do nevertheless introduce a few examples of potential links between these models in order to demonstrate the AerospaceEngineeringAssociation concept from Chapter Three.

The fact that UCRS integrates Use Case Models, Scenarios and Message Sequence Charts suggests a need for traceability within the structure itself. Hence in Chapter Six we illustrate some potential (intra-micro) horizontal associations between these notations using associations proposed in subsection 3.3.6.3.2. For instance, we can assert that a particular scenario constitutes a 'path-through' a use case (in the sense of elaborating the use case description), and that the textual view of a scenario is 'illustrated-by' its message sequence chart equivalent.

Discussions with aerospace practitioners indicates that Use Case Modelling is often used in conjunction with Real-Time Networks, a design methodology considered in the next subsection. This in turn implies that (intra-micro) vertical traceability should exist between elements of the two notations, a point to which we return in subsection 4.4.4.

Note the need for a thorough investigation into inter/intra, macro/micro and horizontal/vertical associations that can exist between all artifact types used in avionics systems engineering is identified as a future work item in 7.4.3.

4.3.5 Summary

The modelling of interactions between external entities and a target system is an important facet of requirements engineering in the aerospace industry. Use Case Models, together with Scenarios and their graphical representation as Message Sequence Charts afford established means of accomplishing this. Accordingly, they were chosen as representative requirements notations for the MATrA traceability framework.

From discussions with practitioners and examination of actual commercial specifications, we developed a novel structure to allow integration of these notations. Rules and well-formedness constraints provide

a light-weight semantics for the structure, allowing verification and traceability. In particular, existing literature on Scenarios allowed us to develop a semi-formal foundation (featuring a specialised MNLS from section 4.2) to what is the least formal of the three notations, but which retains the usability of prose representations.

Chapter Six (section 6.2) demonstrates application of the User Centred Requirements Structure using a commercial specification for a sub-system of the Hawk lead-in fighter/trainer aircraft; a full evaluation of UCRS appears in Chapter Seven.

4.4 Real-Time Network Specification Language Structure (Graphical)

4.4.1 Introduction

In this section we introduce a structure capturing the graphical syntax and 'light-weight' formal semantics (i.e., with sufficient rigour for traceability purposes) for a Real-Time Network Specification Language (RTN-SL) currently being developed by the MBDA-UK business unit of BAE SYSTEMS.

4.4.2 Motivation

In Chapter One, we alluded to scale and complexity as common characteristics of avionics systems. A proven method for dealing with any complex system is to partition it into smaller independently operating subsystems which only interact with one another and with the system environment through explicitly defined communication connections. For computer based systems, this approach is known as the Real-Time Network (RTN) architecture in which concurrent processing components exchange information and synchronise through shared data in the connections[16].

MASCOT (Modular Approach to Software, Construction, Operation and Test) is a design methodology based on the Real-Time Network concept (Simpson, 1986). It comprises a design language and graphical notation, together with a process for design derivation based on structural decomposition. This involves identification of computational components of a system (its subsystems and processes) and the interactions between these components (i.e., data-flow paths), as well as protocols that characterise these interactions. MASCOT-3 is advocated for the design of large concurrent or distributed, real-time embedded software systems and has been used extensively throughout the defence industry.

DORIS (Simpson, 1994), the Data-Oriented Requirements Implementation Scheme is a variant of MASCOT-3 developed by MBDA-UK. The main difference is that DORIS distinguishes three levels of design abstraction, such that *application network* designs and *execution network* designs are specified in addition to the *functional* design. The former define the logical architecture of a system, whilst the latter extend the application network to include all additional components required to support distribution across a particular processor network. This enables flexible re-mapping of a design to the hardware platform as the hardware platform evolves (Paynter *et al.* 2000). DORIS also supports a wider-range of synchronous and asynchronous communication protocols appropriate to both shared-memory and message passing implementations (Simpson, 2000a-c).

In this thesis, we focus on support for tracing designs represented using RTN-SL, a specification and design language (intended for integration into MASCOT-3 and DORIS) currently being developed by MBDA-UK for defining the behaviour of Real-Time Networks (Paynter, 2000). RTN-SL features both a formal textual and graphical syntax[17]; in concentrating on the latter[18] we note that the textual syntax

[16] For a comparison of methods for real-time systems development, readers are referred to Hull *et al.* (1991).
[17] The graphical syntax captures a subset of the textual syntax.
[18] This is due to the fact that whilst the graphical syntax is stable, the formal textual syntax is continuing to evolve.

has been influenced by Spark-Ada (Barnes, 1996) and that the same approach used in subsection 4.5 to develop a traceability meta-model for this language can be similarly applied to produce a comparable structure for the RTN-SL textual syntax (we briefly return to this issue in 4.4.3). The following subsection provides an overview of the RTN-SL and its graphical notation in particular.

4.4.2.1 RTN-SL Overview

RTN-SL is used to define flat Real-Time Networks, including the real-time and functional behaviour of their activities. A flat RTN comprises a set of activities (single-threaded processes) connected into a network by ports that interface with communication paths. Between each activity is an intercommunication data area (IDA) which defines the interaction protocol used on that path. Activities may not be directly connected together, but instead must communicate via an IDA (Paynter, 2000).

RTN-SL supports five protocols, namely pool, channel, signal, stimulus and dataless channel; the three basic protocols are the *pool* (similar to a shared variable), *channel* (a bounded buffer) and *signal* (a one-place over-writing buffer). These impose different synchronisation constraints on the reader and writer of the protocol depending on whether they allow data to be destroyed when it is read or written (see table 4.2 for a summary). The other two RTN-SL protocols, namely *stimulus* and *dataless channel* are variants of signal and channel respectively; they differ in that both allow communication of void (null) data.

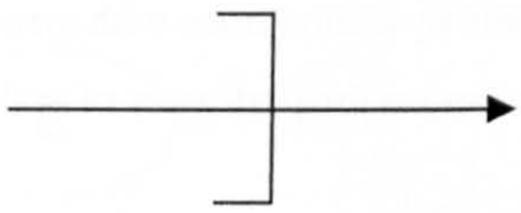
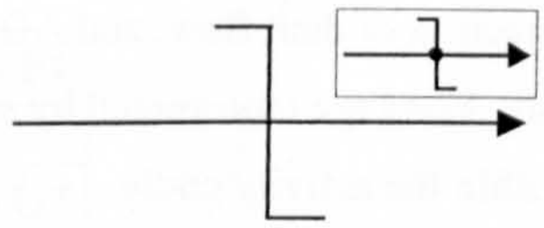
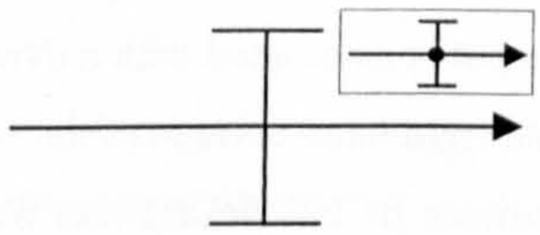
	• Non-destructive reading of data • Reader cannot be delayed	• Destructive reading of data • Reader can be delayed
• Destructive writing of data • Writer cannot be delayed	 **Pool**	 **Signal (Stimulus inset)**
• Non-destructive writing of data • Writer can be delayed		 **Channel (Dataless Channel inset)**

Table 4.2 - 'IDA Communication Protocols'

Abstract data types (ADTs) may be defined to support definition of a flat Real-Time Network. These are necessary when a data type must be visible in more than one activity and/or IDA, where one activity communicates data to another which is not a built-in type (Paynter, 2000).

Conceptually, the RTN-SL includes a sub-language known as Activity Description Language (ADL) for defining the behaviour of activities. In turn, the ADL includes a timed state-machine notation sub-

language termed the Activity State-Machine (ASM) [19] which is used to define the structure and timing constraints of an activity's algorithm.

ASM distinguishes between static and dynamic states; static states model potential blocking-points of an algorithm where an activity is either attempting to communicate using a synchronous protocol, or is engaged in a timed delay. Transitions from a static state are labelled either with the event indicating that the communication may continue or finish, or with the lower and upper bonds of the time delay (Paynter, 2000).

Dynamic states model an activity's computation, each one encapsulating some non-reactive functionality. They have a best-case execution time (BCET) bound, a worst-case execution time (WCET) bound and worst-case response time (WCRT) bound; an optional worst-case response time on read may also be recorded. An activity is normally required to exit a state within these times[20]. Transitions from a dynamic state are labelled with conditions over the local activity's state which are evaluated when a dynamic state terminates (Paynter, 2000). A *composite* dynamic state comprises several dynamic states whose operations may execute in any order.

4.4.2.2 RTN-SL Graphical Syntax

To aid comprehension, RTN-SL has a graphical syntax which we term RTN-SLg and which builds upon the graphical syntax of MASCOT (Simpson, 1986). Activities are represented as circles; IDAs by the appropriate symbol from table 4.2 (which is enclosed within a rectangle where the IDA is defined and hence named); ADTs by diamonds; communication paths by solid arcs with arrows indicating the direction of data-flow; and ADT imports by dotted lines with arrows pointing towards the importing unit. Ports are represented by solid circles on the perimeter of activities and the state machine drawn within the activity circle.

Static ASM states are represented by an ellipse and dynamic states as a rectangle. Where an input or output is associated with a dynamic state, then the appropriate port name is shown in the top left hand and right hand corners of the rectangle respectively. Labels in the bottom left and right hand corners indicate BCET, WCET and WCRT; the optional WCRT on read is shown in a box next to the input port name. The dynamic state graphical syntax is summarised in figure 4.18.

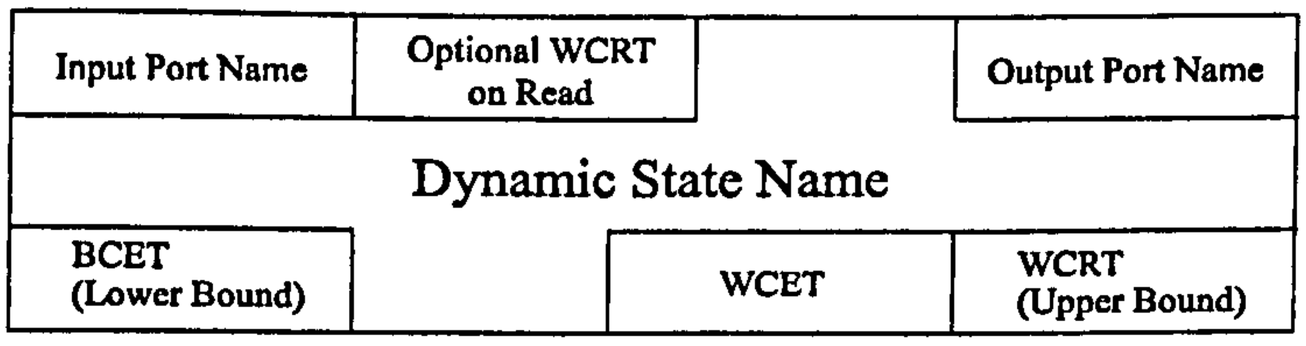


Figure 4.18 - 'ASM Dynamic State Graphical Syntax'

[19] Strictly, the ADL (including ASM) and RTN-SL are a single language.
[20] A discussion on the conditions necessary for this to occur is beyond the scope of this thesis.

Composite dynamic states are depicted by partitioning a dynamic state using dotted lines. Each constituent state may have its own input and output port, although one set of time bounds applies to the whole state. An example composite comprising three dynamic sub-states is shown in figure 4.19.

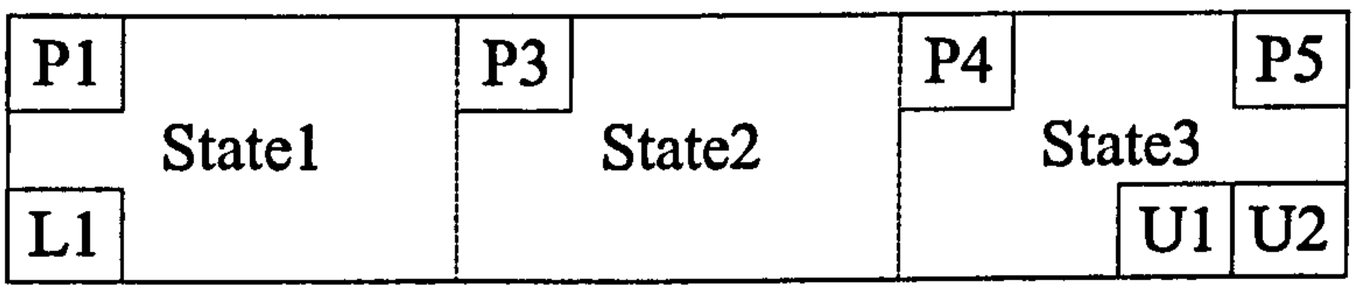


Figure 4.19 - 'ASM Graphical Syntax for Composite Dynamic States'

Transitions between states are depicted by directed arcs pointing from the source to the target state. Conditions, events and time-outs are shown as textual labels adjacent to the appropriate transition. The initial state is shown by being the target of a transition with no source.

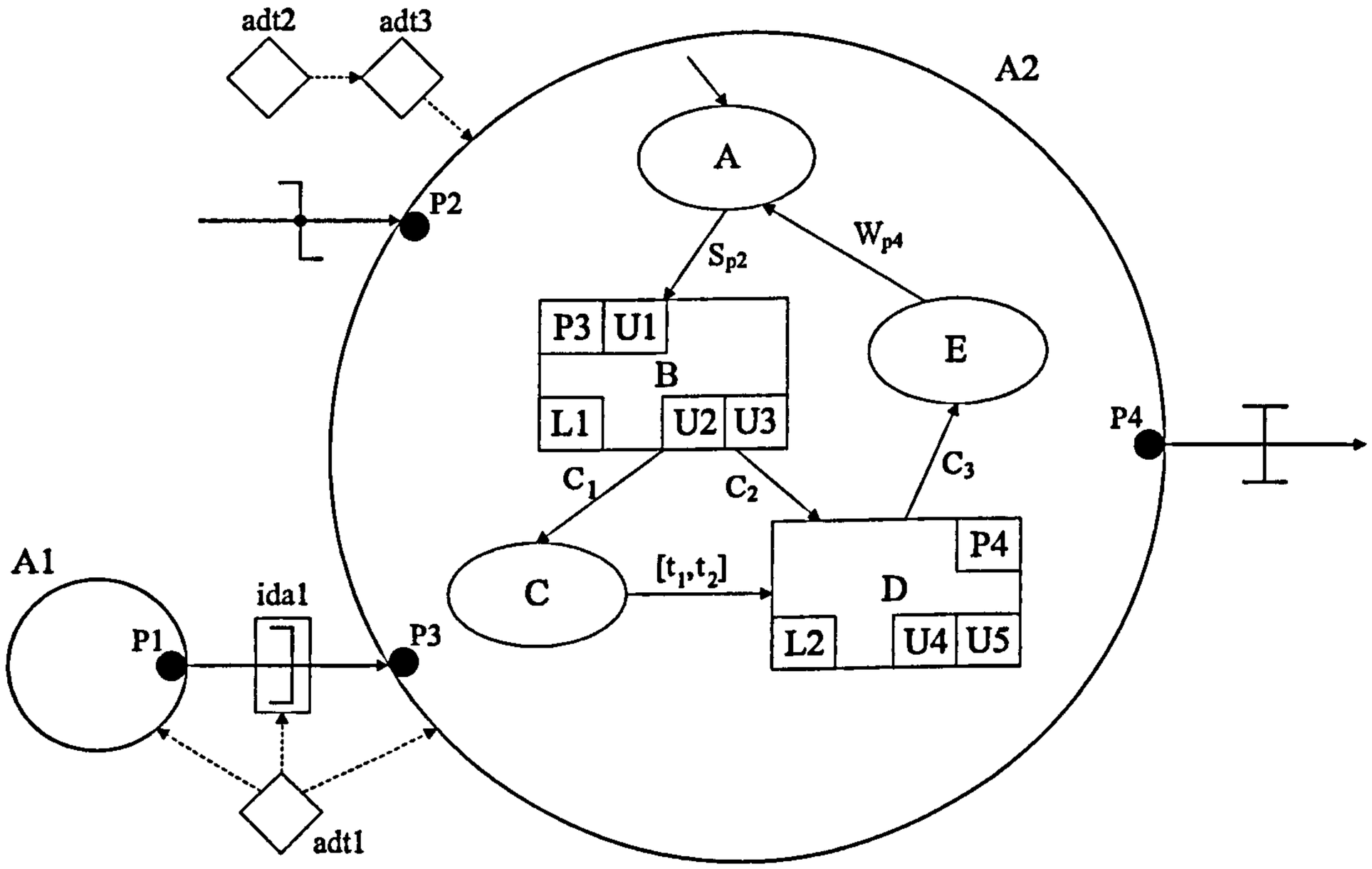


Figure 4.20 - 'Example RTN-SLg Specification' (source Paynter, 2000)

Figure 4.20 illustrates the main constituents of an RTN-SLg specification as described above. Activity A2 includes three static states, A (also the initial state), C and E, together with two dynamic states, B and D. When the activity is in state A and a void data value is present in the stimulus connected to port 2 (P2), then event S_{P2} occurs and the activity moves to state B which reads from the pool on port 3 (P3) within a finish time of U1. The computation (not shown[21]) associated with state B is executed and takes between L1 and U2 time units, although interruptions from the scheduling of other activities may prolong this to U3; conditions C1 and C2 are then evaluated. A transition with a true condition is taken and either state C or D is entered. Assuming state C, the activity is de-scheduled for between t_1 and t_2

[21] Computations are represented solely by the RTN-SL textual syntax.

time units whereupon state D is entered. The algorithm associated with state D (again not shown) is executed between its time bounds (as for state B) and a value written to the channel linked to port 4 (P4). On evaluation of condition C3 to true, the activity enters and waits in state E until the W_{p4} event occurs[22] whereupon it returns to the initial state (A). Activity A1 executes concurrently with A2, communicating with it via IDA ida1. ADT adt1 is used in the definition of A1, A2 and ida1; ADT adt2 is used in the definition of adt3, which in turn is used in the definition of A2.

4.4.3 Tracing Real-Time Network Specifications in MATrA: An RTN-SLg Model

In this subsection, we introduce a meta-model to support traceability of designs specified using the RTN-SLg notation, thereby allowing integration of Real-Time Networks into the MATrA framework.

The fact that RTN-SLg has a corresponding textual language leads to two options for constructing the meta-model:-

1. Employ an identical process to that used for the Use Case and Message Sequence Chart notations in subsection 4.3; i.e., examine components of the graphical notation, along with any well-formedness constraints restricting how these components are connected together; the resultant model is then verified against the textual language subset. Note that if like its textual counterpart the RTN-SLg syntax was also formally defined, perhaps using node-labelled graphs (*cf.* Paynter 1995) or a similarly rich language, then production of the meta-model would be more straightforward and the result more rigorous.

2. Examine the textual language subset that corresponds to the graphical notation; this would involve constructing schemas for each syntactic language element (BNF category) of the subset. It also assumes a function exists based on a mapping between the graphical and textual syntax that translates an RTN-SLg specification to an RTN-SL textual specification; *tool2matra* would then operate over the latter.

Application of both these options should result in two isomorphic models that while potentially different in their labelling of classes and associations, share the same structure. In this subsection we pursue option one, with option two applied after developing an approach for textual languages in subsection 4.5.

4.4.3.1 Concepts

In developing a meta-model to support traceability of RTN-SLg specifications, we have sought to capture the complete graphical syntax described in subsection 4.4.2.2. The model therefore contains representations of ADTs, IDAs, Ports and Activities, together with ASMs comprising static, dynamic and composite dynamic states.

There are numerous well-formedness constraints needed to ensure an RTN-SLg specification is

[22] This will be instantaneous if there is a space in the channel.

internally consistent. In this thesis we confine our interest to the principal restrictions expressed in Paynter (1995) and Paynter (2000).

4.4.3.2 RTN-SLg Meta-model Definitions

In this subsection, we introduce the RTN-SLg meta-model (4.4.3.2.1) which is again specified using the Class Diagram view of UML. We also introduce constraints over the model expressed in OCL (4.4.3.2.2), together with an implementation of its base classes in the O-Telos language (4.4.3.2.3).

4.4.3.2.1 RTN-SLg Meta-model

Figures 4.21 (elements) and 4.22 (associations) depict the UML meta-model for RTN-SLg. Its core class (RTN-SLg), with subject module (subject_module) and other configuration attributes (plus MNLS commenting facility) is an instantiation of the DevelopmentStructure meta-class. RTN-SLg is further defined as an aggregation of StructureElement meta-classes representing both RTN and ASM primitives.

Firstly, we consider those elements necessary to represent real-time networks, namely activity (Activity), abstract data type (Adt), IDA (Ida) and port (Port) entities, together with definitions (ConnectionDef) of network paths linking IDAs and activity ports.

Ida and Activity are both subtypes of the abstract component class (Component) reflecting the fact that RTN aspects of our model are grounded on work towards the formal characterisation of MASCOT in Paynter (1995)[23]. This influence is further evident in the (derived) reflexive associations on Component to record predecessor (predecessor) and successor (successor), together with further associations capturing their respective transitive closure elements (all_predecessors and all_successors)[24]. Our use of the oclType operation also mirrors that of the function Node_Type in Paynter (ibid.)[25]

Activity, Port, Ida and Adt carry (unique) name attributes for the purpose of meaningful identification and cross-verification with Product Data Synthesis elements[26]; the same label (name) is used across all of these classes as per the RTN-SL textual syntax. Ida also features a protocol kind (kind) attribute and an aggregation defining imported Adts (with_adt). Adt itself includes reflexive associations to identify imported 'with' abstract data types (also labelled with_adt), along with the transitive closure of imported 'with' (with_all). A ConnectionDef is formed from an aggregation of a Port and an Ida, the latter over an exclusive-or association denoting the direction of data flow from (from_ida) xor to (to_ida) an Ida.

The Activity class meanwhile is an aggregation of ports, "with-ed" Adts (again, with_adt) and a state machine (StateMachine) which in turn has a number of state definitions (identified through the rolename state_def), with subtypes static state (StaticState), dynamic state (DynamicState) and composite dynamic

---

[23] MASCOT designs are defined as directed-graphs:- MASCOT_DESIGNS::NODES : COMPONENTS; ARCS : COMPONENTS × COMPONENTS.
[24] Paynter (ibid.) uses the functions Predecessors : COMPONENTS → COMPONENTS-set and Successors: COMPONENTS → COMPONENTS-set, which operate over MASCOT_DESIGNS and return the set of all predecessors and set of all successors respectively; appropriate rules in subsection 4.4.3.2.2 (i) derive corresponding elements for our meta-model.
[25] Node_Type : COMPONENTS → {IDA, ACTIVITY} is a (total) function which returns the type of a node (i.e., IDA or Activity); this is similar to the oclType operation (from subsection 2.2.2.2.9) which evaluates to the type of an object.
[26] See OCL constraints in parts iii and iv(1) of subsection 4.4.3.2.2.

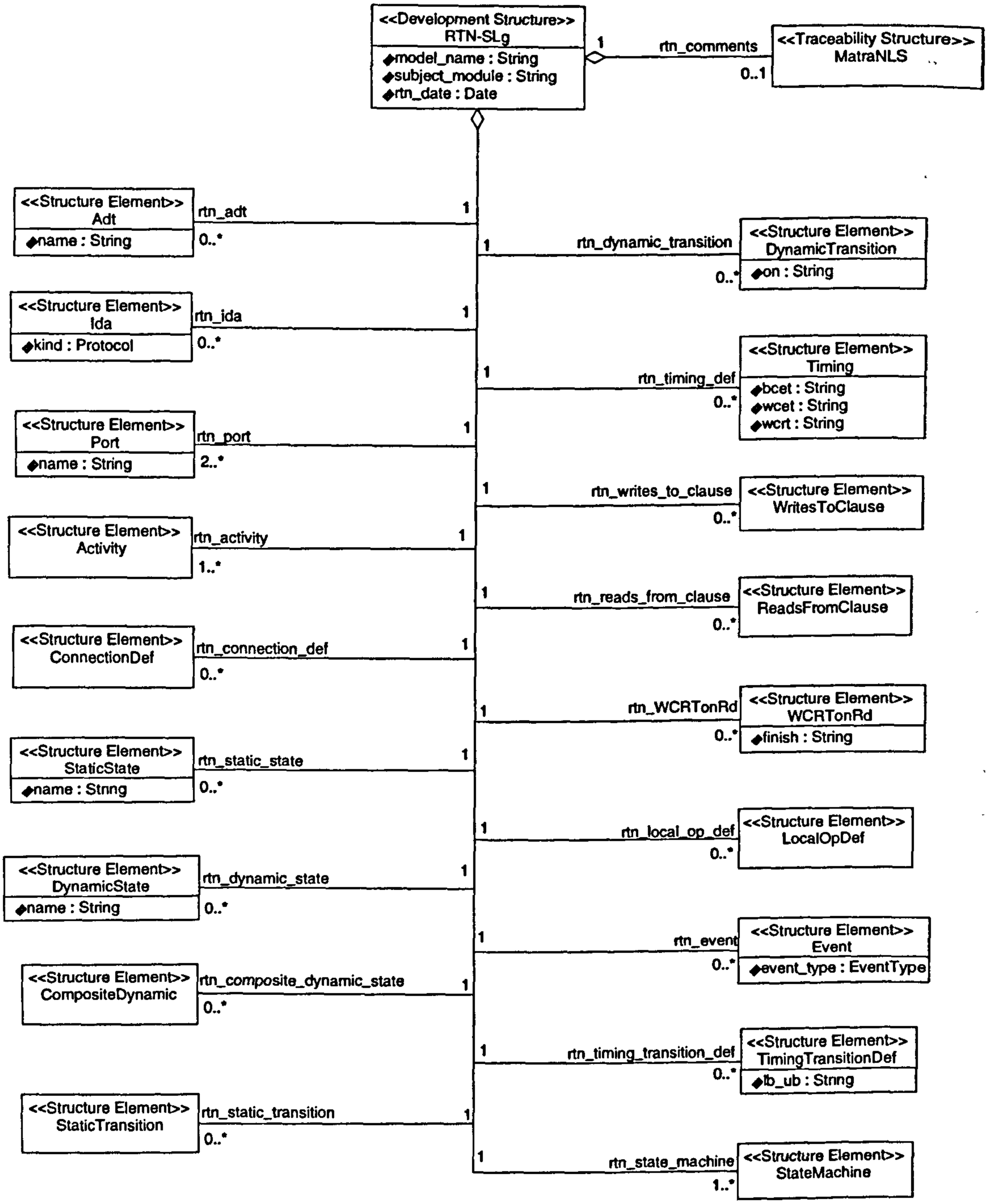


Figure 4.21 - 'RTN-SLg Structure : Elements'

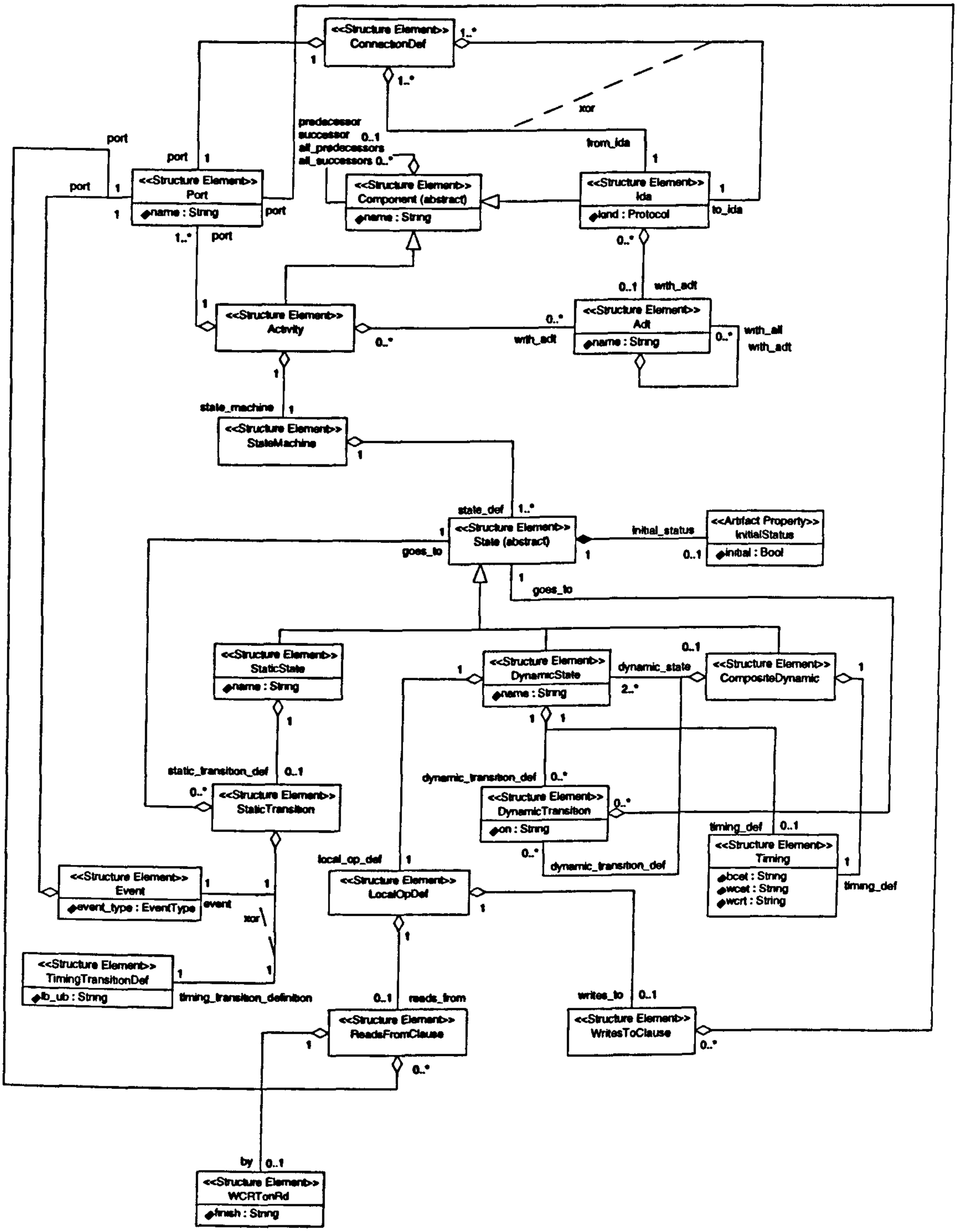


Figure 4.22 - 'RTN-SLg Structure : Associations'

(CompositeDynamic). The state class (State) itself is abstract, with a composition aggregation to initial status (InitialStatus) containing an attribute initial (initial) of type Bool. *Prima facie*, InitialStatus can be encapsulated as an attribute of State; however, we promote it to a class to enable its suppression on dynamic states that form a CompositeDynamic[27].

A StaticState has a unique name (name) attribute with a static transition definition (rolename static_transition_def) defined by the class StaticTransition which goes to (goes_to) a target State. Situations in which the transition is enabled may be either events (Event) of type (event_type) read, write or stim to a particular Port, exclusive-or, a timing definition (TimingTransitionDef) with upper and lower bounds (denoted by the attribute lb_ub).

A DynamicState also has a unique name (name) attribute, together with a dynamic transition definition (rolename dynamic_transition_def) defined by the class DynamicTransition which again goes to (goes_to) a target State on the specified condition holding (denoted by the on attribute). DynamicState is also an aggregation of timing (Timing) and local operation definitions (LocalOpDef). The former is described in terms of timing attributes for best-case execution time (bcet) bound, worst-case execution time (wcet) bound and worst-case response time (wcrt) bound, whilst the latter comprises definitions of the mapping of input (ReadsFromClause) and output (WritesToClause) parameters from and to the appropriate ports. The WCRTonRd class (with attribute finish) aggregated to ReadsFromClause (using the rolename by) supports optional definition of a worst case read time bound.

Finally, a CompositeDynamic state is described in terms of (two or more) dynamic states, together with dynamic transitions and a timing definition; again a constraint[28] ensures suppression of these characteristics for individual dynamic states such that their definitions apply to the whole CompositeDynamic.

4.4.3.2.2 OCL Constraints

In this subsection, we express the following types of constraint over the RTN-SLg meta-model:-

- Well-formedness of Real-Time Network elements;
- Well-formedness of Activity State Machine elements;
- Verification of RTN-SLg elements against the Product Data Synthesis;
- Other structural and consistency constraints attributable to modelling decisions.

I. Well-formed Real-Time Networks

The constraints below apply to Real-Time Network elements of the RTN-SLg meta-model; i.e., activities, ports and IDAs. They are based on rules for a well-formed MASCOT subset (Paynter, 1995) which (as indicated in 4.4.3.2.1) views RTNs as labelled directed graphs and describes relationships among activities and IDAs (i.e., nodes) in terms of their *predecessors* and *successors*.

---

[27] See OCL constraint iv(2) in subsection 4.4.3.2.2.
[28] See OCL constraint iv(3) in subsection 4.4.3.2.2.

- Immediate predecessor and successor are populated using the following deductive axioms:-

Activity
self.allInstances->forall(a |
self.port.connectionDef->forall(c |
c.port.activity->includes(a) and c.from_ida->size =1))
implies
a.predecessor->includes(c.from_ida)

Activity
self.allInstances->forall(a |
self.port.connectionDef->forall(c |
c.port.activity->includes(a) and c.to_ida->size =1))
implies
a.successor->includes(c.to_ida)

Ida
self.allInstances->forall(i |
self.connectionDef->forall(c |
c.to_ida->includes(i)))
implies
i.predecessor->includes(c.port.activity)

Ida
self.allInstances->forall(i |
self.connectionDef->forall(c |
c.from_ida->includes(i)))
implies
i.successor->includes(c.port.activity)

- Similarly, the following rules - this time expressed over the abstract Component class (and by implication of using the .allInstances operation, its Activity and Ida subtypes) - determine all_predecessors and all_successors. These will be used in specifying several of the invariants that follow:-

Component
self.allInstances->forall(c1, c2|
c1.predecessor->includes(c2) or
self.allInstances->exists(c' |
c1.predecessor->includes(c') and c'.all_predecessors->includes(c2)))
implies
c1.all_predecessors->includes(c2)

Component
self.allInstances->forall(c1, c2|
c1.successor->includes(c2) or
self.allInstances->exists(c' |
c1.successor->includes(c') and c'.all_successors->includes(c2)))
implies
c1.all_successors->includes(c2)

Well-formedness Constraints for Real-Time Networks

We are now in a position to define a subset of well-formedness constraints applicable to valid Real-Time Networks:-

1. Each Component is connected to another Component.

   This constraint is captured by the RTN-SLg class diagram and its multiplicity semantics.

2. Every connection path must connect to a Port at one end and to an Ida at the other, a standard MASCOT restriction on direct activity to activity communication.

   This constraint is also captured by the multiplicity semantics of the RTN-SLg class diagram.

3. All design components (i.e., activities and IDAs) with no 'predecessors' are of type Ida; these are termed input IDAs and reflect their use in modelling protocols of the hardware/software interface.

   Component **invariant**
   self.allInstances->forall(c | not(c.all_predecessors->size = 0 and c.oclType <> Ida))

4. Similarly, all design components with no 'successors' are of type Ida (termed output IDAs).

   Component **invariant**
   self.allInstances->forall(c |
   not(c.all_successors->size = 0 and c.oclType <> Ida))

5. Every design component is connected by a path to an input Ida; i.e., no (cyclic) part of a design is not connected to an input device and therefore independent of all inputs.

   Component **invariant**
   self.allInstances->forall(c |
   self.allInstances->exists(c' |
   c.all_predecessors->includes(c') and c'.all_predecessors->size= 0 and c'.oclType = Ida))

6. Similarly, every design component is connected by a path to an output Ida; i.e., no (cyclic) part of a design is not connected to an output device and therefore excluded from contributing to system output (with the result that any computations are wasted).

   Component **invariant**
   self.allInstances->forall(c |
   self.allInstances->exists(c' |
   c.all_successors->includes(c') and c'.all_successors->size= 0 and c'.oclType = Ida))

7. An Ida may only connect to more than one writing activity if it does not have a pool protocol and it is not an output interface Ida.

   ConnectionDef **invariant**
   self.allInstances->forall(c1, c2 |
   self.to_ida->forall(i |
   not(c1 <> c2 and c1.port.activity <> c2.port.activity and
   c1.to_ida->includes(i) and c2.to_ida->includes(i) and (i.all_successors->size = 0 or i.kind = "pool"))))

8. An Ida may only connect to more than one reading Activity if it has a pool protocol.

ConnectionDef **invariant**
self.allInstances->forall(c1, c2 |
self.from_ida->forall(i | not(c1 <> c2 and c1.port.activity <> c2.port.activity
c1.from_ida->includes(i) and c2.from_ida->includes(i) and i.kind <> "pool")))

ii. Well-formed Activity State Machines

The following well-formedness constraints apply to activity state machine elements of the RTN-SLg meta-model and are based on the principal restrictions set out in (Paynter, 2000):-

1. A DynamicState may only read from ports that are connected to data-flows into an Activity (a) - i.e., from an Ida - and write to ports connected to data flows from an Activity (b) - i.e., to an Ida.

a)

DynamicState **invariant**
self.allInstances->forall(d |
self.local_op_def.reads_from.port->not exists (p |
d. local_op_def.reads_from.port->includes(p) and p.connectionDef.to_ida->size <> 0))

b)

DynamicState **invariant**
self.allInstances->forall(d |
self.local_op_def.writes_to.port->not exists (p |
d.local_op_def.writes_to.port->includes(p) and p.connectionDef.from_ida->size <> 0))

2. Three kinds of event labels may annotate transitions from static states, namely "S" (stim), "W" (write) and "R" (read) events. Any Port associated with an "S" event must be connected to a data-flow with a void protocol.

StaticTransition **invariant**
self.allInstances->forall(t |
not(t.event.event_type = "S" and (t.event.port.connectionDef.from_ida.kind = "pool" or
t.event.port.connectionDef.from_ida.kind = "channel" or
t.event.port.connectionDef.from_ida.kind = "signall")))

3. No Port with a void data flow may be read by any DynamicState as there can be no data to read.

DynamicState **invariant**
self.allInstances->forall(d |
not(d.local_op_def.reads_from.port.connectionDef.from_ida.kind = "stimulus" or
d.local_op_def.reads_from.port.connectionDef.from_ida.kind = "dataless"))

4. A transition labelled with an "R" event must terminate at a DynamicState which reads from the same Port.

StaticTransition **invariant**
self.allInstances->forall(t |
not(t.event.event_type = "R" and t.event.port <> t.goes_to.local_op_def.reads_from.port))

5. If a DynamicState reads from a holding protocol (signal or channel), each transition into it must originate from a StaticState, thereby modelling the wait for data.

DynamicState **invariant**
self.allInstances->forall(d1, d2 |
not (d1.dynamic_transition_def.goes_to->includes(d2) and
(d2.local_op_def.reads_from.port.connectionDef.from_ida.kind = "channel" or
d2.local_op_def.reads_from.port.connectionDef.from_ida.kind = "signal")))

6. No DynamicState which reads from a holding protocol may be the initial state.

DynamicState **invariant**
self.allInstances->forall(d |
not((d.local_op_def.reads_from.port.connectionDef.from_ida.kind = "signal" or
d.local_op_def.reads_from.port.connectionDef.from_ida.kind = "channel") and
d.initial_status.initial = True))

7. Event labels on transitions from static states are different.

StaticTransition **invariant**
self.allInstances->forall(t1, t2 |
not(t1 <> t2 and t1.event_type = t2.event_type and
t1.event.port = t2.event.port))

8. A DynamicState which writes to a Port with a channel protocol must be followed by a StaticState which is itself the source of a transition with a "W" (write event) associated with the same Port. This captures the possibility of de-scheduling should the channel be full.

DynamicState **invariant**
self.allInstances->select(self.local_op_def.writes_to.port.connectionDef.to_ida.kind = "channel")->forall(d |
self.dynamic_transition_def.goes_to->exists(s |
d.dynamic_transition_def.goes_to->includes(s) and
s.oclType = StaticState and
s.static_transition_def.event->size = 1 and
s.static_transition_def.event.event_type = "W" and
s.static_transition_def.event.port = d.local_op_def.writes_to.port))

9. The aggregated states in a CompositeDynamicState may neither write to a Port associated with a channel protocol, nor read from one associated with anything other than a pool. This is due to the need to model synchronisation points by explicit static states.

CompositeDynamic **invariant**
self.allInstances->forall(c |
self.dynamic_state->forall(d |
not(c.dynamic_state->includes(d) and
(d.local_op_def.reads_from.port.connectionDef.from_ida.kind <> "pool" or
d.local_op_def.writes_to.port.connectionDef.to_ida.kind = "channel"))))

10. A StaticState may have at most one exit transition. This is handled through a multiplicity constraint, but can also be stated in OCL as follows.

StaticState **invariant**
self.allInstances->forall(s | s.static_transition_def->size <= 1)

11. ADTs must form an acyclic graph.

- First we define a rule to populate the reflexive with_all association on the Adt class:-

```
Adt
self.allInstances->forall(a1, a2 |
a1.with_adt->includes(a2) or
self.allInstances>exists (a' |
a1.with_adt->includes(a') and
a'.with_all->includes(a2)))
implies
a1.with_all->includes(a2)
```

- An invariant can now be defined to prevent cycles.

```
Adt invariant
self.allInstances->forall(a | not(a.with_all->includes(a)))
```

iii. Verification of RTN-SLg Elements against the Product Data Synthesis

To maintain consistency within the MATrA traceability Workspace, we define a number of constraints to verify RTN-SLg elements against the Product Data Synthesis, including:-

1. The RTN-SLg model subject module exists in the PDS.

```
RTN-SLg invariant
self.allInstances->forall(r |
self.bEmodelAEO.build_element->exists (be |
r.subject_module = be.module_name))
```

2. Activities are designated in the PDS as functions of the subject_module.

```
Activity invariant
self.allInstances->forall(a |
self.rTN-SLg.bEmodelAEO.build_element->exists (be |
self.bEelementAEO.build_element->exists(f |
a.rTN-SLg.subject_module = be.module_name and
a.name = f.function_name and
be.encapsulates.target->includes(f))))
```

3. Ports are designated in the PDS as interfaces to functions.

```
Port invariant
self.allInstances->forall(p |
self.activity->exists(a |
self.activity.bEelementAEO.build_element->exists(f |
self.bEelementAEO.build_element->exists(i |
a.port->includes(p) and
a.name = f.function_name and
p.name = i.interface_name and
f.hasInterface.target->includes(i) ))))
```

4. IDAs are specified in the PDS as interfaces with a connection to the appropriate port.

ConnectionDef **invariant**
self.allInstances->forall(c |
self.from_ida->union(self.to_ida).bEelementAEO.build_element->exists(i |
self.port.bEelementAEO.build_element->exists(p |
c.port.name = p.interface_name and
(c.from_ida.name = i.interface_name or
c.to_ida.name = i.interface_name) and
(p.connection.target.connection.target->includes(i) or i.connection.target.connection.target->includes(p)))))

5. ADTs are specified in the PDS as sub-modules of the subject_module[29].

Adt **invariant**
self.allInstances->forall(a |
self.rTN-SLg.bEmodelAEO.build_element->exists(be |
self.bEelementAEO.build_element->exists(m |
a.rTN-SLg.subject_module = be.module_name and
a.name = m.module_name and
be.hasSubmodule.target->includes(m))))

6. States are specified in the PDS as conditions of the Function that corresponds to the Activity containing the ASM to which a State belongs.

State **invariant**
self.allInstances->select (oclType = Static or oclType = Dynamic)->forall(s |
self.stateMachine.activity->exists(a |
self.stateMachine.activity.bEelementAEO.build_element->exists(f |
self.stateMachine.activity.bEelementAEO.build_element.hasCondition.target->exists(c |
a.state_machine.state_def->includes(s) and
a.name = f.function_name and
s.name = c.condition_label and
f.hasCondition.target->includes(c)))))

CompositeDynamic **invariant**
self.allInstances->forall(d |
self.stateMachine.activity->exists(a |
self.stateMachine.activity.bEelementAEO.build_element->exists(f |
self.stateMachine.activity.bEelementAEO.build_element.hasCondition.target->exists(c |
a.state_machine.state_def->includes(d) and
a.name = f.function_name and
f.hasCondition.target->includes(c) and
c.hasSubcondition.target.condition_label->includesAll(d.dynamic_state.name)))))

7. Transitions (including source and target states) are defined in the PDS as corresponding and correctly related conditions[30].

StaticTransition **invariant**
self.allInstances->forall(t |
self.staticState.stateMachine.activity->exists(a |
self.staticState.stateMachine.activity.bEelementAEO.build_element->exists(f |
self.staticState.stateMachine.activity.bEelementAEO.build_element.hasCondition.target->exists(c |

---

[29] An Abstract Data Type in the RTN-SL is a module in which attribute types and functions may be defined (Paynter, 2000).
[30] The RTN-SLg syntax names only constituent states of a CompositeDynamic (see figure 4.19); therefore it is not possible to verify a transition destination state of this type against the PDS.

```
self.staticState.stateMachine.activity.bEelementAEO.build_element.hasCondition.target.occurringIn.source
->exists(e |
a.name = f.function_name and
f.hasCondition.target->includes(c) and
e.occurringIn.target->includes(c) and
t.staticState.name = c.condition_label and
e.leadsTo.target.condition_label =
(t.goes_to->reject(t.goes_to.oclType = CompositeDynamic)).name and
((t.event.event_type.concat(t.event.port.name) = e.condition_label) or
(t.timing_transition_definition.lb_ub = e.condition_label)) )))))
```

DynamicTransition **invariant**

```
self.allInstances->select(self.compositeDynamic->size = 0)->forall(t |
self.dynamicState.stateMachine.activity->exists(a |
self.dynamicState.stateMachine.activity.bEelementAEO.build_element->exists(f |
self.dynamicState.stateMachine.activity.bEelementAEO.build_element.hasCondition.target->exists(c |
self.dynamicState.stateMachine.activity.bEelementAEO.build_element.hasCondition.target.occurringIn.source
->exists(e |
a.name = f.function_name and
f.hasCondition.target->includes(c) and
e.occurringIn.target->includes(c)
t.dynamicState.name = c.condition_label and
e.leadsTo.target.condition_label =
(t.goes_to->reject(t.goes_to.oclType = CompositeDynamic)).name and
t.on = e.condition_label)))))
```

Note: the invariant on DynamicTransition is over transitions from a DynamicState; an invariant over transitions from a CompositeDynamic may be similarly expressed, but without PDS verification of the source state.

iv. Other RTN-SLg Consistency Constraints

We conclude our round-up of constraints over the RTN-SLg meta-model by considering restrictions arising from modelling decisions (alluded to in subsection 4.4.3.2.1). These are as follows:-

1. All Activity, Port, Ida, Adt and State names are unique[31].

Activity **invariant**

```
self.allInstances->forall(a1, a2 |
not(a1.name = a2.name and a1 <> a2))
```

Port **invariant**

```
self.allInstances->forall(p1, p2 |
not(p1.name = p2.name and p1 <> p2))
```

Ida **invariant**

```
self.allInstances->forall(i1, i2 |
not(i1.name = i2.name and i1 <> i2))
```

Adt **invariant**

```
self.allInstances->forall(a1, a2 |
not(a1.name = a2.name and a1 <> a2))
```

[31] Assumes scope is an individual RTN-SLg model.

StaticState **invariant**
self.allInstances->forall(s1, s2 |
not(s1.name = s2.name and s1 <> s2))

DynamicState **invariant**
self.allInstances->forall(d1, d2 |
not(d1.name = d2.name and d1 <> d2))

2. All states must have an InitialStatus except for dynamic states that form part of a CompositeDynamic.

State **invariant**
self.allInstances->forall(s | not (s.initial_status->size = 0 and (s.oclType <> DynamicState or
s.compositeDynamic->size <> 1)))

3. Dynamic states that are part of composite dynamics have no individual timing definition or state transitions.

CompositeDynamic **invariant**
self.allInstances->forall(c |
self.dynamic_state->forall(d |
not(c.dynamic_state->includes(d) and (d.dynamic_transition_def-> size > 0 or d.timing_def-> size > 0))))

4. Only one State in a StateMachine has a true initial status.

StateMachine **invariant**
self.allInstances->forall(m |
self.state_def->forall(s1, s2 |
not(m.state_def->includes(s1) and m.state_def->includes(s2) and
s1.initial_status=True and s2.initial_status=True and s1 <> s2)))

5. Dynamic states that are not part of a CompositeDynamic have a timing definition.

DynamicState **invariant**
self.allInstances->forall(d |
not (d.CompositeDynamic->size = 0 and d.timing_def-> size = 0))

4.4.3.2.3 O-Telos Implementation of RTN-SLg Base Classes

The O-Telos code below implements RTN-SLg meta-model base class elements.

```
Definition of Artifact Properties

Protocol in ArtifactProperty, SimpleClass
isA String
with
constraint
    enum_protocol: $
forall p/Protocol
(p = "pool") or
(p = "signal") or
(p = "channel") or
(p = "stimulus") or
(p = "dataless") $
end

EventType in ArtifactProperty,
SimpleClass
isA String
with
constraint
    enum_event_type: $
forall e/EventType
(e = "S") or
(e = "R") or
(e = "W") $
end

InitialStatus in ArtifactProperty,
SimpleClass
with
described_by
    initial : Bool
end
```

Definition of RTN-SLg Primitives

```
Adt in StructureElement, SimpleClass isA
AerospaceEngineeringObject with
has_property
    name : String
has_part
    with_adt : Adt
has_transitive_part
    with_all : Adt
end

Component in StructureElement,
SimpleClass isA
AerospaceEngineeringObject
with
has_property
    name : String
has_part
    predecessor : Component;
    successor : Component
has_transitive_part
    all_successors : Component;
    all_predecessors : Component
constraint
abstract_component:
$ forall t/Token s/SimpleClass
(t in s) ==> not (t in Component) $
end

Ida in StructureElement, SimpleClass isA
Component with has_property
    kind : Protocol
has_part
    with_adt : Adt
end

Port in StructureElement, SimpleClass isA
AerospaceEngineeringObject with
has_property
    name : String
end

ConnectionDef in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with has_part
    port : Port;
    from_ida : Ida;
    to_ida : Ida
end

State in StructureElement, SimpleClass
isA AerospaceEngineeringObject with
has_property
    initial_status : InitialStatus
constraint
abstract_state:
$ forall t/Token s/SimpleClass
(t in s) ==> not (t in State) $
end

StaticState in StructureElement,
SimpleClass isA State with
has_property
    name : String
has_part
    static_transition_def :
StaticTransition
end

DynamicState in StructureElement,
SimpleClass isA State with
has_property
    name : String
has_part
    dynamic_transition_def :
DynamicTransition;
    local_op_def : LocalOpDef;
    timing_def : Timing
end

CompositeDynamic in StructureElement,
SimpleClass isA State
with
has_part
    dynamic_state : DynamicState;
    dynamic_transition_def :
DynamicTransition;
    timing_def : Timing
end

StateMachine in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with has_part
    state_def : State
end

Activity in StructureElement, SimpleClass
isA Component with
has_part
    with_adt : Adt;
    port : Port;
    state_machine : StateMachine
end

StaticTransition in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_part
    goes_to : State;
    event : Event;
    timing_transition_definition :
TimingTransitionDef
end

DynamicTransition in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_property
    on : String
has_part
    goes_to : State
end

Timing in StructureElement, SimpleClass
isA AerospaceEngineeringObject with
has_property
    bcet : String;
    wcet : String;
    wcrt : String
end

WritesToClause in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with has_part
    port : Port
end

ReadsFromClause in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_part
    port : Port;
    by : WCRTonRd
end

WCRTonRd in StructureElement, SimpleClass
isA AerospaceEngineeringObject
with
has_property
    finish : String
end

LocalOpDef in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_part
    reads_from : ReadsFromClause;
    writes_to : WritesToClause
end

Event in StructureElement, SimpleClass
```

```
isA AerospaceEngineeringObject
with has_property
    event_type : EventType
has_part
    port : Port
end

TimingTransitionDef in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_property
    lb_ub : String
end
```

Definition of RTN-SLg Specification

```
RTN_SLg in DevelopmentStructure,
SimpleClass isA
AerospaceEngineeringObject with
has_property
    model_name : String;
    subject_module : String;
    rtn_date: Date
has_structure
    rtn_comments :
 MatraNaturalLanguageStructure
has_element
    rtn_adt : Adt;
    rtn_port : Port;
    rtn_ida : Ida;
    rtn_activity : Activity;
    rtn_connection_def : ConnectionDef;
    rtn_static_state : StaticState;
    rtn_dynamic_state : DynamicState;
    rtn_composite_dynamic_state :
 CompositeDynamic;
    rtn_static_transition :
StaticTransition;
    rtn_dynamic_transition :
DynamicTransition;
    rtn_timing_def: Timing;
    rtn_writes_to_clause :
WritesToClause;
    rtn_reads_from_clause :
ReadsFromClause;
    rtn_WCRTonRd : WCRTonRd;
    rtn_local_op_def : LocalOpDef;
    rtn_event : Event;
    rtn_timing_transition_def :
TimingTransitionDef;
    rtn_state_machine : StateMachine
end
```

4.4.3.3 RTN-SLg Worked Examples

We now illustrate aspects of the RTN-SLg meta-model by instantiating the above classes with some worked examples. Specifically:-

- Hypothetical RTN-SLg Example (from subsection 4.4.2.2);
- A hypothetical Composite Dynamic State;
- An RTN-SLg specification fragment for a Missile Tracking System.

I. Hypothetical RTN-SLg Example

In subsection 4.4.2.2 we introduced an example RTN-SLg specification (illustrated in figure 4.20) to demonstrate key aspects of the language's graphical syntax. The following is therefore an O-Telos implementation of base classes for this example:-

Sample Population of RTN-SLg (from figure 4.20)

```
Adt1Type in Adt, Token with
name
    adtName : "adt1"
end

Port1 in Port, Token with
name
    portName : "P1"
end

Activity1 in Activity, Token with
name
    activityName : "A1"
with_adt
    withAdt1 : Adt1Type
port
    port1 : Port1
end

Ida1 in Ida, Token with
name
    idaName : "Ida1"
kind
    idaKind : "pool"
with_adt
    withAdt1 : Adt1Type
end

Ida2 in Ida, Token with
kind
    idaKind : "stimulus"
end

Ida3 in Ida, Token with
kind
    idaKind : "channel"
end

Adt2Type in Adt, Token with
name
    adtName : "adt2"
end

Adt3Type in Adt, Token with
name
    adt_name : "adt3"
with_adt
    withAdt1 : Adt2Type
end
```

```
Port2 in Port, Token with
name
    portName : "P2"
end

Port3 in Port, Token with
name
    portName : "P3"
end

Port4 in Port, Token with
name
    portName : "P4"
end

StaticStateA in StaticState, Token with
name
    staticStateName : "A"
initial_status
    initialStatus : StaticStateAStatus
static_transition_def
    staticTransitionDef :
StaticTransitionAtoB
end

StaticStateAStatus in InitialStatus,
Token with
initial
    initialState : True
end

StaticTransitionAtoB in StaticTransition,
Token with
goes_to
    goesTo : DynamicStateB
event
    transEvent : AtoBEvent
end

AtoBEvent in Event, Token with
event_type
    eventType : "S"
port
    eventPort   : Port2
end

DynamicStateB in DynamicState, Token with
name
    dynamicStateName : "B"
initial_status
    initialStatus : DynamicStateBStatus
dynamic_transition_def
    dynamicTransitionDef1 :
DynamicTransitionBtoC;
    dynamicTransitionDef2 :
DynamicTransitionBtoD
local_op_def
    localOpDef : LocalOpDefStateB
timing_def
    timingDef : TimingDefStateB
end

DynamicStateBStatus in InitialStatus,
Token with
initial
    initialState : False
end

DynamicTransitionBtoC in
DynamicTransition, Token with
on
    transitionOn : "C1"
goes_to
    goesTo : StaticStateC
end

DynamicTransitionBtoD in
DynamicTransition, Token with
on
    transitionOn : "C2"
goes_to
    goesTo : DynamicStateD
end

LocalOpDefStateB in LocalOpDef, Token
with
reads_from
    readsFrom : ReadsFromClauseStateB
end

ReadsFromClauseStateB in ReadsFromClause,
Token with
port
    readPort : Port3
by
    byDeadline : WCRTonRdStateB
end

WCRTonRdStateB in WCRTonRd, Token with
finish
    finishTime : "U1"
end

TimingDefStateB in Timing, Token with
bcet
    BCETime : "L1"
wcet
    WCETime : "U2"
wcrt
    WCRTime : "U3"
end

StaticStateC in StaticState, Token with
name
    staticStateName : "C"
initial_status
    initialStatus : StaticStateCStatus
static_transition_def
    staticTransitionDef :
StaticTransitionCtoD
end

StaticStateCStatus in InitialStatus,
Token with
initial
    initialState : False
end

StaticTransitionCtoD in StaticTransition,
Token with
goes_to
    goesTo : DynamicStateD
timing_transition_definition
    timingTransitionDefinition :
CtoDTimingTransition
end

CtoDTimingTransition in
TimingTransitionDef, Token with
lb_ub
    lbUb : "[t1, t2]"
end

DynamicStateD in DynamicState, Token with
name
    dynamicStateName : "D"
initial_status
    initialStatus : DynamicStateDStatus
dynamic_transition_def
    dynamicTransitionDef :
DynamicTransitionDtoE
local_op_def
    localOpDef : LocalOpDefStateD
timing_def
    timingDef : TimingDefStateD
end

DynamicStateDStatus in InitialStatus,
Token with
initial
    initialState : False
```

```
end

DynamicTransitionDtoE in
DynamicTransition, Token with
on
    transitionOn : "C3"
goes_to
    goesTo : StaticStateE
end

LocalOpDefStateD in LocalOpDef, Token
with
writes_to
    writesTo : WritesToClauseStateD
end

WritesToClauseStateD in WritesToClause,
Token with
port
    writePort : Port4
end

TimingDefStateD in Timing, Token with
bcet
    BCETime : "L2"
wcet
    WCETime : "U4"
wcrt
    WCRTime : "U5"
end

StaticStateE in StaticState, Token with
name
    staticStateName : "E"
initial_status
    initialStatus : StaticStateEStatus
static_transition_def
    staticTransitionDef :
StaticTransitionEtoA
end

StaticStateEStatus in InitialStatus,
Token with
initial
    initialState : False
end

StaticTransitionEtoA in StaticTransition,
Token with
goes_to
    goesTo : StaticStateA
event
    transEvent : EtoAEvent
end

EtoAEvent in Event, Token with
event_type
    eventType : "W"
port
    eventPort   : Port4
end

Activity2StateMachine in StateMachine,
Token with
state_def
    stateDef1 : StaticStateA;
    stateDef2 : DynamicStateB;
    stateDef3 : StaticStateC;
    stateDef4 : DynamicStateD;
    stateDef5 : StaticStateE
end

Activity2 in Activity, Token with
name
    activityName : "A2"
with_adt
    withAdt1 : Adt3Type
port
    port1 : Port2;
    port2 : Port3;
    port3 : Port4
state_machine
    stateMachine : Activity2StateMachine
end

P1toIda1 in ConnectionDef, Token with
port
    outPort : Port1
to_ida
    toIda : Ida1
end

Ida1toP3 in ConnectionDef, Token with
port
    inPort : Port3
from_ida
    fromIda : Ida1
end

Ida2toP2 in ConnectionDef, Token with
port
    inPort : Port2
from_ida
    fromIda : Ida2
end

P4toIda3 in ConnectionDef, Token with
port
    outPort : Port4
to_ida
    toIda : Ida3
end

Net1 in RTN_SLg, Token with
model_name
    modelName : "RTN-SLg Example 1"
rtn_adt
    rtnAdt1 : Adt1Type;
    rtnAdt2 : Adt2Type;
    rtnAdt3 : Adt3Type
rtn_port
    rtnPort1 : Port1;
    rtnPort2 : Port2;
    rtnPort3 : Port3;
    rtnPort4 : Port4
rtn_ida
    rtnIda1 : Ida1;
    rtnIda2 : Ida2;
    rtnIda3 : Ida3
rtn_activity
    rtnActivity1 : Activity1;
    rtnActivity2 : Activity2
rtn_connection_def
    rtnConnectionDef1 : P1toIda1;
    rtnConnectionDef2 : Ida1toP3;
    rtnConnectionDef3 : Ida2toP2;
    rtnConnectionDef4 : P4toIda3
rtn_static_state
    rtnStaticState1 : StaticStateA;
    rtnStaticState2 : StaticStateC;
    rtnStaticState3 : StaticStateE
rtn_dynamic_state
    rtnDynamicState1 : DynamicStateB;
    rtnDynamicState2 : DynamicStateD
rtn_static_transition
    rtnStaticTransition1 :
StaticTransitionAtoB;
    rtnStaticTransition2 :
StaticTransitionCtoD;
    rtnStaticTransition3 :
StaticTransitionEtoA
rtn_dynamic_transition
    rtnDynamicTransition1 :
DynamicTranisitionBtoC;
    rtnDynamicTransition2 :
DynamicTranisitionDtoE
rtn_timing_def
    rtnTimingDef1 : TimingDefStateB;
    rtnTimingDef2 : TimingDefStateD
rtn_reads_from_clause
    rtnReadsFromClause1 :
ReadsFromClauseStateB
```

```
rtn_writes_to_clause
    rtnWritesToClause1 :
WritesToClauseStateD
rtn_WCRTonRd
rtnWCRTonRd1 : WRCTonRdStateB
rtn_timing_transition_def
    rtnTimingTransitionDef1 :
CtoDTimingTransition

    rtn_local_op_def
rtnLocalOpDef1 : LocalOpDefStateB;
    rtnLocalOpDef2 : LocalOpDefStateD
rtn_event
    rtnEvent1 : AtoBEvent;
    rtnEvent2 : EtoAEvent
rtn_state_machine
    rtnStateMachine1 :
Activity2StateMachine
end
```

ii. A Hypothetical Composite Dynamic State

We now present O-Telos implementation of an exemplar Composite Dynamic State using the graphical Activity State Machine fragment in figure 4.23:-

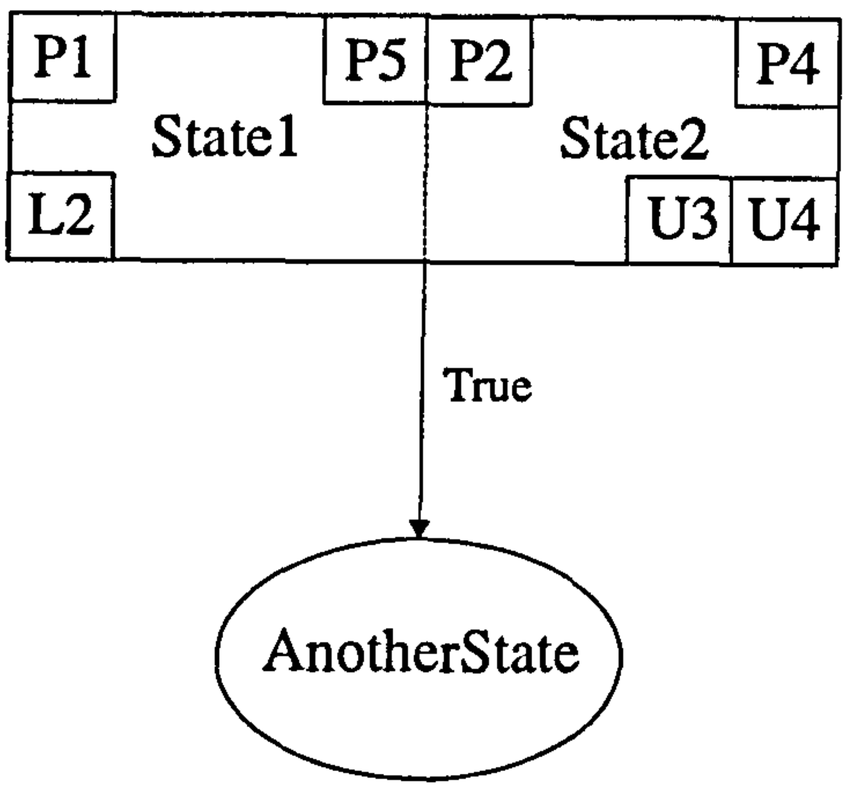


Figure 4.23 - 'Hypothetical Composite Dynamic State'

Sample Population of RTN-SLg Composite Dynamic State

```
ExampleComposite in CompositeDynamic,
Token with
initial_status
    initialStatus :
ExampleCompositeStatus
dynamic_state
    dynamicState1 : DynamicState1;
    dynamicState2 : DynamicState2
dynamic_transition_def
    dynamicTransitionDef :
CompositeDynamicTransition
timing_def
    timingDef : CompositeDynamicTimingDef
end

ExampleCompositeStatus in InitialStatus,
Token with
initial
    initialState : False
end

DynamicState1 in DynamicState, Token with
name
    dynamicStateName : "State1"
local_op_def
    localOpDef : LocalOpDefState1
end

DynamicState2 in DynamicState, Token with
name
    dynamicStateName : "State2"
local_op_def
    localOpDef : LocalOpDefState2
end

LocalOpDefState1 in LocalOpDef, Token
with
reads_from
    readsFrom : ReadsFromClauseState1
writes_to
    writesTo : WritesToClauseState1
end

ReadsFromClauseState1 in ReadsFromClause,
Token with
port
    readPort : Port1
end

WritesToClauseState1 in WritesToClause,
Token with
port
    writePort : Port5
end

LocalOpDefState2 in LocalOpDef, Token
with
reads_from
    readsFrom : ReadsFromClauseState2
writes_to
    writesTo : WritesToClauseState2
end

ReadsFromClauseState2 in ReadsFromClause,
Token with
port
    readPort : Port2
end

WritesToClauseState2 in WritesToClause,
Token with
port
    writePort : Port4
end

CompositeDynamicTransition in
CompositeDynamicTransition, Token with
on
    transitionOn : "True"
goes_to
    goesTo : AnotherState
end

CompositeDynamicTimingDef in Timing,
Token with
bcet
    BCETime : "L2"
wcet
    WCETime : "U3"
wcrt
    WCRTime: "U4"
end
```

iii. An RTN-SLg Specification (Fragment) for a Missile Tracking System

We conclude our demonstration of the RTN-SLg meta-model with a small example network taken from Paynter *et al.* (2000) and illustrated in figure 4.24. It is based on a design fragment for a typical Missile Tracking System and consists of two activities linked by a channel protocol; the arrival of a target Image on port P1 triggers activity A1 which performs some image processing to determine the target co-ordinates and sends them to port P2. This information is then passed to A2 (via the Image Store channel) which reads from port P3, calculates movement of the target and outputs this vector to the rest of the system via port P4.

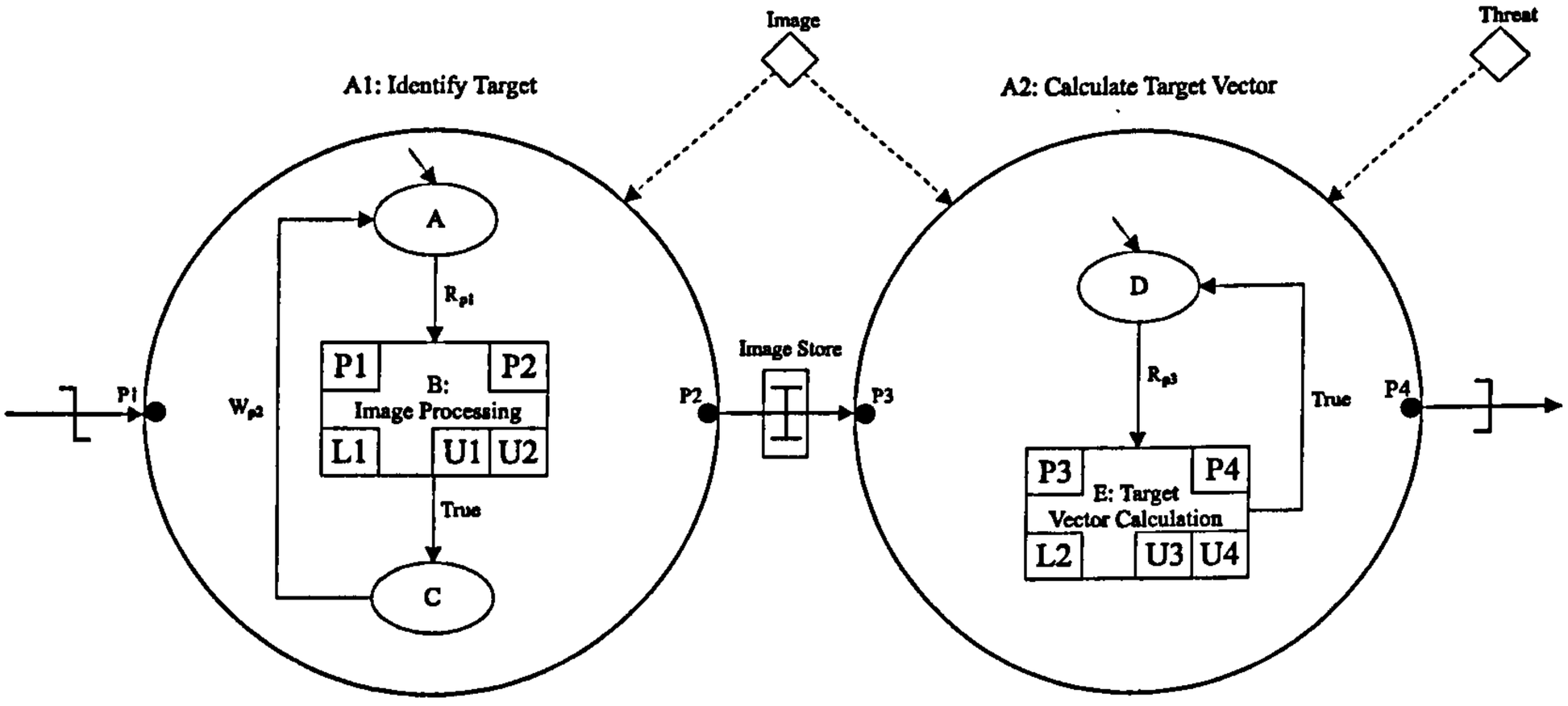


Figure 4.24 - 'RTN-SLg Specification for A Missile Target Tracking System'

O-Telos instantiation of the RTN-SLg meta-model capturing information contained in figure 4.24 is as follows:-

```
Sample Population of RTN-SLg Missile
Tracking System Example

Image in Adt, Token with
name
    adtName : "Image"
end

Port1 in Port, Token with
name
    portName : "P1"
end

Port2 in Port, Token with
name
    portName : "P2"
end

StaticStateA in StaticState, Token with
name
    staticStateName : "A"
initial_status
    initialStatus : StaticStateAStatus
static_transition_def
    staticTransitionDef :
StaticTransitionAtoB
end

StaticStateAStatus in InitialStatus,
Token with
initial
    initialState : True
end

StaticTransitionAtoB in StaticTransition,
Token with
goes_to
    goesTo : DynamicStateB
event
    transEvent : AtoBEvent
end

AtoBEvent in Event, Token with
event_type
    eventType : "R"
port
    eventPort   : Port1
end

DynamicStateB in DynamicState, Token with
name
    dynamicStateName : "B: Image
Processing"
initial_status
    initialStatus : DynamicStateBStatus
dynamic_transition_def
    dynamicTransitionDef1 :
DynamicTransitionBtoC
local_op_def
    localOpDef : LocalOpDefStateB
timing_def
    timingDef : TimingDefStateB
```

```
end

DynamicStateBStatus in InitialStatus,
Token with
initial
    initialState : False
end

DynamicTransitionBtoC in
DynamicTransition, Token with
on
    transitionOn : "True"
goes_to
    goesTo : StaticStateC
end

LocalOpDefStateB in LocalOpDef, Token
with
reads_from
    readsFrom : ReadsFromClauseStateB
writes_to
    writesTo : WritesToClauseStateB
end

ReadsFromClauseStateB in ReadsFromClause,
Token with
port
    readPort : Port1
end

WritesToClauseStateB in WritesToClause,
Token with
port
    writePort : Port2
end

TimingDefStateB in Timing, Token with
bcet
    BCETime : "L1"
wcet
    WCETime : "U1"
wcrt
    WCRTime : "U2"
end

StaticStateC in StaticState, Token with
name
    staticStateName : "C"
initial_status
    initialStatus : StaticStateCStatus
static_transition_def
    staticTransitionDef :
StaticTransitionCtoA
end

StaticStateCStatus in InitialStatus,
Token with
initial
    initialState : False
end

StaticTransitionCtoA in StaticTransition,
Token with
goes_to
    goesTo : StaticStateA
event
    transEvent : CtoAEvent
end

CtoAEvent in Event, Token with
event_type
    eventType : "W"
port
    eventPort   : Port2
end

Activity1StateMachine in StateMachine,
Token with
state_def
    stateDef1 : StaticStateA;
    stateDef2 : DynamicStateB;
    stateDef3 : StaticStateC
end

Activity1 in Activity, Token with
name
    activityName : "A1: Identify Target"
with_adt
    withAdt1 : Image
port
    port1 : Port1;
    port2 : Port2
state_machine
    stateMachine : Activity1StateMachine
end

Ida1 in Ida, Token with
kind
    idaKind : "signal"
end

Ida2 in Ida, Token with
name
    idaName : "Image Store"
kind
    idaKind : "channel"
end

Ida3 in Ida, Token with
kind
    idaKind : "pool"
end

Threat in Adt, Token with
name
    adtName : "Threat"
end

Port3 in Port, Token with
name
    portName : "P3"
end

Port4 in Port, Token with
name
    portName : "P4"
end

StaticStateD in StaticState, Token with
name
    staticStateName : "D"
initial_status
    initialStatus : StaticStateDStatus
static_transition_def
    staticTransitionDef :
StaticTransitionDtoE
end

StaticStateDStatus in InitialStatus,
Token with
initial
    initialState : True
end

StaticTransitionDtoE in StaticTransition,
Token with
goes_to
    goesTo : DynamicStateE
event
    transEvent : DtoEEvent
end

DtoEEvent in Event, Token with
event_type
    eventType : "R"
port
    eventPort   : Port3
end

DynamicStateE in DynamicState, Token with
name
    dynamicStateName : "E: Target Vector
```

```
Calculation"
initial_status
    initialStatus : DynamicStateEStatus
dynamic_transition_def
        dynamicTransitionDef1 :
DynamicTransitionEtoD
local_op_def
    localOpDef : LocalOpDefStateE
timing_def
    timingDef : TimingDefStateE
end

DynamicStateEStatus in InitialStatus,
Token with
initial
    initialState : False
end

DynamicTransitionEtoD in
DynamicTransition, Token with
on
    transitionOn : "True"
goes_to
    goesTo : StaticStateD
end

LocalOpDefStateE in LocalOpDef, Token
with
reads_from
    readsFrom : ReadsFromClauseStateE
writes_to
    writesTo : WritesToClauseStateE
end

ReadsFromClauseStateE in ReadsFromClause,
Token with
port
    readPort : Port3
end

WritesToClauseStateE in WritesToClause,
Token with
port
    writePort : Port4
end

TimingDefStateE in Timing, Token with
bcet
    BCETime : "L2"
wcet
    WCETime : "U3"
wcrt
    WCRTime : "U4"
end

Activity2StateMachine in StateMachine,
Token with
state_def
    stateDef1 : StaticStateD;
    stateDef2 : DynamicStateE
end

Activity2 in Activity, Token with
name
    activityName : "A2: Calculate Target
Vector"
with_adt
    withAdt1 : Image;
    withAdt2 : Threat
port
    port1 : Port3;
    port2 : Port4
state_machine
    stateMachine : Activity2StateMachine
end

Ida1toP1 in ConnectionDef, Token with
port
    inPort : Port1
from_ida
    fromIda : Ida1
end

P2toIda2 in ConnectionDef, Token with
port
    outPort : Port2
to_ida
    toIda : Ida2
end

Ida2toP3 in ConnectionDef, Token with
port
    inPort : Port3
from_ida
    fromIda : Ida2
end

P4toIda3 in ConnectionDef, Token with
port
    outPort : Port4
to_ida
    toIda : Ida3
end

Net2 in RTN_SLg, Token with
model_name
    modelName : "RTN-SLg Example 2"
rtn_adt
    rtnAdt1 : Image;
    rtnAdt2 : Threat
rtn_port
    rtnPort1 : Port1;
    rtnPort2 : Port2;
    rtnPort3 : Port3;
    rtnPort4 : Port4
rtn_ida
    rtnIda1 : Ida1;
    rtnIda2 : Ida2;
    rtnIda3 : Ida3
rtn_activity
    rtnActivity1 : Activity1;
    rtnActivity2 : Activity2
rtn_connection_def
    rtnConnectionDef1 : Ida1toP1;
    rtnConnectionDef2 : P2toIda2;
    rtnConnectionDef3 : Ida2toP3;
    rtnConnectionDef4 : P4toIda3
rtn_static_state
    rtnStaticState1 : StaticStateA;
    rtnStaticState2 : StaticStateC;
    rtnStaticState3 : StaticStateD
rtn_dynamic_state
    rtnDynamicState1 : DynamicStateB;
    rtnDynamicState2 : DynamicStateE
rtn_static_transition
    rtnStaticTransition1 :
StaticTransitionAtoB;
    rtnStaticTransition2 :
StaticTransitionCtoA;
    rtnStaticTransition3 :
StaticTransitionDtoE
rtn_dynamic_transition
    rtnDynamicTransition1 :
DynamicTranisitionBtoC;
    rtnDynamicTransition2 :
DynamicTranisitionEtoD
rtn_timing_def
    rtnTimingDef1 : TimingDefStateB;
    rtnTimingDef2 : TimingDefStateE
rtn_reads_from_clause
    rtnReadsFromClause1 :
ReadsFromClauseStateB;
    rtnReadsFromClause2 :
ReadsFromClauseStateE
rtn_writes_to_clause
    rtnWritesToClause1 :
WritesToClauseStateB;
    rtnWritesToClause2 :
WritesToClauseStateE
rtn_local_op_def
    rtnLocalOpDef1 : LocalOpDefStateB;
    rtnLocalOpDef2 : LocalOpDefStateE
```

```
rtn_event
    rtnEvent1 : AtoBEvent;
    rtnEvent2 : CtoAEvent;
    rtnEvent3 : DtoEEvent
rtn_state_machine
    rtnStateMachine1 :
Activity1StateMachine;
    rtnStateMachine2 :
Activity2StateMachine
end
```

4.4.4 Relationship to the Traceability Dimensions

We reiterate that this thesis is concerned mainly with providing a set of notation meta-models for an avionics traceability environment, rather than with defining actual linkages between them. However, it is worth noting that engineers might conceivably employ the Use Case approach from subsection 4.3 in conjunction with RTN-SLg and in doing so, create vertical trace relations between Use Case and Activity elements using the approach outlined in 3.3.6.3.2. Moreover, for hazard analysis purposes practitioners may wish to link network elements to safety techniques such as HAZOP (again giving vertical traceability), as shown for MASCOT designs in McDermid & Pumfrey (1994).

4.4.5 Summary

Real-Time Networks are a design method used extensively throughout the defence industry (including aerospace). On that basis, we chose RTN-SL as our representative design notation for the MATrA traceability framework.

A novel meta-model capturing the graphical syntax of RTN-SLg specifications was proposed, together with a set of restrictions that preserve their internal and PDS consistency. A partial O-Telos implementation of the model was then populated to demonstrate some worked examples.

Again, evaluation of the RTN-SLg structure is discussed fully in Chapter Seven.

4.5 Towards a SPARK Ada Programming Language Structure

4.5.1 Introduction

This section introduces a structure capturing a subset of the concrete (well-formedness) syntax for SPARK, a programming language supporting development of software for high integrity (including safety-critical) applications.

The structure was developed in parallel with a modelling philosophy - a set of principles (guidelines) by which practitioners may extend the structure to encompass the complete SPARK syntax. We go on to demonstrate how these guidelines may be similarly applied to the development of structures for other languages with a concrete syntax - in this case RTN-SL (textual).

4.5.2 Motivation

In safety-critical systems engineering, choice of programming language is of paramount importance, motivated by a need to increase the likelihood of software behaving as intended and hence reduce the risks arising from errors to an acceptable level. Carré *et al.* (1990) identify a number of factors determining suitability of a programming language for use in high integrity systems:-

- *Logical soundness*: the language should contain no ambiguities;
- *Simplicity of formal description*: it should be relatively simple to describe the language;
- *Expressive power*: the language should be sufficiently rich to describe 'real' systems;
- *Security*: it should be possible to determine statically if a program conforms to the language rules;
- *Verifiability*: program verification should be tractable for industrial-scale applications;
- *Bounded time and space requirements*: the resource requirements of a program should be determinable statically to avoid possible run-time errors due to exhaustion of finite resources.

Ada (Barnes, 1996) was written specifically for use in developing such applications and *includes* a number of features amenable to the production of dependable software. However, as Storey (1996) notes it does not represent an ideal, partly because some of the above factors are in conflict; for instance the corollary of expressive power is often complexity and the attendant problems of verification and security. Therefore, in recent years much effort has been devoted to development of an Ada subset - a so-called 'safe' subset comprising *only* those facilities necessary for writing high integrity programs. Safe subsets of any language (see Cullyer *et al.*, 1991 for a comparison) are formed by excluding and restricting all features or constructs present in the full version that may prevent verification.

Arguably the most prominent Ada subset is SPARK (Barnes, 1997) which is also one of the few programming languages to boast complete formal semantics. The core of SPARK is an executable kernel derived from a subset of Ada 95[32]; subset in the sense that features such as gotos, aliasing, default parameters (for procedures and functions), recursion, tasks, user-defined exceptions and exception handlers have all been omitted, while the type model is simplified through removal of pointers, type

[32] A version of SPARK based on Ada 83 is also available.

aliasing, derived types and anonymous types.

In addition to the kernel, SPARK also includes some additional non-executable features termed *annotations* which are added by users in the form of Ada comments and which permit analysis and proof. Annotations are ignored by standard Ada compilers, but processed by the SPARK tool-set that supports the language. They divide into two categories: those providing flow analysis and those providing formal verification. Flow analysis is permitted at two levels: *data flow* analysis which just concerns the direction of data flow (e.g., checking variables are not read before being initialised), and *information flow* which also checks the coupling between variables (Barnes, 1997). Proof annotations meanwhile permit analysis of dynamic behaviour, including the results of functions, assertions such as loop invariants and pre and post conditions of sub-programs[33].

Ada remains the preferred language for high integrity systems in the defence and aerospace sectors (Wichmann, 1997), often as a means of implementing Real-Time Network design specifications (Paynter, 2000). However SPARK is increasingly finding favour in these domains (*cf.* King et al., 2000), not least due its support for formal verification which helps satisfy the rigorous demands of Defence Standards 00-55 (MoD, 1997) and 00-56 (MoD, 1996). That said, we are concerned purely with representation and so arguments pro and contra[34] use of language subsets (and hence SPARK) are not an issue. Instead we apply a common set of principles from which meta-models representing core and specific features of both Ada *and* SPARK may be formed.

The inclusion of SPARK also enables us to demonstrate structuring of artifacts at the software implementation level, which allied to Circuit Diagrams (hardware implementation) from subsection 3.3.7, together with UCRS and RTN-SLg (subsections 4.3 and 4.4), ensures all life-cycle phases are represented within the MATrA framework shown by this thesis; safety and product management are addressed in Chapter Five.

4.5.2.1 SPARK Ada Overview

The SPARK kernel language comprises standard Ada features such as package, private types, typed constants, unconstrained array types, functions returning composite types and the library system. However, given our level of interest, namely to demonstrate a modelling philosophy on structuring SPARK programs for traceability purposes, a full discussion on these constructs is beyond our scope; interested readers are therefore referred to Barnes (1997).

In order to provide proof of concept for both the philosophy and the structure, we concentrate on representation of a single Ada construct - the package. A package provides means to group entities such as data types, procedures and other packages within a common framework. They also allow information hiding whereby details of the private part and body are not visible to external users of the package.

---

[33] In MATrA, these may conceivably trace back (vertically) to pre and post-conditions of Use Case Models as discussed in subsection 4.3.

[34] See Wichmann for an argument against using 'safe' language subsets.

Packages are defined in two parts, a specification which describes the interface to an external client (and which is the focus for this thesis) and the body which provides implementation details; the two are always textually distinct as the following demonstrates (words in bold, as in all examples that follow, denote reserved words that may not be used for any other purpose):-

```
package P is                          -- specification
      ...    -- visible part
private
      ...    -- private part (optional)
end P;

package body P is                     -- body
      ...
begin
      ...    -- initialisation (optional)
end P;
```

Packages can be nested, with those at the top level - termed library packages - forming separate compilations; the body and specification of a library package may be compiled separately. Library packages can also include child packages. This is specified using a 'dot' notation prefixed with the parent name as follows:-

```
package P.Child is
      ...
end P.Child;
```

The other form of child package is a private child, written as:-

```
private package P.Child is
      ...
end P.Child;
```

As previously indicated, packages can contain types and procedures. Pre-defined types in SPARK are integer, float, boolean, character and string, although additional types can also be defined. For example in the following, BankAngle is an integer with range of values from -45 to +45, whilst WarningLight is an enumerated type with two literal values (On and Off):-

```
type BankAngle is range -45 .. 45;
type WarningLight is (On, Off);
```

Procedure specification statements provide a procedure name, together with the types and modes of their parameters. Valid modes are in and out, indicating direction of information flow; thus in the following Present_Bank of Read_Bank_Indicator is an **in** parameter as it provides the in-going information to be read.

```
procedure Read_Bank_Indicator(Present_Bank: in BankAngle);
```

In addition to language features such as those outlined above, SPARK includes a number of

annotations. These are specified using the '`--#`' convention, two hyphens being the standard Ada comment prefix. Recall that annotations are ignored by the Ada compiler and divide into two groups, those for information and data analysis and those for code verification. In this thesis, we concentrate on a subset of the former. Specifically:-

- **`--# global`** - *global definitions* in procedures (which declare 'imported' or 'exported' global variables) or functions (which import such variables);
- **`--# derives`** - *dependency relations* in procedures (which specify the imported variables required to derive the value of each exported variable);
- **`--# inherit`** - the *inherit clause* in package declarations (which restricts penetration of the package to items specifically imported from other packages);
- **`--# own`** - the *own variable clause* in package specifications (which makes actions on the package state visible to analysis tools);
- **`--# initializes`** - the *initialisation annotation* in package specifications (which indicates initialisation by the package of its own state).

4.5.3 Tracing Software Implementations in MATrA: A SPARK Ada Model

4.5.3.1 Concepts

The previous subsection introduced our modelling scope, i.e. particular SPARK elements to be considered in this thesis - namely package specifications, together with the --# global, --# derives, --# inherit, --# own and --# initializes annotations.

As indicated above, SPARK has a complete formal semantics which in principle could be expressed in OCL as constraints over elements of our meta-model. However, the SPARK tool-set and in particular the Examiner tool which checks conformance to the rules of the kernel language means we can have considerable confidence in the integrity of code produced. It is therefore deemed superfluous to repeat validation during the *tool2matra* transfer process[35].

Further, given that we stated PDS consistency checks (in OCL) for previous notations, we have not specified similar restrictions here. Note however that the following (informal) checks might apply:-

- SPARK packages and child packages map to corresponding PDS modules and sub-modules;
- SPARK procedures map to PDS functions for the corresponding module;
- SPARK types map to PDS attributes for the corresponding module.

4.5.3.1.1 A Modelling Philosophy towards the Object-Based Representation of String Grammars for Specification & Code Level Languages

Representation of the nominated constructs takes as its starting point the concrete SPARK grammar (featured in Appendix One of [Barnes, 1997]) which is stated using Backus Naur Form (BNF) notation.

---

[35] Nor would constraints be required given the availability of an inverse '*matra2tool*' function (a future work item discussed in subsection 7.4.7), which to ensure all edits are conducted using the SPARK tool-set, would not extend to this structure.

In BNF, categories (i.e., entities) to be represented are defined in terms of other categories using productions consisting of the name being defined, followed by the ::= symbol and a defining sequence (which may or may not include punctuation and reserved word 'tokens'); categories that cannot be further decomposed are known as terminals. Other symbols of note are [ ] square brackets enclosing optional items, { } braces enclosing optional items that may be omitted or appear n > 0 times and the | vertical bar separating alternatives.

Our philosophy (developed in parallel with the SPARK meta-model) provides a series of principles *or* guidelines allowing object-based representation of language constructs stated as BNF categories, and to do so at a level of abstraction which is sufficient to identify traceability primitives. The guidelines' phrasing is deliberately general allowing their application to other languages with a concrete BNF syntax. We demonstrate this in subsection 4.5.4 by representing a fragment of the RTN-SL textual syntax. The guidelines are as follows:-

1. Each BNF category is represented as a class (both an instance of the StructureElement metaclass and a specialisation of AerospaceEngineeringObject).

2. Categories forming the defining sequence of a category are themselves represented as classes (related to the subject class through aggregation), except where rule 3 applies.

3. Where nothing is gained traceability-wise by mirroring definition of a category in terms of other categories (and hence the corresponding class in terms of other classes) - that is, no constituent categories can be represented by classes that map to PDS elements (nor trace to elements of other notations) - then it is treated as atomic and represented through specialisation of the standard String type (as well as an instance of StructureElement and a specialisation of AerospaceEngineeringObject).

4. All tokens (i.e., reserved words - such as from, global, inherit, etc. - together with punctuation marks - such as commas, semi-colons, parentheses and ampersands) are represented as specialisations of the standard String class (and also as instances of ArtifactProperty).

5. Categories of a defining sequence that exist exactly once are modelled with a multiplicity constraint of one (1) for aggregate component classes; attributes representing tokens have an implicit multiplicity of one.

6. Optional items from a defining sequence (expressed in BNF using square brackets) are modelled as follows:-

a) Categories are represented by applying a zero-or-one multiplicity constraint (0..1) on the component side of associations between the class representing the category being described (aggregate) and each class representing an optional defining category (component).

b) Tokens are promoted from attributes to classes (linked to their host class using composition) to allow for expression of optionality (see also rule 8 on alternatives).

7. Categories of a defining sequence that may be omitted, appear once, or be repeated several times (expressed in BNF using the braces formalism) are modelled using a zero-to-many multiplicity constraint (0..*) on the component side of associations between the class representing the category being described (aggregate) and each class representing an optional, singular or repeated defining category (component).

8. Categories decomposed into alternatives (expressed in BNF using the vertical bar separator) are modelled differently depending on what form their defining sequence takes.

(a) For a category 'c' whose alternatives are exclusively 1-tuples (e.g. c::= a | b) and which is represented by a class 'C', we adopt the following convention:-

Both categories and tokens (the latter promoted from attributes as per rule 6b) are modelled as component classes of C with an aggregation multiplicity of 1 (or 0..1 if optional), and with a dashed line (bearing an 'exclusive-or' annotation) connecting their Class Diagram icons; semantics are that each occurrence of C *must* (if multiplicities are 1) or *may* (if 0..1) be composed of an occurrence of *one* entity from a set of alternatives, to the exclusion of all others.

(b) For a category 'c' whose alternatives include n > 1-tuples, i.e., a set of category or token elements (e.g., c::= ab | ad) and which is represented by a class 'C', we adopt the following convention(s):-

where a subset of elements common to each alternative exists, e.g., a in ab | ad, then:-

i. if a is a category, we represent it as a component class of C with multiplicity 1 (if mandatory for all alternatives) or 0..1 (if optional for all);
ii. if a is a token, we represent it as an attribute of C (if mandatory for all alternatives) or as a component class of C with multiplicity 0..1 (if optional for all).

These are the main properties of alternatives for which a modelling philosophy can be stated. We make the observation that following subtraction of common elements, the remaining subsets for each alternative in example (b) are all disjoint 1-tuples (i.e. c::= a̶b | a̶d) and therefore corresponding classes may be linked using the diagramming conventions described previously for (a).

However to preserve BNF semantics, most scenarios featuring n > 1 tuples require an OCL invariant to unambiguously state multiplicity and/or valid element combinations. In particular, where n > 1 tuple items must be and-ed together to form an alternative, or where on subtraction of common elements, the remaining subsets include either zero-tuples (e.g. the middle alternative in c::= a̶b | b̶ | b̶c) or tuples whose elements are not disjoint (e.g., c::= a̶b̶d | b̶d | b̶e); note elements that are 'common' to alternatives, but which differ in terms of optionality (e.g. [b], b in c::= a [b] | b c) are treated as non-common.

9. The modelling of a defining sequence in which an item type appears at least once, but which may be repeated (as a comma or semi-colon delimited list) - i.e., category ::= item {, item} - features a subtle variation from the BNF syntax; we represent the mandatory single item as a class (corresponding to a 'list head') and the optional repeated part (enclosed between braces in BNF) as

a separate 'list-item' class containing an appropriate delimiter attribute, together with an aggregation association (multiplicity of one) to the afore-mentioned item class.

It should be noted that there is some information loss in terms of sequencing when moving from a BNF to a UML representation[36]. This is further to the loss (in this particular work) when moving from UML to O-Telos due to our not explicitly re-stating assertions for multiplicity, exclusive-or, etc.

4.5.3.2 SPARK Ada Meta-model Definitions

In this subsection we present a series of schemas representing elements for a SPARK Ada structure (an instantiation of the DevelopmentStructure metaclass[37]) capturing the language subset outlined above. Each element is systematically expressed in terms of its source BNF syntax, corresponding UML representation and implementation in O-Telos using ConceptBase; OCL constraints are also introduced where appropriate to supplement standard UML diagramming conventions[38]. We further highlight the influence of our modelling philosophy (from 4.5.3.1) in deriving these structures. Readers without an Ada background are again referred to Barnes (1997) for details on the featured syntax.

Many of the SPARK BNF productions that follow are identical in Ada. However some - those indicated by an asterisk (*) - have been modified despite retaining the Ada category name. Others - those highlighted with a plus sign (+) - are additional SPARK constructs not present in the core language.

We begin by describing the library_item syntax which marks the starting point for our structure. A SPARK Ada program is normally written as a number of units that may be compiled and linked separately, or else grouped together into one or more compilations. A compilation is therefore a succession of compilation units, of which one permutation comprises a library_item and a context clause specifying interdependence among individual units. For information and to highlight the origin for our modelling, the related BNF syntax is shown below:-

compilation ::= {compilation_unit}

compilation_unit ::= context_clause library_item | context_clause subunit

* library_item ::= [**private**] package_declaration | package_body | main_subprogram

+ main_subprogram ::= [inherit_clause] main_subprogram_annotation subprogram_body

+ main_subprogram_annotation ::= --# main_program;

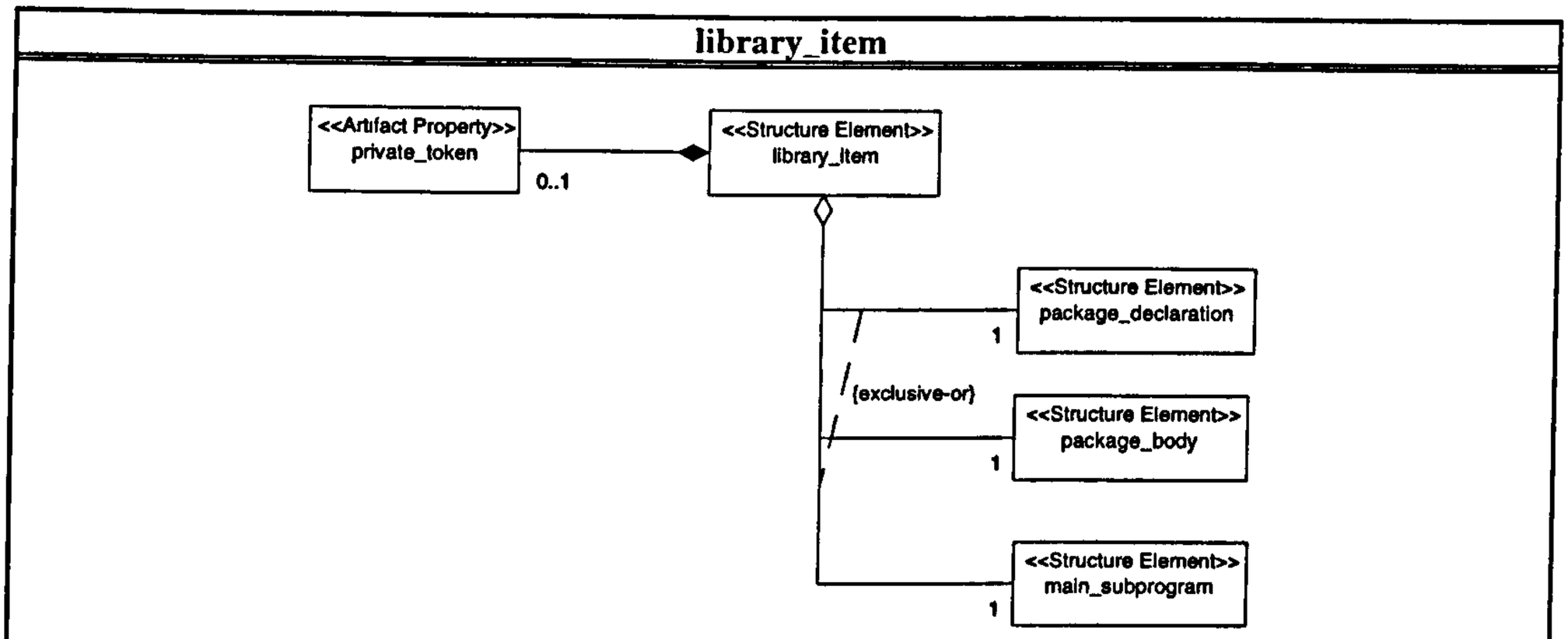
- **library_item**

A library_item (figure 4.25) contains either the optional 'private' (private_token) reserved word, together with a package declaration (package_declaration), or else a package body (package_body) or main

---

[36] As with project NATURE, we make the assumption that issues of layout are addressed by user interfaces to this and all structures featured in the thesis.
[37] The SPARK DevelopmentStructure class (not shown) is simply an aggregation of all elements featured in this section.
[38] OCL is mainly used to state mutual dependencies (among optional categories and tokens), as well in place of standard diagram annotations for multiplicity in complex cases (where for example elements are nested).

subprogram (main_subprogram). Note how we promote private_token to a class in UML in order to specify its optionality, as per rule 6b (from subsection 4.5.3.1.1); rule 8b also applies.



BNF Syntax	OCL	O-Telos (base classes)

library_item ::= **[private]**
package_declaration |
package_body |
main_subprogram
	library_item invariant
	self.allInstances->forall(l |
	not (l.private_token->notEmpty and
	l.package_declaration->isEmpty))
	
	Constraint (in conjunction with 'exclusive-or' in figure) ensuring private_token can exist only when package_declaration exists
		library_item in StructureElement,
		SimpleClass isA AerospaceEngineeringObject with has_property
		private_token : private_token
		has_part
		package_declaration : package_declaration;
		package_body : package_body;
		main_subprogram : main_subprogram
		end
		
		private_token in ArtifactProperty,
		SimpleClass isA String with constraint
		private_Is_Private:
		$ forall p/private_token p = "private"
		$ end

Figure 4.25 - 'library_item schema'

All remaining featured elements enable representation of package declarations, the syntax for which is:-

package_declaration ::= package_specification;

*package_specification ::=
[inherit_clause]
package defining_program_unit_name package_annotation
is
{renaming_declaration}
{package_declarative_item}
end [parent_unit_name .] identifier;

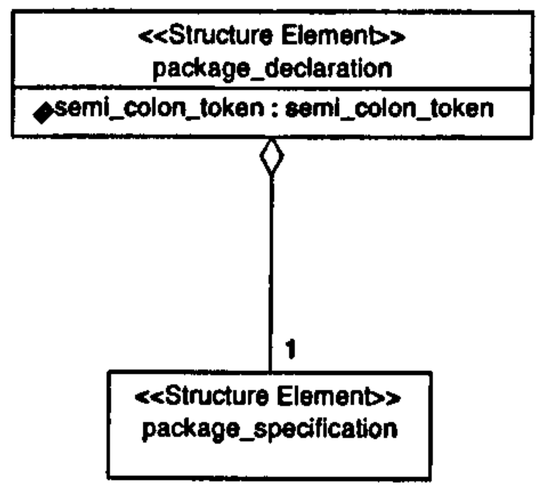
Note, again the above syntax is for reader orientation only; individual schema representations will now

be developed for each of these constructs (except renaming_declaration).

- **package_declaration**

Each package_declaration is defined in terms of a single package specification (package_specification) and terminates with a semi-colon (semi_colon_token) as the schema below (figure 4.26) demonstrates:-

package_declaration



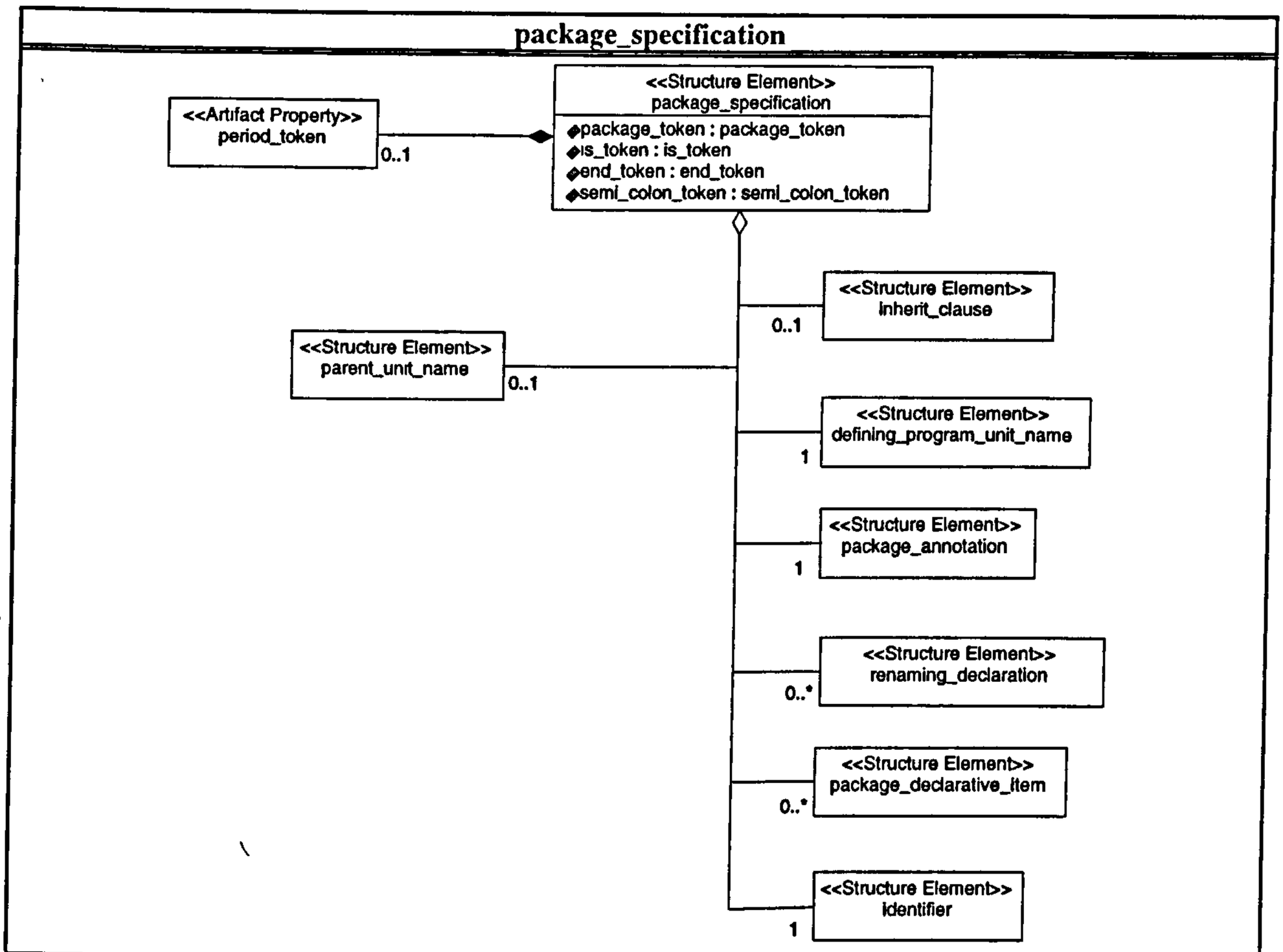
BNF Syntax	O-Telos
package_declaration ::= package_specification;	package_declaration in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property semi_colon_token : semi_colon_token has_part package_specification : package_specification end semi_colon_token in ArtifactProperty, SimpleClass isA String with constraint semicolon_Is_Semicolon: $ forall s/semi_colon_token s = ";" $ end

Figure 4.26 - 'package_declaration schema'

- **package_specification**

In addition to the 'package' (package_token), 'is' (is_token) and 'end' (end_token) reserved words, and semi_colon_token and period (period_token) punctuation, package_specification includes the inherit clause (inherit_clause), defining program unit name (defining_program_unit_name), package annotation (package_annotation), renaming declaration (renaming_declaration), package declarative item (package_declarative_item), parent unit name (parent_unit_name) and identifier category elements.

In UML, we again promote an attribute - period_token - to a class in order to express its optionality (rule 6b); the zero-or-one (0..1) multiplicity constraint on this class and on parent_unit_name is supplemented by an OCL constraint to preserve the BNF optionality syntax such that both or neither of these elements exist. Further, both parent_unit_name and identifier are treated as atomic (and hence as specialisations of the built-in String class which is not shown on the UML diagram, but does feature in the corresponding O-Telos representation) since this granularity is sufficient for traceability purposes (as per rule 3). The package_specification schema is shown in figure 4.27.



BNF Syntax

* package_specification ::=
[inherit_clause]
package defining_program_unit_name
package_annotation
is
{renaming_declaration}
{package_declarative_item}
end [parent_unit_name .] identifier;

parent_unit_name ::= name

identifier ::= identifier_letter {[underlined]
letter_or_digit}

OCL

package_specification invariant
self.allInstances->forall(p |
(p.period_token->isEmpty and p.parent_unit_name-> isEmpty) xor
(p.period_token->notEmpty and p.parent_unit_name->notEmpty))

O-Telos

```
--Token classes
package_token in ArtifactProperty,
SimpleClass isA String
with constraint
package_Is_Package:
    $ forall p/package_token p = "package"
$
end

is_token in ArtifactProperty, SimpleClass
isA String
with constraint
is_Is_Is:
        $ forall i/is_token i = "is" $
end
```

O-Telos (continued)

```
end_token in ArtifactProperty, SimpleClass
isA String with constraint end_Is_End:
    $ forall e/end_token e = "end" $
end

period_token in ArtifactProperty,
SimpleClass isA String with constraint
period_Is_Period:
   $ forall p/period_token p = "." $
end

parent_unit_name in StructureElement,
SimpleClass isA String,
AerospaceEngineeringObject
end

identifier in StructureElement,
SimpleClass isA String,
AerospaceEngineeringObject end

--package_specification class
package_specification in StructureElement,
SimpleClass isA AerospaceEngineeringObject
with
has_property
    package_token : package_token;
    is_token : is_token;
    end_token : end_token;
    period_token : period_token;
    semi_colon_token  : semi_colon_token
has_part
    inherit_clause : inherit_clause;
    defining_program_unit_name :
defining_program_unit_name;
    package_annotation :
package_annotation;
    renaming_declaration :
renaming_declaration;
    package_declarative_item :
package_declarative_item;
    parent_unit_name : parent_unit_name;
    identifier : identifier
end
```

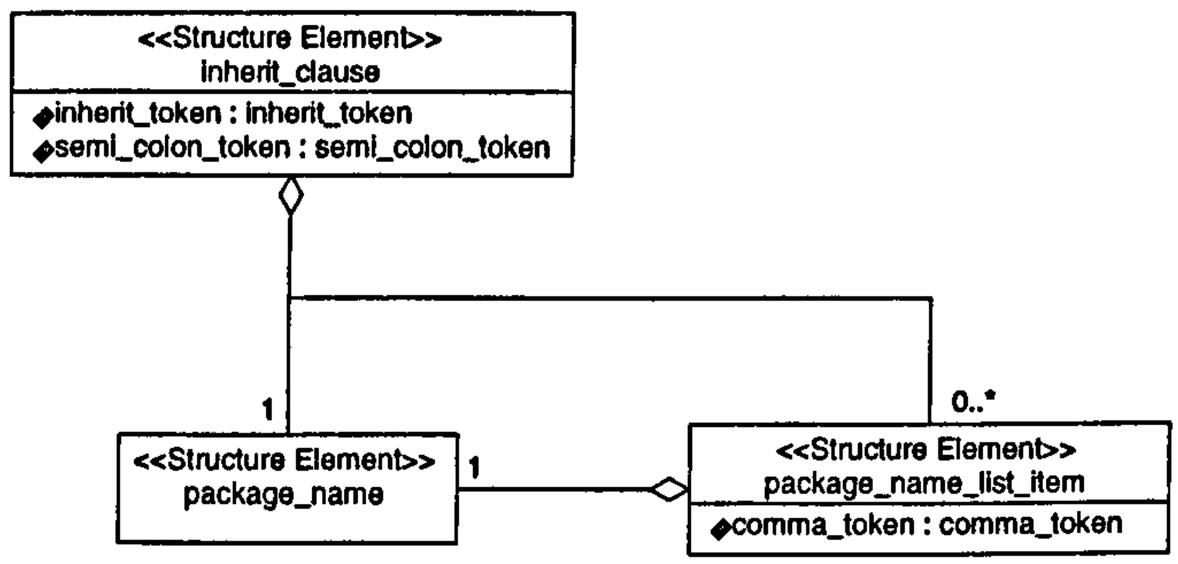
Figure 4.27 - 'package_specification schema'

- **inherit_clause**

This construct includes the '--# inherit' (inherit_token) reserved word annotation together with at least one, but optionally a comma delimited list of package name (package_name) elements. It too terminates with a semi-colon.

In accordance with rule 9, our UML representation (and hence the O-Telos implementation) introduces an additional class - package_name_list_item - as a means of representing elements following the mandatory initial package_name instance. Further, package_name is treated as atomic in accordance with rule 3. The inherit_clause schema is shown in figure 4.28.

inherit_clause



BNF Syntax	O-Telos
+ inherit_clause ::= --# **inherit** package_name {, package_name}; package_name ::= identifier	inherit_clause in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property inherit_token : inherit_token; semi_colon_token : semi_colon_token has_part package_name : package_name; package_name_list_item : package_name_list_item end inherit_token in ArtifactProperty, SimpleClass isA String with constraint inherit_Is_Inherit: $ forall i/inherit_token i = "--# inherit" $ end package_name in StructureElement, SimpleClass isA String, AerospaceEngineeringObject end package_name_list_item in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property comma_token : comma_token has_part package_name : package_name end

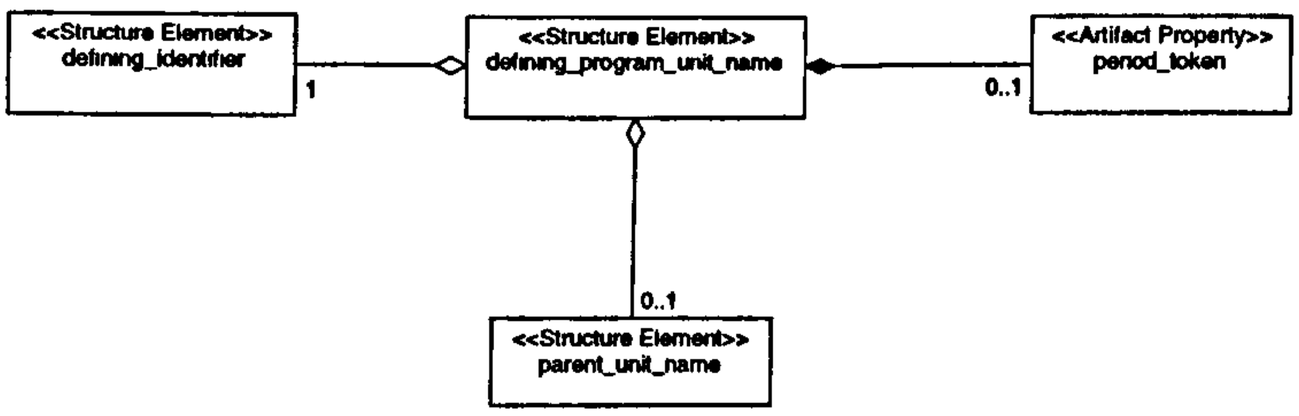
Figure 4.28 - 'inherit_clause schema'

- **defining_program_unit_name**

A defining_program_unit_name (figure 4.29) contains defining identifier (defining_identifier) and parent_unit_name elements, together with the period_token punctuation.

The UML representation of this category includes certain characteristics present in package_specification. Again, period_token is promoted to a class to allow specification of optionality (as per rule 6b); again, the zero-or-one multiplicity imposed on this class and on parent_unit_name is supplemented by an OCL constraint to preserve the BNF optionality syntax such that both or neither of these elements exists; and again defining_identifier is treated as atomic.

defining_program_unit_name



BNF Syntax	OCL	O-Telos (base classes)

defining_program_unit_name
::= [parent_unit_name .]
defining_identifier
 	
defining_identifier ::= identifier
	defining_program_unit_name Invariant
	self.allInstances->forall(d |
	(d.period_token->isEmpty and
	d.parent_unit_name->isEmpty) xor
	(d.period_token->notEmpty and
	d.parent_unit_name->notEmpty))
	
	Constraint preserving the BNF optionality syntax such that both period_token and parent_unit _name exist or neither exists
		`defining_program_unit_name in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property period_token : period_token has_part parent_unit_name : parent_unit_name; defining_identifier : defining_identifier end`
		
		`defining_identifier in StructureElement, SimpleClass isA String, AerospaceEngineeringObject end`

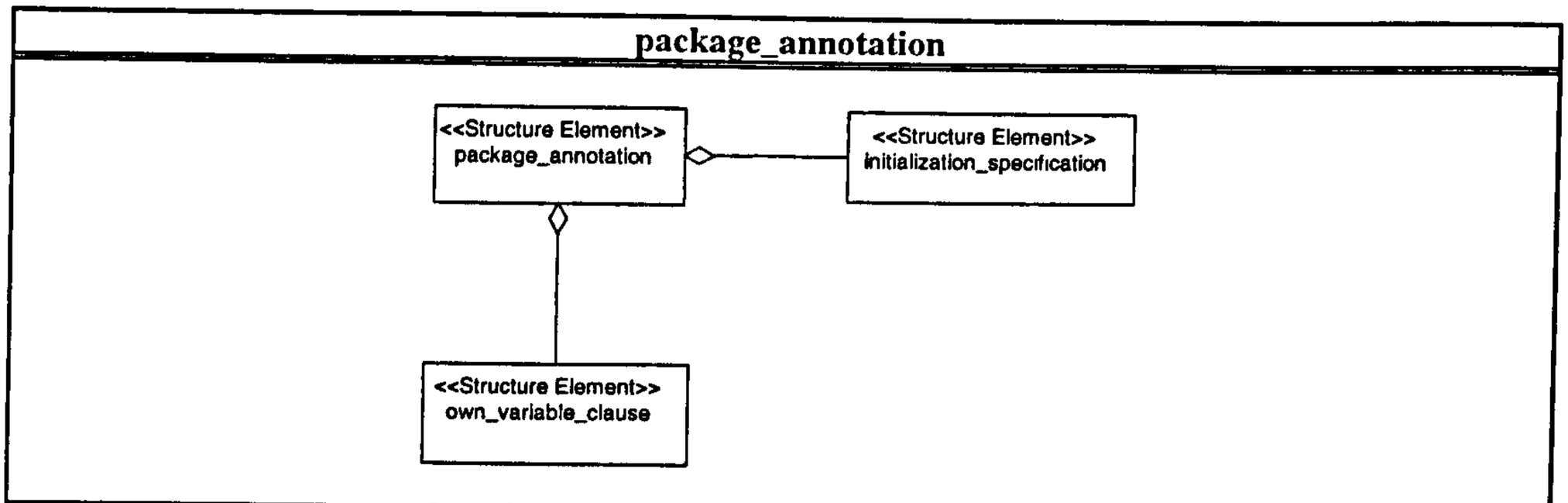
Figure 4.29 - 'defining_program_unit_name schema'

- **package_annotation**

This construct comprises an optional own variable clause (own_variable_clause); if this element exists, then it may also contain an optional initialization specification (initialization_specification). The semantics of this statement are captured in BNF by nesting the square brackets framing these constructs and in the corresponding UML diagram using an OCL constraint (see figure 4.30).

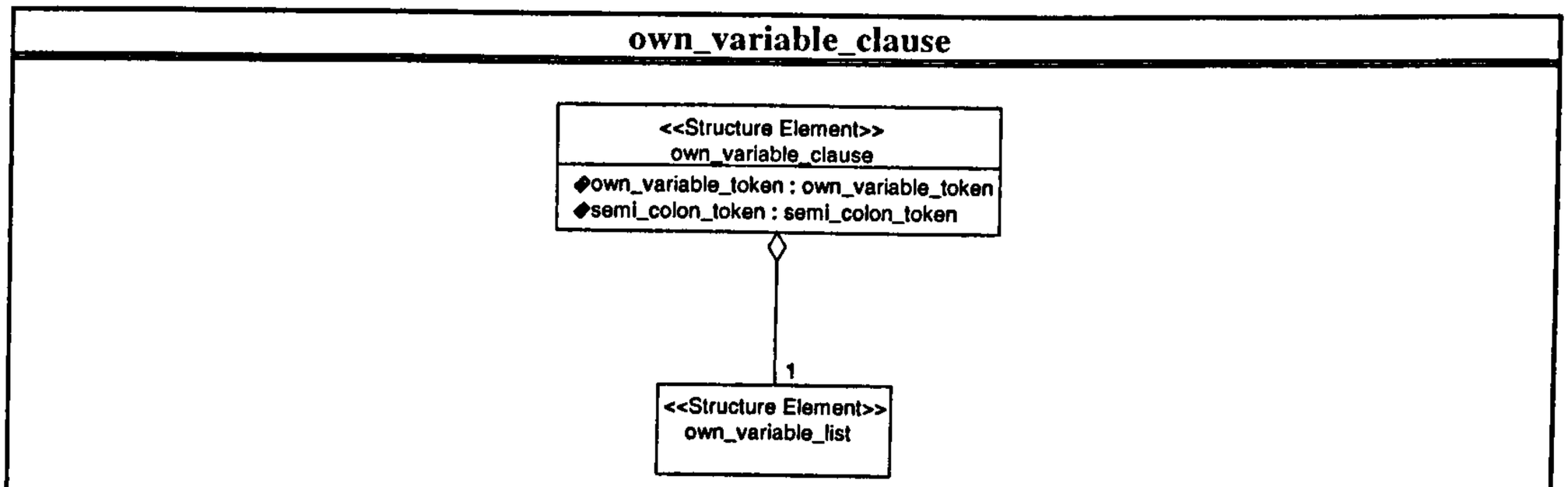
- **own_variable_clause**

An own_variable_clause includes the '--# own' (own_token) reserved word annotation, together with a



BNF Syntax	OCL	O-Telos (base classes)
+ package_annotation ::= [own_variable_clause [initialization_specification]]	package_annotation invariant self.allInstances->forall(p | p.own_variable_clause->size <=1 and p.initialization_specification->size <= 1 and not (p.initialization_specification->size = 1 and p.own_variable_clause->isEmpty)) *Constraint preserving the BNF nested square brackets syntax*	package_annotation in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_part own_variable_clause : own_variable_clause; initialization_specific ation : initialization_specification end

Figure 4.30 - 'package_annotation schema'



BNF Syntax	O-Telos
+ own_variable_clause ::= --# own own_variable_list;	own_variable_clause in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property own_variable_token : own_variable_token; semi_colon_token : semi_colon_token has_part own_variable_list : own_variable_list end own_variable_token in ArtifactProperty, SimpleClass isA String with constraint own_Is_Own: $ forall v/own_variable v = "--# own" $ end

Figure 4.31 - 'own_variable_clause schema'

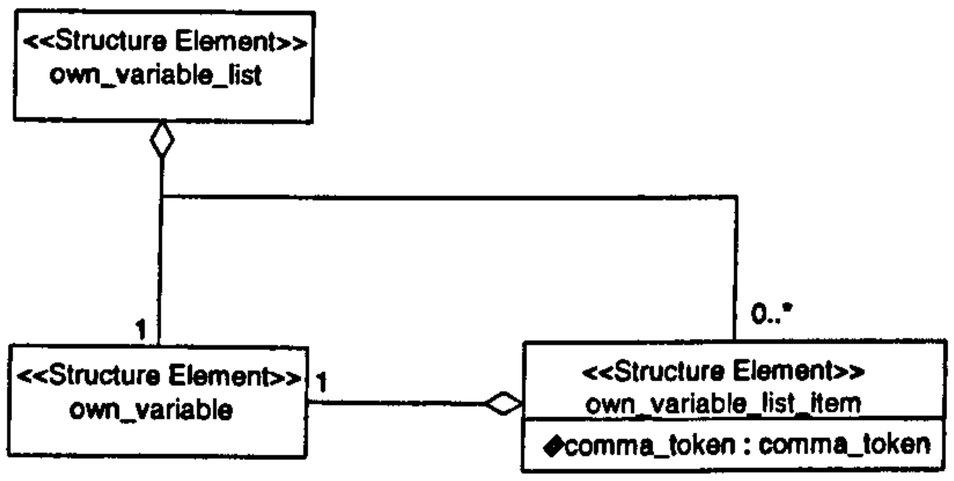
single own variable list (own_variable_list) element; the construct terminates with a semi_colon. This schema is shown in figure 4.31.

- **own_variable_list**

As its name suggests, own_variable_list (figure 4.32) contains one or more own variable (own_variable) elements as a comma-delimited list.

Again (in accordance with rule 9), the UML and O-Telos representations introduce an additional class - own_variable_list_item - to represent optional own_variable elements that may follow the single mandatory instance; own_variable itself is treated as atomic (as per rule 3).

own_variable_list



BNF Syntax	O-Telos
+ own_variable_list ::= own_variable {, own_variable} + own_variable ::= identifier	own_variable_list in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_part own_variable : own_variable; own_variable_list_item : own_variable_list_item end own_variable_list_item in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property comma_token : comma_token has_part own_variable : own_variable end own_variable in StructureElement, SimpleClass isA String, AerospaceEngineeringObject end

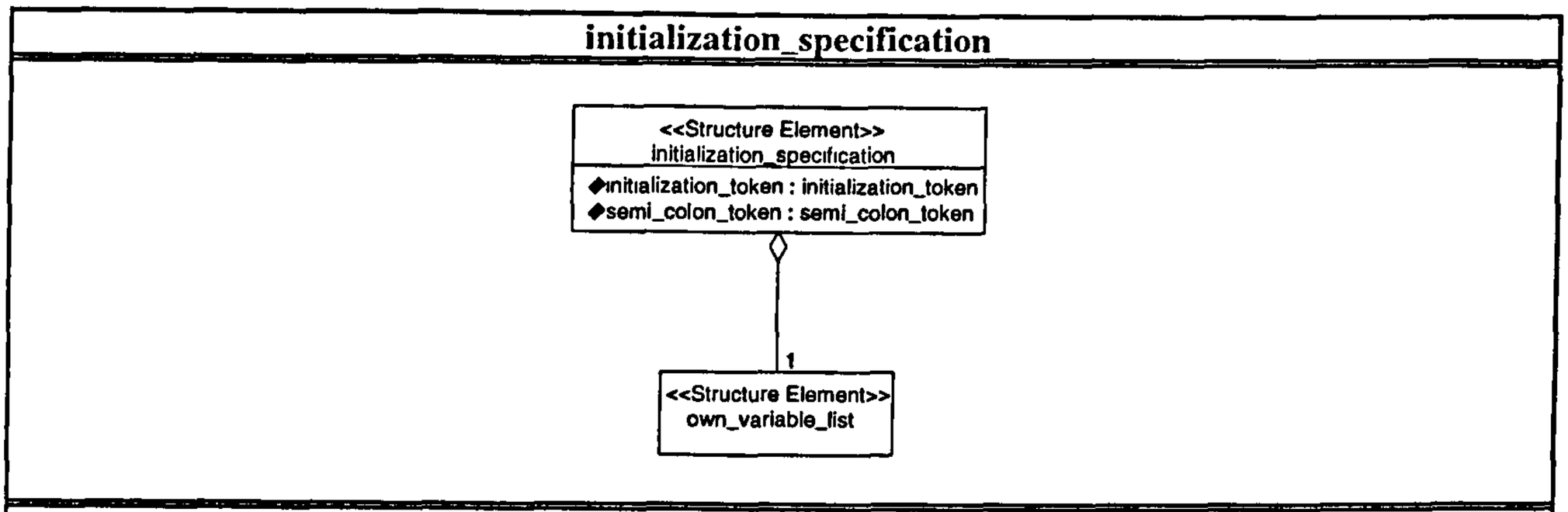
Figure 4.32 - 'own_variable_list schema'

- **initialization_specification**

An initialization_specification (figure 4.33) includes the '--# initializes' (initializes_token) reserved word annotation, together with a single own_variable_list element; this construct also terminates with a semi_colon.

- **package_declarative_item**

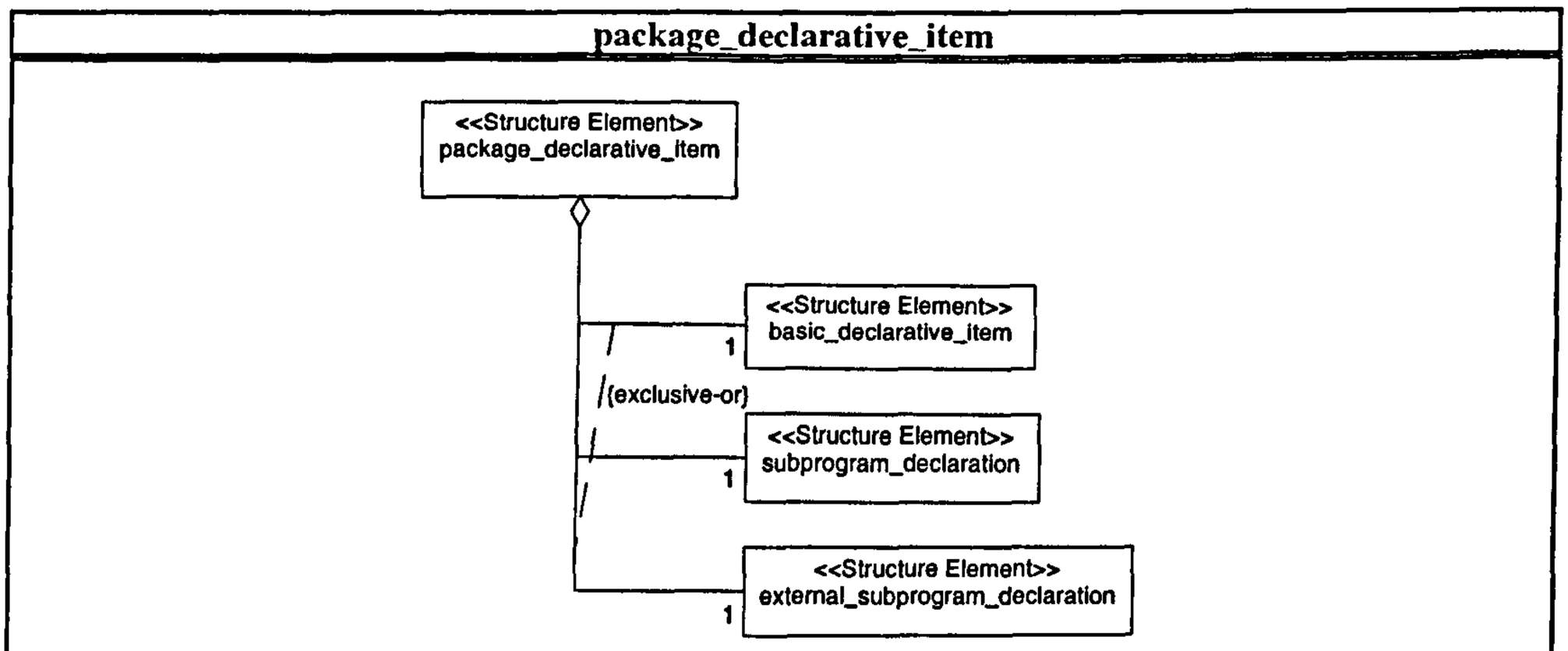
A package_declarative_item contains either a basic declarative item (basic_declarative_item), subprogram declaration (subprogram_declaration) or external subprogram declaration (external_subprogram_declaration); therefore rule 8a applies. The corresponding schema is shown in figure 4.34.



BNF Syntax	O-Telos

+ initialization_specification ::=
--# initializes own_variable_list;
	initialization_specification in StructureElement, SimpleClass isA AerospaceEngineeringObject with
	has_property
	  initialization_token : initialization_token;
	  semi_colon_token : semi_colon_token
	has_part
	  own_variable_list : own_variable_list
	end
	
	initialization_token in ArtifactProperty, SimpleClass isA String with constraint init_Is_Init:
	  $ forall i/initialization_token i = "--# initializes" $
	end

Figure 4.33 - 'initialization_specification schema'



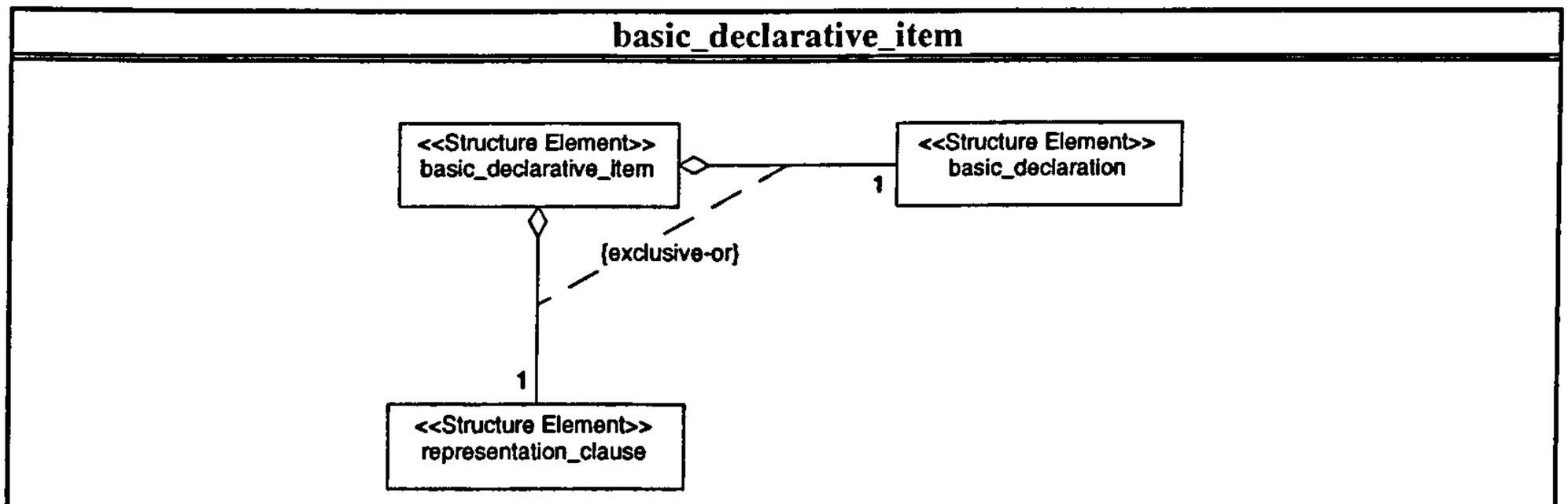
BNF Syntax	O-Telos

+ package_declarative_item ::=
basic_declarative_item | subprogram_declaration |
external_subprogram_declaration
	package_declarative_item in StructureElement, SimpleClass isA AerospaceEngineeringObject with
	has_part
	  basic_declarative_item : basic_declarative_item;
	  subprogram_declaration : subprogram_declaration;
	  external_subprogram_declaration : external_subprogram_declaration
	end

Figure 4.34 - 'package_declarative_item schema'

- **basic_declarative_item**

Each basic_declarative_item (figure 4.35) consists of either a representation clause (representation_clause) or basic declaration (basic_declaration); again rule 8a applies.



BNF Syntax	O-Telos
basic_declarative_item ::= basic_declaration | representation_clause	basic_declarative_item in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_part basic_declaration : basic_declaration; representation_clause : representation_clause end

Figure 4.35 - 'basic_declarative_item schema'

- **basic_declaration**

Similarly, each basic_declaration comprises either an object declaration (object_declaration), a number declaration (number_declaration), a type declaration (type_declaration) or a subtype declaration (subtype_declaration). This is represented by the schema in figure 4.36 (again based on rule 8a).

- **type_declaration**

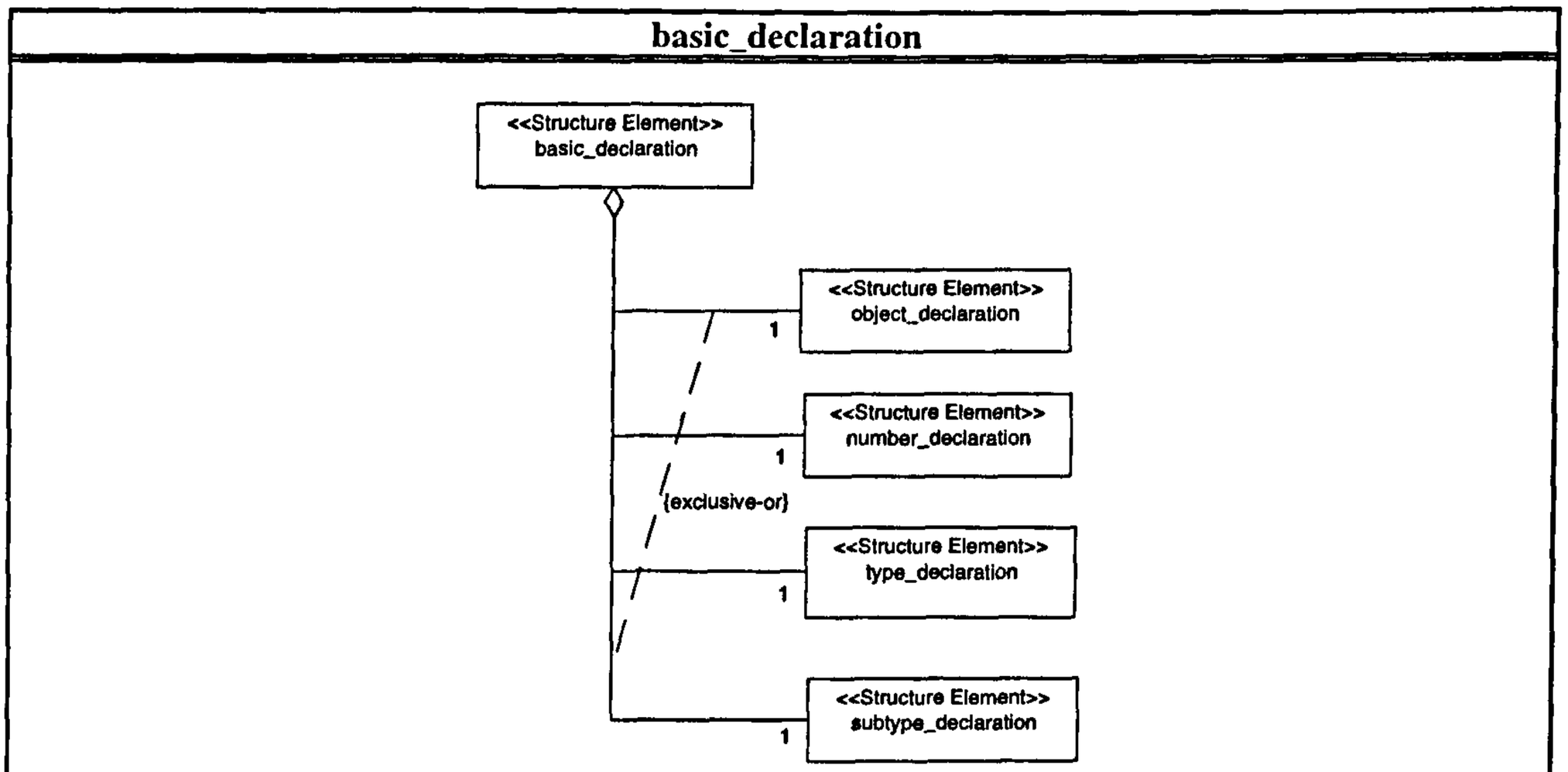
A type_declaration features either a full type declaration (full_type_declaration) or private type declaration (private_type_declaration); the corresponding schema (derived using rule 8a) is shown in figure 4.37.

- **full_type_declaration**

Each full_type_declaration contains the 'type' (type_token) and 'is' (is_token) reserved words, together with a defining_identifier and type definition (type_definition) as shown in figure 4.38; full_type_declaration terminates with a semi-colon.

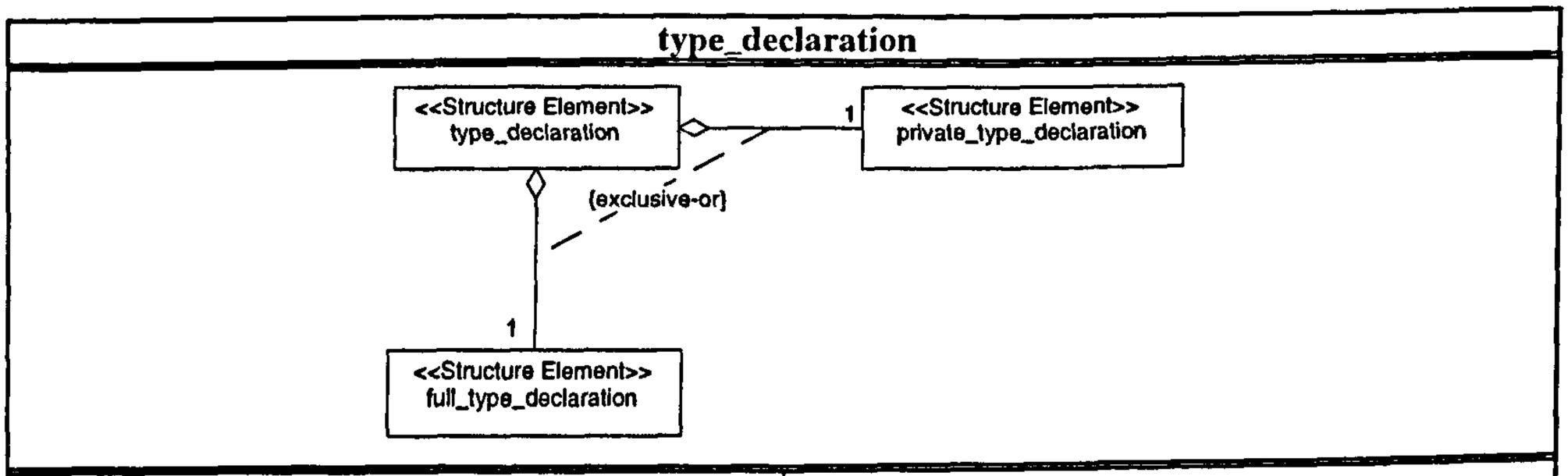
- **type_definition**

Each type_definition consists of an enumeration type definition (enumeration_type_definition), an integer type definition (integer_type_definition), a real type definition (real_type_definition), an array type definition (array_type_definition) or a record type definition (record_type_definition); this schema is also based on rule 8a and is shown in figure 4.39.



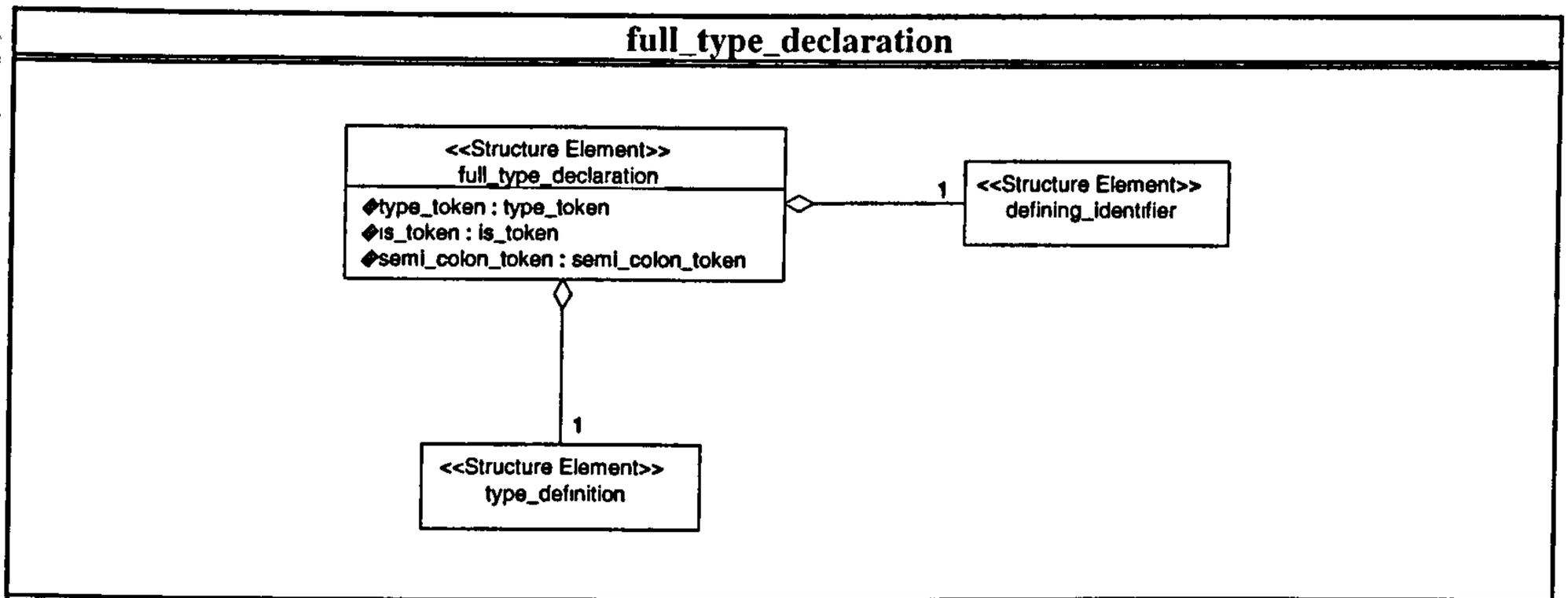
BNF Syntax	O-Telos
* basic_declaration ::= object_declaration | number_declaration | type_declaration | subtype_declaration	basic_declaration in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_part object_declaration : object_declaration; number_declaration : number_declaration; type_declaration : type_declaration; subtype_declaration : subtype_declaration end

Figure 4.36 - 'basic_declaration schema'



BNF Syntax	O-Telos
* type_declaration ::= full_type_declaration | private_type_declaration	type_declaration in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_part full_type_declaration : full_type_declaration; private_type_declaration : private_type_declaration end

Figure 4.37 - 'type_declaration schema'



BNF Syntax	O-Telos
* full_type_declaration ::= **type** defining_identifier **is** type_definition;	full_type_declaration in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property type_token : type_token; is_token : is_token; semi_colon_token : semi_colon_token has_part defining_identifier : defining_identifier; type_definition : type_definition end type_token in ArtifactProperty, SimpleClass isA String with constraint type_Is_Type: $ forall t/ type_token t = "type" $ end

Figure 4.38 - 'full_type_declaration schema'

- **enumeration_type_definition**

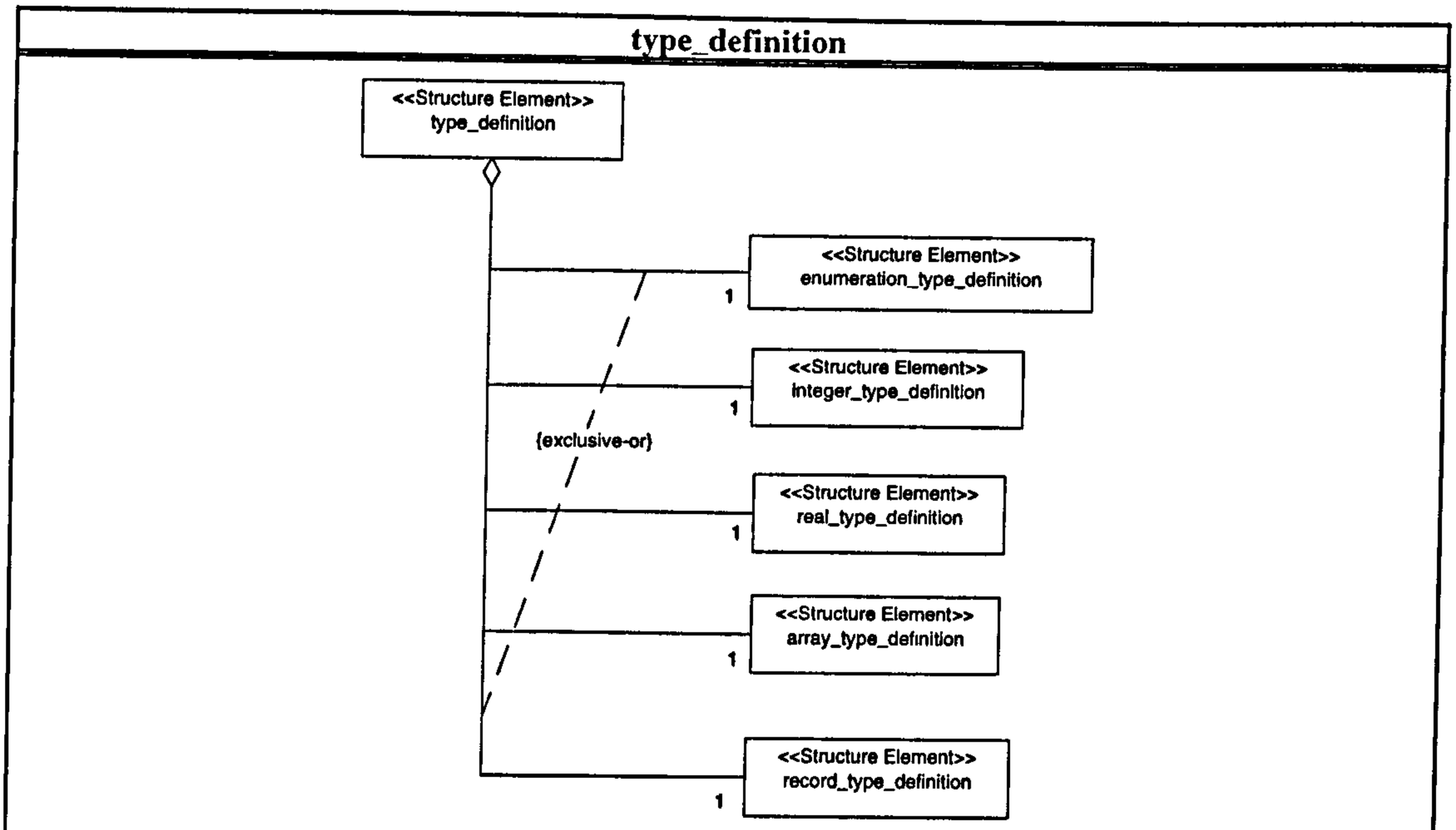
An enumeration_type_definition consists of one or more defining_identifier elements represented as a comma-delimited list; the construct is enclosed between left (left_parenthesis_token) and right (right_parenthesis_token) parentheses.

Again (as per rule 9), the UML and O-Telos representations introduce an additional class - defining_identifier_list_item - to represent optional defining_identifier elements following the single mandatory instance. Figure 4.40 depicts the corresponding enumeration_type_definition schema.

- **subprogram_declaration**

A subprogram_declaration consists of either a procedure specification (procedure_specification) and procedure annotation (procedure_annotation) or a function specification (function_specification) and function annotation (function_annotation), separated by a semi-colon.

The common semi_colon_token element is included once as an attribute of the subprogram_declaration class (in accordance with rule 8b); an OCL constraint describes the alternative combinations (see figure 4.41).



BNF Syntax	O-Telos
* type_definition ::= enumeration_type_definition | integer_type_definition | real_type_definition | array_type_definition | record_type_definition	type_definition in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_part enumeration_type_definition : enumeration_type_definition; integer_type_definition : integer_type_definition; real_type_definition : real_type_definition; array_type_definition : array_type_definition; record_type_definition : record_type_definition end

Figure 4.39 - 'type_definition schema'

- **procedure_specification**

Each procedure_specification (figure 4.42) consists of the 'procedure' (procedure_token) reserved word, followed by defining_identifier and parameter profile (parameter_profile) elements.

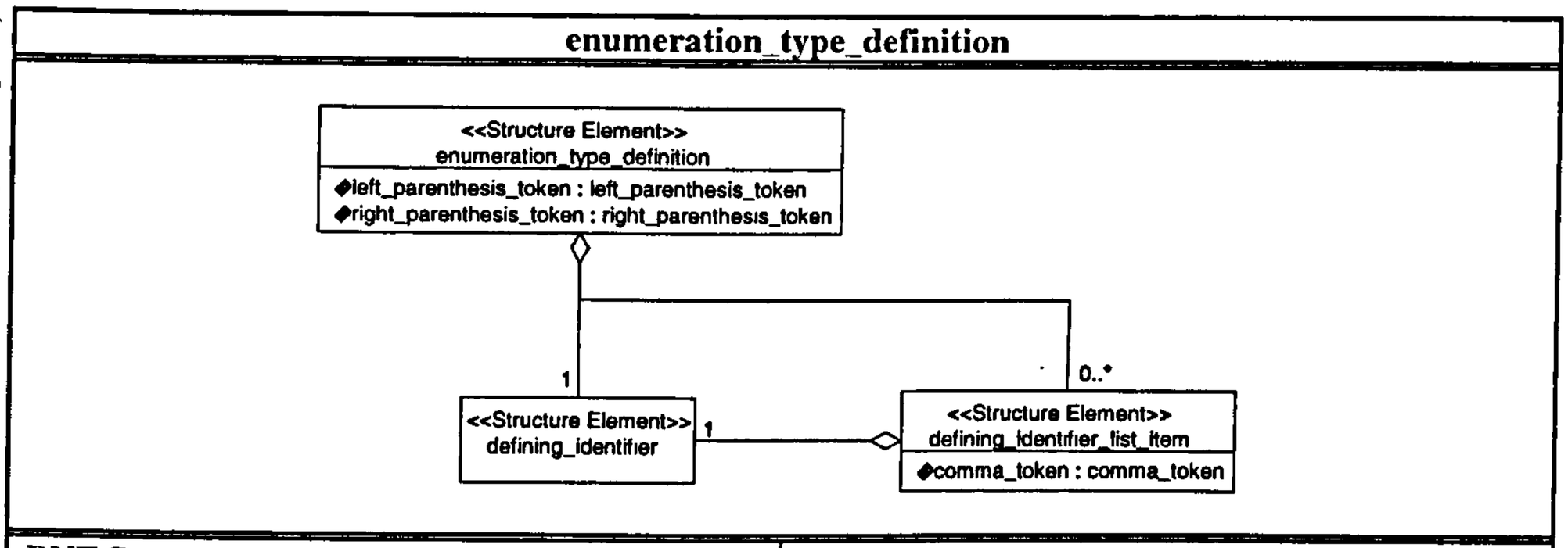
- **parameter_profile**

A parameter_profile simply comprises an optional formal part (formal_part) element (see figure 4.43).

- **formal_part**

The formal_part element (figure 4.44) consists of one or more parameter specifications (parameter_specification) represented as a semi-colon-delimited list between left (left_parenthesis_token) and right (right_parenthesis_token) parentheses.

As with all featured list based constructs, the UML and O-Telos representations introduce an additional class (in accordance with rule 9) - in this case parameter_specification_list_item - to represent optional parameter_specification elements following the single mandatory instance.



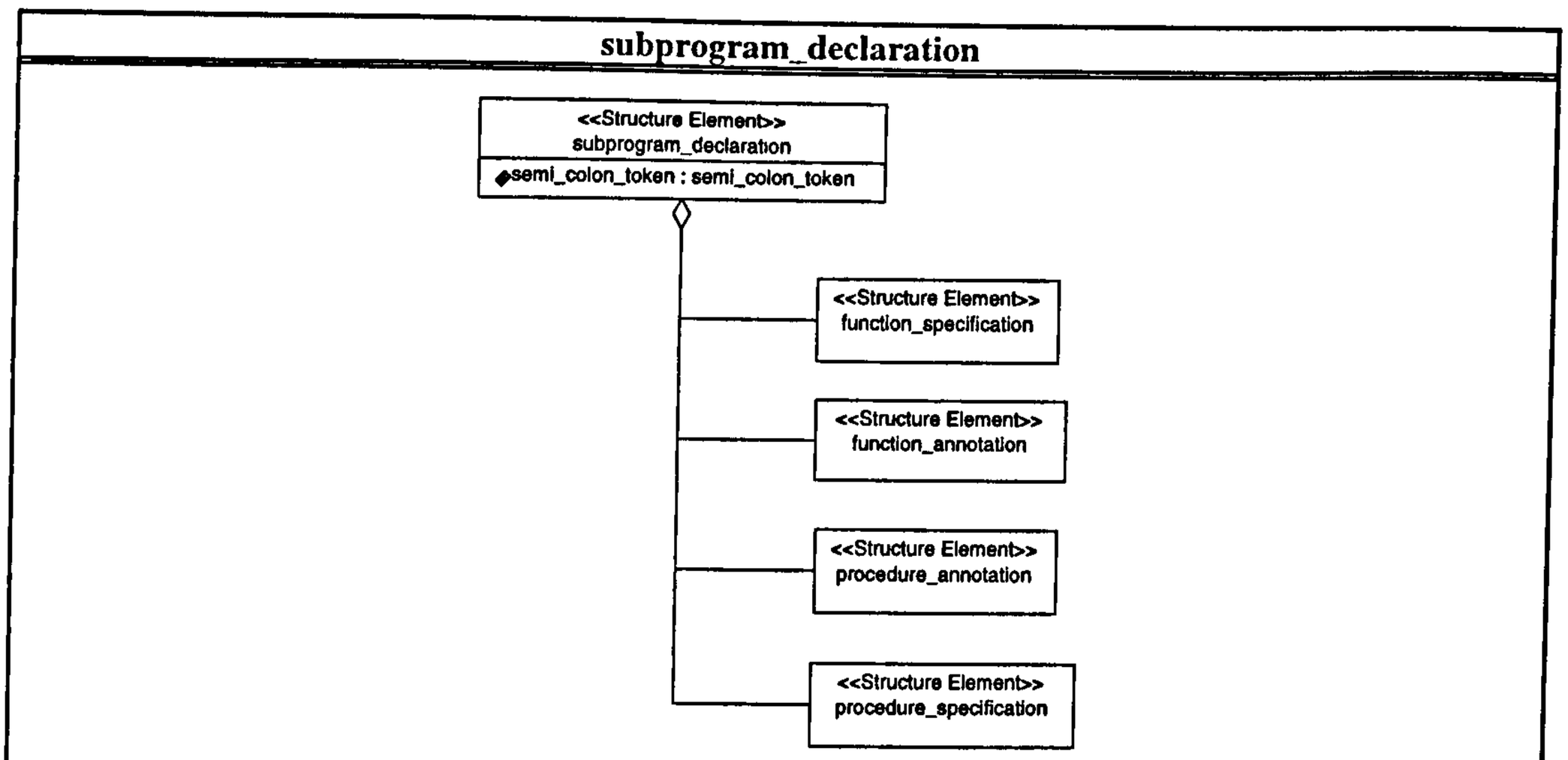
BNF Syntax	O-Telos
* enumeration_type_definition ::= (defining_identifier {, defining_identifier})	enumeration_type_definition in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property left_parenthesis_token : left_parenthesis_token; right_parenthesis_token : right_parenthesis_token has_part defining_identifier : defining_identifier; defining_identifier_list_item : defining_identifier_list_item end left_parenthesis_token in ArtifactProperty, SimpleClass isA String with constraint left_Is_Left: $ forall l/left_parenthesis_token l = "(" $ end right_parenthesis_token in ArtifactProperty, SimpleClass isA String with constraint right_Is_Right: $ forall r/right_parenthesis_token r = ")" $ end defining_identifier_list_item in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property comma_token : comma_token has_part defining_identifier : defining_identifier end

Figure 4.40 - 'enumeration_type_definition schema'

- **parameter_specification**

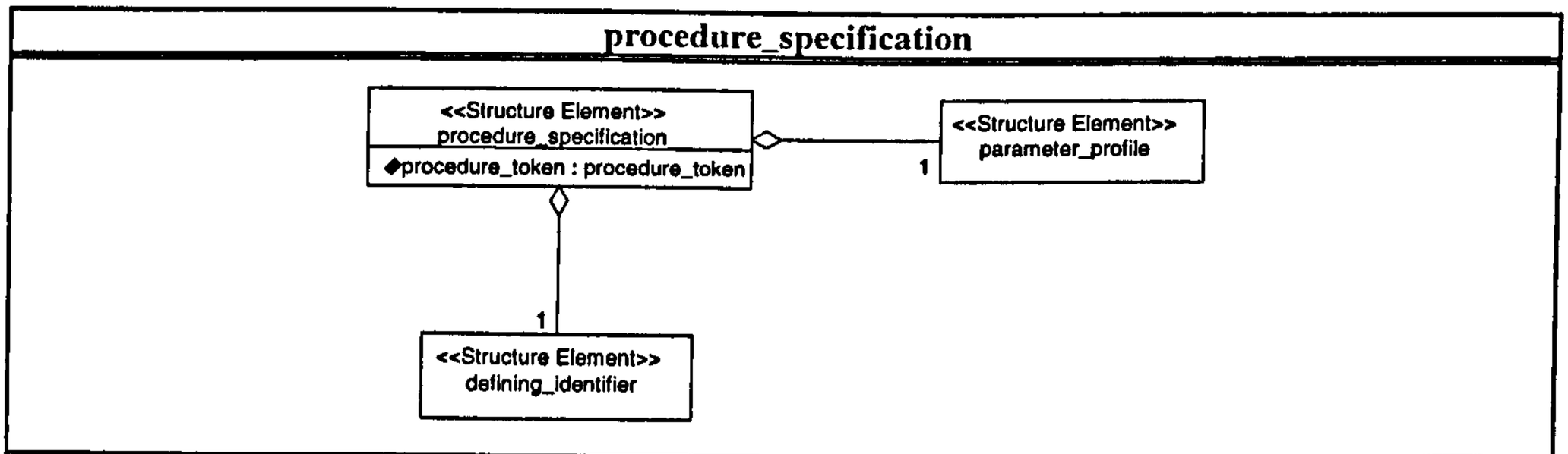
A parameter_specification contains a defining identifier list (defining_identifier_list), the colon punctuation (colon_token), mode and subtype mark (subtype_mark) elements.

In the UML model, mode and subtype_mark are both treated as specialisations of the String class as per rule 3; the former bears an OCL constraint restricting instantiations to the BNF alternatives shown in figure 4.45.



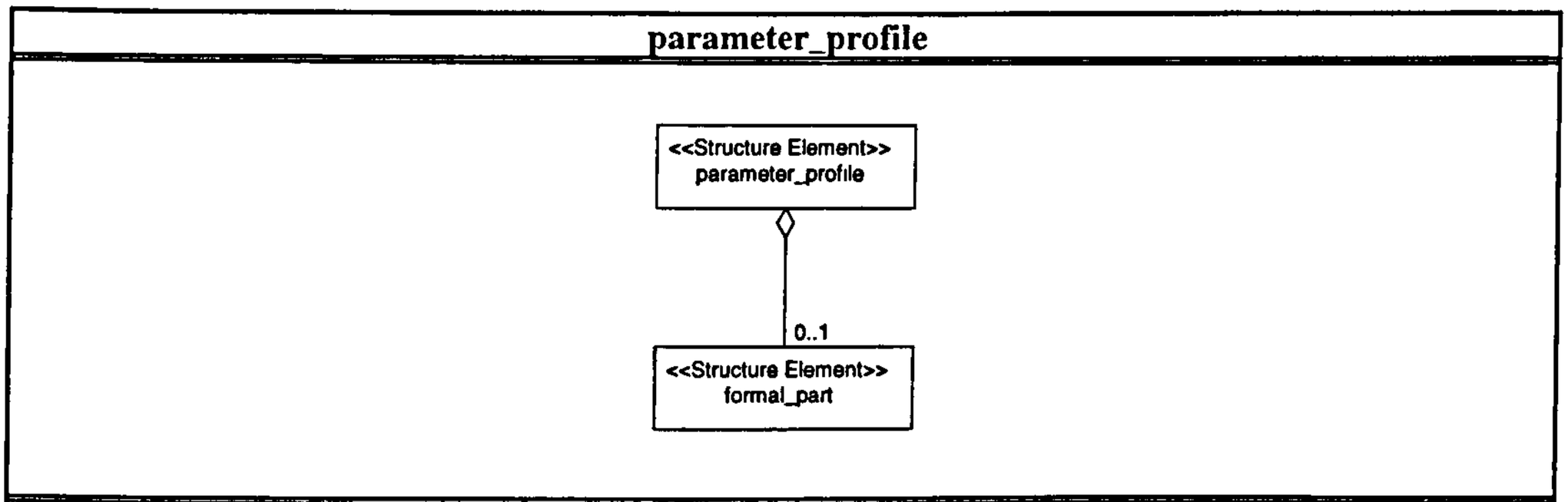
BNF Syntax	OCL	O-Telos (base classes)
* subprogram_declaration ::= procedure_specification ; procedure_annotation | function_specification ; function_ annotation	subprogram_declaration invariant self.allInstances->forall(s | (s.procedure_specification->size =1 and s.procedure_annotation->size = 1 and s.function_specification->isEmpty and s.function_annotation->isEmpty) xor (s.procedure_specification->isEmpty and s.procedure_annotation->isEmpty and s.function_specification->size = 1 and s.function_annotation->size =1)) *Constraint preserving the BNF alternatives syntax*	subprogram_declaration in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property semi_colon_token : semi_colon_token has_part procedure_specification: procedure_specification; procedure_annotation : procedure_annotation; function_specification : function_specification; function_annotation : function_annotation end

Figure 4.41 - 'subprogram_declaration schema'



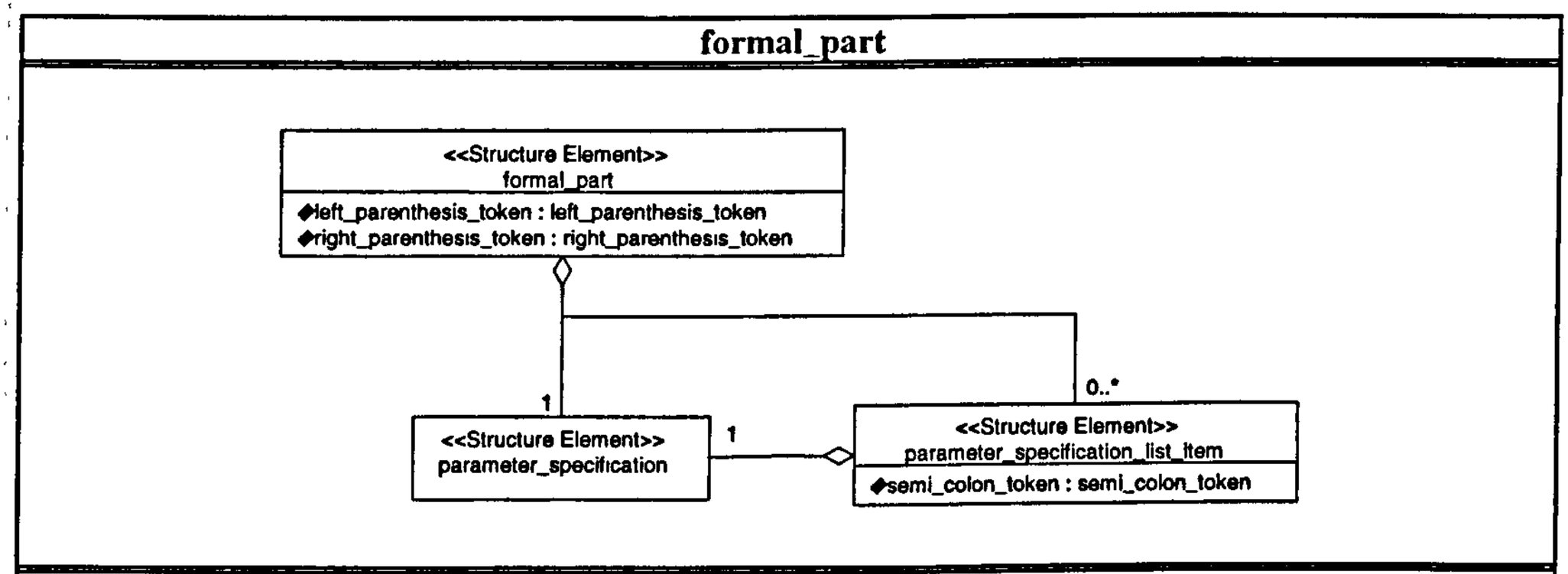
BNF Syntax	O-Telos
+ procedure_specification ::= **procedure** defining_identifier parameter_profile	procedure_specification in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property procedure_token : procedure_token has_part defining_identifier : defining_identifier; parameter_profile : parameter_profile end procedure_token in ArtifactProperty, SimpleClass isA String with constraint proc_Is_Proc: $ forall p/ procedure_token p = "procedure" $ end

Figure 4.42 - 'procedure_specification schema'



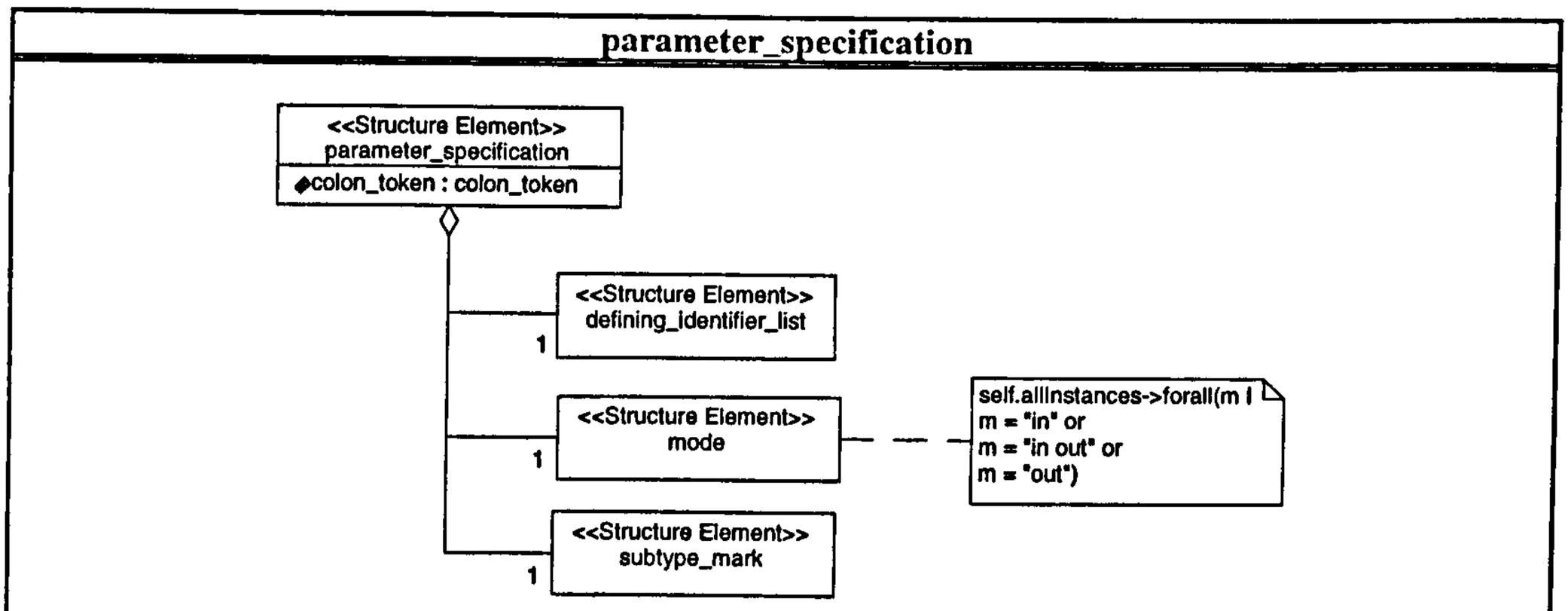
BNF Syntax	O-Telos
parameter_profile ::= [formal_part]	parameter_profile in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_part formal_part : formal_part end

Figure 4.43 - 'parameter_profile schema'



BNF Syntax	O-Telos
formal_part ::= (parameter_specification {; parameter_specification})	formal_part in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property left_parenthesis_token : left_parenthesis_token; right_parenthesis_token : right_parenthesis_token has_part parameter_specification : parameter_specification; parameter_specification_list_item : parameter_specification_list_item end parameter_specification_list_item in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property semi_colon_token : semi_colon_token has_part parameter_specification : parameter_specification end

Figure 4.44 - 'formal_part schema'



BNF Syntax	O-Telos
* parameter_specification ::= defining_identifier_list : mode subtype_mark mode ::= **in** | **in out** | **out** subtype_mark ::= name	parameter_specification in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property colon_token : colon_token has_part defining_identifier_list : defining_identifier_list; mode : mode; subtype_mark : subtype_mark end colon_token in ArtifactProperty, SimpleClass isA String with constraint colon_Is_Colon: $ forall c/colon_token c = ":" $ end mode in StructureElement, SimpleClass isA String, AerospaceEngineeringObject with constraint enum_Mode: $forall m/mode (m = "in") or (m = "in out") or (m = "out")$ end subtype_mark in StructureElement, SimpleClass isA String, AerospaceEngineeringObject end

Figure 4.45 - 'parameter_specification schema'

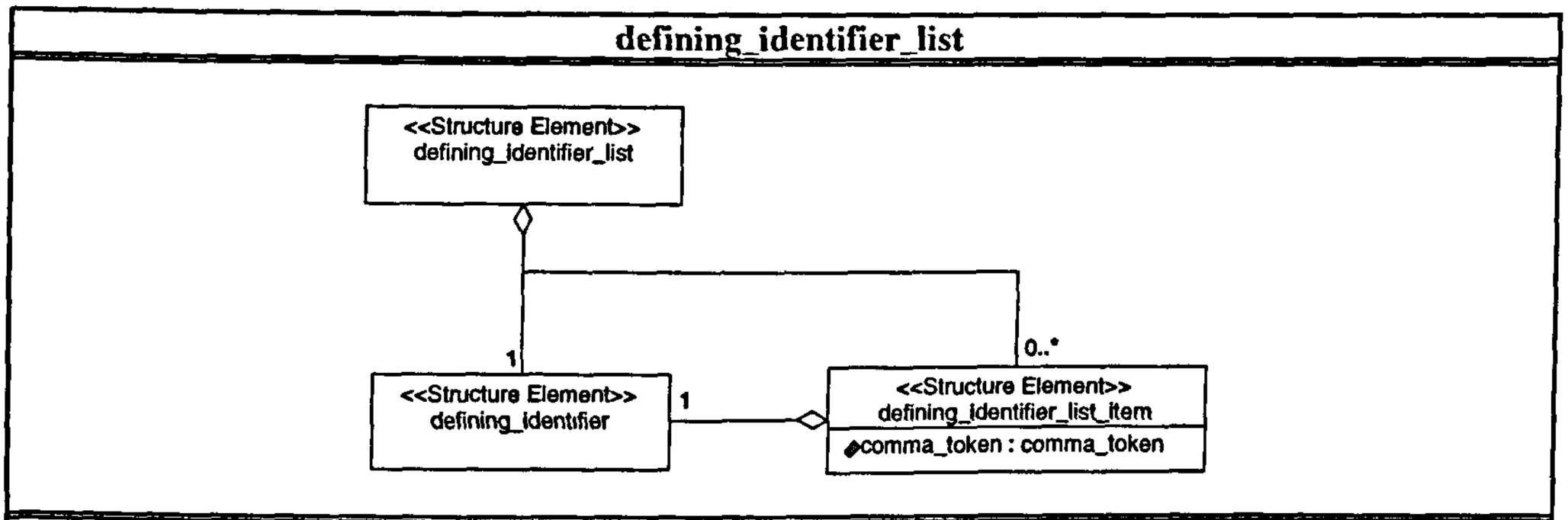
- **defining_identifier_list**

The defining_identifier_list (figure 4.46) consists of one or more comma-delimited defining identifiers (defining_identifier).

As per rule 9, the UML and O-Telos representations again employ an additional class - defining_identifier_list_item - to represent optional defining_identifier elements following the single mandatory instance.

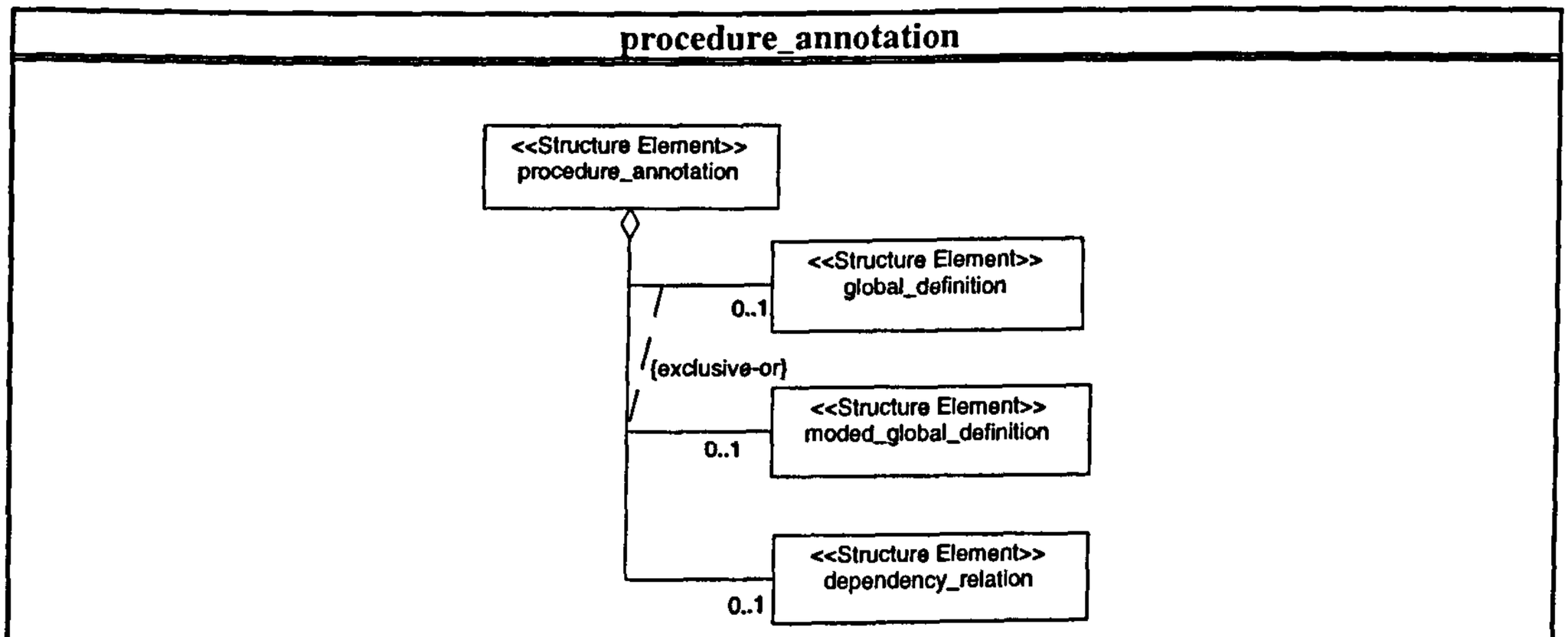
- **procedure_annotation**

A procedure_annotation features an optional global definition (global_definition) or moded global



BNF Syntax	O-Telos
defining_identifier_list ::= defining_identifier {, defining_identifier}	defining_identifier_list in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_part defining_identifier : defining_identifier; defining_identifier_list_item : defining_identifier_list_item end

Figure 4.46 - 'defining_identifier_list schema'



BNF Syntax	O-Telos
+ procedure_annotation ::= [global_definition | moded_global_definition] [dependency_relation]	procedure_annotation in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_part global_definition : global_definition; moded_global_definition : moded_global_definition; dependency_relation : dependency_relation end

Figure 4.47 - 'procedure_annotation schema'

definition (moded_global_definition), and an optional dependency relation (dependency_relation).

As per rule 8a, an exclusive-or annotation and dashed line connecting global_definition and moded_global_definition expresses the alternatives semantics for this element (figure 4.47).

- **moded_global_definition**

A moded_global_definition contains the '--# global' (global_token) reserved word annotation, together with global mode (global_mode) and entire variable list (entire_variable_list) elements, followed by a semi-colon. This sequence exists once, but can be repeated (--# global annotation apart).

Modelling this repetition in UML (and hence O-Telos) requires introduction of a moded_global_definition_list_item class (as per rule 9) comprising the elements described above.

The global_mode element is defined as a specialisation of the String class (as per rule 3), with an OCL constraint restricting its instantiation to the BNF alternatives shown in figure 4.48.

- **entire_variable_list**

An entire_variable_list (figure 4.49) consists of one or more comma-delimited entire variables (entire_variable).

Again, in accordance with rule 9, the UML and O-Telos representations introduce an additional class - entire_variable_list_item - to represent optional entire_variable elements following the single mandatory instance.

- **entire_variable**

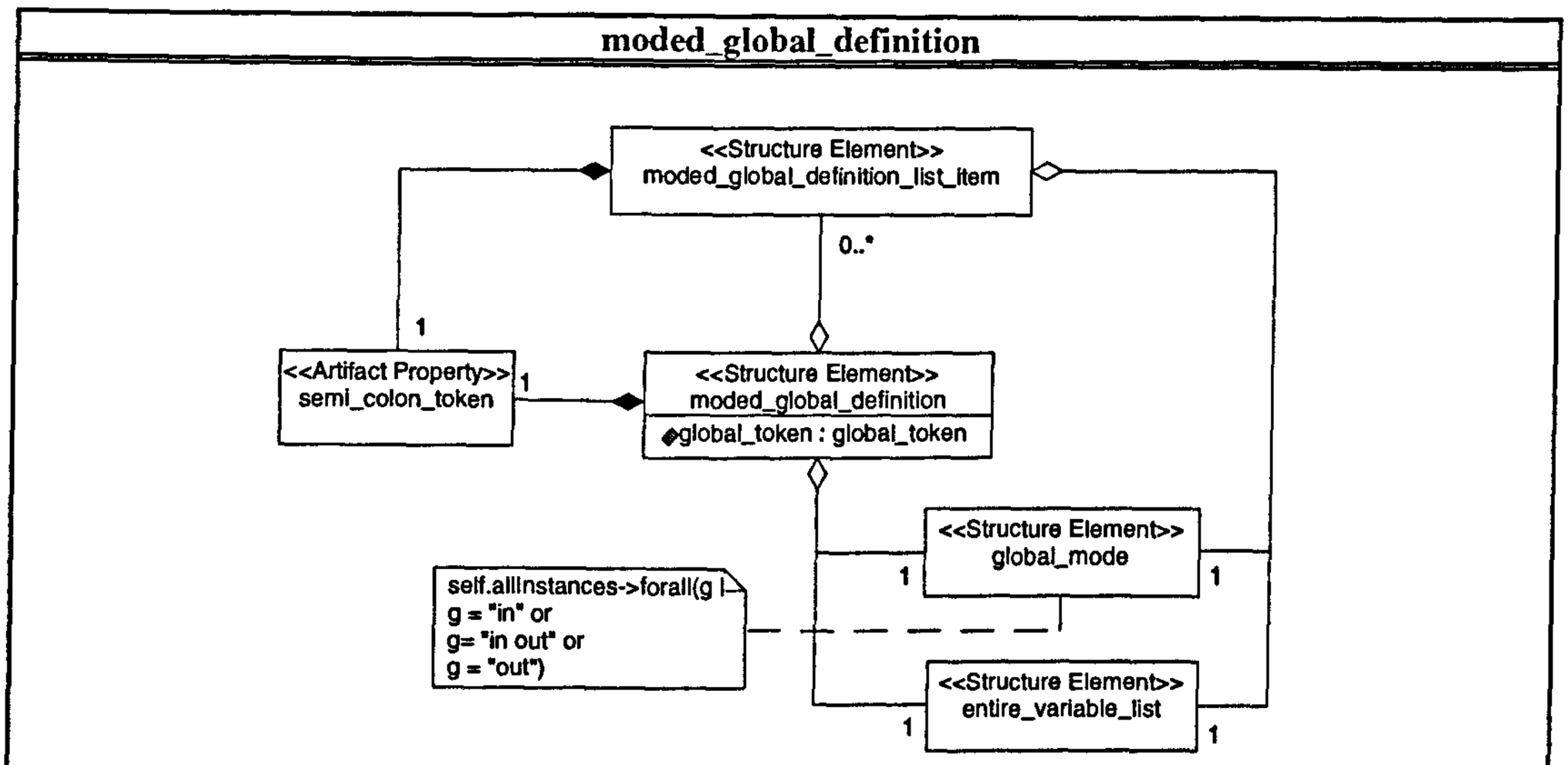
The entire_variable element (figure 4.50) consists of direct name (direct_name) and package_name elements, together with the period_token punctuation.

In accordance with rule 6b, period_token is promoted to a class allowing specification of optionality; again, the zero-or-one multiplicity imposed on this class and on package_name is supplemented by an OCL constraint to preserve the BNF optionality syntax such that both or neither of these elements exist. Note also that direct_name is treated as atomic (as per rule 3).

- **dependency_relation**

A dependency_relation comprises the '--# derives' (derives_token) reserved word annotation, together with zero or more ampersand-delimited dependency clause (dependency_clause) elements; the construct terminates with a semi-colon.

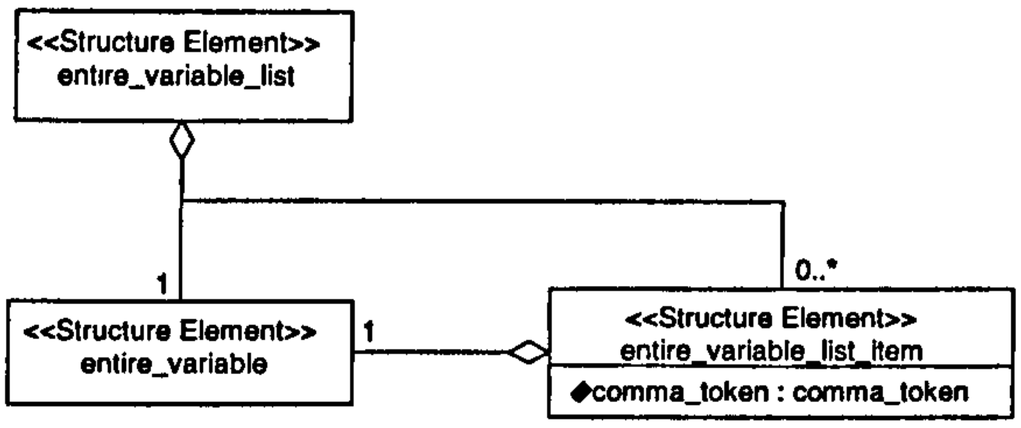
Once again, following rule 9, the UML and O-Telos representations introduce an additional class - dependency_clause_list_item - to represent dependency_clause elements following the initial instance. However, unlike similar list-base constructs making up the SPARK model (*cf.* own_variable_list,



BNF Syntax	O-Telos
+ moded_global_definition ::= --# **global** global_mode entire_variable_list; {global_mode entire_variable_list;} + global_mode ::= **in** | **in out** | **out**	moded_global_definition in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property global_token : global_token; semi_colon_token : semi_colon_token has_part global_mode : global_mode; entire_variable_list : entire_variable_list; moded_global_definition_list_item : moded_global_definition_list_item end global_token in ArtifactProperty, SimpleClass isA String with constraint global_Is_Global: $ forall g/global_token g = "--# global" $ end global_mode in StructureElement, SimpleClass isA String, AerospaceEngineeringObject with constraint enum_Global_Mode: forall g/global_mode (g = "in") or (g = "in out") or (g = "out")$ end moded_global_definition_list_item in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property semi_colon_token : semi_colon_token has_part global_mode : global_mode; entire_variable_list : entire_variable_list end

Figure 4.48 - 'moded_global_definition schema'

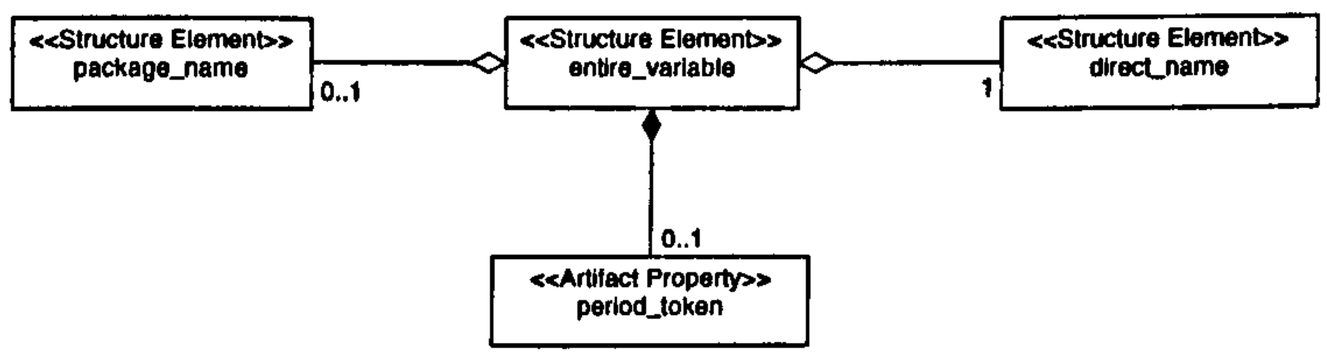
entire_variable_list



BNF Syntax	O-Telos
+ entire_variable_list ::= entire_variable {, entire_variable}	entire_variable_list in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_part entire_variable : entire_variable; entire_variable_list_item : entire_variable_list_item end entire_variable_list_item in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property comma_token : comma_token has_part entire_variable : entire_variable end

Figure 4.49 - 'entire_variable_list schema'

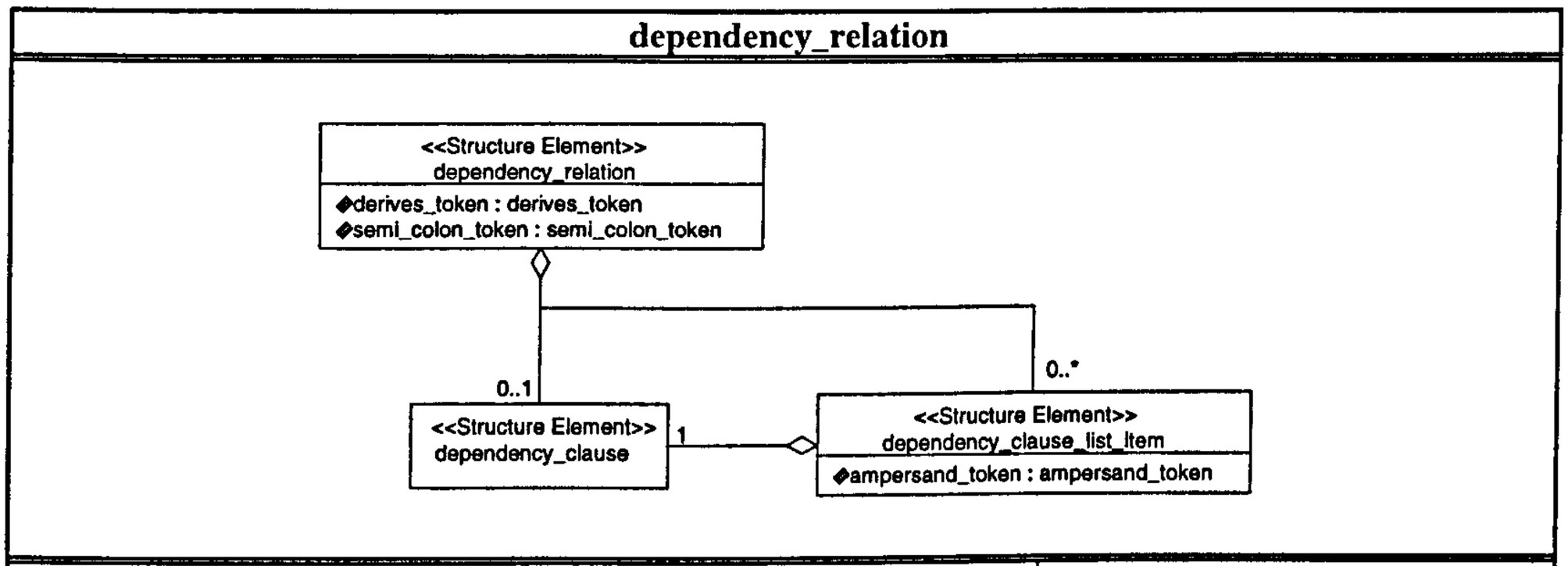
entire_variable



BNF Syntax	OCL	O-Telos (base classes)
+ entire_variable ::= [package_name .] direct_name direct_name ::= identifier	entire_variable Invariant self.allInstances->forall(i | (e.period_token->isEmpty and e.package_name->isEmpty) xor (e.period_token->notEmpty and e. package_name->notEmpty)) *Constraint preserving the BNF optionality syntax such that both period_token and package_name exist or neither exists*	entire_variable in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property period_token : period_token has_part package_name : package_name; direct_name : direct_name end direct_name in StructureElement, SimpleClass isA String, AerospaceEngineeringObject end

Figure 4.50 - 'entire_variable schema'

enumeration_type_definition), a dependency_relation list can be empty; we therefore specify an OCL constraint ensuring that if dependency_clause is empty, then dependency_clause_list_item is also empty. The dependency_relation schema appears in figure 4.51.



BNF Syntax

+ dependency_relation ::=
--# derives [dependency_clause {& dependency_clause}];

OCL

dependency_relation **invariant**
self.allInstances->forall(d |
not(d.dependency_clause->isEmpty and
d.dependency_clause_list_item->notEmpty))

Constraint preserving the BNF optionality syntax

O-Telos (base classes)

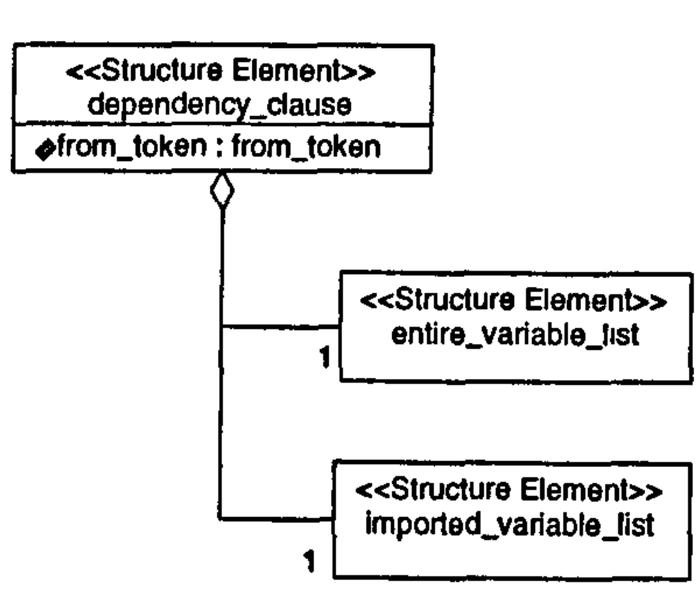
```
dependency_relation in
StructureElement,
SimpleClass isA
AerospaceEngineeringObject
with
has_property
    derives_token :
derives_token;
    semi_colon_token :
semi_colon_token
has_part
    dependency_clause :
dependency_clause;
    dependency_clause_list_
item :
dependency_clause_list_item
end

derives_token in
ArtifactProperty,
SimpleClass isA String
with
constraint
derives_Is_Derives:
    $ forall
d/derives_token d = "--#
derives" $
end

dependency_clause_list_item
in StructureElement,
SimpleClass isA
AerospaceEngineeringObject
with
has_property
    ampersand_token :
ampersand_token
has_part
    dependency_clause :
dependency_clause
end

ampersand_token in
ArtifactProperty,
SimpleClass isA String
with
constraint
ampersand_Is_Ampersand:
    $ forall
a/ampersand_token a = "&" $
end
```

Figure 4.51 - 'dependency_relation schema'

- **dependency_clause**

A dependency_clause is defined in terms of the 'from' (from_token) reserved word which separates entire_variable_list and imported variable list (imported_variable_list) elements. The schema for this construct is as follows (figure 4.52):-

dependency_clause



BNF Syntax

+ dependency_clause ::= entire_variable_list **from** imported_variable_list

O-Telos

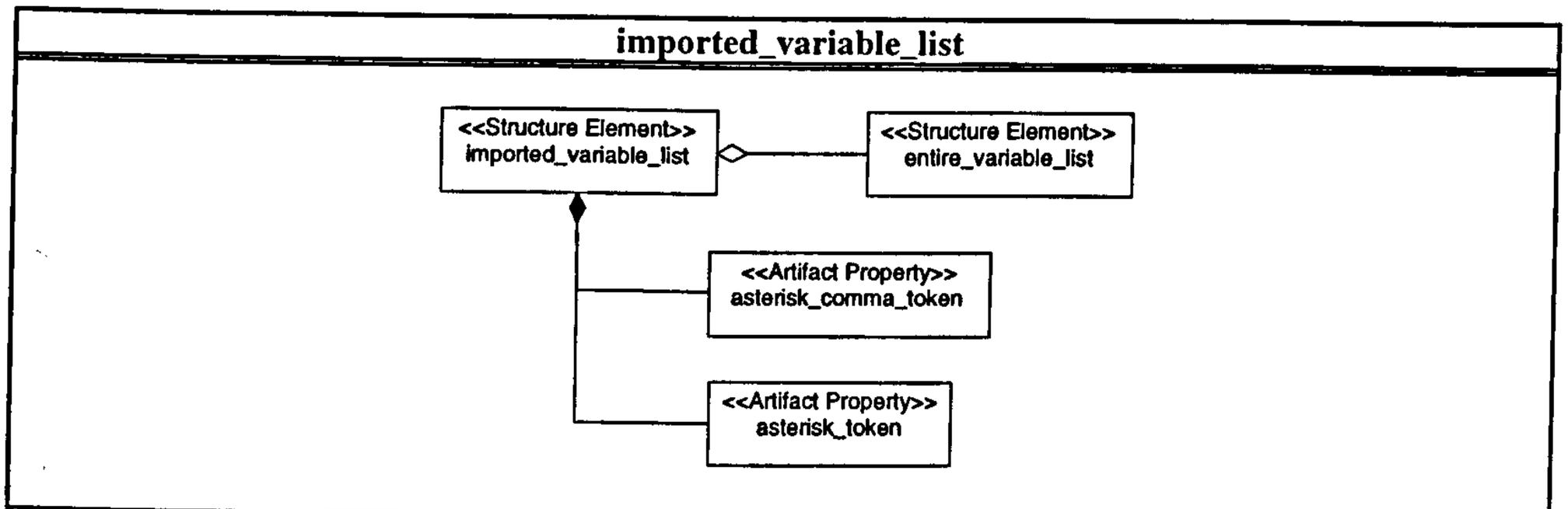
```
dependency_clause in StructureElement,
SimpleClass isA
AerospaceEngineeringObject
with
has_property
    from_token : from_token
has_part
    entire_variable_list :
entire_variable_list;
    imported_variable_list :
imported_variable_list
end

from_token token in ArtifactProperty,
SimpleClass isA String
with
constraint
from_Is_From:
    $ forall f/from_token
      f = "from" $
end
```

Figure 4.52 - 'dependency_clause schema'

- **imported_variable_list**

Finally, imported_variable_list contains either an optional asterisk '*' (asterisk_token), or an optional asterisk-comma '*,' (asterisk_comma_token) and an entire_variable_list element.

As per rule 6b, asterisk_token and asterisk_comma_token are promoted to classes allowing their optionality and exclusivity to be described. This is done using an OCL constraint (according to rule 8b), as the schema in figure 4.53 illustrates.



BNF Syntax	OCL	O-Telos (base classes)
+ imported_variable_list ::= [*] | [* ,] entire_variable_list	imported_variable_list invariant self.allInstances->forall(i | ((i.asterisk_token->isEmpty xor i.asterisk_token->size = 1) and i.asterisk_comma_token-> isEmpty and i.entire_variable_list-> isEmpty) xor (i.asterisk_token->isEmpty and (i.asterisk_comma_token->isEmpty xor i.asterisk_comma_token->size = 1) and i.entire_variable_list->size = 1)) *Constraint preserving the BNF optionality/alternatives syntax*	imported_variable_list in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property asterisk_token : asterisk_token; asterisk_comma_token : asterisk_comma_token has_part entire_variable_list : entire_variable_list end asterisk_token in ArtifactProperty, SimpleClass isA String with constraint asterisk_Is_Asterisk: $ forall a/asterisk_token a = "*" $ end asterisk_comma_token in ArtifactProperty, SimpleClass isA String with constraint asterisk_comma_Is_Asterisk_ Comma: $ forall a/asterisk_comma_token a = "* ," $ end

Figure 4.53 - 'imported_variable_list schema'

4.5.3.3 SPARK Ada Meta-model: Worked Examples

This subsection applies the SPARK Ada structure developed above to two program fragments (taken from the appendix to Barnes - 1997) from an autopilot system controlling altitude and heading for a hypothetical aircraft. The autopilot includes a control panel containing three binary-state switches with positions on and off. A package declaring access to the switches as a private child of the main autopilot package AP is specified as follows:-

```
private package AP.Controls
--# own Master_Switch, Altitude_Switch, Heading_Switch;
--# initializes Master_Switch, Altitude_Switch, Heading_Switch;
is
   type Switch is (On, Off);

   procedure Read_Master_Switch(Position: out Switch);
   --# global in out Master_Switch;
   --# derives Position, Master_Switch from Master_Switch;

   procedure Read_Altitude_Switch(Position: out Switch);
   --# global in out Altitude_Switch;
   --# derives Position, Altitude_Switch from Altitude_Switch;

   procedure Read_Heading_Switch(Position: out Switch);
   --# global in out Heading_Switch;
   --# derives Position, Heading_Switch from Heading_Switch;

end AP.Controls;
```

We now present the O-Telos representation for this code fragment[39]:-

Representation of the 'private' library_item clause

```
ap_controls_library_item in
library_item, Token with
private_token
    privateToken : "private"
package_declaration
    packageDeclaration :
ap_controls_package_declaration
end
```

Representation of the AP.Controls package

```
ap_controls_package_declaration in
package_declaration, Token with
package_specification
    packageSpecification :
ap_controls_package_specification
end

ap_controls_package_specification in
package_specification, Token with
package_token
    packageToken :  "package"
defining_program_unit_name
    definingProgramUnitName :
ap_controls_defining_program_unit_name
package_annotation
    packageAnnotation :
```

[39] We make the observation that while fifteen lines of SPARK has yielded five and a half pages of O-Telos code, there is a 1:1 mapping between the underlying BNF syntactic language elements and schemas for these syntactic elements.

```
ap_controls_package_annotation
is_token
    isToken : "is"
package_declarative_item
    packageDeclarativeItem1 :
type_package_declarative_item;
    packageDeclarativeItem2 :
proc1_package_declarative_item;
    packageDeclarativeItem3 :
proc2_package_declarative_item;
    packageDeclarativeItem4 :
proc3_package_declarative_item
end_token
    endToken : "end"
parent_unit_name
    parentUnitName : "AP"
period_token
    periodToken : "."
identifier :
    packageIdentifier : "Controls"
semi_colon_token
    semiColonToken : ";"
end
```

Representation of the AP.Controls package name

```
ap_controls_defining_program_unit_name
in defining_program_unit_name, Token
with
parent_unit_name
    parentUnitName : "AP"
period_token
    periodToken : "."
defining_identifier
    definingIdentifier: "Controls"
end
```

Representation of package annotations

```
ap_controls_package_annotation in
package_annotation, Token with
own_variable_clause
    ownVariableClause :
ap_controls_own_variable_clause
initialization_specification
    initializationSpecification :
ap_controls_initialization_specificatio
n
end
```

Representation of the '--# own' package annotation

```
ap_controls_own_variable_clause in
own_variable_clause, Token with
own_variable_token
    ownVariableToken : "--# own"
own_variable_list
    ownVariableList :
own_annotation_ap_controls_own_variable
_list
semi_colon_token
    semiColonToken : ";"
end

own_annotation_ap_controls_own_variable
_list in own_variable_list, Token with
own_variable
    ownVariable : "Master_Switch"
own_variable_list_item
    own_variable_list_item1 :
own_altitude_switch_own_variable_list_i
tem;
    own_variable_list_item2 :
own_heading_switch_own_variable_list_it
em
end

own_altitude_switch_own_variable_list_i
tem in own_variable_list_item, Token
with
comma_token
    commaToken : ","
own_variable
    ownVariable : "Altitude_Switch"
end

own_heading_switch_own_variable_list_it
em in own_variable_list_item, Token
with
comma_token
    commaToken : ","
own_variable
    ownVariable : "Heading_Switch"
end
```

Representation of the '--# initializes' package annotation

```
ap_controls_initialization_specificatio
n in initialization_specification,
Token with
initialization_token
    initializationToken : "--#
initializes"
own_variable_list
    ownVariableList :
initializes_annotation_ap_controls_own_
variable_list
semi_colon_token
    semiColonToken : ";"
end

initializes_annotation_ap_controls_own_
variable_list in own_variable_list,
Token with
own_variable
    ownVariable : "Master_Switch"
own_variable_list_item
    own_variable_list_item1 :
initializes_altitude_switch_own_variabl
e_list_item;
    own_variable_list_item2 :
initializes_heading_switch_own_variable
_list_item
end

initializes_altitude_switch_own_variabl
e_list_item in own_variable_list_item,
Token with
comma_token
    commaToken : ","
own_variable
    ownVariable : "Altitude_Switch"
end

initializes_heading_switch_own_variable
_list_item in own_variable_list_item,
Token with
comma_token
    commaToken : ","
own_variable
    ownVariable : "Heading_Switch"
end
```

Representation of the Switch type declaration

```
type_package_declarative_item in
package_declarative_item, Token with
basic_declarative_item
    basicDeclarativeItem :
switch_basic_declarative_item
end

switch_basic_declarative_item in
```

```
basic_declarative_item, Token with
basic_declaration
    basicDeclaration :
switch_basic_declaration
end

switch_basic_declaration in
basic_declaration, Token with
type_declaration
    typeDeclaration :
switch_type_declaration
end

switch_type_declaration in
type_declaration, Token with
full_type_declaration
    fullTypeDeclaration :
switch_full_type_declaration
end

switch_full_type_declaration in
full_type_declaration, Token with
type_token
    typeToken : "type"
defining_identifier
    definingIdentifier : "Switch"
is_token
    isToken : "is"
type_definition
    typeDefinition : switch_positions
semi_colon_token
    semiColonToken : ";"
end

switch_positions in type_definition,
Token with
enumeration_type_definition
    enumerationTypeDefinition :
enum_switch_positions
end

enum_switch_positions in
enumeration_type_definition, Token with
left_parenthesis
    leftParenthesis : "("
defining_identifier
    definingIdentifier : "On"
defining_identifier_list_item
    definingIdentifierListItem :
switch_defining_identifier_list_item
right_parenthesis
    rightParenthesis : ")"
end

switch_defining_identifier_list_item in
defining_identifier_list_item, Token
with
comma_token
    commaToken : ","
defining_identifier
    definingIdentifier : "Off"
end
```

Representation of the Read_Master_Switch procedure

```
proc1_package_declarative_item in
package_declarative_item, Token with
subprogram_declaration
    subprogramDeclaration:
read_master_switch_subprogram_declarati
on
end

read_master_switch_subprogram_declarati
on in subprogram_declaration, Token
with
procedure_specification
    procedureSpecification :
read_master_switch_procedure_specificat
ion
semi_colon_token
    semiColonToken : ";"
procedure_annotation
    procedureAnnotation :
read_master_switch_procedure_annotation
end

read_master_switch_procedure_specificat
ion in procedure_specification, Token
with
procedure_token
    procedureToken : "procedure"
defining_identifier
    definingIdentifier :
"Read_Master_Switch"
parameter_profile
    parameterProfile :
read_master_switch_parameter_profile
end

read_master_switch_parameter_profile in
parameter_profile, Token with
formal_part
    formalPart :
read_master_switch_formal_part
end

read_master_switch_formal_part in
formal_part, Token with
left_parenthesis_token
    leftParenthesisToken : "("
parameter_specification
    parameterSpecification :
read_master_switch_parameter_specificat
ion
right_parenthesis_token
    rightParenthesisToken : ")"
end

read_master_switch_parameter_specificat
ion in parameter_specification, Token
with
defining_identifier_list
    definingIdentifierList :
read_master_switch_defining_identifier_
list
colon_token
    colonToken : ":"
mode
    parameterMode : "out"
subtype_mark
    subtypeMark : "Switch"
end

read_master_switch_defining_identifier_
list in defining_identifier_list, Token
with
defining_identifier
    definingIdentifier : "Position"
end

read_master_switch_procedure_annotation
in procedure_annotation, Token with
moded_global_definition
    modedGlobalDefinition :
read_master_switch_moded_global_definit
ion
dependency_relation
    dependencyRelation :
read_master_switch_dependency_relation
end
```

Representation of Read_Master_Switch '--# global' procedure annotation

```
read_master_switch_moded_global_definit
ion in moded_global_definition, Token
with
```

```
global_token
    globalToken : "--# global"
global_mode
    globalMode : "in out"
entire_variable_list
    entireVariableList :
read_master_switch_entire_variable_list
semi_colon_token
    semiColonToken : ";"
end

read_master_switch_entire_variable_list
in entire_variable_list, Token with
entire_variable
    entireVariable :
master_switch_entire_variable
end

master_switch_entire_variable in
entire_variable, Token with
direct_name
    directName : "Master_Switch"
end
```

Representation of Read_Master_Switch '--# derives' procedure annotation

```
read_master_switch_dependency_relation
in dependency_relation, Token with
derives_token
    derivesToken : "--# derives"
dependency_clause
    dependencyClause :
read_master_switch_dependency_clause
semi_colon_token
    semiColonToken : ";"
end

read_master_switch_dependency_clause in
dependency_clause, Token with
entire_variable_list
    entireVariableList :
read_master_switch_dependency_entire_va
riable_list
from_token
    fromToken : "from"
imported_variable_list
    importedVariableList :
read_master_switch_dependency_imported_
variable_list
end

read_master_switch_dependency_entire_va
riable_list in entire_variable_list,
Token with
entire_variable
    entireVariable :
read_master_switch_dependency_position
entire_variable_list_item
    entireVariableListItem :
read_master_switch_dependency_master_sw
itch_list_item
end

read_master_switch_dependency_position
in entire_variable, Token with
direct_name
    directName : "Postion"
end

read_master_switch_dependency_master_sw
itch_list_item in
entire_variable_list_item, Token with
comma_token
    commaToken : ","
entire_variable
    entireVariable :
read_master_switch_dependency_master_sw
itch
end

read_master_switch_dependency_master_sw
itch in entire_variable, Token with
direct_name
    directName : "Master_Switch"
end

read_master_switch_dependency_imported_
variable_list in
imported_variable_list, Token with
entire_variable_list
    entireVariableList :
read_master_switch_dependency_entire_va
riable_list_imported
end

read_master_switch_dependency_entire_va
riable_list_imported in
entire_variable_list, Token with
entire_variable
    entireVariable :
read_master_switch_dependency_master_sw
itch_imported
end

read_master_switch_dependency_master_sw
itch_imported in entire_variable, Token
with
direct_name
    directName : "Master_Switch"
end
```

Representation of the Read_Altitude_Switch procedure

```
proc2_package_declarative_item in
package_declarative_item, Token with
subprogram_declaration
    subprogramDeclaration:
read_altitude_switch_subprogram_declara
tion
end

read_altitude_switch_subprogram_declara
tion in subprogram_declaration, Token
with
procedure_specification
    procedureSpecification :
read_altitude_switch_procedure_specific
ation
semi_colon_token
    semiColonToken : ";"
procedure_annotation
    procedureAnnotation :
read_altitude_switch_procedure_annotati
on
end

read_altitude_switch_procedure_specific
ation in procedure_specification, Token
with
procedure_token
    procedureToken : "procedure"
defining_identifier
    definingIdentifier :
"Read_Altitude_Switch"
parameter_profile
    parameterProfile :
read_altitude_switch_parameter_profile
end

read_altitude_switch_parameter_profile
in parameter_profile, Token with
formal_part
    formalPart :
read_altitude_switch_formal_part
end

read_altitude_switch_formal_part in
formal_part, Token with
```

```
left_parenthesis_token
    leftParenthesisToken : "("
parameter_specification
    parameterSpecification :
read_altitude_switch_parameter_specific
ation
right_parenthesis_token
    rightParenthesisToken : ")"
end

read_altitude_switch_parameter_specific
ation in parameter_specification, Token
with
defining_identifier_list
    definingIdentifierList :
read_altitude_switch_defining_identifie
r_list
colon_token
    colonToken : ":"
mode
    parameterMode : "out"
subtype_mark
    subtypeMark : "Switch"
end

read_altitude_switch_defining_identifie
r_list in defining_identifier_list,
Token with
defining_identifier
    definingIdentifier : "Position"
end

read_altitude_switch_procedure_annotati
on in procedure_annotation, Token with
moded_global_definition
    modedGlobalDefinition :
read_altitude_switch_moded_global_defin
ition
dependency_relation
    dependencyRelation :
read_altitude_switch_dependency_relatio
n
end
```

Representation of Read_Altitude_Switch '--# global' procedure annotation

```
read_altitude_switch_moded_global_defin
ition in moded_global_definition, Token
with
global_token
    globalToken : "--# global"
global_mode
    globalMode : "in out"
entire_variable_list
    entireVariableList :
read_altitude_switch_entire_variable_li
st
semi_colon_token
    semiColonToken : ";"
end

read_altitude_switch_entire_variable_li
st in entire_variable_list, Token with
entire_variable
    entireVariable :
altitude_switch_entire_variable
end

altitude_switch_entire_variable in
entire_variable, Token with
direct_name
    directName : "Altitude_Switch"
end
```

Representation of Read_Altitude_Switch '--# derives' procedure annotation

```
read_altitude_switch_dependency_relatio
n in dependency_relation, Token with
derives_token
    derivesToken : "--# derives"
dependency_clause
    dependencyClause :
read_altitude_switch_dependency_clause
semi_colon_token
    semiColonToken : ";"
end

read_altitude_switch_dependency_clause
in dependency_clause, Token with
entire_variable_list
    entireVariableList :
read_altitude_switch_dependency_entire_
variable_list
from_token
    fromToken : "from"
imported_variable_list
    importedVariableList :
read_altitude_switch_dependency_importe
d_variable_list
end

read_altitude_switch_dependency_entire_
variable_list in entire_variable_list,
Token with
entire_variable
    entireVariable :
read_altitude_switch_dependency_positio
n
entire_variable_list_item
    entireVariableListItem :
read_altitude_switch_dependency_altitud
e_switch_list_item
end

read_altitude_switch_dependency_positio
n in entire_variable, Token with
direct_name
    directName : "Postion"
end

read_altitude_switch_dependency_altitud
e_switch_list_item in
entire_variable_list_item, Token with
comma_token
    commaToken : ","
entire_variable
    entireVariable :
read_altitude_switch_dependency_altitud
e_switch
end

read_altitude_switch_dependency_altitud
e_switch in entire_variable, Token with
direct_name
    directName : "Altitude_Switch"
end

read_altitude_switch_dependency_importe
d_variable_list in
imported_variable_list, Token with
entire_variable_list
    entireVariableList :
read_altitude_switch_dependency_entire_
variable_list_imported
end

read_altitude_switch_dependency_entire_
variable_list_imported in
entire_variable_list, Token with
entire_variable
    entireVariable :
read_altitude_switch_dependency_altitud
e_switch_imported
end

read_altitude_switch_dependency_altitud
e_switch_imported in entire_variable,
Token with
```

```
direct_name
    directName : "Altitude_Switch"
end
```

Representation of the Read_Heading_Switch procedure

```
proc3_package_declarative_item in
package_declarative_item, Token with
subprogram_declaration
    subprogramDeclaration:
read_heading_switch_subprogram_declarat
ion
end

read_heading_switch_subprogram_declarat
ion in subprogram_declaration, Token
with
procedure_specification
    procedureSpecification :
read_heading_switch_procedure_specifica
tion
semi_colon_token
    semiColonToken : ";"
procedure_annotation
    procedureAnnotation :
read_heading_switch_procedure_annotatio
n
end

read_heading_switch_procedure_specifica
tion in procedure_specification, Token
with
procedure_token
    procedureToken : "procedure"
defining_identifier
    definingIdentifier :
"Read_Heading_Switch"
parameter_profile
    parameterProfile :
read_heading_switch_parameter_profile
end

read_heading_switch_parameter_profile
in parameter_profile, Token with
formal_part
    formalPart :
read_heading_switch_formal_part
end

read_heading_switch_formal_part in
formal_part, Token with
left_parenthesis_token
    leftParenthesisToken : "("
parameter_specification
    parameterSpecification :
read_heading_switch_parameter_specifica
tion
right_parenthesis_token
    rightParenthesisToken : ")"
end

read_heading_switch_parameter_specifica
tion in parameter_specification, Token
with
defining_identifier_list
    definingIdentifierList :
read_heading_switch_defining_identifier
_list
colon_token
    colonToken : ":"
mode
    parameterMode : "out"
subtype_mark
    subtypeMark : "Switch"
end

read_heading_switch_defining_identifier
_list in defining_identifier_list,
Token with
defining_identifier
    definingIdentifier : "Position"
end

read_heading_switch_procedure_annotatio
n in procedure_annotation, Token with
moded_global_definition
    modedGlobalDefinition :
read_heading_switch_moded_global_defini
tion
dependency_relation
    dependencyRelation :
read_heading_switch_dependency_relation
end
```

Representation of Read_Heading_Switch '--# global' procedure annotation

```
read_heading_switch_moded_global_defini
tion in moded_global_definition, Token
with
global_token
    globalToken : "--# global"
global_mode
    globalMode : "in out"
entire_variable_list
    entireVariableList :
read_heading_switch_entire_variable_lis
t
semi_colon_token
    semiColonToken : ";"
end

read_heading_switch_entire_variable_lis
t in entire_variable_list, Token with
entire_variable
    entireVariable :
heading_switch_entire_variable
end

heading_switch_entire_variable in
entire_variable, Token with
direct_name
    directName : "Heading_Switch"
end
```

Representation of Read_Heading_Switch '--# derives' procedure annotation

```
read_heading_switch_dependency_relation
in dependency_relation, Token with
derives_token
    derivesToken : "--# derives"
dependency_clause
    dependencyClause :
read_heading_switch_dependency_clause
semi_colon_token
    semiColonToken : ";"
end

read_heading_switch_dependency_clause
in dependency_clause, Token with
entire_variable_list
    entireVariableList :
read_heading_switch_dependency_entire_v
ariable_list
from_token
    fromToken : "from"
imported_variable_list
    importedVariableList :
read_heading_switch_dependency_imported
_variable_list
end

read_heading_switch_dependency_entire_v
ariable_list in entire_variable_list,
Token with
entire_variable
    entireVariable :
```

```
read_heading_switch_dependency_position
entire_variable_list_item
    entireVariableListItem :
read_heading_switch_dependency_heading_
switch_list_item
end

read_heading_switch_dependency_position
in entire_variable, Token with
direct_name
    directName : "Position"
end

read_heading_switch_dependency_heading_
switch_list_item in
entire_variable_list_item, Token with
comma_token
    commaToken : ","
entire_variable
    entireVariable :
read_heading_switch_dependency_heading_
switch
end

read_heading_switch_dependency_heading_
switch in entire_variable, Token with
direct_name
    directName : "Heading_Switch"
end

read_heading_switch_dependency_imported
_variable_list in
imported_variable_list, Token with
entire_variable_list
    entireVariableList :
read_heading_switch_dependency_entire_v
ariable_list_imported
end

read_heading_switch_dependency_entire_v
ariable_list_imported in
entire_variable_list, Token with
entire_variable
    entireVariable :
read_heading_switch_dependency_heading_
switch_imported
end

read_heading_switch_dependency_heading_
switch_imported in entire_variable,
Token with
direct_name
    directName : "Heading_Switch"
end
```

Our second code fragment (taken from the same example) represents the autopilot package itself which features a procedure called Control. This is specified as follows (note abbreviation of the global annotation):-

```
--# inherit Surfaces, Instruments;
package AP
--# own State;
--# initializes State;
is
   procedure Control;
   --# global in out State, Surfaces.Elevators, Surfaces.Ailerons ...
end AP;
```

We now consider the O-Telos representation for this code:-

Representation of the AP package

```
ap_package_declaration in
package_declaration, Token with
package_specification
    packageSpecification :
ap_package_specification
end

ap_package_specification in
package_specification, Token with
inherit_clause
    inheritClause: ap_inherit_clause
package_token
    packageToken :  "package"
defining_program_unit_name
    definingProgramUnitName :
ap_defining_program_unit_name
package_annotation
    packageAnnotation :
ap_package_annotation
is_token
    isToken : "is"
package_declarative_item
    packageDeclarativeItem1 :
ap_proc1_package_declarative_item
end_token
    endToken : "end"
identifier :
    packageIdentifier : "AP"
semi_colon_token
    semiColonToken : ";"
end
```

Representation of the '--# inherit' AP package annotation

```
ap_inherit_clause in inherit_clause,
Token with
inherit_token
    inheritToken : "--# inherit"
package_name
```

```
    packageName : "Surfaces"
package_name_list_item
    packageNameListItem :
instruments_package_name_list_item
semi_colon_token  :
    semiColonToken ";"
end

instruments_package_name_list_item in
package_name_list_item, Token with
comma_token
    commaToken ","
package_name
    packageName : "Instruments"
end
```

Representation of the AP package name

```
ap_defining_program_unit_name in
defining_program_unit_name, Token with
defining_identifier
    definingIdentifier : "AP"
end
```

Representation of package annotations

```
ap_package_annotation in
package_annotation, Token with
own_variable_clause
    ownVariableClause :
ap_own_variable_clause
initialization_specification
    initializationSpecification :
ap_initialization_specification
end
```

Representation of the '--# own' package annotation

```
ap_own_variable_clause in
own_variable_clause, Token with
own_variable_token
    ownVariableToken : "--# own"
own_variable_list
    ownVariableList :
own_annotation_ap_own_variable_list
semi_colon_token
    semiColonToken : ";"
end

own_annotation_ap_own_variable_list in
own_variable_list, Token with
own_variable
    ownVariable : "State"
end
```

Representation of the '--# initializes' package annotation

```
ap_initialization_specification in
initialization_specification, Token
with
initialization_token
    initializationToken : "--#
initializes"
own_variable_list
    ownVariableList :
initializes_annotation_ap_own_variable_
list
semi_colon_token
    semiColonToken : ";"
end

initializes_annotation_ap_own_variable_
list in own_variable_list, Token with
own_variable
    ownVariable : "State"
end
```

Representation of the Control procedure

```
ap_proc1_package_declarative_item in
package_declarative_item, Token with
subprogram_declaration
    subprogramDeclaration:
control_subprogram_declaration
end

control_subprogram_declaration in
subprogram_declaration, Token with
procedure_specification
    procedureSpecification :
control_procedure_specification
semi_colon_token
    semiColonToken : ";"
procedure_annotation
    procedureAnnotation :
control_procedure_annotation
end

control_procedure_specification in
procedure_specification, Token with
procedure_token
    procedureToken : "procedure"
defining_identifier
    definingIdentifier : "Control"
end
```

Representation of Control '--# global' procedure annotation

```
control_procedure_annotation in
procedure_annotation, Token with
moded_global_definition
    modedGlobalDefinition :
control_moded_global_definition
end

control_moded_global_definition in
moded_global_definition, Token with
global_token
    globalToken : "--# global"
global_mode
    globalMode : "in out"
entire_variable_list
    entireVariableList :
control_entire_variable_list
semi_colon_token
    semiColonToken : ";"
end

control_entire_variable_list in
entire_variable_list, Token with
entire_variable
    entireVariable :
state_entire_variable
entire_variable_list_item
    entireVariableListItem1:
surfaces_elevators_entire_variable_list
_item;
    entireVariableListItem2:
surfaces_ailerons_entire_variable_list_
item
end

state_entire_variable in
entire_variable, Token with
direct_name
    directName : "State"
end

surfaces_elevators_entire_variable_list
_item in entire_variable_list_item,
Token with
comma_token
    commaToken : ","
```

```
entire_variable
    entireVariable :
surfaces_elevators_entire_variable
end

surfaces_elevators_entire_variable in
entire_variable, Token with
package_name
    packageName : "Surfaces"
period_token
    periodToken : "."
direct_name
    directName : "Elevators"
end

surfaces_ailerons_entire_variable_list_
item in entire_variable_list_item,
Token with
comma_token
    commaToken : ","
entire_variable
    entireVariable :
surfaces_ailerons_entire_variable
end

surfaces_ailerons_entire_variable in
entire_variable, Token with
package_name
    packageName : "Surfaces"
period_token
    periodToken : "."
direct_name
    directName : "Ailerons"
end
```

4.5.4 Application to RTN-SL Textual Specifications

To demonstrate versatility of the modelling philosophy introduced in subsection 4.5.3.1.1 (and used to develop the SPARK structure in 4.5.3.2), we now employ it to follow option two for constructing meta-models in MATrA (subsection 4.4.3) for a subset of RTN-SL (Paynter, 2000). A comparison of models yielded by both approaches appears in 4.5.4.4.

4.5.4.1 Towards An RTN-SL (Textual) Structure

RTN-SL is a textual notation for the specification of flat Real-Time Networks; the graphical RTN-SLg notation described in section 4.4 provides a subset of features contained in this language and is therefore mainly an aid to comprehension. We note that RTN-SL is the subject of ongoing research within MBDA (UK) and hence the syntax is subject to revision (although RTN-SLg is altogether more stable). We also reiterate that our purpose here is purely to provide a 'flavour' of how another textual language with a formal foundation may be represented using the approach set out above and not to discuss features of RTN-SL in depth. Interested readers are instead referred to Paynter (2000).

The RTN-SL subset of interest in this thesis is the set of constructs that enable specification of ports; recall from section 4.4 that ports provide the interface between activities (single-threaded processes) within a Real-Time Network. The syntax is as follows:-

```
ports
  port_id_list : (protocol, data_type, direction);
end ports
```

For each list of port names *or* identifiers, a three tuple describing the interface to these ports is defined. Specifically, the protocol on paths connected to these ports, a type of data communicable through that protocol and the direction of data-flow (in or out) along its path.

4.5.4.2 Meta-model Definitions

This section introduces schemas towards a partial RTN-SL meta-model. Again the BNF syntax, UML meta-model and O-Telos implementation of base classes are all considered, together with any OCL

structural constraints arising from modelling decisions. We begin by describing the activity element in order to place our schemas for ports in context.

- **activity**

An activity (figure 4.54) is described in terms of its name (followed by the reserved word is) and a list of imported ADTs (with_list), together with declarations of the ports, auxiliary definitions (auxiliary_definitions), local state (local_state), operations and state machine (state_machine) elements; with_list, auxilliary_definitions and local_state are optional. All elements are framed between activity and end activity reserved words; the construct terminates with a semi-colon.

- **ports**

The ports statement (figure 4.55) contains a port definitions (port_defs) element, framed between ports and end ports reserved words; again this contruct terminates with a semi-colon.

- **port_defs**

Port definitions (port_defs) is defined in terms of one or more port definition (port_def) statements. This is shown in figure 4.56.

- **port_def**

Each port_def (figure 4.57) is made up of a port id_list and a description of the port type (port_type) applicable to these ports (the two are spearated by a colon character); this construct also terminates with a semi-colon.

- **id_list**

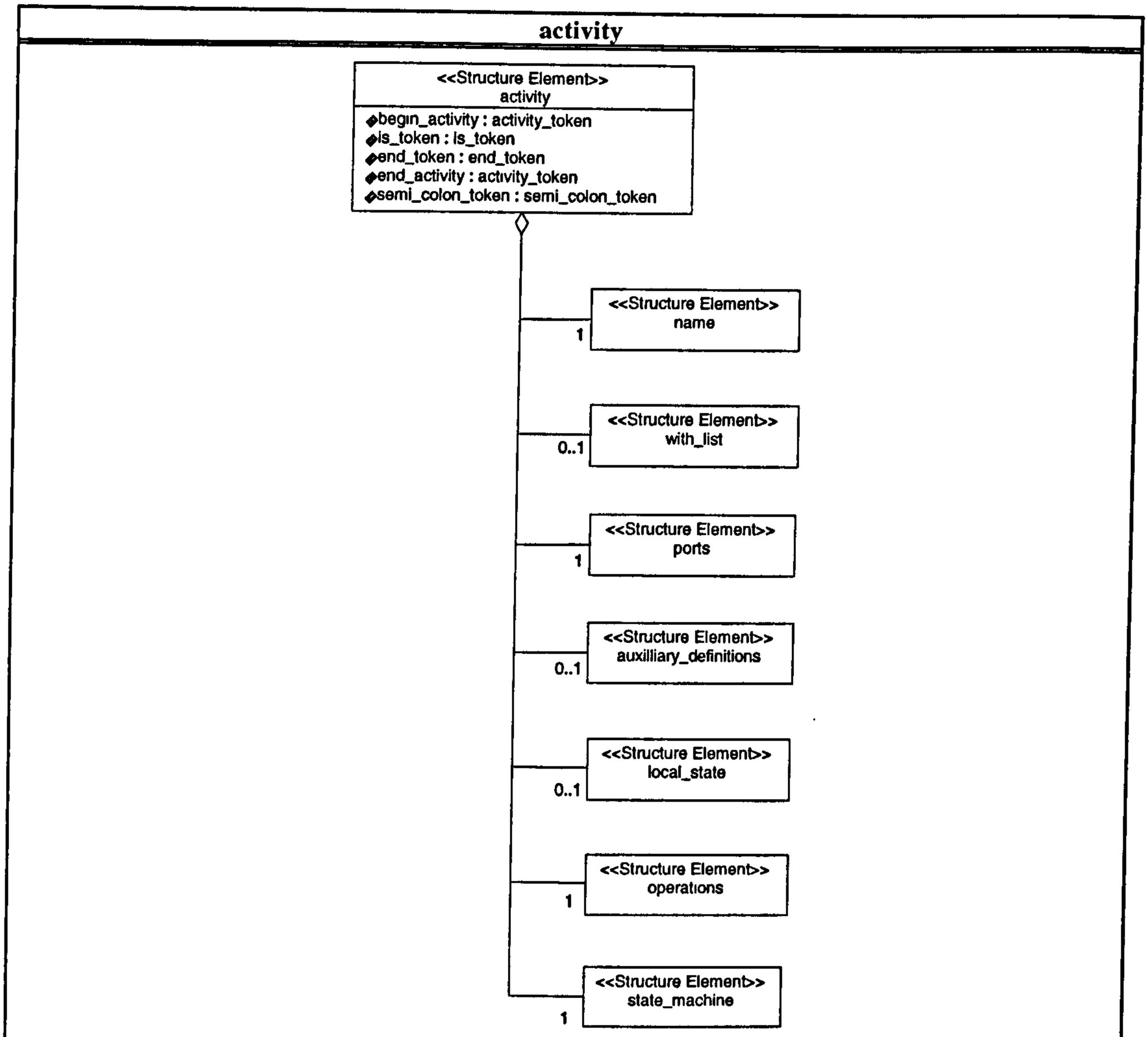
As its name suggests, the id_list (figure 4.58) contains one or more port identifiers (names) as a comma-delimitted list.

- **port_type**

This element defines the interface to ports named in the id_list which, as previously described, contains their communication protocol (signal, pool, channel, dataless-channel or stimulus), data type (a_type_ref) and a reserved word - in or out -indicating direction of data flow along the path connected; port_type is enclosed in parentheses and shown in figure 4.59.

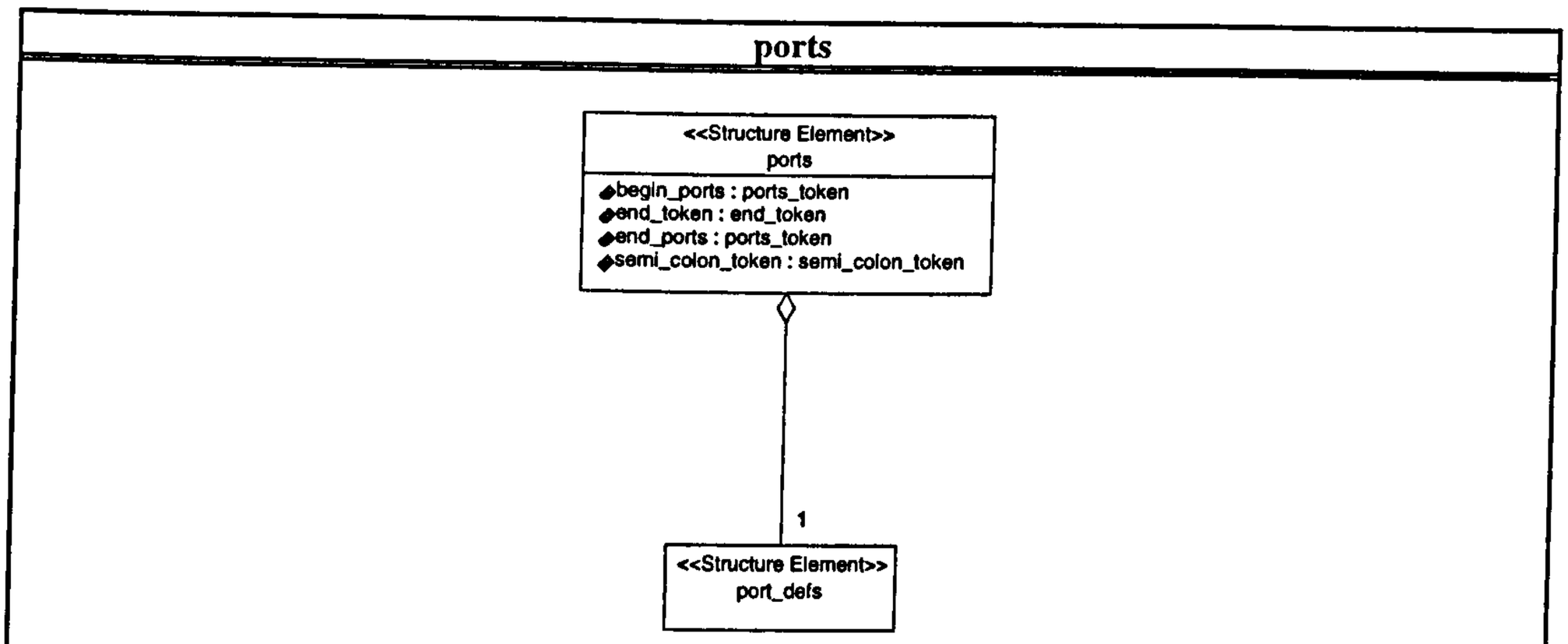
- **a_type_ref**

From figure 4.60 it can be seen that a data type (a_type_ref) is defined either as a built-in *or* basic type (basic_type) type such as bool, integer, character, etc., or else using the name of an Abstract Data Type (ADT). As indicated in section 4.4, ADTs may be used in a hierarchical manner, in which case it is necessary to prefix imported ADTs with the name of the ADT in which they are defined; the two are separated by a period token. This is modelled by introducing rolenames for ADT and parent (adt_name and parent_name respectively) to differentiate references to the name class (*cf.* the BNF representation).



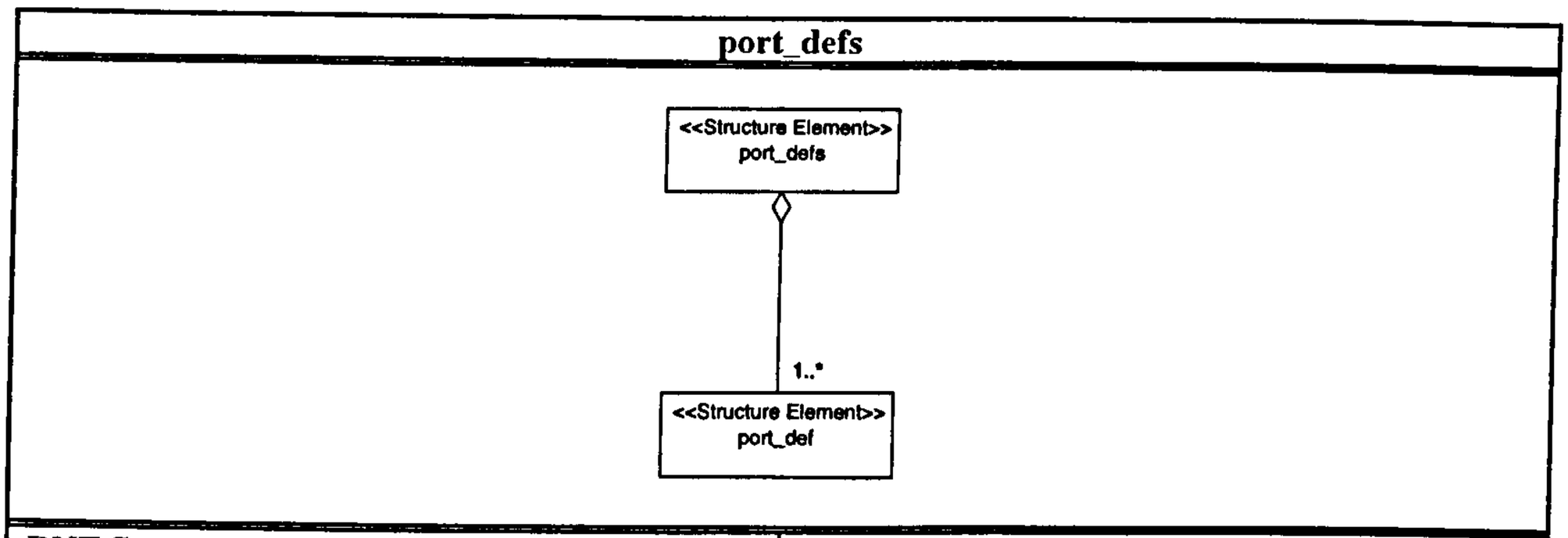
BNF Syntax	O-Telos
activity ::= **activity** name **is** [with_list] ports [auxillary_definitions] [local_state] operations state_machine **end** **activity;**	activity in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property begin_activity : activity_token; is_token : is_token; end_token : end _token; end_activity : activity_token; semi_colon_token : semi_colon_token has_part name : name; with_list : with_list; ports : ports; auxilliary_definitions : auxilliary_definitions; local_state : local_state; operations : operations; state_machine : state_machine end name in StuctureElement, SimpleClass isA String, AerospaceEngineeringObject end activity_token in ArtifactProperty, SimpleClass isA String with constraint activity_Is_Activity: $ forall a/activity_token a = "activity" $ end

Figure 4.54 - 'activity schema'



BNF Syntax	O-Telos
ports ::= **ports** port_defs **end ports** ;	ports in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property begin_ports : ports_token; end_token : end _token; end_ports : ports_token; semi_colon_token : semi_colon_token has_part port_defs : port_defs end ports_token in ArtifactProperty, SimpleClass isA String with constraint ports_Is_Ports: $ forall p/ports_token p = "ports" $ end

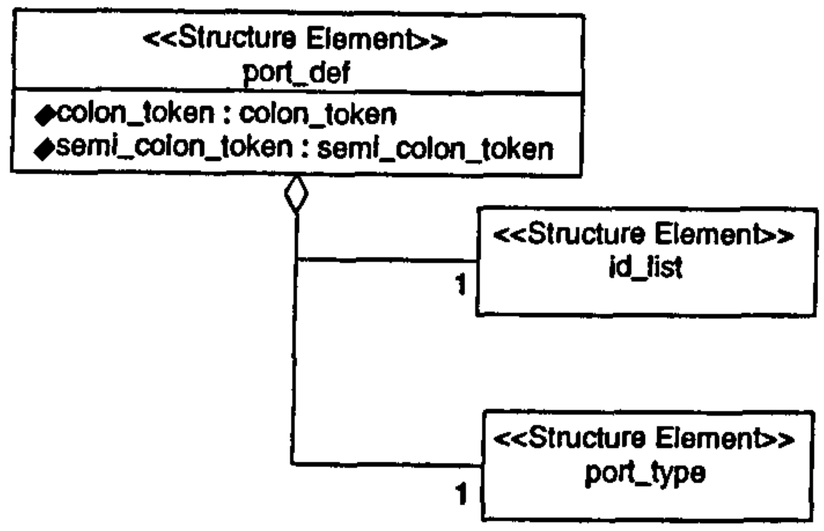
Figure 4.55 - 'ports schema'



BNF Syntax	O-Telos
port_defs ::= port_def {port_def}	port_defs in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_part port_def : port_def end

Figure 4.56 - 'port_defs schema'

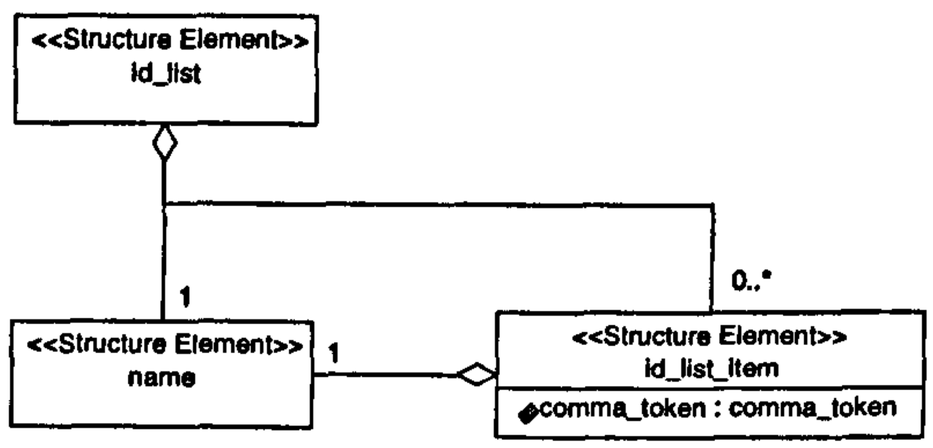
port_def



BNF Syntax	O-Telos
port_def ::= id_list : port_type ;	port_def in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property colon_token : colon_token; semi_colon_token : semi_colon_token has_part id_list : id_list; port_type : port_type end

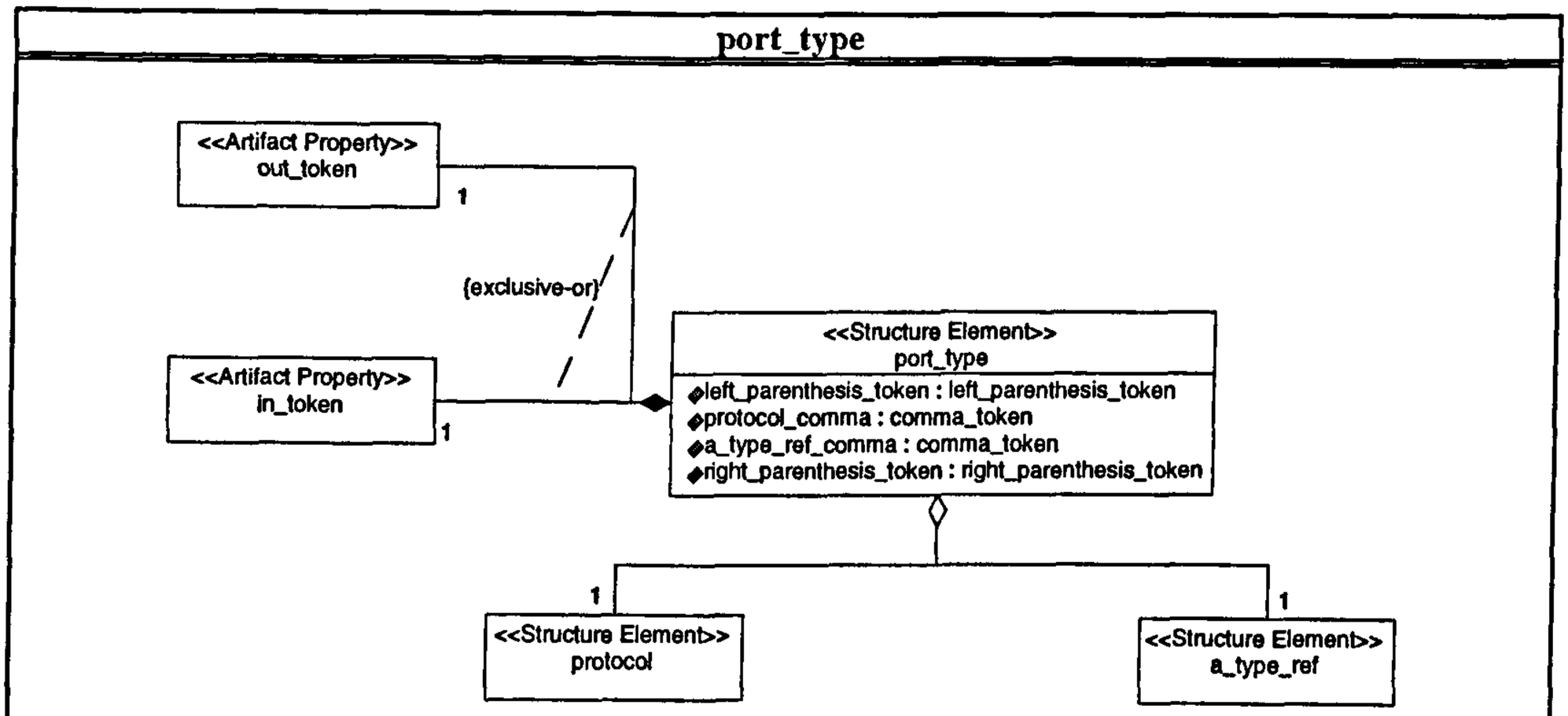
Figure 4.57 - 'port_def schema'

id_list



BNF Syntax	O-Telos
id_list ::= name {, name}	id_list in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_part name : name; id_list_item : id_list_item end id_list_item in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property comma_token : comma_token has_part name : name end

Figure 4.58 - 'id_list schema'



BNF Syntax

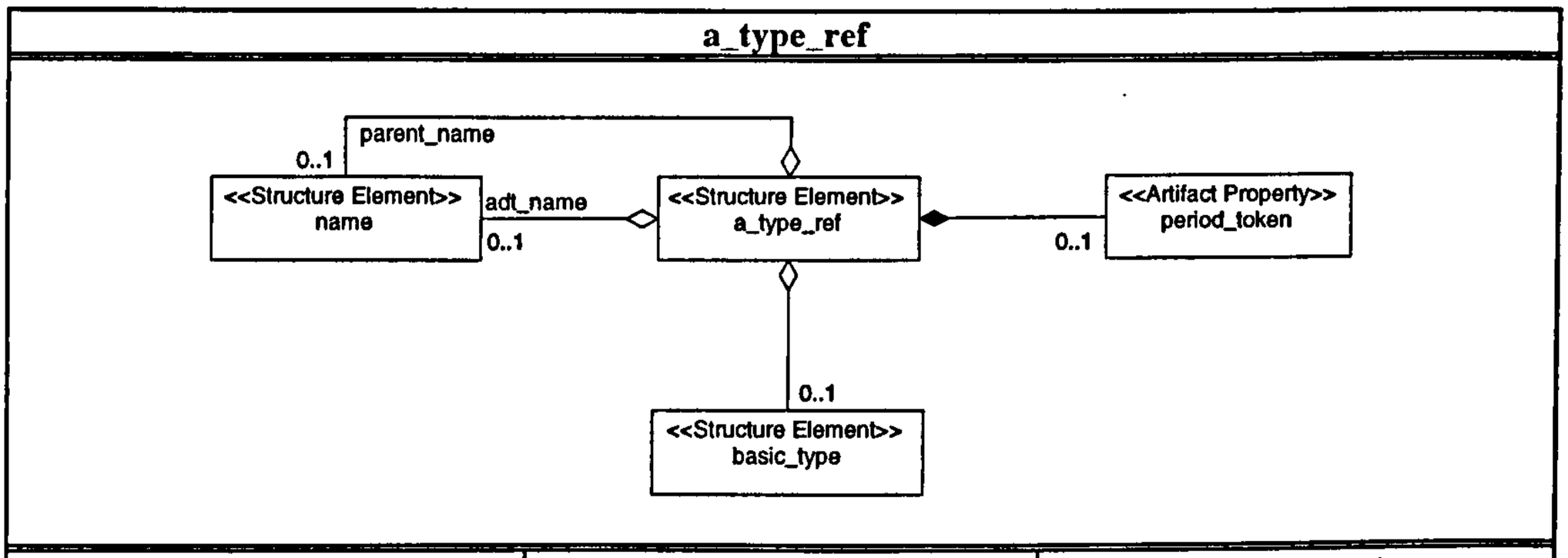
port_type ::= (protocol , a_type_ref , in) |
(protocol , a_type_ref , out)

protocol ::= pool | channel | signal | stimulus |
dataless_channel

O-Telos

```
port_type in StructureElement, SimpleClass
isA AerospaceEngineeringObject
with
has_property
    left_parenthesis_token :
left_parenthesis_token;
    protocol_comma : comma_token;
    a_type_ref_comma : comma_token;
    in_token : in_token;
    out_token : out_token;
    right_parenthesis_token :
right_parenthesis_token
has_part
    protocol : protocol;
    a_type_ref : a_type_ref
end

in_token in ArtifactProperty, SimpleClass
isA String
with constraint in_Is_In:
    $ forall i/in_token i = "in" $
end

out_token in ArtifactProperty, SimpleClass
isA String
with constraint out_Is_Out:
    $ forall o/out_token o = "out" $
end

protocol in StructureElement, SimpleClass
isA String, AerospaceEngineeringObject
with constraint
enum_Basic_Type:
    $forall p/protocol
    (p = "pool") or
    (p = "channel") or
    (p = "signal") or
    (p = "stimulus") or
    (p = "dataless_channel") $
end
```

Figure 4.59 - 'port_type schema'



BNF Syntax	OCL	O-Telos (base classes)
a_type_ref ::= basic_type | name . name | name basic_type ::= bool | nat | nat1 | integer | real | char | null	a_type_ref Invariant self.allInstances->forall(a | (a.adt_name->size =1 and a.parent_name->isEmpty and a. period_token->isEmpty and a.basic_type->isEmpty) xor (a.parent_name->size = 1 and a.period_token->size = 1 and a.adt_name->size = 1 and a.basic_type->isEmpty) xor (a.basic_type->size = 1 and a.parent_name->isEmpty and a.period_token->isEmpty and a.adt_name->isEmpty)) *Constraint preserving the BNF alternatives syntax*	a_type_ref in StructureElement, SimpleClass isA AerospaceEngineeringObject with has_property period_token : period_token has_part basic_type : basic_type; parent_name : name; adt_name : name end basic_type in StructureElement, SimpleClass isA String, AerospaceEngineeringObject with constraint enum_Basic_Type: $forall b/basic_type (b = "bool") or (b = "nat") or (b = "nat1") or (b = "integer") or (b = "real") or (b = "char") or (b ="null") $ end

Figure 4.60 - 'a_type_ref schema'

4.5.4.3 Specifying Activities and Ports using the RTN-SL Structure: A Worked Example

We now demonstrate how an O-Telos implementation of the structure elements introduced in subsection 4.5.4.2 may be used to represent ports for a simple Real-Time Network activity specified using the RTN-SL textual notation. The activity is stated as follows:-

```
activity a1 is
 ports
    p1 :       (signal, image.raw_image, in);
    p2 :       (channel, image.processed_image, out);
    p3, p4 :  (pool, integer, in);
    p5 :       (channel, bool, out);
 end ports
end activity;
```

Activity a1 has five ports. Each has a name (identifier) - p1, p2, p3, p4 and p5 - and an interface defining the protocol, data type and direction as previously described. Observe that data types communicated are user-defined in the case of p1 and p2, and built-in for p3, p4 and p5. Also note that ports p3 and p4 share the same interface characteristics. We now present the O-Telos representation of this RTN-SL code fragment:-

Sample population of port constructs for activity a1

Definition of a1

```
a1_activity in activity, Token with
begin_activity
    beginActivity : "activity"
name
    _name : "a1"
is_token
    isToken : "is"
ports
    ports : a1_ports
auxilliary_definitions
    auxilliaryDefinitions : --not shown
local_state
    localState : --not shown
operations
    _operations : --not shown
state_machine
    stateMachine : --not shown
end_token
    endToken : "end"
end_activity
    endActivity : "activity"
semi_colon_token
    semiColonToken : ";"
end
```

Definition of ports for a1

```
a1_ports in ports, Token with
begin_ports
    beginPorts : "ports"
port_defs
    portDefs : a1_port_defs
end_token
    endToken : "end"
end_ports
    endPorts : "ports"
semi_colon_token
    semiColonToken : ";"
end

a1_port_defs in port_defs, Token with
port_def
    port_def1 : p1_port_def;
    port_def2 : p2_port_def;
    port_def3 : p3_and_p4_port_def;
    port_def4 : p5_port_def
end

p1_port_def in port_def, Token with
id_list
    idList : p1_port_def_id_list
colon_token
    colonToken : ":"
port_type
    portType : p1_port_type
semi_colon_token
    semiColonToken : ";"
end

p2_port_def in port_def, Token with
id_list
    idList : p2_port_def_id_list
colon_token
    colonToken : ":"
port_type
    portType : p2_port_type
semi_colon_token
    semiColonToken : ";"
end

p3_and_p4_port_def in port_def, Token
with
id_list
    idList : p3_and_p4_port_def_id_list
colon_token
    colonToken : ":"
port_type
    portType : p3_and_p4_port_type
semi_colon_token
    semiColonToken : ";"
end

p5_port_def in port_def, Token with
```

```
id_list
    idList : p5_port_def_id_list
colon_token
    colonToken : ":"
port_type
    portType : p5_port_type
semi_colon_token
    semiColonToken : ";"
end

p1_port_def_id_list in id_list, Token
with
name
    _name : "p1"
end

p2_port_def_id_list in id_list, Token
with
name
    _name : "p2"
end

p3_and_p4_port_def_id_list in id_list,
Token with
name
    _name : "p3"
id_list_item
    idListItem : p4_list_item
end

p4_list_item in id_list_item, Token
with
comma_token
    commaToken : ","
name
    _name : "p4"
end

p5_port_def_id_list in id_list, Token
with
name
    _name : "p5"
end

p1_port_type in port_type, Token with
left_parenthesis_token
    leftParenthesisToken : "("
protocol
    _protocol : "signal"
protocol_comma
    protocolComma : ","
a_type_ref
    aTypeRef : p1_a_type_ref
a_type_ref_comma
    aTypeRefComma : ","
in_token
    inToken : "in"
right_parenthesis_token
    rightParenthesisToken : ")"
end

p2_port_type in port_type, Token with
left_parenthesis_token
    leftParenthesisToken : "("
protocol
    _protocol : "channel"
protocol_comma
    protocolComma : ","
a_type_ref
    aTypeRef : p2_a_type_ref
a_type_ref_comma
    aTypeRefComma : ","
out_token
    outToken : "out"
right_parenthesis_token
    rightParenthesisToken : ")"
end

p3_and_p4_port_type in port_type, Token
with
left_parenthesis_token
    leftParenthesisToken : "("
protocol
    _protocol : "pool"
protocol_comma
    protocolComma : ","
a_type_ref
    aTypeRef : p3_and_p4_a_type_ref
a_type_ref_comma
    aTypeRefComma : ","
in_token
    inToken : "in"
right_parenthesis_token
    rightParenthesisToken : ")"
end

p5_port_type in port_type, Token with
left_parenthesis_token
    leftParenthesisToken : "("
protocol
    _protocol : "channel"
protocol_comma
    protocolComma : ","
a_type_ref
    aTypeRef : p5_a_type_ref
a_type_ref_comma
    aTypeRefComma : ","
out_token
    outToken : "out"
right_parenthesis_token
    rightParenthesisToken : ")"
end

p1_a_type_ref in a_type_ref, Token with
parent_name
    parentName : "image"
period_token
    periodToken : "."
adt_name
    adtName : "raw_image"
end

p2_a_type_ref in a_type_ref, Token with
parent_name
    parentName : "image"
period_token
    periodToken : "."
adt_name
    adtName : "processed_image"
end

p3_and_p4_a_type_ref in a_type_ref,
Token with
basic_type
   basicType : "integer"
end

p5_a_type_ref in a_type_ref, Token with
basic_type
   basicType : "bool"
end
```

4.5.4.4 Relationship Between RTN Meta-Models

Having now proposed RTN-SL meta-models developed using both modelling options enumerated in subsection 4.4.3, it is worth briefly reflecting on the results yielded by these differing approaches.

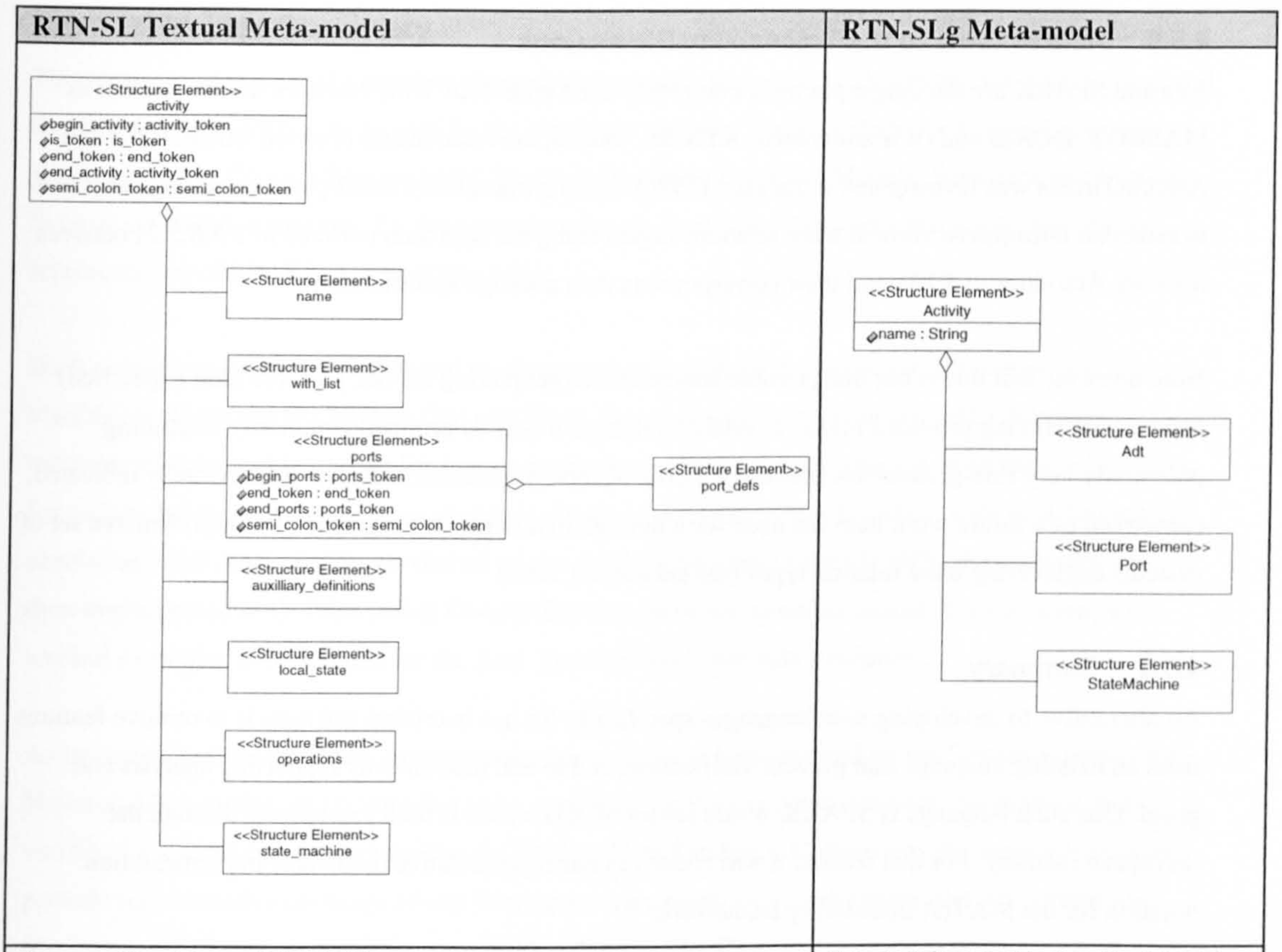


Figure 4.61 - 'RTN-SL Textual and RTN-SLg Meta-model Fragments'

Figure 4.61 juxtaposes the featured textual RTN-SL model fragment (from figures 4.54 and 4.55, subsection 4.5.4.2), with the corresponding RTN-SLg fragment from figure 4.22 (subsection 4.4.3.2.1); table 4.3 demonstrates the mapping between elements of these two representations: i.e., activity to Activity, with_list to Adt, ports to Port and state_machine to StateMachine (note local_state, auxilliary_definitions and operations are not represented in RTN-SLg and have therefore been removed).

RTN-SL Class	RTN-SLg Class
• activity	• Activity
• with_list	• Adt
• ports	• Port
• state_machine	• StateMachine

Table 4.3 - 'Mapping Table : RTN-SL (Textual) to RTN-SLg Graphical Meta-model Elements'

The two UML fragments can be considered isomorphic under the mapping of table 4.3. We make the observation that in RTN-SLg the name attribute of Activity (inherited from the abstract Component class - not shown) is represented as a class in the RTN-SL model, but that (as indicated in subsection 2.2.2.1.1) relationships between a class (or entity) and its attributes essentially present the same Conceptual Modelling abstraction as aggregation (Peckham & Maryanski, 1988); alternatively, in the RTN-SLg model, name could be promoted to a class. With this minor cosmetic change, the two models are isomorphic.

4.5.5 Relationship to the Traceability Dimensions

Ada and SPARK are the languages most commonly used with Real-Time Network notations such as MASCOT, DORIS and (it is anticpated) RTN-SL. Indeed, the relationship between MASCOT 3 and Ada constructs was investigated in Jackson (1986). From a traceability stand-point, engineers may wish to establish intra-micro vertical trace relations (again using the approach outlined in 3.3.6.3.2) between network Activities or IDAs and their corresponding Ada package specifications.

Note however that this is but one possible source and target pairing for one possible (and uspecified) association. Having provided means to establish links at a user determined granularity (including potentially very fine-grained associations for critical code fragments), we have, as previously indicated, earmarked as a future work item the need for a through investigation to establish a comprehensive set of systems engineering trace relation types (see subsection 7.4.3).

4.5.6 Summary

An alternative to developing new languages specifically for use in critical software is to remove features from an existing language that prevent verification, and to add mechanisms supporting analysis and proof. One such language is SPARK, a safe subset of Ada which is used extensively through the aerospace industry. For that reason, it was chosen as our representative (software) implementation notation for the MATrA traceability framework.

Accordingly we proposed a novel meta-model capturing a small number of SPARK constructs based on the BNF string grammar. Its granularity of expression supports verification of primitives against the PDS, as well as allowing flexibility in the setting up of trace-relations, both among SPARK elements and also between SPARK elements and those from other structures; for critical code fragments, these relations can if necessary be extremely fine-grained (e.g., between individual data elements in the specification and implementation). This, together with a desire to provide full compatibility with the source language were the main motivation in our decision to 'pitch' the model at such a detailed level.

A 'modelling philosophy' was also introduced detailing a series of mechanical steps that may be used to extend the SPARK model to include the remaining language features, or as subsequently demonstrated, to produce models for other languages expressed as a string grammar - in this case RTN-SL. To provide proof of concept, partial O-Telos implementations of both models were populated using sample code fragments.

Again, the SPARK Ada structure is fully evaluated in Chapter Seven.

4.6 Chapter Summary

This chapter has presented a number of novel meta-models (traceability structures) for well-defined and flexible *development* notations used by the aerospace industry. These included a Natural Language structure, a User Centred Requirements Structure (featuring Use Case Models, Scenarios and Message Sequence Charts), a structure for the representation of Real-Time Networks and a structure for the representation of SPARK Ada program code.

Each notation is potentially supported by disparate tools, with all the attendant difficulties for traceability discussed in Chapters One and Three. Our aim was therefore to provide a common representation to enable traceability across notations and hence data originating from these tools. Thus, for each notation we expressed key syntactic elements as a UML Class Diagram, with well-formedness, consistency and other constraints (for all except the Ada structure) stated in OCL. Base classes were then implemented in O-Telos (using ConceptBase) to show one possible means of automation, with worked examples also included for the Real-Time Network and Ada structures.

As indicated in Chapter Three, each structure has a common basis assured by the System Engineering Notation Meta-model, and is intended to be populated via the *tool2matra* transfer mechanism and verified for overall consistency against the Product Data Synthesis. Collectively the featured structures provide representative coverage of one Workspace viewpoint, i.e. development; the *assessment* and *product management* perspectives are considered in Chapter Five.

Chapter 5 Structuring Safety Assessment and Product Management Artifacts

5.1 Introduction

Chapter Five introduces further meta-models (traceability structures) which again provide input to the MATrA Workspace, this time representing well-defined and flexible notations for *safety assessment* and *product management*. The product management theme is further investigated through a structure to support traceability of revisions and variants. As in the previous chapter, we state factors motivating the inclusion of a structure, summarise the main concepts and relate it to the dimensions (from Chapter One). We also present an appropriate UML Class Diagram, OCL constraints and partial O-Telos implementation. Again, worked examples are provided to demonstrate key aspects for meta-models not featured in our main case studies in Chapter Six.

5.2 Fault Tree Analysis Structure

5.2.1 Introduction

In this section we propose a structure capturing the graphical syntax (again with a 'light-weight' formal semantics amenable to traceability) for Fault Tree Analysis, a technique used extensively in the aerospace industry for identifying and relating all events which alone or in combination may lead to an undesirable (safety significant) failure condition.

5.2.2 Motivation

Safety engineers use a range of analytical techniques, each one providing different coverage of the target system. One such technique is Fault Tree Analysis (FTA) which is widely used in the defence, aerospace and electronics industries. It is also recommended by several product assurance standards, including those by the International Electrotechnical Commission (IEC 61508, 1998), UK MoD (MoD, 1996) and Society of Automotive Engineers EUROCAE (1996b); indeed, we use case study material from the latter in Chapter Six as a platform for demonstrating work in this thesis. FTA was originally conceived in the 1960s as a means of analysing hardware failures, having been jointly developed by Bell Laboratories and the United States Airforce to help investigate inadvertent launch conditions for the Minuteman missile system. However, Leveson & Harvey have since extended the principles of FTA to software systems (1983).

Two complementary strategies underpin safety analysis techniques; these have been termed deductive and inductive approaches (Vesely *et al.*, 1981). Deductive techniques such as Fault Tree Analysis start from a system failure and then reason about system or component states contributing to that failure. Conversely, inductive techniques such as Failure Modes and Effects Analysis (see subsection 5.3) consider a particular fault in a system component and then attempt to ascertain its consequences. We therefore consider it appropriate to incorporate both approaches within the MATrA framework; thus Fault Tree Analysis provides our deductive example.

Results of the various analytical techniques are typically represented either graphically (as per Fault Tree Analysis), or else in tabular form (as per Failure Modes and Effects and Analysis). Again, it is appropriate to include both formats within the MATrA framework; thus Fault Tree Analysis also provides our graphical example.

5.2.2.1 Fault Tree Analysis Overview

As indicated above, Fault Tree Analysis is a deductive technique in that it starts from one particular undesirable event - termed the *top event* - and provides an approach to investigating potential causes. The choice of undesirable event is particularly important; too general and the fault tree becomes unmanageable; too specific and the analysis may fail to provide a sufficiently broad view[1]. Analysts then examine the system (or a model of the system) to determine ways in which a top event may occur. In doing so a range of factors are considered, from component and human failures, to random events occurring in the system environment.

The fault tree itself provides a graphical representation of event combinations that can lead to the undesirable event. A number of different event types commonly occur in fault trees, including intermediate, basic, undeveloped, external and conditional. These are explained in table 5.1. The different event types are represented by rectangle, circle, diamond, house and ellipse symbols respectively.

EVENT TYPES

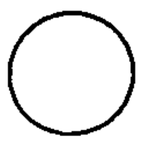
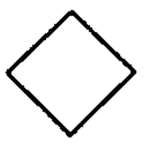
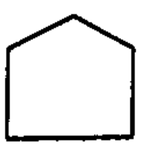
Name	Description	Symbol
• Intermediate	A fault arising from one or more preceding causes acting through a logic gate	
• Basic	An event that is internal to the system under analysis and which requires no further decomposition	
• Undeveloped	An event that is not developed further, either because it has little impact on the top level event, or because information for its development is not readily available	
• External	An event that is normally expected to occur	
• Conditional	Restriction expressed over a logical connective (normally a PRIORITY-AND or INHIBIT gate - see table 5.2)	

Table 5.1 - 'Fault Tree Event Types'

Events are connected together by logical operators known as *gates* that either enable or prevent the flow of a fault up a tree. Common types of connective include the `AND-gate`, `OR-gate`, `PRIORITY-AND-gate`, `EXCLUSIVE-OR-gate` and `INHIBIT-gate`; these are described in table 5.2, which

[1]Readers are referred to (EUROCAE1996b) for a discussion on factors influencing the choice of top event and other procedural issues pertaining to Fault Tree Analysis.

also includes corresponding graphical symbols.

Note: given their diverse application, it is perhaps surprising that the symbols for events and gates used in constructing fault trees have remained largely 'standard'. Practitioners generally regard the Nuclear Regulatory Commission Fault Tree Handbook (Vesely *et al.*, ibid.) - from which the descriptions here are taken - as providing the definitive definition.

GATE TYPES

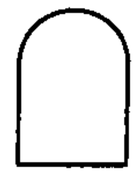
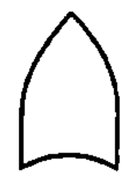
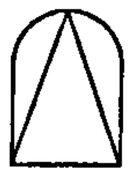
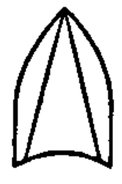
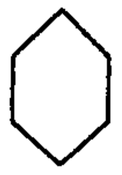
Name	Description	Symbol
• AND	Output fault occurs when all input faults occur	
• OR	Output fault occurs when one or more input faults occur	
• PRIORITY-AND	Output fault occurs when all input faults occur in a particular sequence (which is usually represented by a Conditional Event attached to the gate)	
• EXCLUSIVE-OR	Output fault occurs when exactly one of the input faults occur	
• INHIBIT	Output fault occurs if the single input fault occurs in the presence of an enabling condition (represented by a Conditional Event attached to the gate)	

Table 5.2 - 'Fault Tree Gate Types'

Once the fault tree logic is complete, it can be used to compute event probabilities. In order to do so, the tree must first be reduced to what is termed *minimal-cut-set-form*. That is, the smallest set of events capable of causing the top event.

Basic events are then annotated with their probability of occurrence. Calculation of intermediate probabilities then progresses up through the tree until probability of the top event can be calculated. Probabilities for output events of the two most common event connectives - and gates and or gates - are determined by the product and sum of their respective input events. Where applicable, it is also common to state failure rate (typically per flight hour for civil aircraft) and exposure time of basic events; event probabilities are then calculated from the product of these two values.

Figure 5.1 presents an example Fault Tree Analysis demonstrating the above concepts for the 'Loss of All Wheel Braking' hazard for an aircraft braking system.

Loss of All Wheel Braking occurs due to simultaneous loss of the three braking sub-systems; i.e., Loss of Normal Braking (NBS) AND Loss of Alternative Braking (ABS) AND Loss of Emergency Braking (EBS). Note that

probability of failure of the Emergency Brake System is set to 1.0 indicating a design intent to discount its contribution in meeting the requirement for the top event.

Downward development of Loss of Normal Braking shows that this event can occur due to Loss of Hydraulic Supply for the Green Hydraulic System OR Loss of All Hydraulic Components for the Normal Brake System OR Loss of Command Braking Ability for the BSCU (Braking System Control Unit).

The BSCU Loss of Command Braking Ability event is further decomposed into the causes BSCU Loss of Braking Commands OR BSCU1 Loss of Electrical Power WHEN BSCU2 Loss of Electrical Power. The latter differs from all other events in the tree which are expressed over a single (build) element and a condition from that element's state space. In contrast, LOSSELECPWR captures coincidental failure of two elements (BSCU1 and BSCU2), suggesting a distinction can be made between different types of event. We return to this issue in subsection 5.2.3.1.

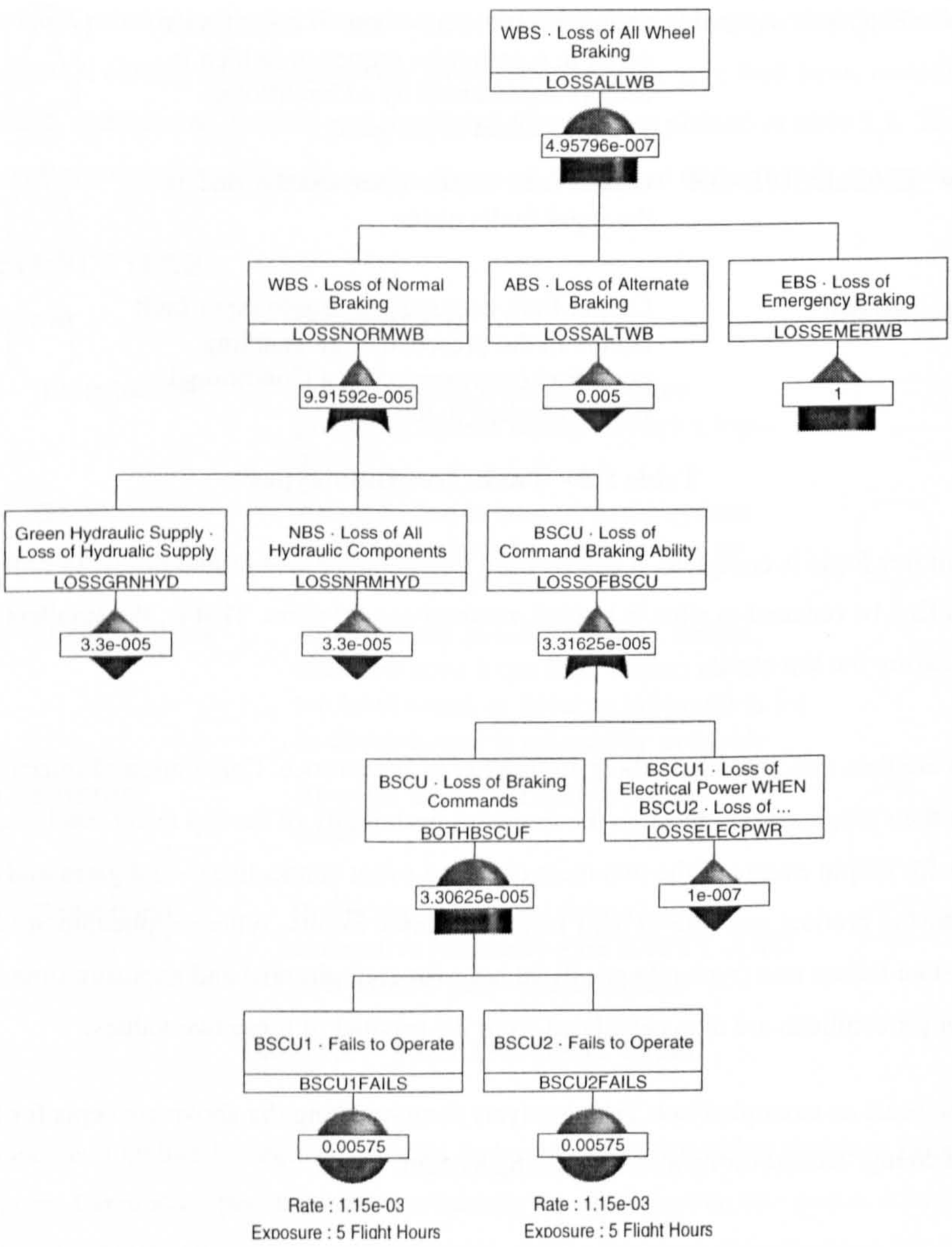


Figure 5.1 - 'Example Fault Tree for Aircraft Wheel Braking System - investigating causes of Loss of All Wheel Braking (source APR 4761)'

Finally, BSCU Loss of Braking Commands is defined by the basic events BSCU1 Fails to Operate AND BSCU2 Fails to Operate. As indicated previously, probabilities for both are derived from their respective values for rate and exposure.

5.2.3 Tracing Safety Properties in MATrA: An FTA Model

This subsection introduces a meta-model allowing integration of Fault Tree Analysis into the MATrA traceability framework. As with UCRS, bespoke tool support is assumed.

5.2.3.1 Concepts

Fault trees in MATrA support most of the standard concepts set out in subsection 5.2.2.1, including a subset of event types (Intermediate, Basic, External and Undeveloped) and gate types (`And` and `Or`), as well as means to create the minimal cut set expression. Our research indicates that these are sufficient for the majority of analyses[2].

In addition, MATrA fault trees reflect usage within the aerospace domain, notably as part of the ARP 4754/4761 assessment process outlined in subsection 1.4.6.2.1. Within this process, fault trees are used to determine budget probabilities - i.e. safety objectives (established prior to design) for the target aircraft, its systems and their items – as part of the Functional Hazard and Preliminary System Safety Assessments. Updated versions of these trees are subsequently produced by the System Safety Assessment to affirm whether the original safety objectives have been met; both the preliminary and updated trees form submissions to the appropriate regulatory body as evidence towards certification.

Accordingly, a MATrA Fault Tree Analysis is composed of an optional preliminary tree and a mandatory updated tree. As may be expected, there is a high degree of event commonality between the two. Therefore, to minimise redundancy (and increase traceability), MATrA fault trees support the sharing of events (or more specifically, elements of their descriptions) through the notion of 'event profiles'. Hence, an event has two profiles, the preliminary event profile and updated event profile. Preliminary profiles comprise an event type and label, together with budget probability, failure rate and exposure properties; failure rate and exposure time are applicable to basic event types only. An updated profile also has a type which may differ from that for the preliminary profile - as demonstrated by the case study in subsection 6.3 - although this is atypical. In addition, the budget probability is retained by the updated profile, while the actual probability is added. New exposure and failure rates (where applicable) may also be expressed, or alternatively, the originals reused. The same is true of event labels which, like event types are normally the same but (as the case study also demonstrates) exhibit the potential for change.

Following our observation on event types in 5.2.2.1, the labels themselves differentiate between 'Simple', 'Composed' and 'Synchronisation' categories as derived from a taxonomy proposed by Górski & Wardziñski (1995). Simple events are described in terms of a subject entity and a condition;

---

[2] Note the MATrA Fault Tree Structure can be easily extended to accommodate the complete range of event and gate types featured in 5.2.2.1.

e.g., Valve • Stuck Open. Composed events meanwhile refer to the coincidence of two or more simple events; this is often expressed as two events joined using the "when" conjunction. For example, Valve • Stuck Closed **when** Pump • Stuck On[3]. Finally, Synchronisation describes the temporal relationship between two simple events E1, E2 (normally separated by the preposition "upon") such that in boolean logic, E1 already holds when E2 becomes True; e.g. Tank • Full **upon** Engine • StartUp[4].

Event profiles are connected by gates. In contrast to the events themselves, these are not shared between the preliminary and updated trees as described above, but instead belong exclusively to either one or the other. This is to allow for changes in structure of the tree, for example the addition or removal of events. And because there are no further properties to be shared between the respective trees, nothing would be gained from using common gates.

Finally, a number of constraints are imposed over MATrA fault trees. These range from well formedness rules, to restrictions arising from modelling decisions. We further specify 'safety-criteria' identifying common cause and single failures. Checks against the Product Data Synthesis are also stated, though this time informally.

5.2.3.2 FTA Meta-model Definitions

We now introduce the UML class diagram for our Fault Tree Analysis structure (5.2.3.2.1), together with OCL constraints over elements of the model (5.2.3.2.2) and O-Telos implementation of its base classes (5.2.3.2.3).

5.2.3.2.1 FTA Meta-model

UML specification of the Fault Tree Analysis meta-model is shown in figures 5.2 (elements) and 5.3 (associations). Its core class (FaultTreeAnalysis) includes subject module (subject_module) and description (fta_description) attributes and is an instantiation of the AssessmentStructure meta-class. In turn, FaultTreeAnalysis is further defined as an aggregation of preliminary fault tree (PreliminaryFaultTree) and updated fault tree (UpdatedFaultTree) - also instantiations of AssessmentStructure - as well as the event (Event) class (with identifier attribute) which instantiates StructureElement.

It is worth noting from figure 5.2, the multiplicity of three-to-many that exists between FaultTreeAnalysis and Event. This arises from our view on what constitutes a minimal fault tree, namely two event inputs to an And-gate or Or-gate, yielding a single event output. We also note (from its zero-or-one multiplicity) that PreliminaryFaultTree is optional, reflecting our intent to increase utility of the structure such that it may be used without developing the preliminary tree (and hence is not hard-wired for a particular assessment process).

---

[3] *cf.* LOSSELECPWR event in figure 5.1.

[4] Górski & Wardziński's classification is not universally accepted, but for the purpose of this representation is assumed to be both coherent and well defined. Alternatively, we could have undertaken a study of the usage of time in fault trees within the aerospace industry and defined our own set of semantics and consistency rules; this was deemed beyond the scope of our work.

Fault Tree Analysis Structure

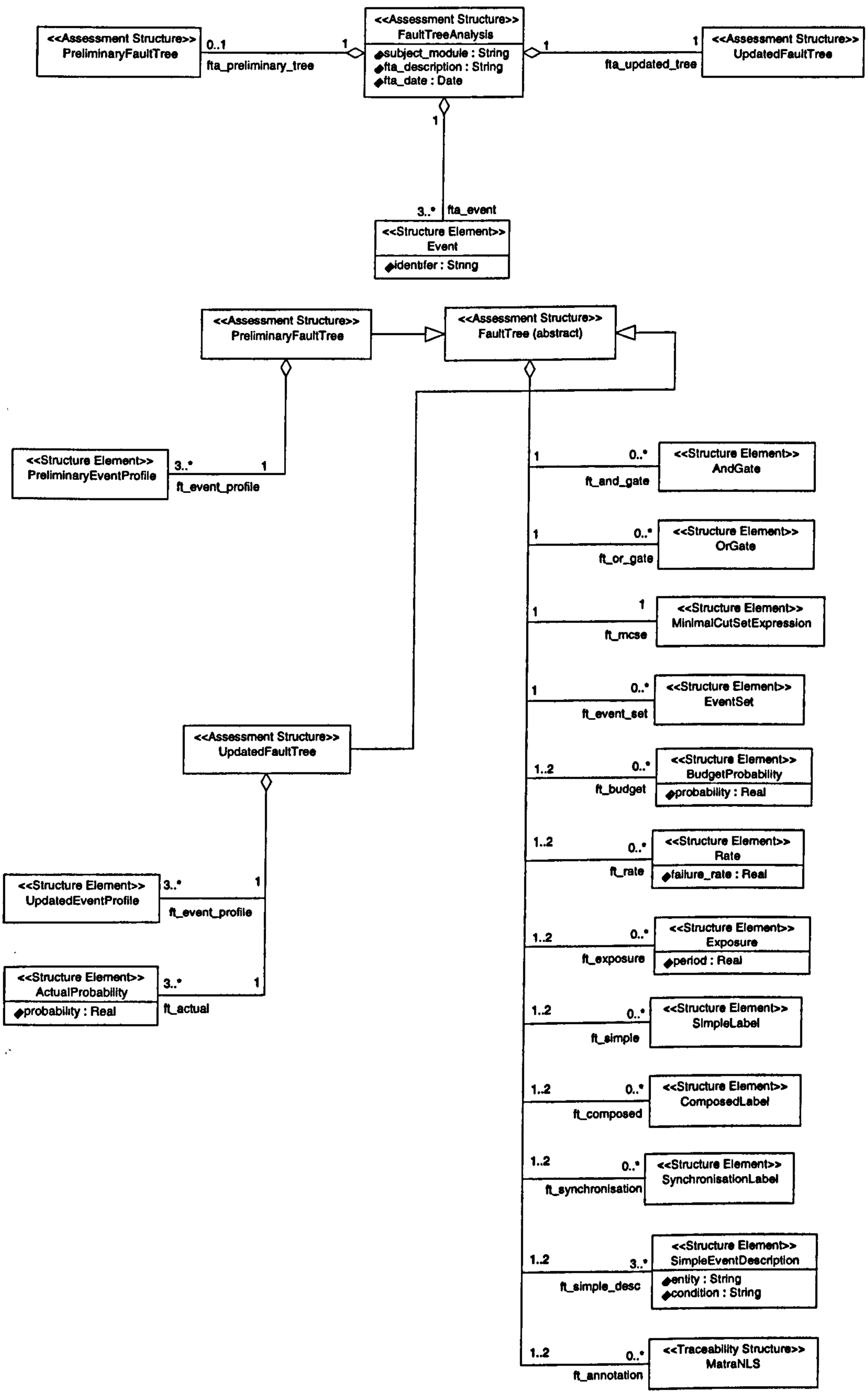


Figure 5.2 - 'Fault Tree Analysis Structure : Elements'

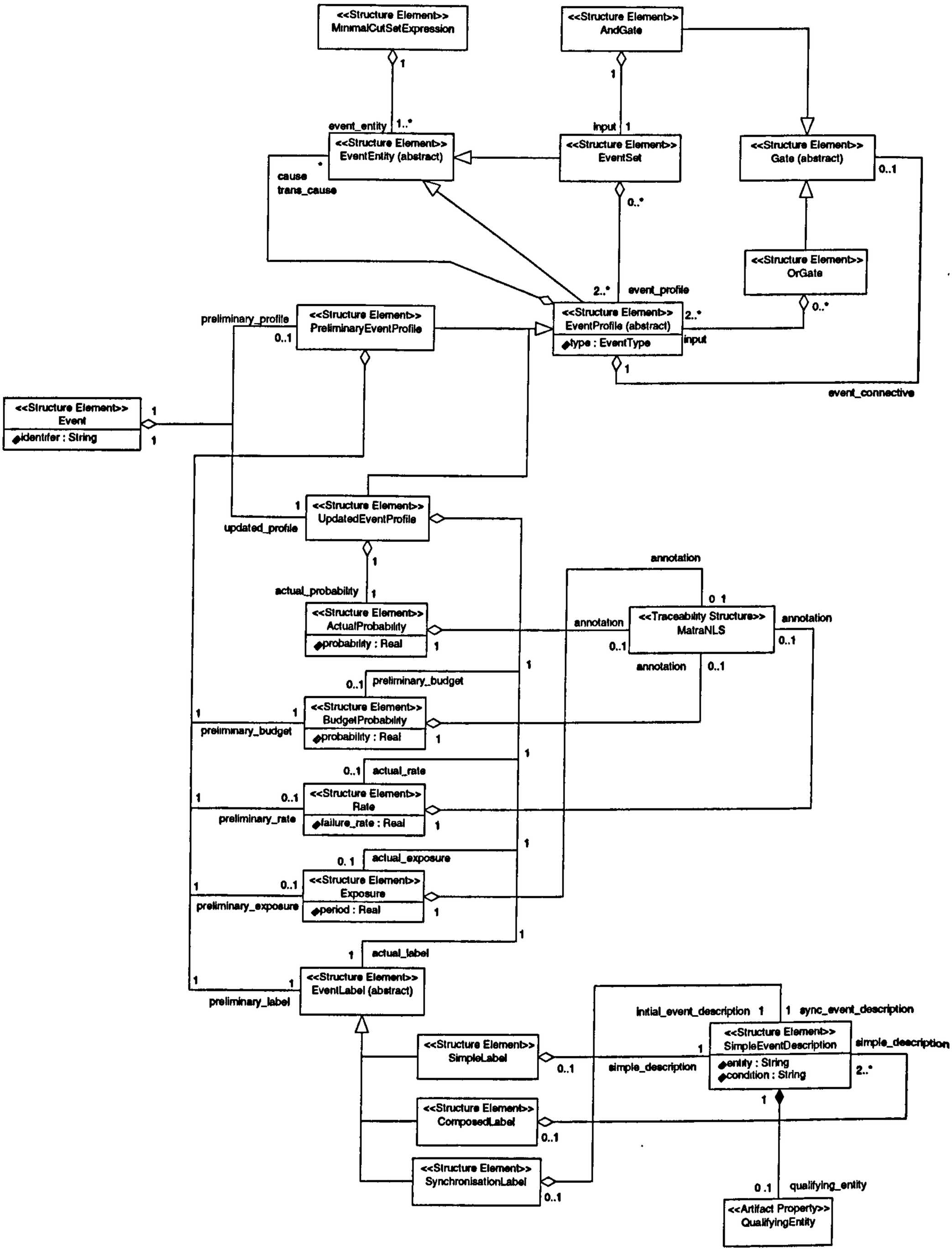


Figure 5.3 - 'Fault Tree Analysis Structure : Associations'

Figure 5.2 shows both PreliminaryFaultTree and UpdatedFaultTree to be specialisations of the abstract FaultTree class, an aggregation of StructureElement meta-classes representing (or capturing the principles behind) concepts from 5.2.3.1 that are common to both tree types. These include And-gate (AndGate) and Or-gate (OrGate) connectives, the minimal cut set expression (MinimalCutSetExpression) and event properties such as exposure (Exposure), rate (Rate) and budget probability (BudgetProbability). The latter are initiated as elements of preliminary trees, but are included in the updated tree (along with the ActualProbability - introduced below) for reasons of clarity[5]; note that multiplicity of BudgetProbability is set as zero-to-many to accommodate updated fault trees for which no preliminary tree exists[6]. Note too the inclusion of a MATrA Natural Language Structure (MatraNLS) enabling annotation of probabilities, rates and exposures. We also employ the notion of an event set (EventSet) which represents the collective input to And-gates and which simplifies expression of rules and constraints requiring examination of paths through a tree.

In addition, FaultTree includes means to represent the various different types of event label (also discussed in subsection 5.2.3.1) - namely Simple (SimpleLabel), Composed (ComposedLabel) and Synchronisation (SynchronisationLabel). Content of these labels is specified using the simple event description (SimpleEventDescription) class, with properties entity and condition.

Besides inheriting the common elements outlined above, PreliminaryFaultTree and UpdatedFaultTree also feature type specific preliminary event profile (PreliminaryEventProfile) and updated event profile (UpdatedEventProfile) elements respectively. UpdatedFaultTree further includes means to state the actual probability (ActualProbability).

Figure 5.3 indicates that a fault tree Event is made up of a single UpdatedEventProfile and an optional PreliminaryEventProfile. It also shows both forms of profile to be specialisations of the (abstract) EventProfile supertype, with attribute type - a specialisation of String (not shown) - restricted to int(ermediate), top, bas(ic), ext(ernal) or und(eveloped).

It can be seen from figure 5.3 that PreliminaryEventProfile comprises mandatory BudgetProbability and EventLabel elements and optional Rate and Exposure elements (which are further restricted to use with basic events by a constraint in subsection 5.2.3.2.2-i). EventLabel is an abstract supertype with the SimpleLabel, ComposedLabel and SynchronisationLabel specialisations introduced previously. Each EventLabel subtype is described either by a single SimpleEventDescription instance for Simple events, two or more instances for Composed events, or two instances (differentiated using the initial event description (initial_event_description) and synchronisation event description (sync_event_description) rolenames) for Synchronisation events[7]. A SimpleEventDescription can be given scope by nominating an optional qualifying entity (QualifyingEntity). This specialisation of the String class is strictly an attribute

---

[5] Clearly it is beneficial to be able to view both budget and updated probabilities for events from within the updated tree in order to determine 'at-a-glance' whether original safety requirements have been met and whether further analysis is required.

[6] A constraint can be defined to ensure instances of PreliminaryFaultTree include at least three budget probabilities.

[7] The 'when' conjunction of composed events and the 'upon' preposition of synchronisation events are deemed to be implicit in their respective class types.

(indicated by it being an instance of ArtifactProperty), which is promoted to a class using composition in order to express optionality.

Like PreliminaryEventProfile, UpdatedEventProfile also includes a mandatory EventLabel, as well as optional Rate and Exposure elements. As per 5.2.3.1, EventLabel and Exposure objects created for a preliminary tree can normally be reused by the updated version, although the capability exists for new instances to be introduced if necessary; this facility is also available to Rate which is *expected* to change. UpdatedEventProfile is completed by the (mandatory) ActualProbability class and its corresponding BudgetProbability created for the preliminary tree; i.e., (as previously indicated), while Rate and Exposure are either retained or replaced, updated trees exhibit both forms of probability (budget *and* actual).

EventProfile (and hence PreliminaryEventProfile and UpdatedEventProfile) connects to the abstract gate (Gate) class, with subtypes OrGate and AndGate. In turn, OrGate takes as input two or more EventProfile elements, while AndGate takes a single EventSet (itself an aggregation of two or more event profiles). Both EventProfile and EventSet are further defined as subtypes of the abstract EventEntity class. This exists partly to allow propagation of the cause and trans_cause associations from EventProfile to both EventProfile itself and to EventSet. The cause and trans_cause associations are used in identifying paths through a fault tree and hence in the expression of constraints and deductive rules that are dependent on this ability (see subsection 5.2.3.2.2).

One such rule populates the minimal cut set expression (MinimalCutSetExpression). This class is defined as an aggregation of one or more EventEntity - i.e., EventProfile or EventSet elements. Presence of the former would indicate that a single failure can lead to the fault tree top event, something normally regarded as an undesirable system property. However, it was decided that to prevent such occurrences (by for example, making MinimalCutSetExpression an aggregation of EventSet elements) would be overly restrictive. We therefore express a 'safety-criterion' indicating the presence of, rather than preventing specification of fault trees that include single failures (see subsection 5.2.3.2.2-ii).

5.2.3.2.2 OCL Constraints

In this subsection, we express the following types of constraint over the Fault Tree Analysis meta-model:-

- Well-formedness of fault tree elements;
- Fault tree 'safety-criteria';
- Constraints reflecting usage;
- Other structural and consistency restrictions attributable to modelling decisions;
- Verification of fault tree elements against the Product Data Synthesis (informal).

Note that a subset of these constraints (expressed in set theory and predicate logic rather than OCL) appeared in Mason & Saeed (1998).

We begin by establishing a rule capturing causality which populates the aggregation association cause for the EventProfile class (see figure 5.3); cause can then be used to populate the trans_cause association. The latter is not shown, but like cause can be expressed by restating the corresponding rule from Mason & Saeed (ibid.) in OCL.

- Rule to populate the cause association.

EventProfile
self.allInstances->forall(e |
self.event_connective->exists(g |
e.event_connective->includes(g)))
implies
e.cause->includesAll(g.input)

I. Well-formed Fault Trees

In defining the following well-formedness constraints and rules for fault trees, we note that a range of other structural constraints identified from the literature - e.g., that leaves are *not* gates and that children of events *must be* gates - are enforced by associations and multiplicities expressed in the UML model itself (figure 5.3).

1. Rule to populate MinimalCutSetExpression.

FaultTree
self.allInstances->forall(f |
self.ft_event_profile->exists(e |
f.ft_event_profile->includes(e) and e.type ="top"))
implies
f.ft_mcse.event_entity->includesAll(e.trans_cause->select ((e.trans_cause.oclIsKindOf(EventProfile) and
e.trans_cause.type="bas") or (e.trans_cause.oclType = EventSet and e.trans_cause.event_profile.type="bas")))

2. Constraint to ensure unique identifiers.

FaultTreeAnalysis **invariant**
self.allInstances->forall(f |
self.fta_event->forall(e1, e2 |
not(f.fta_event->includes(e1) and f.fta_event->includes(e2) and e1 <> e2 and e1.identifer = e2.identifier)))

3. Constraint to ensure non-primary events types have a child gate, while primary event types do not.

EventProfile **invariant**
self.allInstances->forall(e | not(((e.type = "bas" or e.type = "ext" or e.type = "und") and
e.event_connective->size > 0) or ((e.type = "top" or e.type = "int") and e.event_connective->size = 0)))

4. Constraint to ensure a fault tree contains only one top event.

FaultTreeAnalysis **invariant**
self.allInstances->forall(f |
self.fta_event->forall(e1, e2 |
not (f.fta_event->includes(e1) and f.fta_event->includes(e2) and
((e1.preliminary_profile.type = "top" and e2.preliminary_profile.type = "top") or

(e1.updated_profile.type = "top" and e2.updated_profile.type = "top")) and e1 <> e2)))

5. Constraint to ensure that probabilities of output events are correct: i.e. a) outputs for Or-gates equate to the sum of input probabilities; and b) outputs for And-gates equate to the product of input probabilities.

a) Constraint for Or-gates

EventProfile **invariant**
self.allInstances->reject(self.allInstances.type = "bas" or self.allInstances.type = "ext" or self.allInstances.type = "und")->forall(e |
self.event_connective->exists(g |
self.preliminary_budget->union(self.actual_probability)->not exists(p |
(e.event_connective->includes(g) and g.oclType = OrGate and
((e.oclType = PreliminaryEventProfile and e.preliminary_budget->includes(p) and p.probability <>
g.input.preliminary_budget.probability->sum) or
(e.oclType = UpdatedEventProfile and e.actual_probability->includes(p) and p.probability <>
g.input.actual_probability.probability->sum))))))

b) Constraint for And-gates

EventProfile **invariant**
self.allInstances->reject(self.allInstances.type = "bas" or self.allInstances.type = "ext" or self.allInstances.type = "und")->forall(e |
self.event_connective->exists(g |
self.preliminary_budget->union(self.actual_probability)->not exists(p |
(e.event_connective->includes(g) and g.oclType = AndGate and
((e.oclType = PreliminaryEventProfile and e.preliminary_budget->includes(p) and
(g.input.event_profile->iterate(i : PreliminaryEventProfile; acc: real = 0 |
acc * i.preliminary_budget.probability) <> p.probability)) or
(e.oclType = UpdatedEventProfile and e.actual_probability->includes(p) and
(g.input.event_profile->iterate(i : UpdatedEventProfile; acc: real = 0 |
acc * i.actual_probability.probability) <> p.probability)))))))

6. Constraint(s) to ensure correct population of the (budget or actual) probability for basic events as the product of Rate and Exposure.

PreliminaryEventProfile **invariant**
self.allInstances->forall(e |
not(e.preliminary_rate->size = 1 and e.preliminary_exposure->size = 1 and
e.preliminary_budget.probability <> e.preliminary_rate.failure_rate * e.preliminary_exposure.period))

UpdatedEventProfile **invariant**
self.allInstances->forall(e |
not(e.actual_rate->size = 1 and e.actual_exposure->size = 1 and
e.actual_probability.probability <> e.actual_rate.failure_rate * e.actual_exposure.period))

7. Constraint ensuring that Rate and Exposure are stated for basic events only.

EventProfile **invariant**
self.allInstances->forall(e |
not(e.type <> "bas" and ((e.actual_rate->union(e.preliminary_rate)->size >= 1) or
(e.actual_exposure->union(e.preliminary_exposure)->size >= 1))))

Strictly, this constraint is motivated by our modelling decision to define event type as an enumerated property of EventProfile, rather than by using subtypes as we have with gates. This is because EventProfile has already been specialised through the preliminary and updated profile subtypes. Therefore, further specialisation along a different 'dimension' would lead to an exponential growth in classes in order to capture orthogonality - e.g., basic-preliminary, basic-updated, etc.

We note that Mason & Saeed (ibid.) contains further constraints and rules pertaining to well-formed fault trees (including an invariant to prevent cycles within the logical tree structure); again these could be restated in OCL.

ii. Fault Tree Safety-Criteria

The following define what we term 'safety-criteria' in the sense that they represent desirable properties of a fault tree, rather than invariants.

1. Restriction identifying *single failure* causes of a top event.

MinimalCutSetExpression
```
self.allInstances->forall(m | self.event_entity->forall(e | not (m.event_entity->includes(e) and
e.oclIsKindOf(EventProfile)))
```

2. Restriction identifying *common cause failures* through And-gates.

AndGate
```
self.allInstances->forall(g1, g2 | not((g1.input.event_profile->
intersection(g2.input.event_profile)->not Empty) and g1 <> g2))
```

iii. Constraints Reflecting Usage

The following constraints arise from issues relating to usage, notably in terms of support for the ARP 4761 assessment process. In particular, the notion of preliminary and updated fault trees sharing events as constituents of a single Fault Tree Analysis, and the use of event profiles to reduce redundancy and promote traceability in realising this concept.

1. Constraint ensuring that preliminary and updated fault trees have the same top event.

FaultTreeAnalysis **invariant**
```
self.allInstances->forall(f | self.fta_event->forall(e1, e2 |
not (f.fta_event->includes(e1) and f.fta_event->includes(e2) and
e1.preliminary_profile.type = "top" and e2.updated_profile.type = "top" and e1 <> e2)))
```

2. Restriction stating that ActualProbability of failure for the top event of the UpdatedFaultTree is less than or equal to the BudgetProbability of the PreliminaryFaultTree top event.

FaultTreeAnalysis
```
self.allInstances->forall(f |
(f.fta_event.updated_profile->select(f.fta_event.updated_profile.type = "top")).actual_probability.probability >=
(f.fta_event.preliminary_profile->select(f.fta_event.preliminary_profile.type = "top")).
preliminary_budget.probability)
```

3. Constraint ensuring that updated event profiles employ the same BudgetProbability as the preliminary profile.

Event **invariant**
self.allInstances->forall(e |
not (e.preliminary_profile->size = 1 and
e.preliminary_profile.preliminary_budget <>
e.updated_profile.preliminary_budget))

iv. Other Consistency Constraints

As a sample of constraints arising from modelling decisions, we capture an exclusive-or restriction that a SimpleEventDescription must belong to either a SimpleLabel, a ComposedLabel or a SynchronisationLabel.

SimpleEventDescription **invariant**
self.allInstances->forall(s |
s.simpleLabel->size = 1 xor s.composedLabel->size = 1 xor s.synchronisationLabel->size = 1)

Also, and in keeping with our view on what constitutes a minimal fault tree (outlined in subsection 5.2.3.2.1) - specifically the proviso that a well-formed tree contains at least one gate - we state the following:-

FaultTree **invariant**
self.allInstances->forall(f | not(f.ft_and_gate->isEmpty and f.ft_or_gate->isEmpty))

v. Verification of Fault Tree Elements against the Product Data Synthesis

Given that we expressed PDS consistency checks for previous notations (and do so again for the Failure Modes and Effects Analysis structure in section 5.3), similar restrictions are not formally stated over the Fault Tree Analysis meta-model. However, the following (informal) constraints should hold for event labels:-

- The entity attribute maps to a corresponding PDS Module or Function;
- The condition attribute maps to a PDS Condition for the corresponding Module or Function;
- For two events, where one is caused by the other, there exists in the PDS an OccurringIn association between corresponding conditions;
- QualifyingEntity maps to a corresponding PDS Module or Function and includes the qualified Entity within its decomposition.

5.2.3.2.3 O-Telos Implementation of FTA Base Classes

The following O-Telos code implements base class elements for the Fault Tree Analysis meta-model.

```
EventEntity in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
constraint
    abstract_event_entity: $ forall
t/Token s/SimpleClass (t in s) ==> not (t
in  EventEntity)$
end

EventSet in StructureElement, SimpleClass
isA EventEntity with
has_part
    event_profile : EventProfile
end

EventProfile in StructureElement,
SimpleClass isA EventEntity with
has_property
    type : EventType
has_part
```

```
    event_connective : Gate;
    cause : EventEntity
has_transitive_part
    trans_cause : EventEntity
constraint
    abstract_event_profile: $ forall
t/Token s/SimpleClass
    (t in s) ==> not (t in EventProfile)$
end

EventType in ArtifactProperty,
SimpleClass isA String with
constraint
    enum_event_type: $ forall
e/EventType(e = "int") or (e = "top") or
(e = "bas") or (e = "ext") or (e = "und")
$
end

Gate in StructureElement, SimpleClass isA
AerospaceEngineeringObject with
constraint
    abstract_gate: $ forall t/Token
s/SimpleClass (t in s) ==> not (t in
Gate)$
end

PreliminaryEventProfile in
StructureElement, SimpleClass isA
EventProfile with
has_part
    preliminary_budget :
BudgetProbability;
    preliminary_rate : Rate;
    preliminary_exposure : Exposure;
    preliminary_label : EventLabel
end

UpdatedEventProfile in StructureElement,
SimpleClass isA EventProfile with
has_part
    actual_probability :
ActualProbability;
    preliminary_budget :
BudgetProbability;
    actual_rate : Rate;
    actual_exposure : Exposure;
    actual_label : EventLabel
end

ActualProbability in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_property
    probability : Real
has_structure
    annotation :
MatraNaturalLanguageStructure
end

BudgetProbability in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_property
    probability : Real
has_structure
    annotation :
MatraNaturalLanguageStructure
end

Rate in StructureElement, SimpleClass isA
AerospaceEngineeringObject with
has_property
    failure_rate : Real
has_structure
    annotation :
MatraNaturalLanguageStructure
end

Exposure in StructureElement, SimpleClass
isA AerospaceEngineeringObject with
has_property
    period : Real
has_structure
    annotation :
MatraNaturalLanguageStructure
end

EventLabel in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
constraint
    abstract_event_label: $ forall
t/Token s/SimpleClass (t in s) ==> not (t
in  EventLabel)$
end

SimpleLabel in StructureElement,
SimpleClass isA EventLabel with
has_part
    simple_description :
SimpleEventDescription
end

ComposedLabel in StructureElement,
SimpleClass isA EventLabel with
has_part
    simple_description :
SimpleEventDescription
end

SynchronisationLabel in StructureElement,
SimpleClass isA EventLabel with
has_part
    initial_event_description :
SimpleEventDescription;
    sync_event_description :
SimpleEventDescription
end

SimpleEventDescription in
StructureElement, SimpleClass isA
AerospaceEngineeringObject with
has_property
    entity : String;
    condition : String;
    qualifying_entity : QualifyingEntity
end

QualifyingEntity in ArtifactProperty,
SimpleClass isA String end

AndGate in StructureElement, SimpleClass
isA Gate with
has_part
    input : EventSet
end

OrGate in StructureElement, SimpleClass
isA Gate with
has_part
    input : EventProfile
end

Event in StructureElement, SimpleClass
isA AerospaceEngineeringObject with
has_property
    identifer : String
has_part
    preliminary_profile :
PreliminaryEventProfile;
    updated_profile : UpdatedEventProfile
end

MinimalCutSetExpression in
StructureElement, SimpleClass isA
AerospaceEngineeringObject with
has_part
    event_entity : EventEntity
end

FaultTree in AssessmentStructure,
```

```
SimpleClass isA
AerospaceEngineeringObject with
has_structure
    ft_annotation :
MatraNaturalLanguageStructure
has_element
    ft_and_gate : AndGate;
    ft_or_gate : OrGate;
    ft_mcse : MinimalCutSetExpression;
    ft_event_set : EventSet;
    ft_budget : BudgetProbability;
    ft_rate : Rate;
    ft_exposure : Exposure;
    ft_simple : SimpleLabel;
    ft_composed : ComposedLabel;
    ft_synchronisation :
SynchronisationLabel;
    ft_simple_desc :
SimpleEventDescription
constraint
    abstract_ft: $ forall t/Token
s/SimpleClass (t in s) ==> not (t in
FaultTree)$
end

PreliminaryFaultTree in
AssessmentStructure, SimpleClass isA
FaultTree with
has_element
    ft_event_profile :
PreliminaryEventProfile
end

UpdatedFaultTree in AssessmentStructure,
SimpleClass isA FaultTree with
has_element
    ft_event_profile :
UpdatedEventProfile;
    ft_actual : ActualProbability
end

FaultTreeAnalysis in AssessmentStructure,
SimpleClass isA
AerospaceEngineeringObject with
has_property
    subject_module : String;
    fta_description : String;
    fta_date : Date
has_structure
    fta_preliminary_tree :
PreliminaryFaultTree;
    fta_updated_tree : UpdatedFaultTree
has_element
    fta_event : Event
end
```

5.2.4 Relationship to the Traceability Dimensions

Trace relations involving fault trees can occur in the horizontal and vertical dimensions at inter/intra and macro/micro levels. For example, relating a PSSA fault tree for an aircraft braking system, to a PSSA fault tree for one of its components, can be said to capture an intra-macro-horizontal association; intra in the sense that our interest lies within a single system, macro in that it spans two levels of decomposition and horizontal as the artifacts concerned stem from the same phase of assessment. Similarly, if we related the braking system fault tree to braking system requirements derived from analysis of failure conditions, this would constitute intra-micro-vertical traceability; again intra because our interest is a single system, micro as the scope is confined to a single decomposition level and vertical since traceability is between artifacts of different types (i.e., requirements and assessment).

However we make the observation that relationships between fault trees generated by PSSA and SSA are more difficult to position along the dimension axes since they depend in part on interpretation of the dependency between the preliminary and updated trees. Recall from Chapter One that revision traceability is defined as (the ability to navigate) relationships between instances of the same artifact at different stages of maturity. Therefore one view holds that preliminary trees and profiles mature into updated trees and profiles in response to findings from analysis (e.g., FMEA or Common Mode) and so relationships between them exist in the revision dimension[8]. Yet since the stated aims of the two trees are quite different - PSSA is used to derive requirements and evaluate proposed architectures, whereas SSA provides verification that an implemented system satisfies these objectives (and so clearly one is not *replacing* the other in the true sense of a revision) - then it might also be argued such relationships are actually intra-micro-vertical; intra-micro as they concern descriptions within both a single system and single decomposition level and vertical as the artifacts concerned stem from different phases of assessment.

[8] We consider the issue of revision (and more generally, version) traceability in greater detail in subsection 5.5.

5.2.5 Summary

Fault Tree Analysis is a top down method of failure analysis that is widely used throughout the aerospace sector. Accordingly, this subsection has proposed a novel meta-model supporting the main concepts underpinning Fault Tree Analysis, including common gate and event types and minimal cut set expressions. The model also reflects use within the aerospace industry, notably the assessment process prescribed by ARP 4754/4761. It therefore enables events to be shared between a preliminary fault tree (developed during PSSA) - expressing budget safety requirements - and its updated counterpart intended to show realisation of these requirements (developed during SSA). Event sharing is accomplished by means of 'event profiles' which eradicate much of the redundancy between preliminary and updated trees, whilst helping maintain consistency and increase traceability.

A number of well-formedness constraints were expressed over the logical fault tree structure, together with safety-criteria for identifying common cause and single failures. We also introduced a 'light-weight' approach to the formalisation of event labels by typing events according to a taxonomy from the literature and by specifying their content at a level of granularity that allows for their verification against the Product Data Synthesis.

We demonstrate application of the Fault Tree Analysis meta-model to a case study derived from ARP 4761 in subsection 6.3. This case study will also feature a meta-model for the complementary Failure Modes and Effects Analysis technique to be introduced in the next section. A full evaluation of the Fault Tree meta-model is discussed in Chapter Seven.

5.3 Failure Modes and Effects Analysis Structure

5.3.1 Introduction

In this section we propose a structure capturing elements of Failure Modes and Effects Analysis, a technique that tracks the effects of component or functional failures within a system to determine their ultimate consequences and which like FTA, is also widely used in the aerospace industry.

5.3.2 Motivation

Failure Modes and Effects Analysis (FMEA) was first applied to aeronautics in the 1960s and has since been used, among others, on projects ranging from Concorde to the lunar module (Bussolini, 1971); it continues to be a mainstay of safety assessment for contemporary aircraft (FAA, 2001). Accordingly, a number of aerospace related standards (or guidelines) prescribe procedures for conducting FMEA and FMECA (Failure Modes, Effects *and Criticality* Analysis - an extension to FMEA which also takes into account the importance of each failure), either specifically as in the case of IEC (1985), or as part of the overall safety process (EUROCAE, 1996b). Like Fault Tree Analysis, application of FMEA in the assessment of software has also been well documented (*cf.* Fragola & Spahn, 1973; Reifer, 1979).

Recall from subsection 5.2.2 that Failure Modes and Effects Analysis is an inductive technique in the sense that users are attempting to anticipate potential failures, so their source(s) can be eliminated. It is seen as a complimentary approach to Fault Tree Analysis such that a fault tree used to determine the causes of a particular hazard may utilise failure rates from relevant FMEAs[9]. Since we regard it appropriate to include both deductive and inductive approaches within the MATrA framework, Failure Modes and Effects Analysis serves as our inductive example.

We also stated in 5.2.2 that the results of several safety analysis technique are represented in tabular form. Again, as our aim is to incorporate examples of both graphical (as demonstrated by the previous FTA structure) *and* table-based formats, FMEA provides our example of the latter.

5.3.2.1 Failure Modes and Effects Analysis Overview

As previously indicated, Failure Modes and Effects Analysis allows analysts to investigate potential ways in which individual components or functions within a target system might fail. However, unlike Fault Tree Analysis (whose symbols and element types remain largely standard), a raft of different FMEA analyses with varying procedures, intent and reporting formats have emerged; the corollary being that little commonality exists between the various industries in which they are used. We therefore adhere to the format presented in ARP 4761 for aerospace engineering.

It is common to distinguish two types of FMEA, *functional* (where investigation is of the lowest level assemblies in a system - typically functional or block-diagram level) and *piece-part* (where investigation is at the level of individual components within an assembly). As shown by the case study

[9] Wilson & McDermid (1995) identify a number of interdependencies among safety assessment techniques; for FTA and FMEA these are:- i) basic events exists as effects; ii) probabilities are consistent with rates.

example in ARP 4761 (Appendix L), piece-part analyses are normally performed to refine failure rates produced from functional FMEA that do not allow a system or component to meet FTA budget failure probabilities.

Again procedural issues on conducting both forms of FMEA are outside the scope of this thesis; interested readers are instead referred to (EUROCAE, 1996b) and also to (NASA, 1994). However, a typical process framework will involve the definition of components and operating states, identification of their failure modes, determination of effects and investigation of factors for detection and protection, as well as some basis for making recommendations.

While the content of Failure Modes and Effects Analysis tables differs between industries, certain concepts are standard among all safety[10] related variants; these reflect the template procedure outlined above and include columns recording *component* or *function*, known *failure modes* and the *effects* of each failure. Other columns that may be added include *cause* of failure, *frequency* of occurrence (based on historical data and service experience), *severity* (indicating how serious the failure would be), means for *detection* or mitigating against the failure and finally *comments* and recommendations.

ARP 4761, the FMEA reporting format considered in this thesis, suggests the following as *possible* 'worksheet' columns for functional and piece-part analyses:-

Functional FMEA	Piece-Part FMEA
• function name • failure mode • failure rate • flight phase • failure effect • detection method • comments	• component name • component type • failure mode • failure mode rate • failure effect • detection method • comments

Table 5.3 - 'ARP 4761 Functional and Piece-Part FMEA Contents'

Note: Failure effect codes may be assigned and used in place of effect descriptions to simplify the table presentation. A detailed description of each effect code is then included in the accompanying report.

Table 5.4 contains a Functional FMEA fragment for an aircraft Brake System Control Unit power supply (P/S) which is again taken from ARP 4761.

Function Name	Failure Mode	Flight Phase	Failure Rate (E-6)	Failure Effect	Detection Method	Comments
+5 Volt Power Supply	+5 volt out of spec	All	0.2143	P/S Shutdown	The Power Supply Monitor is tripped.	The channel fails.

Table 5.4 - '(Functional) FMEA Fragment for Break System Control Unit Power Supply'

[10] FMEA also has strong associations with reliability engineering; indeed Leveson (1995) argues it is strictly a reliability analysis that is inappropriate for use in a safety process.

5.3.3 Tracing Safety Properties in MATrA: An FMEA Model

This subsection proposes a meta-model for the representation of tables reporting FMEA results, allowing their integration into the MATrA traceability framework.

5.3.3.1 Concepts

As stated previously, industry variations prevent our developing a definitive FMEA meta-model. Instead we concentrate on supporting the suggested functional and piece-part worksheet formats summarised in table 5.3.

Given that results are table-based, we are able to capture well-formedness of FMEAs using multiplicity constraints expressed over meta-model elements. However, checks verifying consistency of table entries against the Product Data Synthesis *are* necessary and are therefore featured below.

5.3.3.2 FMEA Meta-model Definitions

We now introduce the UML meta-model representing elements of piece-part and functional FMEA tables (5.3.3.2.1), together with OCL constraints to verify table entries against the Product Data Synthesis (5.3.3.2.2) and O-Telos implementation of base classes (5.3.3.2.3).

5.3.3.2.1 FMEA Meta-model

Figures 5.4 (elements) and 5.5a/b (associations) depict the FMEA UML meta-model. Its abstract core class (FailureMode&EffectsAnalysis), with subject module (subject_module) and other configuration attributes instantiates the AssessmentStructure meta-class, as do the functional (FunctionalFMEA) and piece-part (PiecePartFMEA) specialisations. Each is defined as an aggregation of StructureElement meta-classes representing FMEA primitives.

The FailureMode&EffectsAnalysis class is an aggregation of elements common to both functional and piece-part analyses, namely failure modes (FailureMode) and effects (FailureEffect), both of which are defined as specialisations of the built-in String class (not shown). Means to record failure detection and comments are also provided through the MATrA Natural Language Structure (MatraNLS).

Besides the inherited elements described above, a FunctionalFMEA is defined as an aggregation of function identifier (FunctionID), failure rate (FailureRate) and flight phase (FlightPhase) elements. FunctionID and FailureRate specialise String and Real (domain < =1) respectively (again not shown), while FlightPhase is an enumerated type - a specialisation of String, whose instantiations are restricted to 'Taxi', 'Take off to Rotation', 'Landing Roll', 'Rejected Take Off' and 'Climb', etc.; or alternatively, the universal 'All' (i.e., all ground and airborne phases).

FunctionalFMEA also includes a number of classes expressly to preserve grouping of repeated elements within the table format[11]. That is, to relate failure behaviours to functions, and to relate failure modes

[11] This arises from the fact that each function may have many failure modes such that the effects and rates of each failure differ for, and must therefore be grouped by, flight phase; detection is grouped on the basis of mode rather than flight phase.

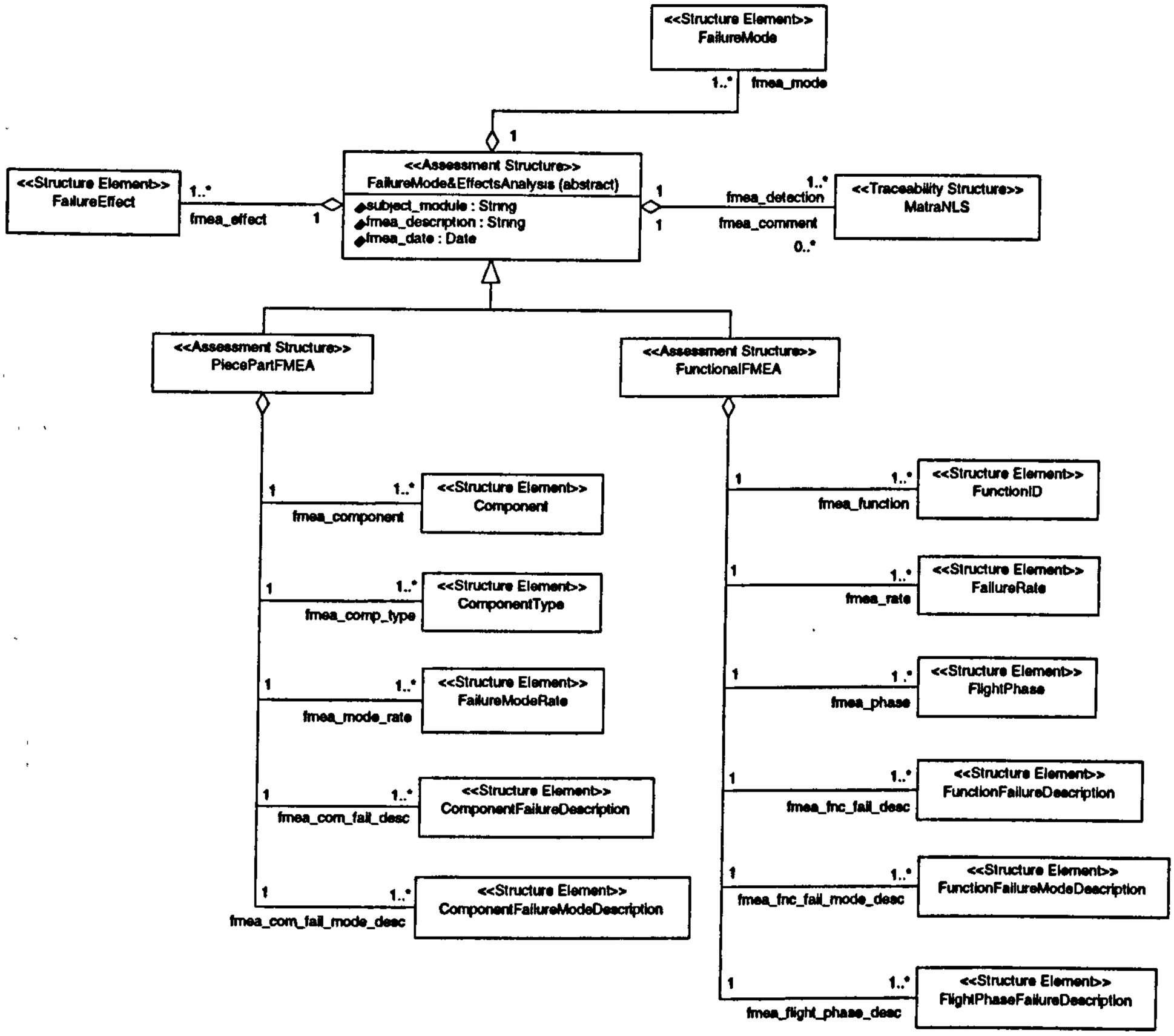


Figure 5.4 - 'FMEA Structure : Elements'

to effects and rates of occurrence for each flight phase. Thus, a FunctionalFMEA is described as an aggregation of function failure descriptions (FunctionFailureDescription) which in turn comprise a single FunctionID and one or more function failure *mode* descriptions (FunctionFailureModeDescription). Accordingly, instances of the latter include a single FailureMode and one or more flight phase failure descriptions (FlightPhaseFailureDescription) allowing the effects (FailureEffect) and rate (FailureRate) of failures to be described by flight phase.

Likewise, in addition to common FMEA elements, a PiecePartFMEA includes String class specialisations (again not shown) for component (Component), and component type (ComponentType), together with the failure mode rate (FailureModeRate) element - a subtype of Real also in range < =1 (not shown).

As with its functional counterpart, the PiecePartFMEA further includes classes to preserve grouping within tables; each component can have many failure modes, which in turn can have many effects. Therefore, a PiecePartFMEA is as an aggregation of component failure descriptions (ComponentFailureDescription) with (single) Component and ComponentType elements and one or more component failure *mode* descriptions (ComponentFailureModeDescription); the latter includes single FailureMode and FailureModeRate and, one or more FailureEffect elements.

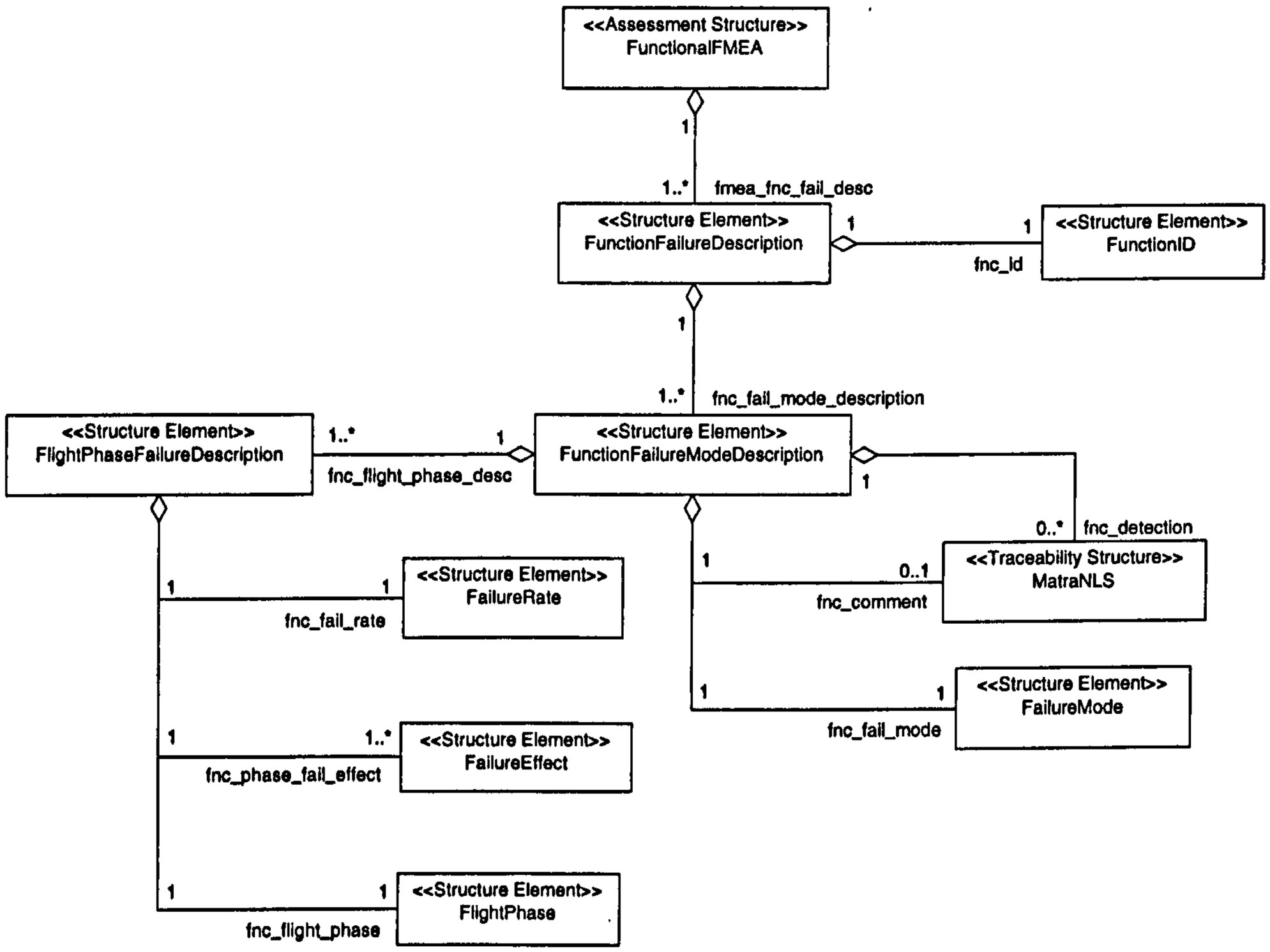


Figure 5.5 -a - 'Functional FMEA Structure : Associations'

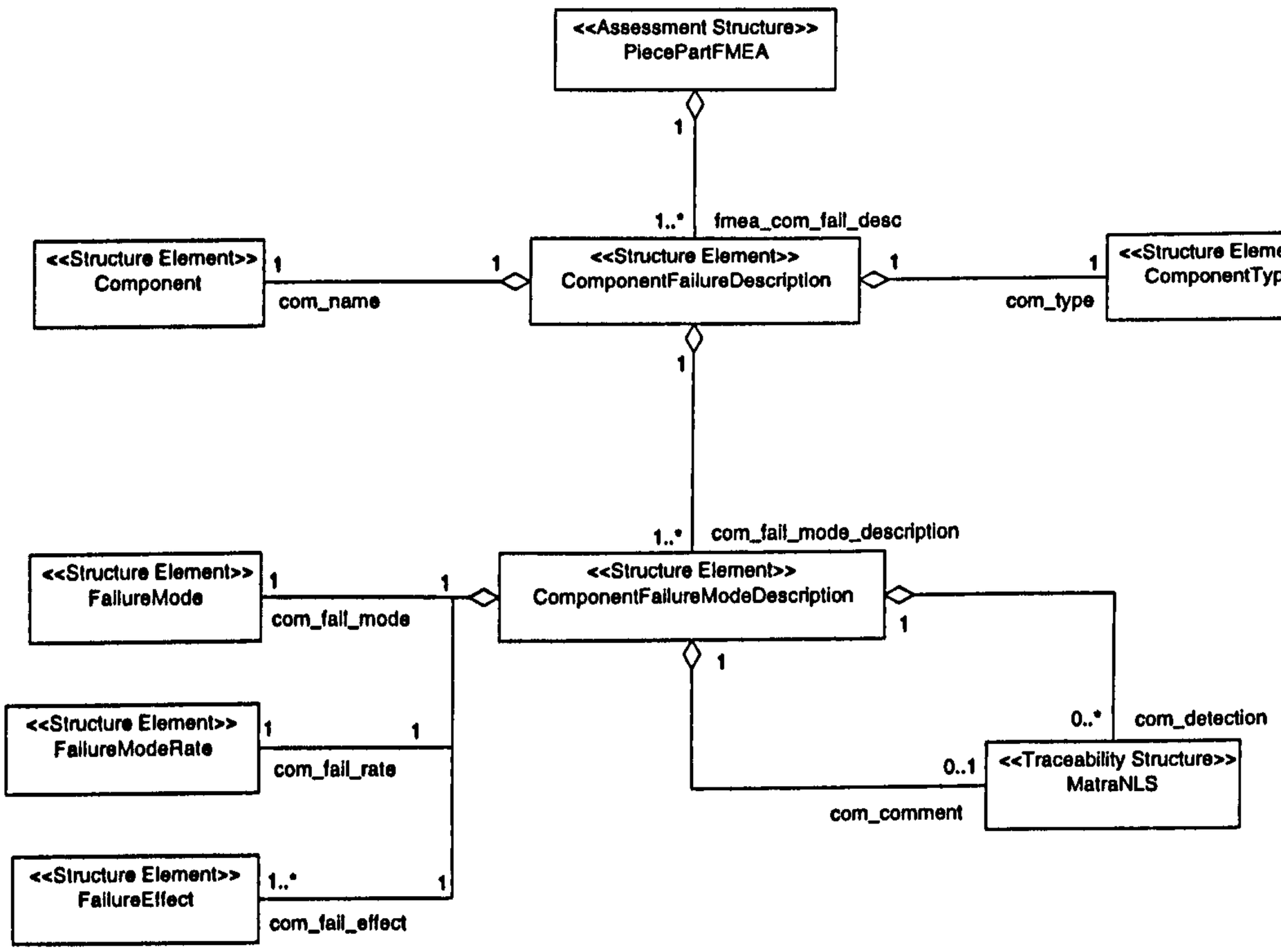


Figure 5.5 -b - 'Piece-Part FMEA Structure Associations'

5.3.3.2.2 OCL Constraints

The tabular format in which results of Failure Modes and Effects Analyses are presented and our ability to preserve this structure through the models presented in subsection 5.3.3.2.1 means that no well-formedness constraints are necessary. However, a number of checks verifying FMEA elements against the Product Data Synthesis may be defined as follows:-

1. The FMEA subject_module exists in the PDS.

FailureMode&EffectsAnalysis **invariant**
self.allInstances->forall(f | self.bEmodelAEO.build_element->exists (be | f.subject_module = be.module_name))

2. a) PiecePartFMEA table components exist in the PDS as sub-modules of the subject_module (a) and FunctionalFMEA identifiers exist in the PDS as functions encapsulated by the subject_module (b).

a)
Component **invariant**
self.allInstances->forall(c |
self.bEelementAEO.build_element->exists(m |
self.piecePartFMEA.bEmodelAEO.build_element->exists(be |
be.module_name = c.piecePartFMEA.subject_module and
c = m.module_name and
be.hasSubmodule.target->includes(m))))

b)
FunctionID **invariant**
self.allInstances->forall(f |
self.bEelementAEO.build_element->exists(e |
self.functionalFMEA.bEmodelAEO.build_element->exists(be |
be.module_name = f.functionalFMEA.subject_module and
f = e.function_name and
be.encapsulates.target->includes(e))))

3. For components (a) and functions (b), failure modes map to Conditions of the corresponding PDS Module or Function.

(a)
FailureMode **invariant**
self.allInstances->select(self.piecePartFMEA->size = 1)->forall(f |
self.bEelementAEO.build_element->exists(c |
self.piecePartFMEA.bEmodelAEO.build_element->exists(be |
self.piecePartFMEA.bEmodelAEO.build_element.hasSubmodule.target->exists(m |
f.piecePartFMEA.subject_module = be.module_name and
be.hasSubmodule.target->includes(m) and
m.module_name = f.componentFailureModeDescription.componentFailureDescription.com_name and
m.hasCondition.target->includes(c) and f = c.condition.label))))

(b)
FailureMode **invariant**
self.allInstances->select(self.functionalFMEA->size = 1)->forall(f |
self.bEelementAEO.build_element->exists(c |
self.functionalFMEA.bEmodelAEO.build_element->exists(be |
self.functionalFMEA.bEmodelAEO.build_element.encapsulates.target->exists(p |
f.functionalFMEA.subject_module = be.module_name and

be.encapsulates.target->includes(p) and
p.function_name = f.functionFailureModeDescription.functionFailureDescription.fnc_id and
p.hasCondition.target->includes(c) and f = c.condition.label))))

4. The PDS contains conditions corresponding to (a) component or (b) function failure effects; these may be effects on the same Module or Function over which the causal FailureMode is expressed, or else on another Module or Function within the same host (i.e., subject_module), or else effects impacting on the subject_module itself (note this is not an invariant).

a)
FailureEffect
self.allInstances->select(self.piecePartFMEA->size =1)->forall(e |
self.bEelementAEO.build_element->exists(c |
self.piecePartFMEA.bEmodelAEO.build_element->exists(be |
self.piecePartFMEA.bEmodelAEO.build_element.hasSubmodule.target->exists(m |
self.piecePartFMEA.bEmodelAEO.build_element.hasSubmodule.target.hasCondition.target->exists(c' |
self.piecePartFMEA.bEmodelAEO.build_element.hasSubmodule.target->exists(m' |
e.piecePartFMEA.subject_module = be.module_name and
be.hasSubmodule.target->includes(m) and
m.module_name = e.componentFailureModeDescription.componentFailureDescription.com_name and
m.hasCondition.target->includes(c') and
c'.condition_label = e.componentFailureModeDescription.com_fail_mode and
(be.hasCondition.target->includes(c) or m.hasCondition.target->includes(c) or
be.hasSubmodule.target->includes(m') and m'.hasCondition.target->includes(c)) and
e = c.condition_label and c'.leadsTo.target->includes(c)))))))

b)
FailureEffect
self.allInstances->select(self.functionalFMEA->size =1)->forall(e |
self.bEelementAEO.build_element->exists(c |
self.functionalFMEA.bEmodelAEO.build_element->exists(be |
self.functionalFMEA.bEmodelAEO.build_element.encapsulates.target->exists(p |
self.functionalFMEA.bEmodelAEO.build_element.encapsulates.target.hasCondition.target->exists(c' |
self.functionalFMEA.bEmodelAEO.build_element.encapsulates.target->exists(p' |
e.functionalFMEA.subject_module = be.module_name and
be.encapsulates.target->includes(p) and
p.function_name =
e. flightPhaseFailureDescription.functionFailureModeDescription.functionFailureDescription.fnc_id and
p.hasCondition.target->includes(c') and
c'.condition_label = e.flightPhaseFailureDescription.functionFailureModeDescription.fnc_fail_mode and
(be.hasCondition.target->includes(c) or p.hasCondition.target->includes(c) or
be.encapsulates.target->includes(p') and p'.hasCondition.target->includes(c)) and
e = c.condition_label and c'.leadsTo.target->includes(c)))))))

5.3.3.2.3 O-Telos Implementation of FMEA Base Classes

The following O-Telos code implements FMEA meta-model base class elements.

```
Definition of Structure Elements
Component in StructureElement,
SimpleClass isA String,
AerospaceEngineeringObject end

ComponentType in StructureElement,
SimpleClass isA String,
AerospaceEngineeringObject end

FailureModeRate in StructureElement,
SimpleClass isA Real,
AerospaceEngineeringObject with
constraint
fmr_in_range: $ forall f/
FailureModeRate (f <= 1)$
end

FailureMode in StructureElement,
SimpleClass isA String,
AerospaceEngineeringObject end
```

```
FailureEffect in StructureElement,
SimpleClass isA String,
AerospaceEngineeringObject end

FunctionID in StructureElement,
SimpleClass isA String,
AerospaceEngineeringObject end

FailureRate in StructureElement,
SimpleClass isA Real,
AerospaceEngineeringObject with
constraint
fr_in_range: $ forall f/ FailureRate
(f <= 1)$
end

FlightPhase in StructureElement,
SimpleClass isA String,
AerospaceEngineeringObject with
constraint
enum_Phase: $ forall f/FlightPhase
(f = "Taxi") or (f = "Takeoff To
Rotation") or (f = "Landing Roll") or
(f = "Rejected Takeoff") or (f =
"Climb") or (f = "All")$
end

FunctionFailureDescription in
StructureElement, SimpleClass isA
AerospaceEngineeringObject with
has_part
    fnc_id : FunctionID;
    fnc_fail_mode_description :
FunctionFailureModeDescription
end

FunctionFailureModeDescription in
StructureElement, SimpleClass isA
AerospaceEngineeringObject with
has_part
    fnc_fail_mode : FailureMode;
    fnc_flight_phase_desc :
FlightPhaseFailureDescription
has_structure
    fnc_detection :
MatraNaturalLanguageStructure;
    fnc_comment :
MatraNaturalLanguageStructure
end

FlightPhaseFailureDescription in
StructureElement, SimpleClass isA
AerospaceEngineeringObject with
has_part
    fnc_flight_phase : FlightPhase;
    fnc_fail_rate : FailureRate;
    fnc_phase_fail_effect :
FailureEffect
end

ComponentFailureDescription in
StructureElement, SimpleClass isA
AerospaceEngineeringObject with
has_part
    com_name : Component;
    com_type : ComponentType;
    com_fail_mode_description :
ComponentFailureModeDescription
end

ComponentFailureModeDescription in
StructureElement, SimpleClass isA
AerospaceEngineeringObject with
has_part
    com_fail_mode : FailureMode;
    com_fail_rate : FailureModeRate;
    com_fail_effect :  FailureEffect
has_structure
    com_detection :
MatraNaturalLanguageStructure;
    com_comment :
MatraNaturalLanguageStructure
end
```

Definition of FailureMode&EffectsAnalysis Structure

```
FailureMode&EffectsAnalysis in
AssessmentStructure, SimpleClass isA
AerospaceEngineeringObject with
has_property
    subject_module : String;
    fmea_description: String;
    fmea_date : Date
has_structure
    fmea_detection :
MatraNaturalLanguageStructure;
    fmea_comment :
MatraNaturalLanguageStructure
has_element
    fmea_mode : FailureMode;
    fmea_effect : FailureEffect
constraint
    abstract_FMEA: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in
FailureMode&EffectsAnalysis)$
end

FunctionalFMEA in AssessmentStructure,
SimpleClass isA
FailureMode&EffectsAnalysis with
has_element
    fmea_fnc_fail_desc :
FunctionFailureDescription;
    fmea_fnc_fail_mode_desc :
FunctionFailureModeDescription;
    fmea_flight_phase_desc :
FlightPhaseFailureDescription;
    fmea_function : FunctionID;
    fmea_rate : FailureRate;
    fmea_phase : FlightPhase
end

PiecePartFMEA in in
AssessmentStructure, SimpleClass isA
FailureMode&EffectsAnalysis with
has_element
    fmea_com_fail_desc :
ComponentFailureDescription;
    fmea_com_fail_mode_desc :
ComponentFailureModeDescription;
    fmea_component : Component;
    fmea_comp_type : ComponentType;
    fmea_mode_rate : FailureModeRate
end
```

5.3.4 Relationship to the Traceability Dimensions

The case study in subsection 6.3 demonstrates traceability between development and assessment artifacts; in particular it shows how components from a Circuit Diagram trace to corresponding entries in FMEA tables. Such relationships constitute intra-micro vertical traceability; intra-micro in the sense

that the Circuit Diagram and FMEA table both concern the same system and level of decomposition and vertical since traceability is between artifacts of different types (development and assessment). Moreover, effects of each failure from the FMEA table may trace to basic events of fault trees; where for instance both artifacts form part of System Safety Assessment, such relationships are located on the (intra-micro) horizontal axis, as are relationships between piece-part and functional FMEAs.

5.3.5 Summary

Failure Modes and Effects Analysis has been widely used throughout the aerospace sector for nigh on forty years. Accordingly, its inclusion within the MATrA traceability framework allows us to demonstrate support for an inductive safety technique whose results are recorded in tabular form (as opposed to the hitherto featured graphical, prose or program code structures).

A novel meta-model was proposed capturing elements for both functional and piece-part FMEA formats as prescribed in the ARP 4761 guidelines for safety assessment of civil airborne systems and equipment. A set of mapping rules over the model for verifying table entries against the Product Data Synthesis was also introduced.

Section 6.3 features a contiguous case study demonstrating use of the FMEA structure (in conjunction with Fault Tree Analysis and Circuit Diagram structures), whilst a full evaluation is again provided in Chapter Seven.

5.4 Programme Evaluation & Review Technique Structure

5.4.1 Introduction

In this section we introduce our final notation meta-model. The proposed structure captures the graphical syntax of the Programme Evaluation & Review Technique which represents inter-relationships between the timing of events and project activities in the form of a network.

5.4.2 Motivation

The Programme Evaluation & Review Technique (PERT) aids in the management, planning and control of projects. It was devised by the United States Navy during the 1950s in an attempt to cut project lead times and is credited with subsequently saving two years in development of the Polaris missile system. PERT graphically demonstrates inter-relationship between the various tasks making up a project, clearly identifying its 'critical' parts. According to Lucey (1992), the technique is most beneficial and so normally applied to projects that are large, complex and subject to various time and cost constraints - characteristics common to projects in the aerospace industry. Moreover, potential usage within that particular sector is life-cycle wide, ranging from the management of requirements and design activities, to scheduling of aircraft maintenance tasks.

Aside from its relevance to our domain of interest, we are also motivated in featuring PERT by a desire to cover all categories of notation and technique used by aerospace practitioners (development and assessment having being covered in Chapter Four and previous sections of Chapter Five respectively).

5.4.2.1 Programme Evaluation & Review Technique Overview

Two types of element are fundamental to all PERT networks; activities (or 'basic activities') - denoted as arcs (and labeled with a shortened description, or alpha-numeric code) - are tasks which take time and resources to perform. The head of an arc indicates the point at which a task ends and the tail, where it begins. We note that arcs are normally drawn from left to right and that they imply precedence only; i.e., length is not proportional to duration.

The other main constituent of PERT networks are events - denoted as circles or *nodes* (and progressively labeled with integer sequence numbers, together with an optional descriptor) - which mark the point in time an activity or activities start or finish (i.e., they represent the achievement of a specific stage of a project).

In addition to basic activities and events, networks can also include the notion of 'dummy activities' - denoted as broken or dotted arcs. These consume neither time nor resources, but rather show logical dependencies between activities, either to preserve precedence (as is the case with examples featured in this thesis), or to prevent the breach of rules for drawing networks (Lucey, ibid.). Of these rules, the principal structural constraints are as follows:-

- A network should have a single point of entry *or* start event and single point of exit *or* finish event.

- Every activity must have one preceding *or* 'tail' event and one succeeding *or* 'head' event; many activities may share the same head event or the same tail event, although no activity can share both the same tail and head event. Dummy activities are used to preserve this constraint.
- Cycles or series of activities leading back to the same event are not permissible since a founding tenet of networks is that they indicate the progression of activities onwards in time.

As shown in figure 5.6, a PERT network is the combination of activities, dummy activities and events in logical sequence according to the constraints outlined above:-

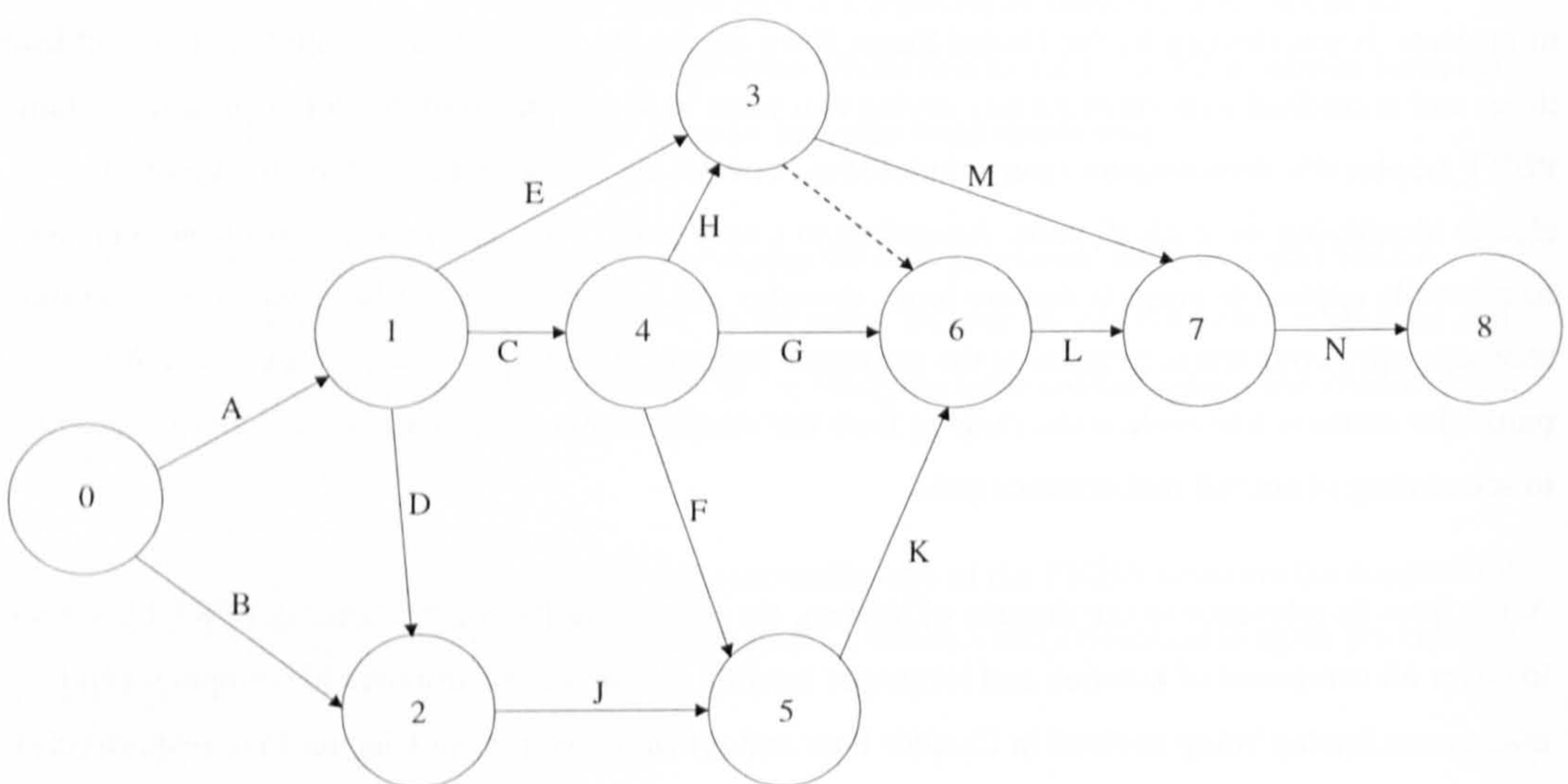


Figure 5.6 - 'Example of a Basic PERT Network'

The logical sequence for the network in figure 5.6 is summarised in table 5.5. Note, a dummy activity (3-6) is used because of the preceding activity requirements of activity L; if activities E and H were not specified to precede this activity, then the dummy would not be necessary.

Activity	Preceding Activity	Activity	Preceding Activity	Activity	Preceding Activity
A	-	F	C	L	E, H, G, K
B	-	G	C	M	E, H
C	A	H	C	N	L, M
D	A	J	B, D	-	-
E	A	K	F, J	-	-

Table 5.5 - 'Activities & Relationships for Basic PERT Network'

Once the network logic has been established, activity durations can then be added enabling the overall completion time for a project to be established and its *critical path* calculated; i.e., the shortest time in which a project can be completed based on the chain of activities with longest duration times. This may or may not run through dummies.

In order to assess total project time, it is necessary to specify the Earliest and Latest Start Times (EST/LST) for each activity. The EST is the earliest point at which a succeeding activity can start; for a head event this is calculated by adding onto the EST of the tail event, its linking activity duration. Where two or more routes feed into an event, the longest route time is taken. This practice is repeated from event zero at time point zero, onwards to the end of the network (termed a forward pass).

The critical path is established by calculating LSTs for each activity. In other words, the latest time a preceding activity can finish without increasing the duration. Calculating Latest Start Times involves starting at the finish event and working backwards through the network, deducting each activity duration from the previously calculated LST (termed a backward pass). Where two or more activities lead from an event, then the lowest number is taken. Activities on the critical path are normally indicated by two small traverse lines placed across their arcs (note also that ESTs and LSTs for each head and tail event on the critical path are identical). These refinements are illustrated in figure 5.7.

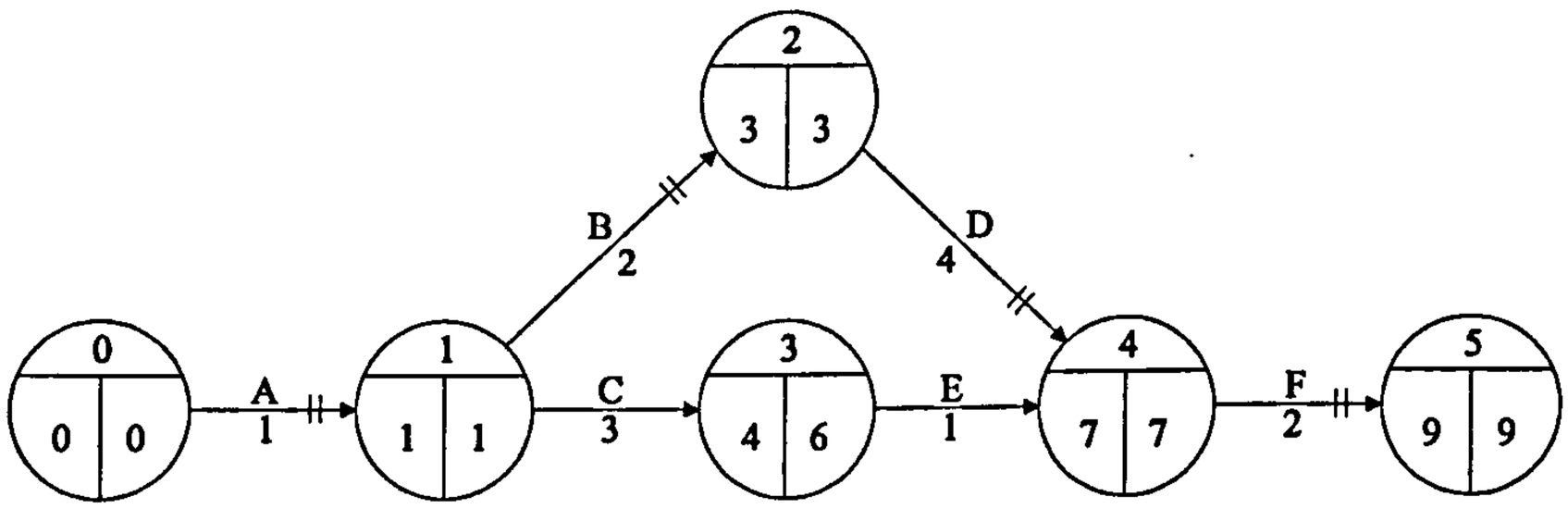


Figure 5.7 - 'Example of a PERT Network - Time Analysis'

In addition to enforcing structural constraints and determining the critical path, tools supporting the drawing of PERT networks often allow annotation of activities with the type and quantity of each resource they consume. Alternatively, this information may be shown separately as a table.

5.4.3 Tracing Programme Evaluation & Review Technique Networks in MATrA: A PERT Model

In this subsection we propose a meta-model for the representation of PERT networks, allowing their integration into the MATrA traceability framework.

5.4.3.1 Concepts

Our meta-model for the Programme Evaluation & Review Technique captures the graphical syntax described in 5.4.2.1. Hence it contains elements representing activities (both dummy and basic) and events (including earliest and latest start times); activities may also be annotated with the resources they consume.

A selection of OCL constraints expressing the semantics of the rules stated (informally) in 5.4.2.1 are also specified. These govern both the drawing of networks, verification of earliest and latest start-times and derivation of the critical path.

5.4.3.2 PERT Meta-model Definitions

This subsection introduces the UML class diagram representing our PERT meta-model (5.4.3.2.1), together with OCL constraints (5.4.3.2.2) and O-Telos implementation of base classes (5.4.3.2.3).

5.4.3.2.1 PERT Meta-model

Figures 5.8 depicts elements and associations of the Programme Evaluation & Review Technique meta-model. Its core class, ProgrammeEvaluationReviewTechnique with subject module (subject_module), model name (model_name) and other configuration attributes instantiates the ProductManagementStructure meta-class.

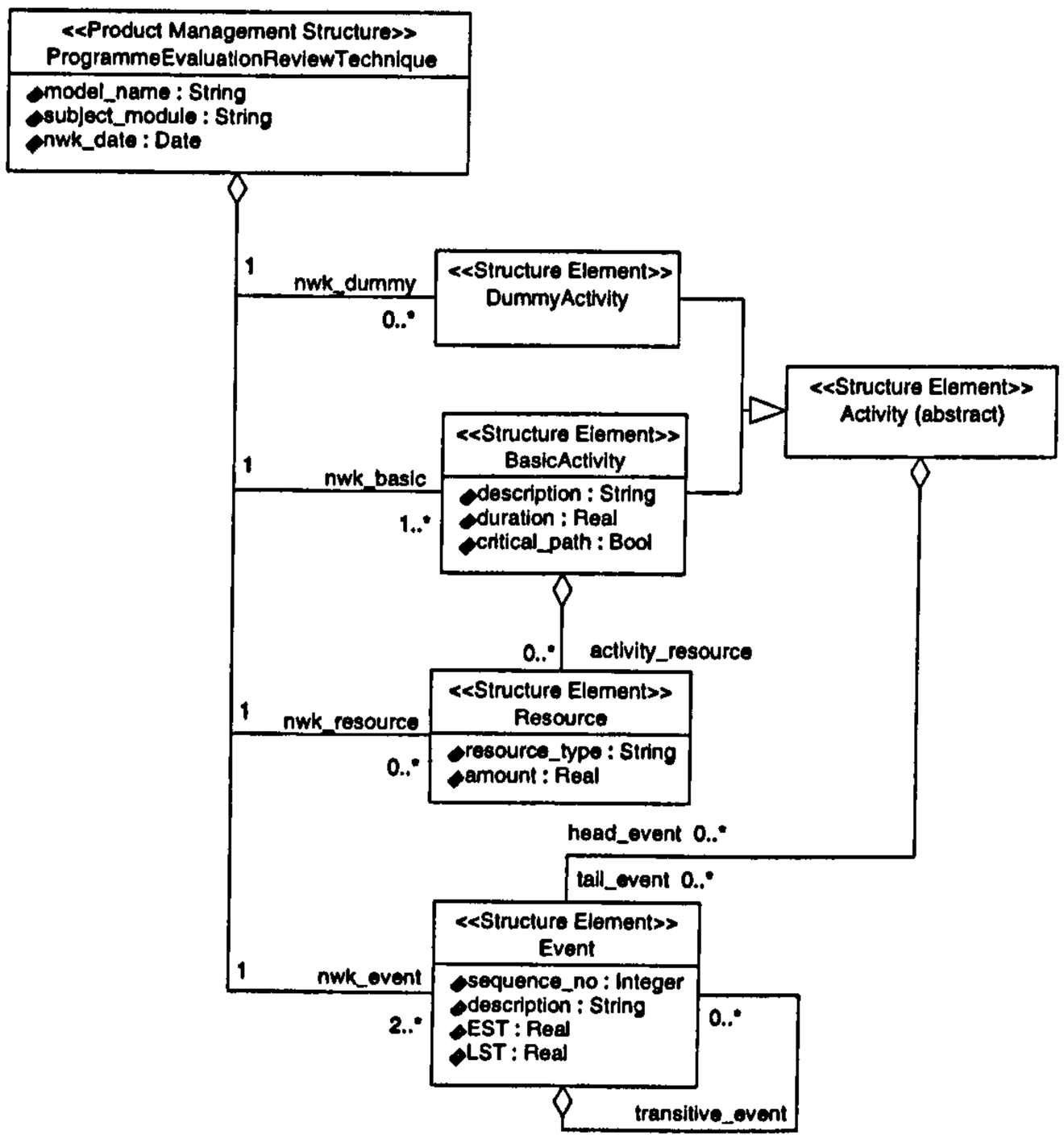


Figure 5.8 - 'Programme Evaluation & Review Technique Structure : Elements and Associations'

A ProgrammeEvaluationReviewTechnique structure is defined as an aggregation of zero-or-more dummy activities (DummyActivity), one-or-more basic activities (BasicActivity) and two-or-more events (Event). Both DummyActivity and BasicActivity are specialisations of the abstract activity (Activity) class which for ease of manipulation, factors the common head event (head_event) and tail event (tail_event) aggregation associations into a general supertype. Basic activities have attributes for description and duration, as well as a boolean critical path (critical_path) indicator; they may also be described in terms of resources (Resource), with resource_type (resource_type) and amount attributes.

The Event class contains sequence number (sequence_no) and description, together with earliest start time (EST) and latest start time (LST) attributes; a reflexive association (transitive_event) allows for recording

of transitive closure events and exists to prevent cycles in networks using an appropriate constraint (as shown in the following subsection).

5.4.3.2.2 OCL Constraints

The following constraints are expressed over the UML meta-model described above and based on the informal restrictions stated in 5.4.2.1:-

1. A network must have only one entry point.

ProgrammeEvaluationReviewTechnique **invariant**
self.allInstances->forall(p |
(p.nwk_dummy.tail_event->union(p.nwk_basic.tail_event)) -
(p.nwk_dummy.head_event->union(p.nwk_basic.head_event))->size = 1)

2. A network must have only one exit point.

ProgrammeEvaluationReviewTechnique **invariant**
self.allInstances->forall(p |
(p.nwk_dummy.head_event->union(p.nwk_basic.head_event)) -
(p.nwk_dummy.tail_event->union(p.nwk_basic.tail_event))->size = 1)

3. No two network activities share the same head and tail events.

Activity **invariant**
self.allInstances->forall(a1, a2 |
not(a1.tail_event = a2.tail_event and
a1.head_event = a2.head_event and a1 <> a2))

4. A network must not contain any 'cycles'.

- rule for determining transitive closure of events

Event
self.allInstances->forall(e1, e2 | self.activity->exists(a1 | a1.tail_event = e1 and a1.head_event = e2) or
self.allInstances->exists(e3 | self.activity->exists (a2 | a2.tail_event = e1 and a2.head_event = e3 and
e3.transitive_event->includes(e2)))) implies e1.transitive_event->includes(e2)

- constraint to prevent cycles within networks

Event **invariant**
self.allInstances->forall(e | not (e.transitive_event->includes(e)))

5. Earliest Start Times (EST) are correct:-

a) where two events are connected by an Activity, the head event EST is calculated by adding onto the EST of the tail event, the duration of the Activity.

Event **invariant**
self.allInstances->forall(e->reject(self.activity.tail_event->not exists(e' | e.activity.tail_event->includes(e'))) |
self.activity->select(self.activity.oclType = BasicActivity)->exists(a |
a.head_event->includes(e) and e.EST = (a.tail_event.EST + a.duration)))

b) where two or more routes arrive at an Event, the longest route time is taken.

Event **Invariant**
self.allInstances->forall(e |
self.activity->select(self.activity.oclType = BasicActivity)->forall(a |
not (a.head_event->includes(e) and e.EST < (a.tail_event.EST + a.duration))))

6. Latest Start Times (LST) are correct:-

a) where two events are connected by an Activity, the tail event LST is calculated by subtracting from the LST of the head event, the duration of the Activity.

Event **Invariant**
self.allInstances->forall(e->reject(self.activity.head_event->not exists(e' | e.activity.head_event->includes(e'))) |
self.activity->select(self.activity.oclType = BasicActivity)->exists(a |
a.tail_event->includes(e) and e.LST = (a.head_event.LST - a.duration)))

b) where the tails of two or more activities join an Event, the shortest route time is taken.

Event **Invariant**
self.allInstances->forall(e |
self.activity->select(self.activity.oclType = BasicActivity)->forall(a |
not (a.tail_event->includes(e) and e.LST > (a.head_event.LST - a.duration))))

7. Rule to identify critical path activities (based on ESTs and LSTs verified by rules 5 and 6).

BasicActivity
self.allInstances->forall(a |
a.tail_event.EST = a.tail_event.LST and
a.head_event.EST = a.head_event.LST
implies
a.critical_path = True)

Note : we do not specify a constraint verifying the subject_module attribute of the ProgrammeEvaluationReviewTechnique class against the PDS as similar rules have been stated for previous models.

5.4.3.2.3 O-Telos Implementation of PERT Base Classes

The following O-Telos code implements the PERT meta-model base class elements.

```
ProgrammeEvaluationReviewTechnique in
ProductManagementStructure, SimpleClass
isA AerospaceEngineeringObject with
has_property
    model_name : String;
    subject_module : String;
    nwk_date : Date
has_element
    nwk_dummy : DummyActivity;
    nwk_basic : BasicActivity;
    nwk_resource : Resource;
    nwk_event : Event
end

Activity in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_part
    tail_event : Event;
    head_event : Event
abstract_Act: $forall t/Token
s/SimpleClass
    (t in s) ==> not (t in Activity) $
end

DummyActivity in StructureElement,
SimpleClass isA Activity end

BasicActivity in StructureElement,
SimpleClass isA Activity with
has_property
    description : String;
    duration : Real;
    critical_path : Bool
```

```
has_part
    activity_resource : Resource
end

Resource in StructureElement,
SimpleClass isA
AerospaceEngineeringObject with
has_property
    resource_type : String;
    amount : Real
end
```

```
Event in StructureElement, SimpleClass
isA AerospaceEngineeringObject with
has_property
    sequence_no : Integer;
    description : String;
    est : Real;
    lst : Real
has_transitive_part
    transitive_event : Event
end
```

5.4.3.3 PERT Worked Example

To illustrate the PERT meta-model, we revisit an example introduced in subsection 5.4.2.1 (figure 5.6). This network has been revised - as shown in figure 5.9 - with the addition of timing properties and the critical path (activities A, C, G, L, N with a duration of 29 days).

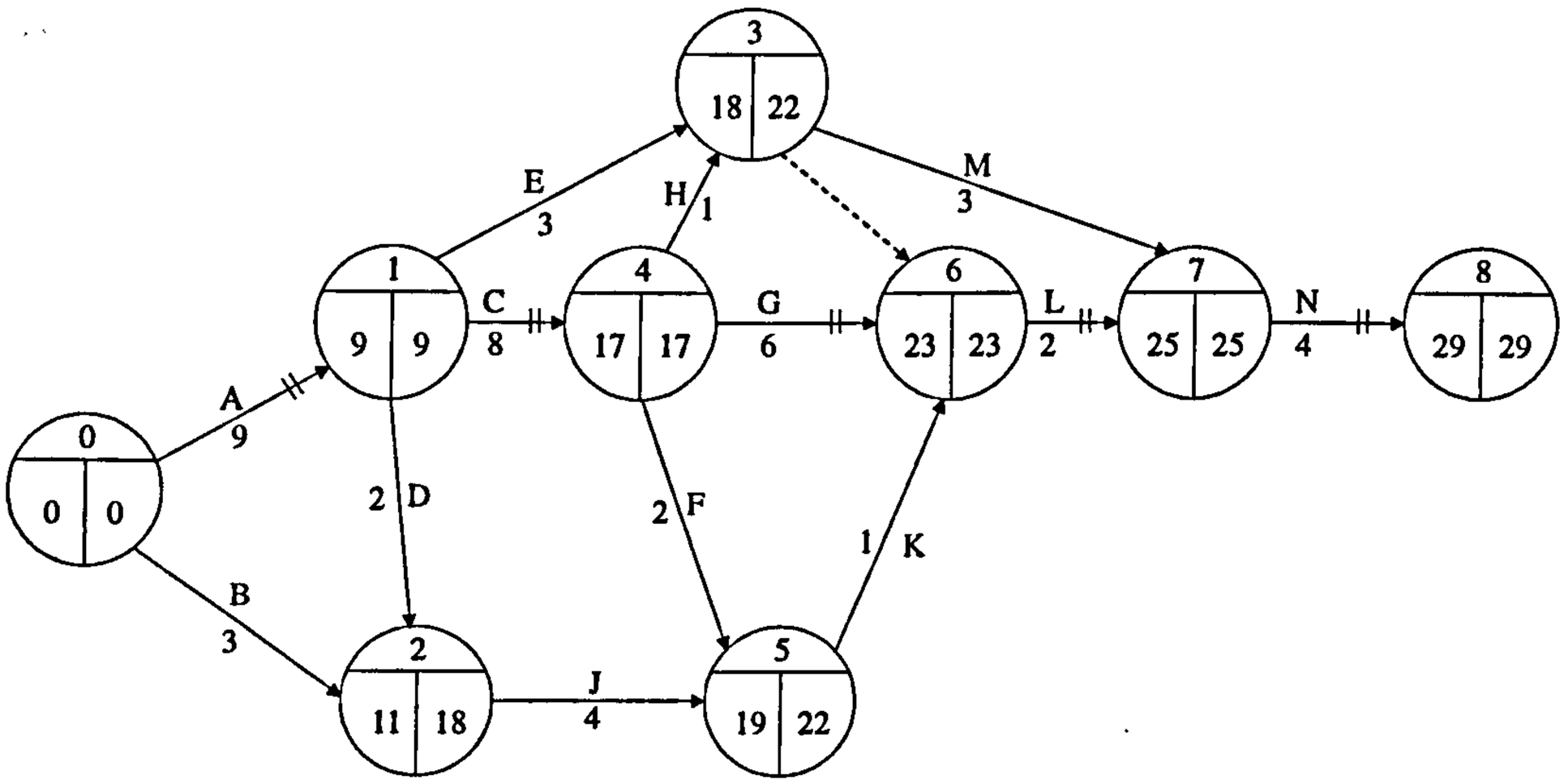


Figure 5.9 - 'PERT Network - Worked Example'

O-Telos instantiation of the PERT meta-model capturing information contained in figure 5.9 (together with additional data on resource usage) is as follows:-

```
Instantiation of Programme Evaluation
Review Technique Structure

Event0 in Event, Token with
sequence_no
    sequenceNo : 0
est
    EST : 0
lst
    LST : 0
end

Event1 in Event, Token with
sequence_no
    sequenceNo : 1
est
    EST : 9
lst
    LST : 9
end
```

```
Event2 in Event, Token with
sequence_no
    sequenceNo : 2
est
    EST : 11
lst
    LST : 18
end

Event3 in Event, Token with
sequence_no
    sequenceNo : 3
est
    EST : 18
lst
    LST : 22
end

Event4 in Event, Token with
sequence_no
    sequenceNo : 4
```

```
est
    EST : 17
lst
    LST : 17
end

Event5 in Event, Token with
sequence_no
    sequenceNo : 5
est
    EST : 19
lst
    LST : 22
end

Event6 in Event, Token with
sequence_no
    sequenceNo : 6
est
    EST : 23
lst
    LST : 23
end

Event7 in Event, Token with
sequence_no
    sequenceNo : 7
est
    EST : 25
lst
    LST : 25
end

Event8 in Event, Token with
sequence_no
    sequenceNo : 8
est
    EST : 29
lst
    LST : 29
end

ActivityA in BasicActivity, Token with
description
    Description : "A"
duration
    Duration : 9
critical_path
    criticalPath : True
tail_event
    tailEvent : Event0
head_event
    headEvent : Event1
activity_resource
    activityResource : ActivityAResource
end

ActivityB in BasicActivity, Token with
description
    Description : "B"
duration
    Duration : 3
critical_path
    criticalPath : False
tail_event
    tailEvent : Event0
head_event
    headEvent : Event2
activity_resource
    activityResource : ActivityBResource
end

ActivityC in BasicActivity, Token with
description
    Description : "C"
duration
    Duration : 8
critical_path
    criticalPath : True
tail_event
    tailEvent : Event1
head_event
    headEvent : Event4
activity_resource
    activityResource : ActivityCResource
end

ActivityD in BasicActivity, Token with
description
    Description : "D"
duration
    Duration : 2
critical_path
    criticalPath : False
tail_event
    tailEvent : Event1
head_event
    headEvent : Event2
activity_resource
    activityResource : ActivityDResource
end

ActivityE in BasicActivity, Token with
description
    Description : "E"
duration
    Duration : 3
critical_path
    criticalPath : False
tail_event
    tailEvent : Event1
head_event
    headEvent : Event3
activity_resource
    activityResource : ActivityEResource
end

ActivityF in BasicActivity, Token with
description
    Description : "F"
duration
    Duration : 2
critical_path
    criticalPath : False
tail_event
    tailEvent : Event4
head_event
    headEvent : Event5
activity_resource
    activityResource : ActivityFResource
end

ActivityG in BasicActivity, Token with
description
    Description : "G"
duration
    Duration : 6
critical_path
    criticalPath : True
tail_event
    tailEvent : Event4
head_event
    headEvent : Event6
activity_resource
    activityResource : ActivityGResource
end

ActivityH in BasicActivity, Token with
description
    Description : "H"
duration
    Duration : 1
critical_path
    criticalPath : False
tail_event
    tailEvent : Event4
head_event
    headEvent : Event3
activity_resource
    activityResource : ActivityHResource
end
```

```
ActivityJ in BasicActivity, Token with
description
    Description : "J"
duration
    Duration : 4
critical_path
    criticalPath : False
tail_event
    tailEvent : Event2
head_event
    headEvent : Event5
activity_resource
    activityResource : ActivityJResource
end

ActivityK in BasicActivity, Token with
description
    Description : "K"
duration
    Duration : 1
critical_path
    criticalPath : False
tail_event
    tailEvent : Event5
head_event
    headEvent : Event6
activity_resource
    activityResource : ActivityKResource
end

ActivityL in BasicActivity, Token with
description
    Description : "L"
duration
    Duration : 2
critical_path
    criticalPath : True
tail_event
    tailEvent : Event6
head_event
    headEvent : Event7
activity_resource
    activityResource : ActivityLResource
end

ActivityM in BasicActivity, Token with
description
    Description : "M"
duration
    Duration : 3
critical_path
    criticalPath : False
tail_event
    tailEvent : Event3
head_event
    headEvent : Event7
activity_resource
    activityResource : ActivityMResource
end

ActivityN in BasicActivity, Token with
description
    Description : "N"
duration
    Duration : 4
critical_path
    criticalPath : True
tail_event
    tailEvent : Event7
head_event
    headEvent : Event8
activity_resource
    activityResource : ActivityNResource
end

DummyActivity3to6 in DummyActivity,
Token with
tail_event
    tailEvent : Event3
head_event
    headEvent : Event6
end

ActivityAResource in Resource, Token
with
resource_type
    resourceType : "labour"
amount
    Amount : 20
end

ActivityBResource in Resource, Token
with
resource_type
    resourceType : "labour"
amount
    Amount : 10
end

ActivityCResource in Resource, Token
with
resource_type
    resourceType : "labour"
amount
    Amount : 10
end

ActivityDResource in Resource, Token
with
resource_type
    resourceType : "labour"
amount
    Amount : 10
end

ActivityEResource in Resource, Token
with
resource_type
    resourceType : "labour"
amount
    Amount : 20
end

ActivityFResource in Resource, Token
with
resource_type
    resourceType : "labour"
amount
    Amount : 10
end

ActivityGResource in Resource, Token
with
resource_type
    resourceType : "labour"
amount
    Amount : 20
end

ActivityHResource in Resource, Token
with
resource_type
    resourceType : "labour"
amount
    Amount : 5
end

ActivityJResource in Resource, Token
with
resource_type
    resourceType : "labour"
amount
    Amount : 5
end

ActivityKResource in Resource, Token
with
resource_type
    resourceType : "labour"
amount
    Amount : 5
end
```

```
ActivityLResource in Resource, Token
with
resource_type
    resourceType : "labour"
amount
    Amount : 20
end

ActivityMResource in Resource, Token
with
resource_type
    resourceType : "labour"
amount
    Amount : 10
end

ActivityNResource in Resource, Token
with
resource_type
    resourceType : "labour"
amount
    Amount : 20
end

PERTExample in
ProgrammeEvaluationReviewTechnique,
Token with
model_name
    modelName : "Sample Network"
subject_module
    subjectModule : "Sample Module"
nwk_dummy
    nwkDummy1 : DummyActivity3to6
nwk_basic
    nwkBasic1 : ActivityA;
    nwkBasic2 : ActivityB;
    nwkBasic3 : ActivityC;
    nwkBasic4 : ActivityD;
    nwkBasic5 : ActivityE;
    nwkBasic6 : ActivityF;
    nwkBasic7 : ActivityG;
    nwkBasic8 : ActivityH;
    nwkBasic9 : ActivityJ;
    nwkBasic10 : ActivityK;
    nwkBasic11 : ActivityL;
    nwkBasic12 : ActivityM;
    nwkBasic13 : ActivityN
nwk_resource
    nwkResource1 : ActivityAResource;
    nwkResource2 : ActivityBResource;
    nwkResource3 : ActivityCResource;
    nwkResource4 : ActivityDResource;
    nwkResource5 : ActivityEResource;
    nwkResource6 : ActivityFResource;
    nwkResource7 : ActivityGResource;
    nwkResource8 : ActivityHResource;
    nwkResource9 : ActivityJResource;
    nwkResource10 : ActivityKResource;
    nwkResource11 : ActivityLResource;
    nwkResource12 : ActivityMResource;
    nwkResource13 : ActivityNResource
nwk_event
    nwkEvent1 : Event1;
    nwkEvent2 : Event2;
    nwkEvent3 : Event3;
    nwkEvent4 : Event4;
    nwkEvent5 : Event5;
    nwkEvent6 : Event6;
    nwkEvent7 : Event7;
    nwkEvent8 : Event8
end
```

5.4.4 Summary

The Programme Evaluation & Review Technique is widely used throughout the aerospace industry and indeed all sectors where means are required to manage large-scale projects. On that basis, we chose it as our representative product management technique for the MATrA traceability framework.

A novel meta-model capturing the graphical syntax of PERT networks was proposed, together with a selection of well-formedness constraints; a partial O-Telos implementation of the model was then populated to demonstrate a worked example.

Again, Chapter Seven includes an evaluation of the PERT structure.

5.5 The MATrA Configuration Model

5.5.1 Introduction

So far, while considering a range of traceability structures (including meta-models of notations, plus the PDS to maintain consistency) we have disregarded means of managing their evolution. Therefore in this subsection we propose the MATrA Configuration Model (MCM), a structure supporting traceability across both version types discussed in Chapter One - i.e., revisions and variants. We also demonstrate integration of MCM with existing work on the representation and expression of argumentation. This is based on the wildly held belief that version management, together with maintenance of rationale are the main change management tools at an engineers disposal. Aspects of the model are illustrated using a worked example from the aerospace domain.

5.5.2 Motivation

Chapter One (subsection 1.2) identified the ability to trace across versions of artifacts as a major topic of interest among aerospace practitioners; recall our conceptualisation of traceability according to four axes - horizontal, vertical, revision and variant - such that the first three provide dimensions for a cube recording links between project artifacts, while the fourth relates artifacts across different projects (i.e., cubes) and across product families within the same project. The terms revision and variant merely capture different versioning intent; revisions replace one another whereas variants coexist.

Reader understanding of the significance of version traceability to aerospace practitioners will profit from a brief insight into the industry itself. We couch this discussion (which considers revisions and variants, along with the related topic of alternatives) in the context of civil aviation as it provides the focus for our worked example in subsection 5.5.3.3.

- **Revisions**

Passenger aircraft are among the most complex engineering projects to be undertaken by private corporations. They must be both economical and dependable; safe and reliable of course, but also available and maintainable. Put simply, airlines do not earn money from grounded aircraft! The cost of developing systems with multiple redundancies and sophisticated in-built diagnostics that help realise these objectives mean manufactures continually strive to extend the life-time of an aircraft by keeping it competitive. This is accomplished by evolving the basic design to take account of technological advances in aerodynamics, materials, avionics, etc. For example, the 747 has undergone four major refinements since its maiden flight in 1969, the latest revision, the 747-400, being released in 1989 as a replacement for its predecessor the 747-300.

- **Variants**

The kinds of aircraft demanded by major carriers can be broadly defined in terms of two macro-level parameters - namely passenger load (approximately 100 to 500) and range (essentially targeting short, extended, long and ultra long routes). Accordingly, the dominant manufacturing philosophy has been to engineer 'families' of aircraft (based on common components) aligned to these demands, from which

variants of models within a given family may be derived over time to fill a particular market niche. For instance, apart from military or 'one-off' modifications (e.g., to carry the space shuttle), various 747 revisions have spawned longer range, increased take-off-weight, high density shuttle and swing nosed freighter variants of what is effectively the same basic design. Moreover, to maximise resources (and share artifacts between projects), manufacturers will often proceed simultaneously with development of two or more derivatives - as is the case with the Airbus A340-500 and A340-600.

From these examples, we can discern two distinct forms of variant which differ according to the time dimension; *serial* development where artifacts from one or more existing projects are applied to a new project - the goal being to 'maximise artifact reuse' (be it whole or partial), and *parallel* development whereby projects proceed concurrently - the goal being to 'minimise artifact redundancy'.

- **Alternatives**

We regard support for tracing *alternatives* as part of the overall versions topic area. During development, different definitions of modules are often proposed in response to a decision problem (commonly referred to as option space exploration), while some justification or rationale must normally be given for the eventual choice. This continues to be an important research strand within DCSC, but is not considered further here. Instead, we consolidate MATrA with an existing technique for tracing alternatives using a global status property (incorporated into AerospaceTraceabilityEntity) - see Appendix B, Part 1. Riddle & Saeed (2000) have shown this to be a more effective way of structuring options than Klein's approach (subsection 3.2.3, figure 3.4) based on associations (*has-option*, *is-best-option-for*, etc.) Readers are also referred to Appendix B, Part 2 which includes an Argumentation Structure (again influenced by Riddle & Saeed, ibid.) allowing rationale to be appended to any MATrA element (as shown by the example in 5.5.3.3).

5.5.2.1 Configuration Management Overview

Configuration describes the control of change in evolving systems. In this subsection we briefly investigate some key concepts from configuration management literature that have shaped the MCM.

Configuration management theory distinguishes between the notions of *product* space and *version* space. These represent descriptions of the target system (which in MATrA constitutes both the PDS and Workspace) and the organisation of versions of these descriptions respectively. A version space can be said to capture the state of an evolving product (and constituent artifacts of that product) at different stages of maturity (i.e., along the time dimension).

The difference between two versions of a managed artifact is called a *delta* (also abbreviated to the Δ symbol). For instance, a delta between versions v_1 and v_2 of an artifact can be defined in terms of properties specific to both v_1 and v_2; i.e., $\Delta (v_1, v_2) = (v_1 - v_2) \cup (v_2 - v_1)$. This is termed a symmetric delta. In cases where an artifact undergoes major change with many successive versions created, then the common properties may become progressively smaller and smaller (Conradi & Westfechtel, 1998).

The evolution history (audit trail) of versioned artifacts can be represented in terms of a graph (typically a sequence) comprising a set of versions connected by relationships of a single type. These are termed successor relationships such that 'v_2 *succeeds* v_1' means that v_2 has been derived from v_1.

Different product versions can be produced by combining different constituent artifacts and different versions of constituents into what is termed a *configuration*. The degree of flexibility permitted in producing such combinations depends on the version model underlying the configuration process. Conradi & Westfechtel (1998) distinguish three such models (figure 5.10) classified by their *selection order*, specifically: i) *product first* - the product structure is selected first, followed by the versions of each module (such that each configuration has the same structure); ii) *version first* - the product version is selected first which uniquely determines module versions (allowing different versions to be structured differently, though in the event of change, new versions must be created for all 'parents' of the affected module - this is known as *version proliferation*); and iii) the *intertwined model* - components and versions are selected in alternating order (so preventing version proliferation).

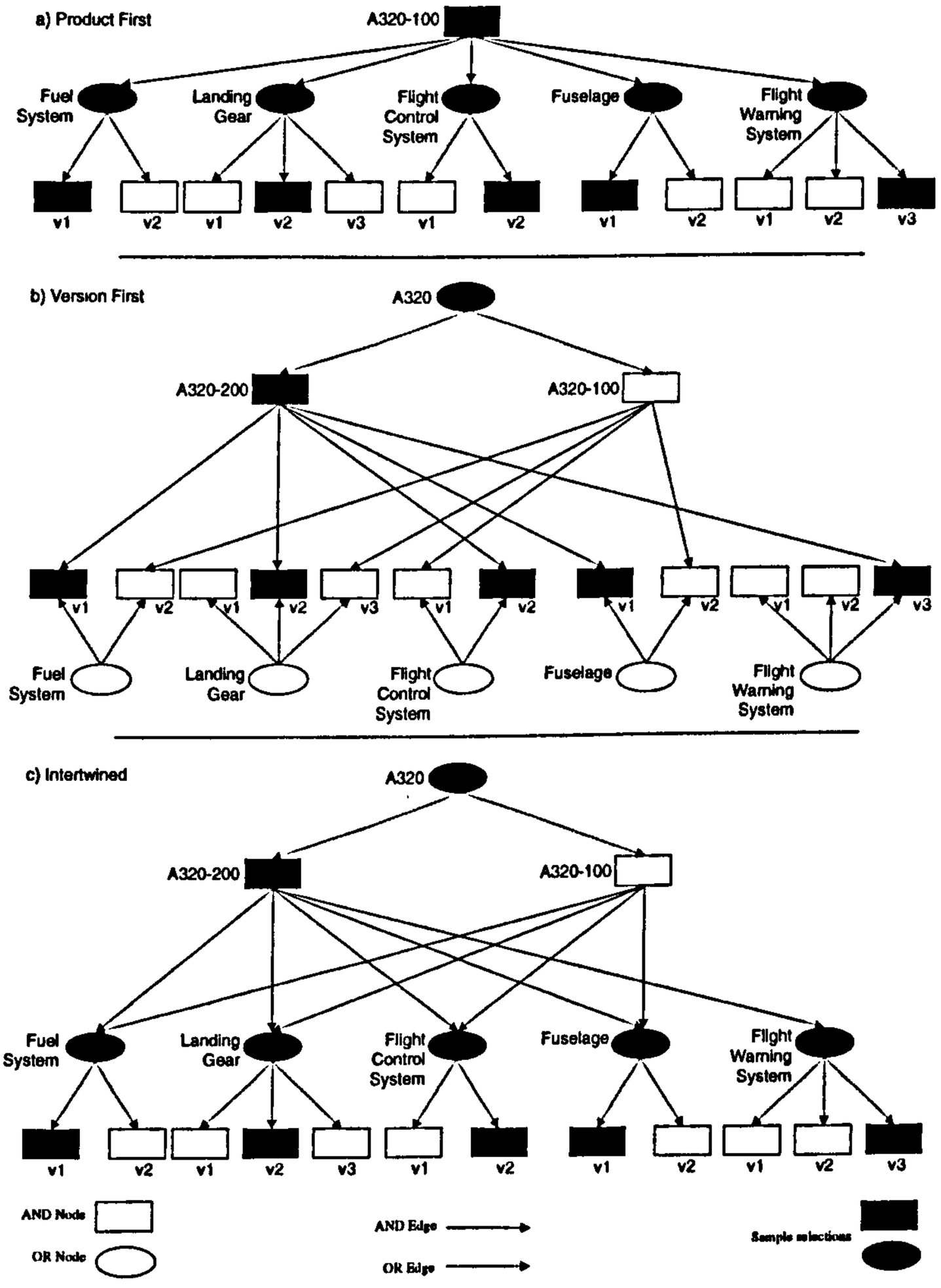


Figure 5.10 - 'Product First (a), Version First (b) and Intertwined Models (c)'

This section merely touches on a few core issues regarding configuration management and then only briefly to provide background for the MCM. The notion of baselines, releases and promotions, as well as alternative forms of delta and version model are beyond the scope of this thesis. Interested readers are instead referred to Conradi & Westfechtel (1998) or else, the IEEE guidelines on configuration management (IEEE STD 1042, 1987). With the concepts outlined above in mind, we now introduce the MATrA Configuration Model.

5.5.3 Across Revisions and Variants in MATrA: A Configuration Model for Tracing Evolutionary Development

As previously indicated, the MATrA product space consists of two parts; a tool independent view (Product Data Synthesis) and the tool dependent view (Workspace). For configuration management it is necessary to introduce constructs to permit handling of revisions and variants for both views.

5.5.3.1 Concepts

MCM encapsulates the notion of *product* and *version* space (from 5.5.2.1) by integrating features necessary to represent the latter in the context of existing features (supporting the former) from the traceability framework introduced in subsection 3.3 - specifically, BuildElement and BuildAssociation (PDS), and AerospaceEngineeringObject and AerospaceEngineeringAssociation (Workspace).

The 'version-oriented' features to be introduced in this subsection are drawn from general configuration management theory and are motivated by a number of requirements. For the PDS, these requirements are support for:- r1) identifying and structuring revisions and variants (for which we adopt an *intertwined* modelling approach); r2) impact change analysis; r3) revision audit trails; r4) definition of configurations; and r5) configuration deltas (i.e., differences between configurations). Similarly, for the Workspace our requirements are support for:- r1) revision audit trails; and r2) meta-model deltas (i.e., differences between meta-models). We make the observation in stating these requirements that the Workspace presents only partial models of the emerging system, whereas the PDS provides a complete model and hence specifies all constituent elements (and their relationships) at given points in time; impact analysis and hence change is therefore driven from the PDS. This explains why there are fewer requirements for the Workspace.

5.5.3.2 MATrA Configuration Model Definitions

We now introduce the class diagram for our MATrA Configuration Model (5.5.3.2.1), together with OCL constraints and rules over elements of the model (5.5.3.2.2) and O-Telos implementation of its base classes (5.5.3.2.3).

5.5.3.2.1 MATrA Configuration Model

Figure 5.11 shows elements and relationships of the MATrA Configuration Model. Essentially, it divides into two zones (denoted by 'swimlanes'): constructs (and their subtypes) for representation and version management of the Product Data Synthesis - namely build object (BuildObject), build

dependency (BuildDependency), Configuration and configuration delta (ConfigurationDelta) - and those for representation and version management of the traceability Workspace - namely aerospace engineering object (AerospaceEngineeringObject), aerospace engineering association (AerospaceEngineeringAssociation) and aerospace engineering delta (AerospaceEngineeringDelta). The zones are connected by subtypes of aerospace link entity (AerospaceLinkEntity), BEelementAEO and BEmodelAEO (not shown) which are as described in subsection 3.3.6.4.4.

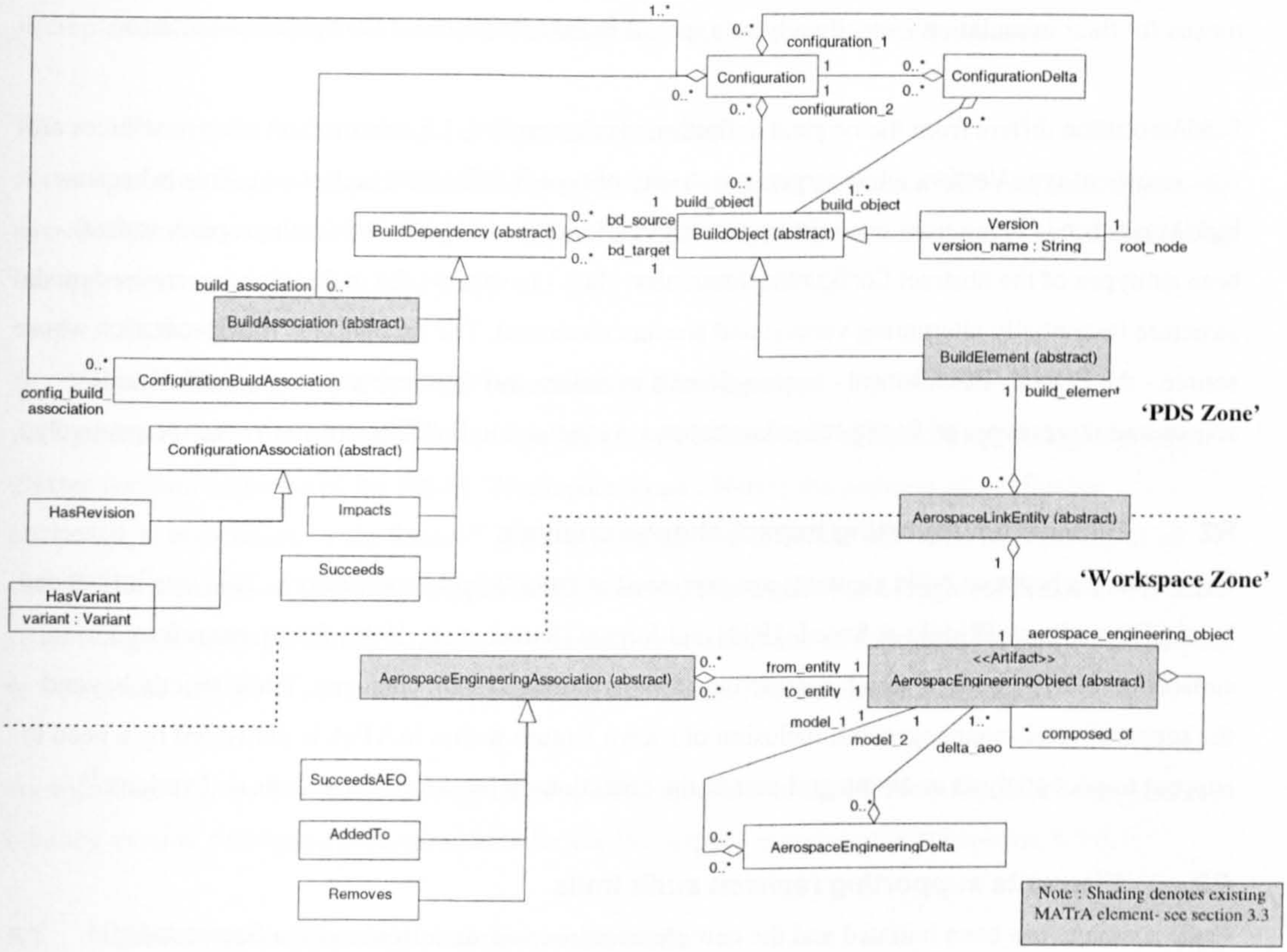


Figure 5.11 - 'MATrA Configuration Model (MCM)'

i. Version Management for the Product Data Synthesis

From figure 5.11, it can be seen that the core element in the 'PDS zone' is BuildObject, an abstract class subsuming Version (with property version_name of type String) and build element (BuildElement) subtypes. It was introduced as the result of a modelling decision to represent all PDS relationships - build association (BuildAssociation), configuration association (ConfigurationAssociation), Impacts, Succeeds and configuration build association (ConfigurationBuildAssociation) - using the abstract BuildDependency class. BuildDependency greatly simplifies the MCM by generalising the behaviour of each of these subtypes through common associations for source (bd_source) and target (bd_target) elements. However, since bd_source and bd_target can either be of type Version or of type BuildElement depending on the BuildDependency type to which they apply - for instance, the source of a ConfigurationAssociation must be of type BuildElement and the target of type Version - so BuildObject generalises the behaviour of BuildElement and Version. Appropriate invariants (see subsection 5.5.3.2.2(i.1)) over BuildDependency subtypes ensure type restrictions on bd_source and bd_target are maintained.

We now consider the support provided by specific elements of the MATrA Configuration Model in meeting version management requirements for the PDS introduced in subsection 5.5.3.1.

R1 Elements supporting an *intertwined* approach to the identification and structuring of revisions and variants

To support the identification of revisions and variants and to enable them to be structured using an intertwined approach, MCM uses the above-mentioned Version and BuildElement classes along with means for their association - specifically subtypes of BuildAssociation and ConfigurationAssociation.

BuildAssociation differs from the original definition in subsection 3.3.5 inasmuch as subtype sources are now *mostly* of type Version, while targets are strictly of type BuildElement (as before). This is because BuildAssociation is being used in conjunction with HasRevision and HasVariant (with property variant) - both subtypes of the abstract ConfigurationAssociation class - to express the underlying *intertwined* model structure (essentially alternating version and product elements). The exception is HasSpecification whose source - the Property BuildElement - is considered a primitive and therefore not versioned[12]. Recall, source and target types of ConfigurationAssociation are confined to BuildElement and Version respectively.

R2 Elements supporting impact change analysis

Dependencies between build elements are expressed as Impacts build associations. This was influenced by the Dependency (Riddle & Saeed, 1998) and Impact (Saeed *et al.*, 1995) Structures referred to in subsection 2.2.1.3, both of which capture interactions among system elements. While strictly beyond the scope of version management, inclusion of such a feature within MATrA is motivated by a need to support impact analysis as an integral part of the evolutionary process for revisions and variants[13].

R3 Elements supporting revision audit trails

Once a change has been initiated and the new element inserted, an instance of the Succeeds build association can be used to relate the revised instance to its predecessor, thereby capturing (for audit trail purposes) the temporal ordering (as described in 5.5.2.1).

R4 Elements supporting definition of configurations

Definition of configurations is supported by the Configuration class, a (manually selected) collection of build objects. A Configuration has at its root a single Version element (indicated by the root_node rolename in figure 5.11). From the root_node it is necessary to project the actual product structure implied by BuildObject selections. This is the motivation for the (abstract) ConfigurationBuildAssociation class whose subtypes (not shown), including has-configuration-submodule (HasConfigurationSubmodule) and consumes-configuration XIO (ConsumesConfigurationXIO), etc., correspond to conventional build associations. These are used to express transitive associations between versioned product elements; for example, if ModuleA (*MA*) version$_i$ (MAv_i) has-submodule ModuleB (*MB*) and *MB* has-version version$_i$

[12] Note, we have not specified this as an OCL invariant since the revised HasSpecification class (as with all specialisations of BuildAssociation) is not shown in figure 5.11.

[13] Note that Impacts associations are inherently pessimistic in that they simply indicate a degree of dependency among related elements; practitioners must still investigate tolerance to change based on engineering judgement.

(MBv_i) such that a Configuration *C1* includes MAv_i and MBv_i, then a HasConfigurationSubmodule association between these two elements is derived for *C1* using the rule stated in 5.5.3.2.2(i.2). A Configuration may also incorporate conventional BuildElement and BuildAssociation subtypes (the latter derivable through the rule in 5.5.3.2.2(i.3)), typically instances of Property and Specification (as primitives) and accordingly, HasProperty and HasSpecification. We note also that instances of the Condition build element (mainly 'simple', non-versioned states and events), along with build associations used in conjunction can also be included as part of a Configuration (a point illustrated by our worked example in 5.5.3.3). Again, invariants (not stated) may be used to enforce restrictions.

R5 Elements for creating configuration deltas

A configuration delta (ConfigurationDelta) represents the symmetric difference between build objects in two configurations (rolenames configuration_1 and configuration_2). Its content can also be derived using the appropriate rule from 5.5.3.2.2 (ii.1).

ii. Version Management for the Traceability Workspace

As figure 5.11 indicates, the existing AerospaceEngineeringObject and AerospaceEngineeringAssociation[14] classes are core elements of the MCM 'Workspace Zone'. Notice the addition of a reflexive composed_of association on the former[15]. This is a mechanism to enable universal referencing of all constituent elements of all AEO subtypes throughout the Workspace via a single rolename and is used in deriving elements pertaining to (version-oriented) specialisations of AerospaceEngineeringAssociation to be introduced below; composed_of is populated via rule iii.1 in subsection 5.5.3.2.2.

As with the PDS, we now consider support of specific elements of the MATrA Configuration Model in meeting version management requirements for the Workspace introduced in subsection 5.5.3.1.

R1 Elements supporting revision audit trails

The version history of a TraceabilityStructure is recorded using the Succeeds-AEO (SucceedsAEO) association which again orders successive instances as per 5.5.2.1 (and hence serves the same purpose as Succeeds for PDS elements). We also introduce the Added To (AddedTo) and Removes associations; respectively, this pairing relate elements of a new model to a predecessor in which those elements were not present, and relate the new model to elements of its predecessor not present in the revision. Both AddedTo and Removes may be derived using rules in 5.5.3.2.2 (specifically, iii.2 and iii.3).

R2 Elements supporting meta-model deltas

The revision audit trail associations in r1 (above), further enable derivation of elements of the AerospaceEngineeringDelta class (populated using the rule in 5.5.3.2.2(ii.3)) which records the symmetric difference, in terms of structure elements (rolename delta_aeo), for two Workspace meta-models (rolenames model_1 and model_2).

---

[14] To simplify figure 5.11, the AEE subtype has been omitted. The constraints expressed in subsection 5.5.3.2.2(iii.4) restrict from_entity and to_entity ends of the AerospaceEngineeringAssociation class.
[15] Note, a corresponding addition to the «Artifact» meta-class (not shown) from 3.3.3 is required.

5.5.3.2.2 OCL Constraints

As indicated above, we state a number of constraints and rules over the MCM. These are as follows:-

I. Build Dependency

1. The following constraints ensure correct instantiation of source and/or target elements for BuildDependency subtypes.

- The target of a BuildAssociation is of type BuildElement.

BuildAssociation **invariant**
self.allInstances->forall(b | b.bd_target.oclIsKindOf(BuildElement))

- The source of a ConfigurationAssociation is of type BuildElement and the target of type Version.

ConfigurationAssociation **invariant**
self.allInstances->forall(c | c.bd_source.oclIsKindOf(BuildElement) and c.bd_target.oclType = Version)

- The target of a ConfigurationBuildAssociation is of type Version.

ConfigurationBuildAssociation **invariant**
self.allInstances->forall(b | b.bd_target.oclType = Version)

2. This rule derives population of the ConfigurationBuildAssociation class.

Configuration
self.allInstances->forall(c | self.build_object->forall(b1, b2 |
self.build_object.buildDependency->select
(self.build_object.buildDependency.oclIsKindOf(BuildAssociation))->forall(b |
self.config_build_association->exists(a |
c.build_object->includes(b1) and c.build_object->includes(b2) and b.bd_source->includes(b1) and
(b.bd_target.hasRevision.bd_target->includes(b2) or b.bd_target.hasVariant.bd_target->includes(b2)))))) implies
c.config_build_association->includes(a) and a.bd_source->includes(b1) and a.bd_target->includes(b2)

Note : an additional rule (not shown) ensures instances of ConfigurationBuildAssociation (variable 'a' in the above) correspond to instances of BuildAssociation (variable 'b' in the above) from which they are derived; e.g., b.oclType = HasSubmodule implies a.oclType = HasConfigurationSubmodule.

3. This rule derives population of the BuildAssociation class.

Configuration
self.allInstances->forall(c | self.build_object->forall(b1, b2 |
self.build_object.buildDependency->select
(self.build_object.buildDependency.oclIsKindOf(BuildAssociation))->forall(b |
c.build_object->includes(b1) and c.build_object->includes(b2) and
b.bd_source->includes(b1) and b.bd_target->includes(b2) and
b2.hasRevision->isEmpty and b2.hasVariant->isEmpty))) implies
c.build_association->includes(b)

II. Configuration Delta and Aerospace Engineering Delta

1. The following rule derives population of ConfigurationDelta elements.

ConfigurationDelta **invariant**
self.allInstances->forall(d |
self.configuration_1->forall(c1 | self.configuration_2->forall(c2 |
d.configuration_1->includes(c1) and d.configuration_2->includes(c2)))) implies
d.build_object->includesAll((c1.build_object - c2.buildObject)->union(c2.buildObject - c1.buildObject))

2. Constraint to ensure that AEOs specified as subjects of an AerospaceEngineeringDelta (over rolenames model_1 and model_2) are forms of TraceabilityStructure.

AerospaceEngineeringDelta **invariant**
self.allInstances->forall(a |
a.model_1.oclType.oclType.oclIsKindOf (TraceabilityStructure) and
a.model_2.oclType.oclType.oclIsKindOf(TraceabilityStructure))

3. Rule to derive population of AerospaceEngineeringDelta elements.

AerospaceEngineeringDelta **invariant**
self.allInstances->forall(d |
self.model_1->forall(m1 | self.model_2->forall(m2 |
self.model_2.removes.to_entity->union(self.model_1.addedTo.from_entity)->forall(c |
self.model_2.succeedsAEO->exists(s |
d.model_1->includes(m1) and
d.model_2->includes(m2) and
s.from_entity->includes(m2) and s.to_entity->includes(m1) and
d.model_2.removes.to_entity->union(d.model_1.addedTo.from_entity)->includes(c)))))
implies
d.delta_aeo->includes(c)

iii. Aerospace Engineering Association

1. Rule to populate composed_of associations of the AerospaceEngineeringObject class for use in deriving AddedTo and Removes associations between AEOs.

AerospaceEngineeringObject
self.allInstances->forall(a1, a2 |
self.associationEnds->forall(e |
a1.associationEnds->includes(e) and a1.e->includes(a2)))
implies
a1.composed_of->includes(a2)

2. Rule to derive AddedTo associations.

AerospaceEngineeringObject
self.allInstances->select(self.allInstances.oclType.oclType.oclIsKindOf(TraceabilityStructure))->forall(m1 |
self.succeedsAEO.to_entity->exists(m2 |
self.addedTo->exists(d |
self.composed_of->forall(c1 |
self.succeedsAEO.to_entity.composed_of->not exists(c2 |
self.composed_of->forall(c' |
self.succeedsAEO.to_entity.composed_of->not exists(c" |
self.composed_of.attributes->forall(a |
self.composed_of.attributes->forall(a' |
self.composed_of.associationEnds->forall(e |
m1.succeedsAEO.to_entity->includes(m2) and
m1.composed_of->includes(c1) and m2.composed_of->includes(c2) and

```
c1.oclType = c2.oclType and
c1.attributes->includes(a) and c2.attributes->includesAll(c1.attributes) and
c1.a = c2.a and
c1.associationEnds->includes(e) and c2.associationEnds->includesAll(c1.associationEnds) and
c1.e->includes(c') and c2.e->includes(c'') and c'.oclType = c''.oclType and
c'.attributes->includes(a') and c''.attributes->includesAll(c'.attributes) and
c'.a' = c''.a')))))))))
implies
d.from_entity->includes(c1) and d.to_entity->includes(m2)
```

3. Rule to derive Removes associations.

```
AerospaceEngineeringObject
self.allInstances->select(self.allInstances.oclType.oclType.oclIsKindOf(TraceabilityStructure))->forall(m1 |
self.succeedsAEO.to_entity->exists(m2 |
self.removes->exists(r |
self.composed_of->not exists(c1 |
self.succeedsAEO.to_entity.composed_of->forall (c2 |
self.composed_of->not exists(c' |
self.succeedsAEO.to_entity.composed_of->forall (c'' |
self.succeedsAEO.to_entity.composed_of.attributes->forall(a |
self.succeedsAEO.to_entity.composed_of.attributes->forall(a' |
self.succeedsAEO.to_entity.composed_of.associationEnds->forall(e |
m1.succeedsAEO.to_entity->includes(m2) and
m1.composed_of->includes(c1) and m2.composed_of->includes(c2) and
c1.oclType = c2.oclType and
c2.attributes->includes(a) and c1.attributes->includesAll(c2.attributes) and
c1.a = c2.a and
c2.associationEnds->includes(e) and c1.associationEnds->includesAll(c2.associationEnds) and
c2.e->includes(c'') and c1.e->includes(c') and c'.oclType = c''.oclType and
c''.attributes->includes(a') and c'.attributes->includesAll(c''.attributes) and
c''.a' = c'.a')))))))))
implies
r.from_entity->includes(m1) and r.to_entity->includes(c2)
```

We note that rules to populate AddedTo or Removes associations are based on the tenet that 'equivalent' elements appearing in separate models are in fact represented by different objects. This results from the assumed mapping process between CASE tools and the MATrA Workspace. Thus we cannot simply consider whether two objects are the same, but instead must determine their equivalence - i.e., whether they are of the same type, have the same attributes with the same values and are connected to the same set of 'equivalent' elements. We return to this issue in the section on future work (7.4.10).

4. The following ensure correct instantiation of source and target elements for the SucceedsAEO, AddedTo and Removes AerospaceEngineeringAssociation subtypes.

```
SucceedsAEO Invariant
self.allInstances->forall(s |
s.from_entity.oclType.oclType.oclIsKindOf(TraceabilityStructure) and
s.to_entity.oclType.oclType.oclIsKindOf(TraceabilityStructure))
```

```
AddedTo Invariant
self.allInstances->forall(a |
a.from_entity.oclType.oclType = StructureElement and
```

a.to_entity.oclType.oclType.oclIsKindOf(TraceabilityStructure))

Removes **invariant**
self.allInstances->forall(r |
r. from_entity.oclType.oclType.oclIsKindOf(TraceabilityStructure) and
r.to_entity.oclType.oclType = StructureElement)

We reiterate that the above are merely a selection of constraints and rules expressing possible behaviour of the MCM. Further areas to consider include invariants relating to an element's status[16], of which the following provides a flavour. Specifically, it imposes a restriction that the source of a Succeeds association must have an "active" status, whilst the status of its target must be "abandoned" [17].

Succeeds **invariant**
self.allInstances->forall(s | s.bd_source.status = "active" and s.bd_target.status = "abandoned")

5.5.3.2.3 O-Telos Implementation of MATrA Configuration Model Base Classes

The following O-Telos code implements MCM base classes as per figure 5.11, along with extensions to the Framework Model in Chapter Three (see Appendix B, Part 1 for the 'equivalent' UML extensions).

```
Aerospace Management Entity - MCM
subtypes

AerospaceConfigurationEntity in
SimpleClass isA AerospaceManagementEntity
with constraint
    abstract_ACE: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in
AerospaceConfigurationEntity)$ end

Aerospace Configuration Entity subtypes

AerospaceEngineeringDelta in SimpleClass
isA AerospaceConfigurationEntity
with attribute
    model_1 : AerospaceEngineeringObject;
    model_2 : AerospaceEngineeringObject;
    delta_aeo :
AerospaceEngineeringObject
end

ConfigurationDelta in SimpleClass isA
AerospaceConfigurationEntity
with attribute
    configuration_1 : Configuration;
    configuration_2 : Configuration;
    build_object : BuildObject
end

Configuration in SimpleClass isA
AerospaceConfigurationEntity
with attribute
    root_node : Version;
    build_association : BuildAssociation;
    config_build_association :
ConfigurationBuildAssociation;
    build_object : BuildObject
end

Version in SimpleClass isA
AerospaceConfigurationEntity, BuildObject
with attribute
    version_name : String
end

Build Object (abstract supertype of
Version and BuildElement)

BuildObject in SimpleClass
with constraint
    abstract_BO: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in BuildObject)$
end

Aerospace Build Entity - MCM subtypes

BuildElement in SimpleClass isA
AerospaceBuildEntity, BuildObject
with
constraint
    abstract_BE: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in BuildElement)$
end

BuildDependency in SimpleClass isA
AerospaceBuildEntity
with attribute
    bd_source : BuildObject;
    bd_target : BuildObject
constraint
    abstract_BD: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in
```

[16] Recall status is a property of AerospaceTraceabilityEntity and so part of every MATrA framework class (see Appendix B, Part 1).

[17] As we do not consider option space exploration and the different status' an element may have, all revisions are assumed to be 'active' and their predecessor, 'abandoned'.

```
BuildDependency)$ end

Build Dependency subtypes

BuildAssociation in SimpleClass isA
BuildDependency
with
constraint
    abstract_BA: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in
BuildAssociation)$
end

Note: Build Association subtypes (for
original class) were defined in UML in
Chapter 3 (subsection 3.3.5.2)

Succeeds in SimpleClass isA
BuildDependency end

Impacts in SimpleClass isA
BuildDependency end

ConfigurationAssociation in SimpleClass
isA BuildDependency
with
constraint
    abstract_CA: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in
ConfigurationAssociation)$
end

ConfigurationBuildAssociation in
SimpleClass isA BuildDependency
with
constraint
    abstract_CBA: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in
ConfigurationBuildAssociation)$
end

Configuration Association subtypes

HasRevision in SimpleClass isA
ConfigurationAssociation end

HasVariant in SimpleClass isA
ConfigurationAssociation
with attribute
    variant : Variant
end

Variant in SimpleClass isA String end

Configuration Build Association subtypes

HasConfigurationSubmodule in SimpleClass
isA ConfigurationBuildAssociation end

HasConfigurationFTsubmodule in
SimpleClass isA
ConfigurationBuildAssociation end

HasConfigurationSubfunction in
SimpleClass isA
ConfigurationBuildAssociation end

HasConfigurationCondition in SimpleClass
isA ConfigurationBuildAssociation end

HasConfigurationSubCondition in
SimpleClass isA
ConfigurationBuildAssociation end

ConsumesConfigurationXIO in SimpleClass
isA ConfigurationBuildAssociation end

EncapsulatesConfiguration in SimpleClass
isA ConfigurationBuildAssociation end

OccuringInConfiguration in SimpleClass
isA ConfigurationBuildAssociation end

LeadsToConfiguration in SimpleClass isA
ConfigurationBuildAssociation end

Aerospace Engineering Entity - MCM
subtypes

AerospaceEngineeringObject in Artifact,
SimpleClass isA
AerospaceEngineeringEntity
with
is_composed_of
    composed_of :
AerospaceEngineeringObject
constraint
    abstract_AEO: $ forall t/Token,
s/SimpleClass
    (t in s) ==> not (t in
AerospaceEngineeringObject)$
end

Aerospace Engineering Association - MCM
subtypes

AddedTo in SimpleClass IsA
AerospaceEngineeringAssociation end

Removes in SimpleClass IsA
AerospaceEngineeringAssociation end

SucceedsAEO in SimpleClass IsA
AerospaceEngineeringAssociation end

Note: Recall a further selection of
Aerospace Engineering Association
subtypes were defined in Chapter 3
(subsection 3.3.6.3.2) for use in the
main case studies (Chapter 6, subsections
6.2 and 6.3).
```

5.5.3.3 MCM Worked Example : Tracing Revisions for the Airbus A320-100/A320-200 Flight Control System

To illustrate key concepts of the MCM, we now present a detailed worked example. It should be noted that whereas the meta-models introduced previously represented established notations (or domain-specific variants thereof), this section has proposed a novel structure which as such, has no recognised syntax. Therefore to describe elements of the model in a uniform and "canonical" formalism, a graph-based notation similar to DRCS (subsection 3.2.3) is adopted.

The example demonstrates support provided by the MATrA Configuration Model for tracing revisions in the context of Flight Control Systems for the Airbus A320-100 and A320-200 aircraft. It considers the interplay between product space and version space, as well as management of Aerospace Engineering Objects.

5.5.3.3.1 Background

Designed to carry 150 passengers over short-to-medium routes, A320 was Airbus' first narrowbody jetliner. However, only twenty-one of the initial -100 (pronounced 'dash 100') were built, before production switched to the -200 revision. Effects of this evolution on the Flight Control System serve as the focus of our example.

Flight Control Systems provide functions for take-off and landing, as well as in-flight manoeuvres such as banking and climb. These are commanded through a number of primary and secondary control surfaces that dictate air-flow over the wings, body and tail-plane. Our example concerns the 'slats', secondary control surfaces preventing stall located on the wings leading edge. Readers are referred to Mair & Birdsall (1992) for more information on aircraft control surfaces.

A320 was the first aircraft to adopt a completely 'fly-by-wire' approach. On conventional aircraft, mechanical linkages transmit pilot orders to actuators, which in turn move the control surfaces. Though power applied to each surface is supplied from hydro-mechanical servo-amplifiers, their precise movements are co-ordinated solely by the flight crew. In contrast, A320 pilots provide instructions to flight control computers which are interpreted and used to generate actuator commands. This enables control law constraints to be applied to the aircraft to maintain 'flight envelope protection', thereby preventing certain pilot commanded actions - e.g. slat retraction at low speed - which may induce hazardous conditions (for instance, engine stall).

The FCS architecture comprises three computer types: ELevator and Aileron Computers (ELACs), Spoiler and Elevator Computers (SECs) and Slat and Flap Control Computers (SFCCs). Redundancy, is essential given reliance on the system and manoeuvring difficulties in the event of total loss. In this scenario, we concentrate on the dual SFCCs; both divide into two channels Slat and Flap, with each channel further sub-divided into two lanes. Readers are referred to Favre (1994) or to Pearson & Rowlands (1996) for more information on A320 Flight Control Systems.

5.5.3.3.2 Scenario

This scenario concerns revisions to the A320-100 towards production of A320-200 - an extended range and increased take-off weight derivative. The MATrA Configuration Model is used to support modification of -100 SFCCs to accommodate (hypothetical) parameter variances stemming from the revised range and take-off weight requirements. In particular, we examine a function that prevents slat retraction by overriding pilot commands under specified conditions - the aim being to avert hazardous stall conditions. Our scenario comprises a number of 'episodes' which progress the example from

definition of the A320-100 base aircraft, to creation of change deltas between this and the A320-200.

The following serves as a route-map identifying the purpose of each episode, along with their relevance to the MCM requirements stated in subsection 5.5.3.1:-

- **Episode 1** (partially) describes the PDS (using an intertwined representation) for the A320-100 base aircraft, including definition of the FCS and its subsystems. We also show an audit trail example for successive instances of one element; exhibits PDS requirements R1 and R3 (and provides context for Episodes 4 and 5).
- **Episode 2** (partially) describes the Workspace for the A320-100 using a Statechart meta-model fragment for a key function of the SFCCs (together with Aerospace Link Entities associating appropriate parts of the meta-model with corresponding PDS elements); provides context for Episodes 6 and 8.
- **Episode 3** demonstrates a partial configuration for the A320-100; exhibits PDS requirement R4.
- **Episode 4** demonstrates a partial impact change analysis over properties of the A320-100; exhibits PDS requirement R2.
- **Episode 5** is included for completeness and describes updating of the PDS towards definition of the A320-200 derivative aircraft in response to findings from the impact change analysis; also provides a context for Episode 7.
- **Episode 6** updates the Statechart meta-model from Episode 2 for the A320-200 revision and inserts appropriate audit trail associations; exhibits Workspace requirement R1.
- **Episode 7** demonstrates a partial configuration delta between A320-100 and -200 elements; exhibits PDS requirement R5.
- **Episode 8** demonstrates an aerospace engineering delta for the A320-100 and -200 meta-model fragments featured in Episode 6; exhibits Workspace requirement R2.

Episode 1 - Describing the A320-100 Base Aircraft

We begin by populating the MCM with elements describing the A320-100. Firstly, a 'container' class for the A320 project (A320 Project) as a whole is created[18], together with a Product Data Synthesis (A320 PDS) for this particular project. The PDS includes our base aircraft A320-100 (of type Version), a revision of the generic A320 (BuildElement of type Module) for which a number of properties (BuildElement(s) of type Property) are defined, as shown in figure 5.12. Specifically, Gross Wing Area, Landing Distance, WingLoading, Fuel Capacity, Maximum Takeoff Weight, Maximum Lift Coefficient, Payload, Range, Touch Down Speed, Approach Speed and Stalling Speed[19].

[18] This will contain all A320 revisions, together with variants including A321 and A319 (as indicated by the A321-100 'stub'). Variants are not considered further in this example as their application in terms of Configurations and Configuration Deltas, etc. is the same as that for revisions (except of course that multiple variants can co-exist).
[19] Interested readers are referred to Mair & Birdsall (1992) for the precise meaning of these terms.

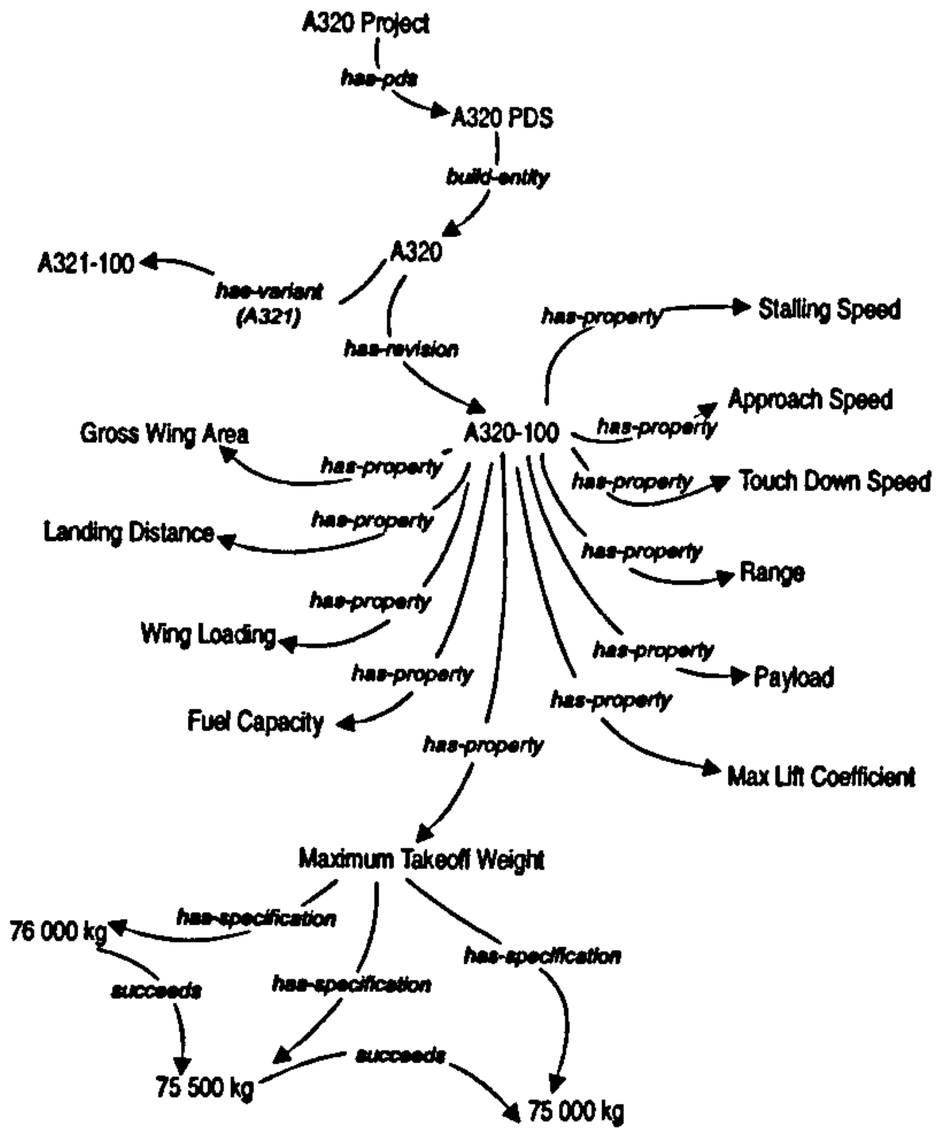


Figure 5.12 - 'A320-100 Product Data Synthesis Fragment - Properties'

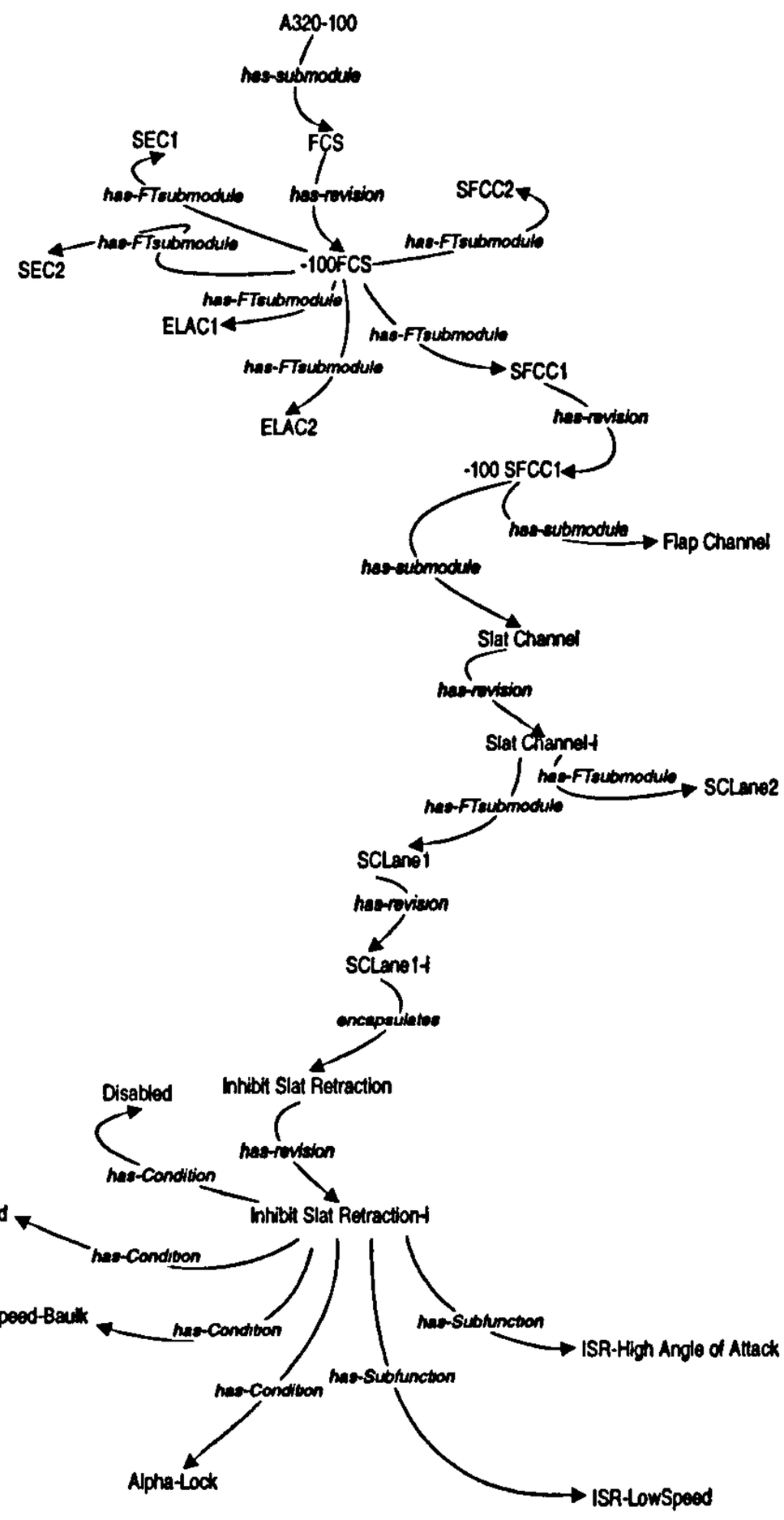


Figure 5.13 - 'A320-100 Product Data Synthesis Fragment - Architecture'

At this point, our concern is purely to provide a context for the scenario and in particular, a set of properties with which to demonstrate use of Impacts associations in assessing change (Episode 4), and a set of architectural elements (to be introduced below) for illustrating modifications to the base aircraft as a result of this analysis (Episode 5). However, to give an early indication of how an audit trail of multiple revisions is represented using the MATrA Configuration Model, Maximum Takeoff Weight is shown as an emergent property captured through a succession of value specifications.

Figure 5.13 extends our base aircraft description. It shows a (partially versioned[20]) vertical path through the FCS architecture, including twin fault tolerant SEC (SEC1 and SEC2), ELAC (ELAC1 and ELAC2) and SFCC (SFCC1 and SFCC2) submodules. SFCC1 is further decomposed to show the Slat and Flap channels (Slat Channel and Flap Channel) for this particular computer. The former is likewise decomposed to lanes 1 and 2 (SCLane1 and SCLane2); for lane 1, we show the Inhibit Slat Retraction function and its two subfunctions ISR-Low Speed and ISR-High Angle of Attack. In addition, conditions (states) that this function may assume, namely disabled (Disabled), not engaged (Not-Engaged), speed baulk (Speed-Baulk) and alpha lock (Alpha-Lock) are also identified. Note the alternating Version/BuildElement (featuring Module, Function and Condition subtypes) pattern that characterises an intertwined approach.

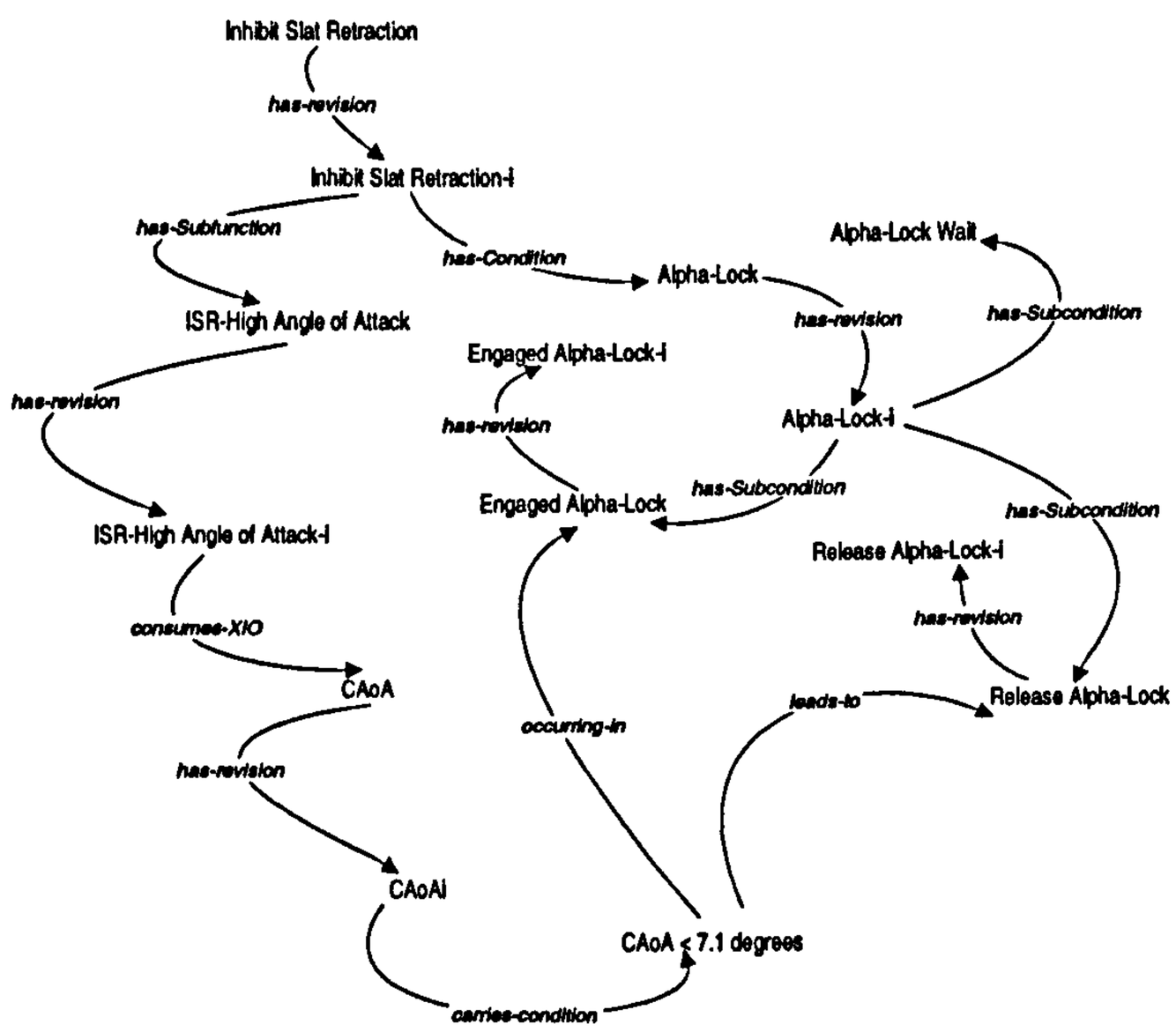


Figure 5.14 - 'Decomposition of Inhibit Slat Retraction at High Angles of Attack (A320-100)'

Figure 5.14 further refines this decomposition through the introduction of sub-conditions for Alpha-Lock - namely Alpha-Lock Wait (Alpha-Lock Wait), Engaged Alpha-Lock (Engaged Alpha-Lock) and Release Alpha-Lock (Release Alpha-Lock). The ISR-High Angle of Attack sub-function consumes a flow of type Corrected Angle of Attack (CAoA) produced by external sensor devices (not shown). A transition from Engaged Alpha-Lock to Release Alpha-Lock occurs when the CAoA data flow value is less than 7.1 degrees

[20] Again, multiple revision elements are not shown to reduce complexity of the diagram.

(CAoA < 7.1 degrees); this event is 'carried' in the data flow[21].

Similarly, figure 5.15 introduces sub-conditions for Speed-Baulk - namely Speed Baulk Wait (Speed-Baulk Wait), Engaged Speed Baulk (Engaged Speed-Baulk) and Release Speed Baulk (Release Speed-Baulk). The ISR-Low Speed sub-function consumes a flow of type Computed Air Speed (CAS), again produced by external sensors. A transition from Engaged Speed-Baulk to Release Speed-Baulk occurs when CAS exceeds one hundred and fifty four knots (CAS > 154 knots).

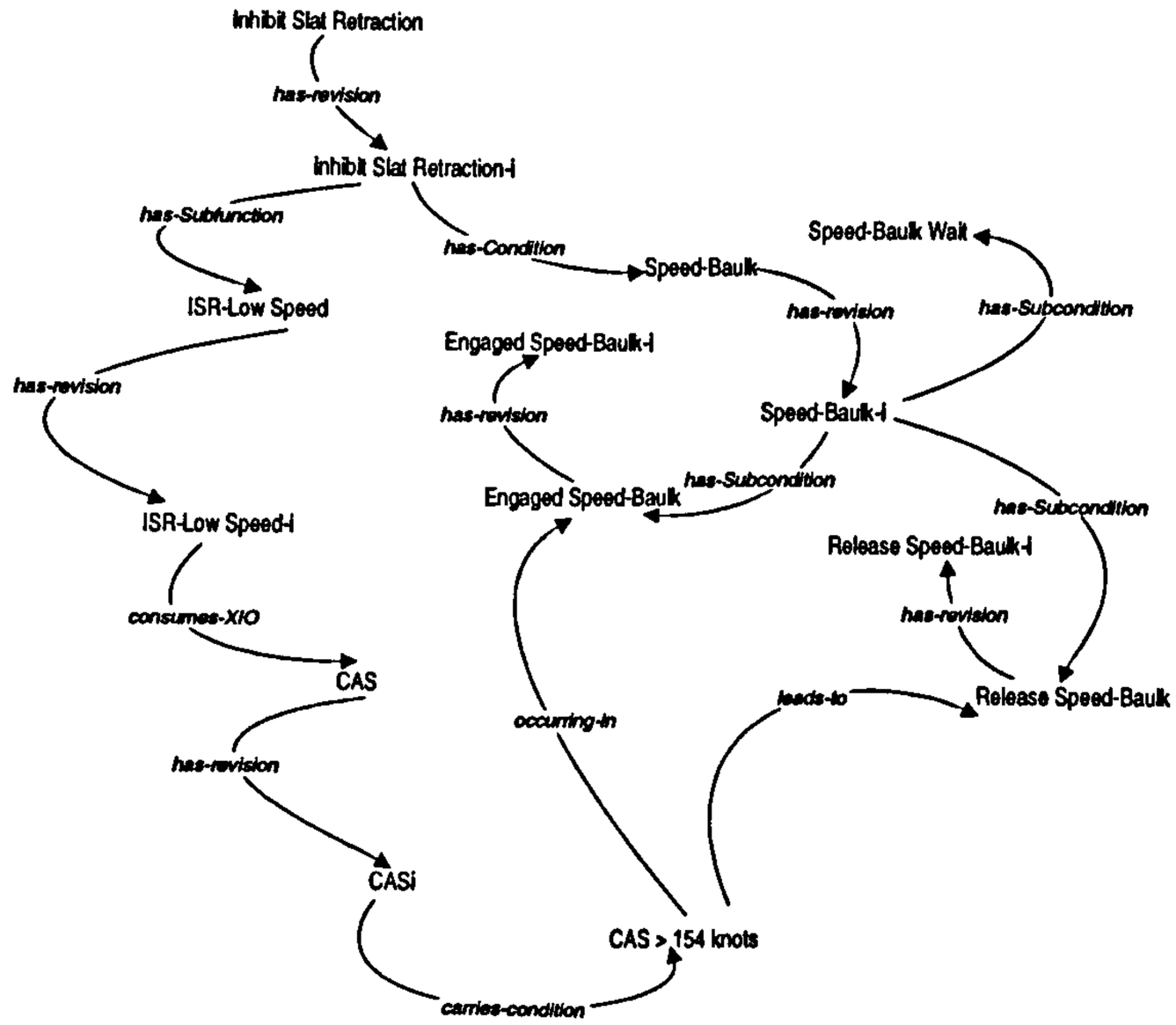


Figure 5.15 - 'Decomposition of Inhibit Slat Retraction at Low Speed (A320-100)'

O-Telos objects capturing (partial) information from figures 5.12 through 5.15 are as follows:-

Instantiation of elements in figure 5.12

```
A320 in AerospaceEngineeringProject,
Token with
project_title
    projectTitle : "A320 Project"
has_pds
    hasPDS : A320PDS
end

A320PDS in ProductDataSynthesis, Token
with
build_entity
    buildEntity1 : AirbusA320;
    buildentity2 : GrossWingArea;
    buildEntity3 : LandingDistance;
    buildEntity4 : WingLoading;
    buildEntity5 : FuelCapacity;
    buildEntity6 :
MaximumLiftCoefficient;
    buildEntity7 : Payload;
    buildEntity8 : Range;
    buildEntity9 : TouchDownSpeed;
    buildEntity10 : ApproachSpeed;
    buildEntity11 : StallingSpeed;
    buildEntity12 : MTOW
....
end

AirbusA320 in Module, Token with
module_name
    moduleName : "A320"
end

A320HasVer100 in HasRevision, Token with
bd_source
```

[21] Note the Condition build element can be either versioned or treated as a primitive as needs dictate. As a rule of thumb, conditions representing hierarchical states composed of sub-states *are* versioned, (e.g., Alpha Lock), whereas simple states and events (as with specifications) *are not* (e.g., CAoA < 7.1 degrees) - see figures 5.14 and 5.15.

```
    bdSource : AirbusA320
bd_target
    bdTarget : Dash100
end

Dash100 in Version , Token with
version_name
    versionName : "A320-100"
end

Dash100HasPropertyGrossWingArea in
HasProperty, Token with
bd_source
    bdSource : Dash100
bd_target
    bdTarget : GrossWingArea
end

GrossWingArea in Property, Token with
property_name
    propertyName : "Gross Wing Area"
end

Dash100HasPropertyMTOW in HasProperty,
Token with
bd_source
    bdSource : Dash100
bd_target
    bdTarget : MTOW
end

MTOW in Property, Token with
property_name
    propertyName : "Maximum Takeoff Weight"
end

-- see App.B, Pt.3 for other properties

MTOWHasSpecificationSpec1 in
HasSpecification, Token with
bd_source
    bdSource : MTOW
bd_target
    bdTarget : MTOWSpec1
end

MTOWSpec1 in Specification, Token with
value_specification
    valueSpecification : "75 000 kg"
end

MTOWHasSpecificationSpec2 in
HasSpecification, Token with
bd_source
    bdSource : MTOW
bd_target
    bdTarget : MTOWSpec2
end

MTOWSpec2 in Specification, Token with
value_specification
    valueSpecification : "75 500 kg"
end

MTOWHasSpecificationSpec3 in
HasSpecification, Token with
bd_source
    bdSource : MTOW
bd_target
    bdTarget : MTOWSpec3
end

MTOWSpec3 in Specification, Token with
value_specification
    valueSpecification : "76 000 kg"
end

MTOWSpecSucceeds1 in Succeeds, Token with
bd_source
    bdSource : MTOWSpec2
bd_target
    bdTarget : MTOWSpec1
end

MTOWSpecSucceeds2 in Succeeds, Token with
bd_source
    bdSource : MTOWSpec3
bd_target
    bdTarget : MTOWSpec2
end
```

Instantiation of elements in figure 5.13

```
FlightControlSystem in Module, Token with
module_name
    moduleName : "FCS"
end

FCSHasVerDash100FCS in HasRevision, Token
with
bd_source
    bdSource : FlightControlSystem
bd_target
    bdTarget : Dash100FCS
end

Dash100FCS in Version , Token with
version_name
    versionName : "-100 FCS"
end

Dash100FCSHasFTsubmoduleSEC1 in
HasFTSubmodule, Token with
bd_source
    bdSource : Dash100FCS
bd_target
    bdTarget : SEC1
end

SEC1 in Module, Token with
module_name
    moduleName : "SEC1"
end

-- see App.B, Pt.3 for SEC2 objects

Dash100FCSHasFTsubmoduleELAC1 in
HasFTSubmodule, Token with
bd_source
    bdSource : Dash100FCS
bd_target
    bdTarget : ELAC1
end

ELAC1 in Module, Token with
module_name
    moduleName : "ELAC1"
end

-- see App.B, Pt.3 for ELAC2 objects

Dash100FCSHasFTsubmoduleSFCC1 in
HasFTSubmodule, Token with
bd_source
    bdSource : Dash100FCS
bd_target
    bdTarget : SFCC1
end

SFCC1 in Module, Token with
module_name
    moduleName : "SFCC1"
end

-- see App.B, Pt.3 for SFCC2 objects

SFCC1HasVerDash100SFCC1 in HasRevision,
Token with
bd_source
    bdSource : SFCC1
bd_target
```

```
    bdTarget : Dash100SFCC1
end

Dash100SFCC1 in Version , Token with
version_name
    versionName : "-100 SFCC1"
end

-- see App.B, Pt.3 for Flap Channel
   objects

Dash100SFCC1HasSubmoduleSlatChannel in
HasSubmodule, Token with
bd_source
    bdSource : Dash100SFCC1
bd_target
    bdTarget : SlatChannel
end

SlatChannel in Module, Token with
module_name
    moduleName : "Slat Channel"
end

SlatChannelHasVerSlatChanneli in
HasRevision, Token with
bd_source
    bdSource : SlatChannel
bd_target
    bdTarget : SlatChanneli
end

SlatChanneli in Version , Token with
version_name
    versionName : "Slat Channel-i"
end

SlatChanneliHasFTsubmoduleSCLanel in
HasFTSubmodule, Token with
bd_source
    bdSource : SlatChanneli
bd_target
    bdTarget : SlatChannelLanel
end

SlatChannelLanel in Module, Token with
module_name
    moduleName : "SCLanel"
end

-- see App.B, Pt.3 for Slat Channel Lane
   2 objects

SlatChannelLanelHasVerSlatChannelLaneli
in HasRevision, Token
with
bd_source
    bdSource : SlatChannelLanel
bd_target
    bdTarget : SlatChannelLaneli
end

SlatChannelLaneli in Version , Token with
version_name
    versionName : "SCLanel-i"
end

SlatChannelLaneliEncapsulatesInhibtSlatRe
traction in Encapsulates, Token
with
bd_source
    bdSource : SlatChannelLaneli
bd_target
    bdTarget : InhibitSlatRetraction
end

InhibitSlatRetraction in Function, Token
with
function_name
    functionName : "Inhibit Slat
Retraction"
end

InhibitSlatRetractionHasVerInhibitSlatRet
ractioni in HasRevision, Token with
bd_source
    bdSource : InhibitSlatRetraction
bd_target
    bdTarget : InhibitSlatRetractioni
end

InhibitSlatRetractioni in Version , Token
with
version_name
    versionName : "Inhibit Slat
                   Retraction-i"
end

-- see App.B, Pt.3 for 'Disabled' and
   'Not-Engaged' condition objects

InhibitSlatRetractioniHasConditionSpeedBa
ulk in HasCondition, Token with
bd_source
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : SpeedBaulk
end

SpeedBaulk in Condition, Token with
condition_label
    conditionLabel : "Speed-Baulk"
end

InhibitSlatRetractioniHasConditionAlphaLo
ck in HasCondition, Token
with
bd_source
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : AlphaLock
end

AlphaLock in Condition, Token with
condition_label
    conditionLabel : "Alpha-Lock"
end

InhibitSlatRetractioniHasSubfunctionISRLo
wSpeed in HasSubfunction, Token with
bd_source
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : ISRLowSpeed
end

ISRLowSpeed in Function, Token with
function_name
    functionName : "ISR-Low Speed"
end

InhibitSlatRetractioniHasSubfunctionISRHi
ghAoA in HasSubfunction, Token
with
bd_source
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : ISRHighAoA
end

ISRHighAoA in Function, Token with
function_name
    functionName : "ISR-High Angle of
Attack"
end
```

Instantiation of elements in figure 5.14

```
ISRHighAoAHasVerISRHighAoAi in
HasRevision, Token
with
```

```
bd_source
    bdSource : ISRHighAoA
bd_target
    bdTarget : ISRHighAoAi
end

ISRHighAoAi in Version , Token with
version_name
    versionName : "ISR-High Angle of
Attack-i"
end

AlphaLockHasVerAlphaLocki in HasRevision,
Token
with
bd_source
    bdSource : AlphaLock
bd_target
    bdTarget : AlphaLocki
end

AlphaLocki in Version , Token with
version_name
    versionName : "Alpha-Lock-i"
end

AlphaLockiHasSubconditionEngagedAlphaLock
in HasSubcondition, Token
with
bd_source
    bdSource : AlphaLocki
bd_target
    bdTarget : EngagedAlphaLock
end

EngagedAlphaLock in Condition, Token with
condition_label
    conditionLabel : "Engaged Alpha-Lock"
end

EngagedAlphaLockHasVerEngagedAlphaLocki
in HasRevision, Token
with
bd_source
    bdSource : EngagedAlphaLock
bd_target
    bdTarget : EngagedAlphaLocki
end

EngagedAlphaLocki in Version , Token with
version_name
    versionName : "Engaged Alpha-Lock-i"
end

AlphaLockiHasSubconditionReleaseAlphaLock
in HasSubcondition, Token with
bd_source
    bdSource : AlphaLocki
bd_target
    bdTarget : ReleaseAlphaLock
end

ReleaseAlphaLock in Condition, Token with
condition_label
    conditionLabel : "Release Alpha-Lock"
end

ReleaseAlphaLockHasVerReleaseAlphaLocki
in HasRevision, Token
with
bd_source
    bdSource : ReleaseAlphaLock
bd_target
    bdTarget : ReleaseAlphaLocki
end

ReleaseAlphaLocki in Version , Token with
version_name
    versionName : "Release Alpha-Lock-i"
end

ISRHAoAiConsumesCAoA in
ConsumesExternalIO, Token
with
bd_source
    bdSource : ISRHighAoAi
bd_target
    bdTarget : CAoA
end

CAoA in InputOutput, Token with
flow_name
    flowName : "CAoA"
end

CAoAHasVerCAoAi in HasRevision, Token
with
bd_source
    bdSource : CAoA
bd_target
    bdTarget : CAoAi
end

CAoAi in Version, Token with
version_name
    versionName "CAoAi"
end

CAoAiCarriesConditionCAoA7Pt1Event in
CarriesCondition, Token
with
bd_source
    bdSource : CAoAi
bd_target
    bdTarget : CAoA7Pt1Event
end

CAoA7Pt1Event in Condition, Token with
condition_label
    conditionLabel : "CAoA < 7.1 degrees"
end

CAoA7Pt1EventOccurringInEngagedAlphaLock
in OccurringIn, Token
with
bd_source
    bdSource : CAoA7Pt1Event
bd_target
    bdTarget : EngagedAlphaLock
end

CAoA7Pt1EventLeadsToReleaseAlphaLock in
LeadsTo, Token
with
bd_source
    bdSource : CAoA7Pt1Event
bd_target
    bdTarget : ReleaseAlphaLock
end


-- see App.B, Pt.3 for instantiation of
   elements in figure 5.15
```

The following episode introduces artifacts from the traceability Workspace of our featured project. Again, the intention is to provide further contextual information - this time in the form of Aerospace Engineering Objects - for 'versioning' in subsequent episodes.

Episode 2 - Modelling the Behaviour of A320-100 SFCCs Using Statecharts

Practitioners will typically model behaviour of Inhibit Slat Retraction as a Statechart (Harel, 1988). In a MATrA context, this implies a meta-model exists capable of receiving data mapped from an appropriate tool. Statecharts are not a feature of our work here as project NATURE (Pohl, 1996) produced a meta-model for the OMT dynamic model (an extension of Statecharts), and because a Statechart meta-model for UML also exists in the public domain. Instead, we use a simplified version of the latter (Appendix B, Part 4) - based on version 1.3 of the UML Specification (Rational Software Corporation, 1997a) - to demonstrate their representation in this example.

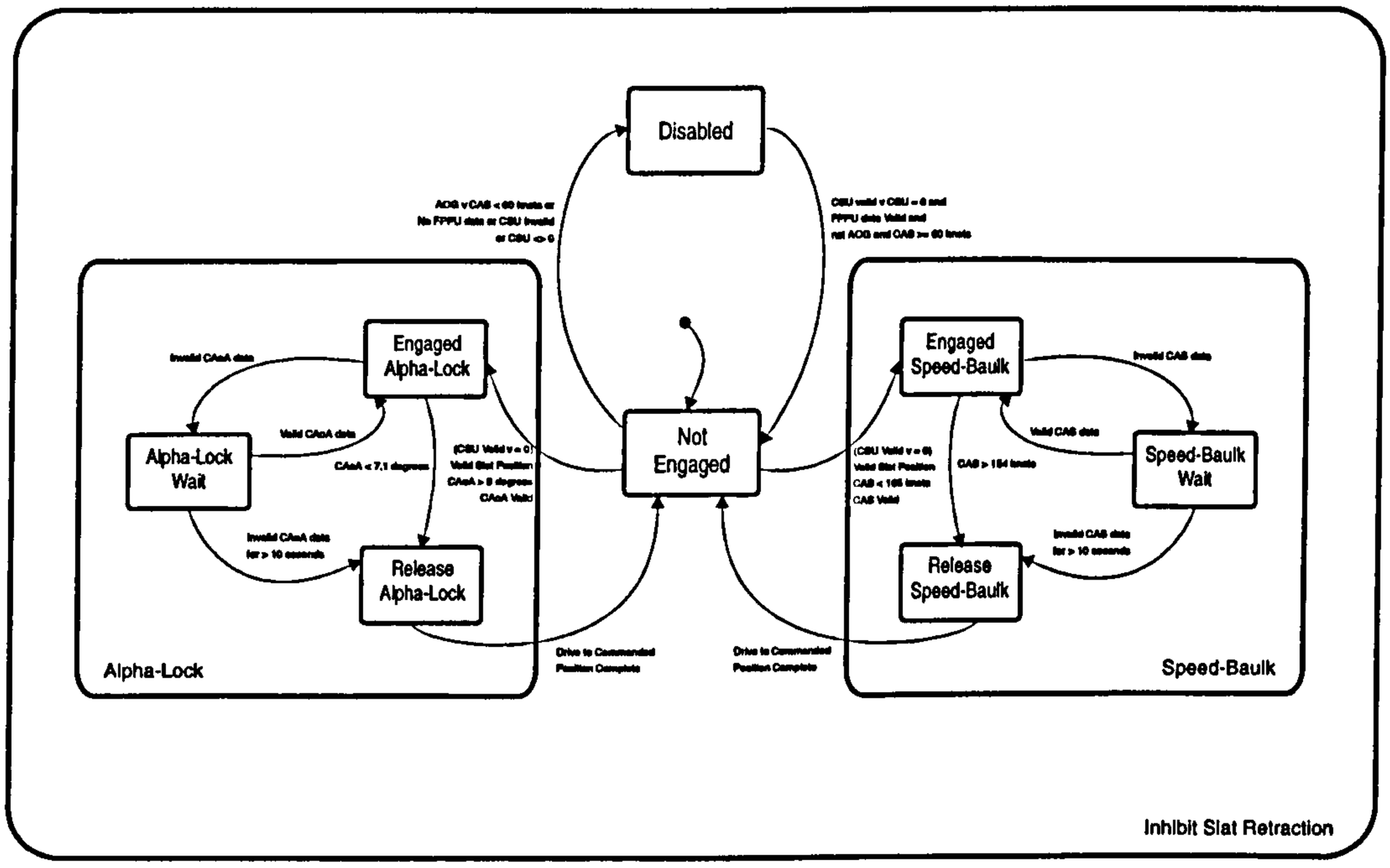


Figure 5.16 - 'Statechart Representation of Inhibit Slat Retraction'

The Inhibit Slat Retraction function has been modelled with ten states (conditions) as previously described in figures 5.14 and 5.15; for reader orientation the complete Statechart is shown in figure 5.16. Essentially, we are interested in events triggering a transition from Engaged Alpha-Lock to Release-Alpha Lock and from Engaged Speed-Baulk to Release Speed-Baulk; recall from the PDS, these occur under conditions CAoA < 7.1 degrees and CAS > 154 knots respectively. However as we later demonstrate, both are required to change as an indirect result of increased range and take-off-weight requirements for the dash 200 revision. This is shown for the former by analysis of Impacts associations in Episode 4.

Mapping the Statechart in figure 5.16, from the tool in which it was developed into the MATrA Workspace establishes BEelementAEO and BEmodelAEO associations between the PDS and corresponding objects of the StateMachine meta-model. We demonstrate this at the logical level (i.e., as it appears to MATrA users) in figure 5.17, with the Statechart on the left and Product Data Synthesis on the right[22].

[22] To maintain readability, PDS revisions are suppressed in figure 5.17.

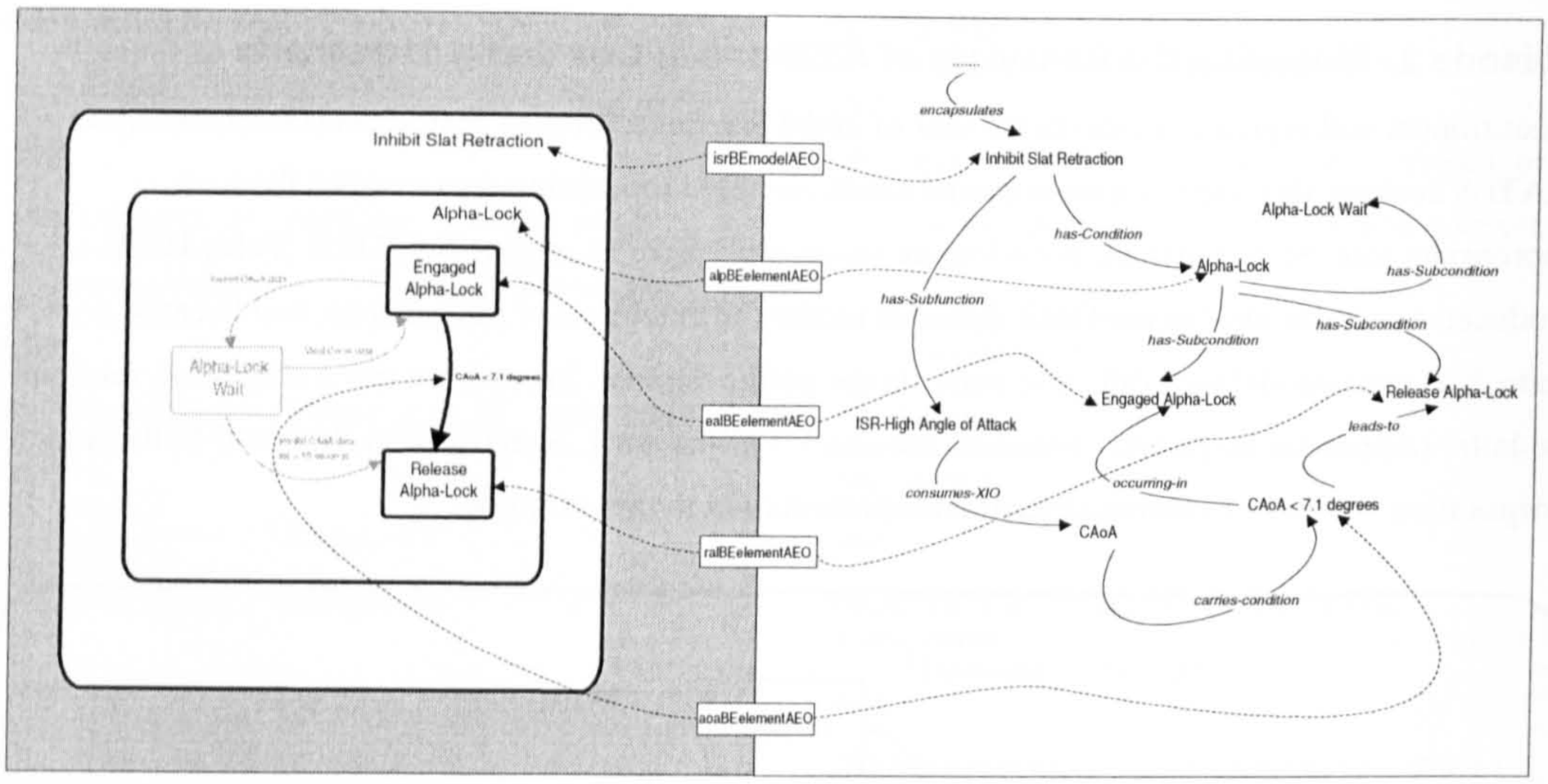


Figure 5.17 - 'Linking the Traceability Workspace and PDS over Aerospace Link Entities'

O-Telos code capturing information contained in figure 5.17 appears below. Specifically, we present instantiation of the partial StateMachine meta-model and Aerospace Link Entity (BEmodelAEO and BEelementAEO) classes.

Definition of State Machine Elements (subset)

```
InhibitSlatRetractionStateMachine in
StateMachine, Token with
subject
    _Subject: "Inhibit Slat Retraction"
state
    _State : AlphaLockState
end

AlphaLockState in SubMachineState, Token
with
state_name
    stateName "Alpha-Lock"
sub_machine
    subMachine : AlphaLockStateMachine
end

AlphaLockStateMachine in StateMachine,
Token with
state
    _State1 : EngagedAlphaLockState;
    _State2 : ReleaseAlphaLockState
transition
    _Transition : EngagedToReleaseCAoA
end

EngagedAlphaLockState in State, Token
with
state_name
    stateName "Engaged Alpha-Lock"
end

ReleaseAlphaLockState in State, Token
with
state_name
    stateName "Release Alpha-Lock"
end

EngagedToReleaseCAoA in Transition, Token
with
source
    transSource : EngagedAlphaLock
target
    transTarget : ReleaseAlphaLock
trigger
    trans_trigger :
EngagedToReleaseTriggerCAoA
end

EngagedToReleaseTriggerCAoA in Event,
Token with
event_description
    eventDescription : "CAoA < 7.1
degrees"
end
```

Definition of Aerospace Link Entity Elements (subset)

```
IsrBEmodelAEO in BEmodelAEO, Token with
build_element
    buildElement : InhibitSlatRetraction
aerospace_engineering_object
    aerospaceEngineeringObject :
InhibitSlatRetractionStateMachine
end

AlpBEelementAEO in BEelementAEO, Token
with
build_element
    buildElement : AlphaLock
aerospace_engineering_object
    aerospaceEngineeringObject :
AlphaLockState
end

EalBEelementAEO in BEelementAEO, Token
with
build_element
    buildElement : EngagedAlphaLock
aerospace_engineering_object
    aerospaceEngineeringObject :
EngagedAlphaLockState
end

RalBEelementAEO in BEelementAEO, Token
with
build_element
    buildElement : ReleaseAlphaLock
```

```
aerospace_engineering_object
    aerospaceEngineeringObject :
ReleaseAlphaLockState
end

AoaBEelementAEO in BEelementAEO, Token
with
```

```
build_element
    buildElement : CAoA7Pt1Event
aerospace_engineering_object
    aerospaceEngineeringObject :
EngagedToReleaseTriggerCAoA
end
```

Next we describe a configuration constructed from versions of build elements featured in the models for Episode 1.

Episode 3 - Creating a Configuration for A320-100

To create a configuration (instantiating the Configuration class) for A320-100, it is necessary to identify constituent elements from the versioned PDS data-set. While we purposely limit inclusion of multiple version elements for presentation purposes, a configuration can still be created to provide a flavour of what this practice involves (figure 5.18). Note the example features a representative subset of elements from the structures in Episode 1. Note also the omission of 'spine' associations (rolename build_object). and that all configuration build associations are assumed to be populated by the rule in 5.5.3.2.2(i.2).

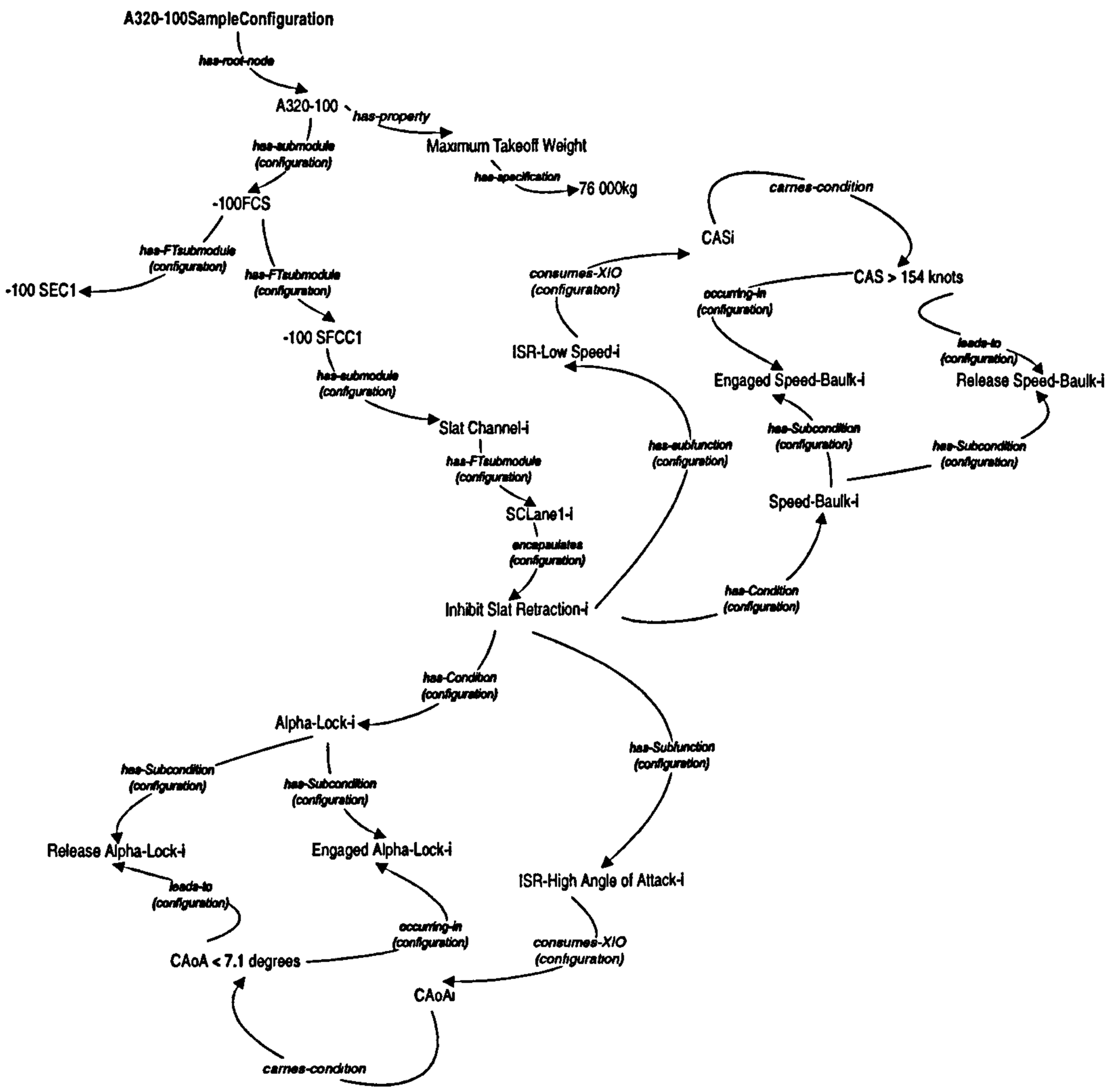


Figure 5.18 - 'Example Configuration for A320-100'

In the following, we provide O-Telos code capturing information contained in the above figure (5.18).

Configuration Instantiation

```
A320100SampleConfiguration in
Configuration, Token
with
root_node
    rootNode : Dash100
build_association
    buildAssociation1 :
Dash100HasPropertyMTOW;
    buildAssociation2 :
MTOWHasSpecificationSpec3;
    buildAssociation3 :
CAoAiCarriesConditionCAoA7Pt1Event;
    buildAssociation4 :
CASiCarriesConditionCAS154KtsEvent
--Configuration Build Associations
config_build_association
    configBuildAssociation1 :
Dash100HasConSubmoduleDash100FCS;
    configBuildAssociation2 :
Dash100FCSHasConFTsubmoduleDash100SFCC1;
    configBuildAssociation3 :
Dash100FCSHasConFTsubmoduleDash100SEC1;
    configBuildAssociation4 :
Dash100SFCC1HasConSubmoduleSlatChanneli;
    configBuildAssociation5 :
SlatChanneliHasConFTsubmoduleSCLanei;
    configBuildAssociation6 :
SlatChannelLanei1EncapsulatesConISRi;
    configBuildAssociation7 :
ISRiHasConSubfunctionISRHighAoAi;
    configBuildAssociation8 :
ISRiHasConConditionAlphaLocki;
    configBuildAssociation9 :
AlphaLockiHasConSubconditionEALi;
    configBuildAssociation10 :
AlphaLockiHasConSubconditionRALi;
    configBuildAssociation11 :
ISRiHasConSubfunctionISRLowSpeedi;
    configBuildAssociation12 :
ISRiHasConConditionSpeedBaulki;
    configBuildAssociation13 :
SpeedBaulkiHasConSubconditionESBi;
    configBuildAssociation14 :
SpeedBaulkiHasConSubconditionRSBi;
    configBuildAssociation15 :
ISRLowSpeediConsumesConXIOCASi;
    configBuildAssociation16 :
ISRHAoAiConsumesConXIOCAoAi;
    configBuildAssociation17 :
CAoA7Pt1EventOccurringInConEALi;
    configBuildAssociation18 :
CAS154KtsEventOccurringInConESBi;
    configBuildAssociation19 :
CAoA7Pt1EventLeadsToConRALi;
    configBuildAssociation20 :
CAS154KtsEventLeadsToConRSBi
--Build Objects
build_object
    buildObject1 : MTOW;
    buildObject2 : MTOWSpec3;
    buildObject3 : Dash100;
    buildObject4 : Dash100FCS;
    buildObject5 : Dash100SFCC1;
    buildObject6 : Dash100SEC1;
    buildObject7 : SlatChanneli;
    buildObject8 : SlatChannelLaneli;
    buildObject9 :
InhibitSlatRetractioni;
    buildObject10 : ISRHighAoAi;
    buildObject11 : AlphaLocki;
    buildObject12 : EngagedAlphaLocki;
    buildObject13 : ReleaseAlphaLocki;
    buildObject14 : ISRLowSpeedi;
    buildObject15 : SpeedBaulki;
    buildObject16 : EngagedSpeedBaulki;
    buildObject17 : ReleaseSpeedBaulki;
    buildObject18 : CAoAi;
    buildObject19 : CAoA7Pt1Event;
    buildObject20 : CASi;
    buildObject21 : CAS154KtsEvent
end
```

Configuration Build Associations

```
Dash100HasConSubmoduleDash100FCS in
HasConfigurationSubmodule, Token
with
bd_souce
    bdSource : Dash100
bd_target
    bdTarget : Dash100FCS
end

Dash100FCSHasConFTsubmoduleDash100SFCC1
in HasConfigurationFTsubmodule, Token
with
bd_souce
    bdSource : Dash100FCS
bd_target
    bdTarget : Dash100SFCC1
end

Dash100FCSHasConFTsubmoduleDash100SEC1in
HasConfigurationFTsubmodule, Token
with
bd_souce
    bdSource : Dash100FCS
bd_target
    bdTarget : Dash100SEC1
end

Dash100SFCC1HasConSubmoduleSlatChanneli
in HasConfigurationSubmodule, Token
with
bd_souce
    bdSource : Dash100SFCC1
bd_target
    bdTarget : SlatChanneli
end

SlatChanneliHasConFTsubmoduleSCLanei in
HasConfigurationFTsubmodule, Token
with
bd_souce
    bdSource : SlatChanneli
bd_target
    bdTarget : SlatChannelLaneli
end

SlatChannelLanei1EncapsulatesConISRi in
HasConfigurationFTsubmodule, Token
with
bd_souce
    bdSource : SlatChannelLaneli
bd_target
    bdTarget : InhibitSlatRetractioni
end

ISRiHasConSubfunctionISRHighAoAi in
HasConfigurationSubfunction, Token
with
bd_souce
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : ISRHighAoAi
end

ISRiHasConConditionAlphaLocki in
HasConfigurationCondition, Token
with
bd_souce
    bdSource : InhibitSlatRetractioni
```

```
bd_target
    bdTarget : AlphaLocki
end

AlphaLockiHasConSubconditionEALi in
HasConfigurationCondition, Token
with
bd_souce
    bdSource : AlphaLocki
bd_target
    bdTarget : EngagedAlphaLocki
end

AlphaLockiHasConSubconditionRALi in
HasConfigurationCondition, Token
with
bd_souce
    bdSource : AlphaLocki
bd_target
    bdTarget : ReleaseAlphaLocki
end

ISRiHasConSubfunctionISRLowSpeedi in
HasConfigurationSubfunction,
Token
with
bd_souce
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : ISRLowSpeedi
end

ISRiHasConConditionSpeedBaulki in
HasConfigurationCondition, Token
with
bd_souce
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : SpeedBaulki
end

SpeedBaulkiHasConSubconditionESBi in
HasConfigurationCondition, Token
with
bd_souce
    bdSource : SpeedBaulki
bd_target
    bdTarget : EngagedSpeedBaulki
end

SpeedBaulkiHasConSubconditionRSBi in
HasConfigurationCondition, Token
with
bd_souce
    bdSource : SpeedBaulki
bd_target
    bdTarget : ReleaseSpeedBaulki
end

ISRLowSpeediConsumesConXIOCASi in
ConsumesConfigurationXIO, Token
with
bd_souce
    bdSource : ISRLowSpeedi
bd_target
    bdTarget : CASi
end

ISRHAoAiConsumesConXIOCAoAi in
ConsumesConfigurationXIO, Token
with
bd_souce
    bdSource : ISRHighAoAi
bd_target
    bdTarget : CAoAi
end

CAoA7Pt1EventOccurringInConEALi in
OccurringInConfiguration,
Token
with
bd_souce
    bdSource : CAoA7Pt1Event
bd_target
    bdTarget : EngagedAlphaLocki
end

CAS154KtsEventOccurringInConESBi in
OccurringInConfiguration, Token
with
bd_souce
    bdSource : CAS154KtsEvent
bd_target
    bdTarget : EngagedSpeedBaulki
end

CAoA7Pt1EventLeadsToConRALi in
LeadsToConfiguration, Token
with
bd_souce
    bdSource : CAoA7Pt1Event
bd_target
    bdTarget : ReleaseAlphaLocki
end

CAS154KtsEventLeadsToConRSBi in
LeadsToConfiguration, Token
with
bd_souce
    bdSource : CAS154KtsEvent
bd_target
    bdTarget : ReleaseSpeedBaulki
end
```

Episode 4 - Impact Analysis of A320-100

At this point we shift emphasis to the consideration of Impacts dependencies between elements introduced in Episode 1. As indicated in subsection 5.5.3.2.1, this is necessary to assess the need for modifications across a populated Product Data Synthesis - either to facilitate evolutionary change, or to assist in the development of product variants.

The intention is for the dependencies themselves to be inserted as development proceeds and so this episode is purely concerned with their application. Specifically, how changes in Range and Maximum-Takeoff Weight impact on various other aircraft performance properties and ultimately on the triggering of transitions from Engaged Alpha-Lock to Release-Alpha Lock and from Engaged Speed-Baulk to Release Speed-Baulk.

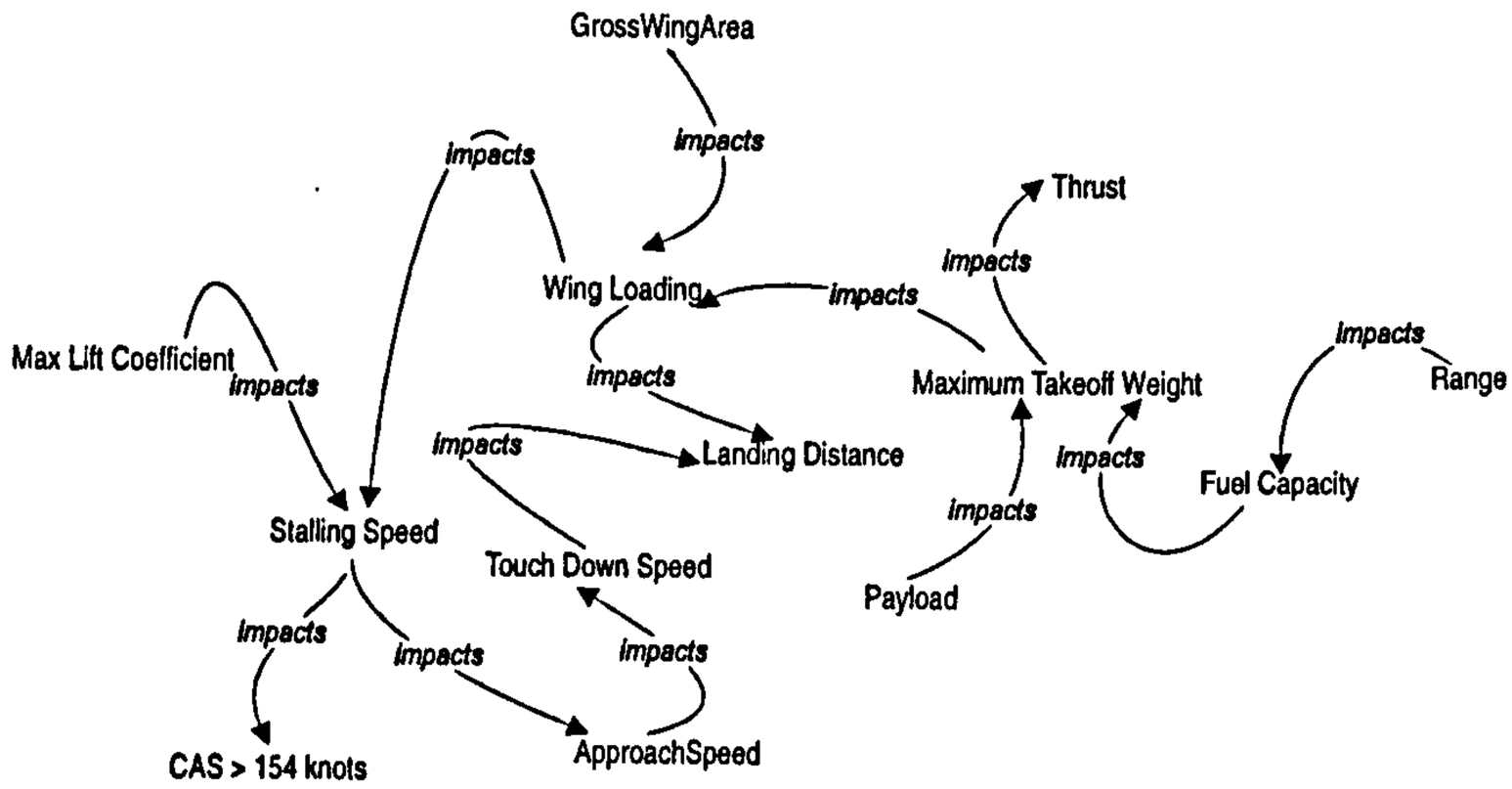


Figure 5.19 - 'Impacts Associations Showing Dependency Propagation'

It can be seen from figure 5.19 that Range influences Fuel Capacity which in turn has a bearing on the Maximum Takeoff Weight; this affects Wing Loading and hence Stalling Speed such that the latter impacts on our condition triggering the transition from Engaged Speed-Baulk to Release Speed-Baulk. Recall that the featured approach is pessimistic in that it simply alerts engineers to that fact that one build element is in some way influenced by another[23]. And whilst the element in question may exhibit some degree of 'tolerance' to change, this must be affirmed by investigation. Here we assume a change to the condition in question *is* necessary and demonstrate how it is handled within MATrA in later episodes. A similar investigation would of course be necessary to establish whether the condition triggering transitions from Engaged Alpha-Lock to Release Alpha-Lock also needs to be changed.

We now present an O-Telos example of the Impacts association class from figure 5.19, with source Maximum Takeoff Weight and target Wing Loading:-

```
MtowImpactsWL in Impacts, Token with
bd_source
    bdSource: MTOW
bd_target
    bdTarget : WingLoading
end
```

The remaining episodes in our scenario relate to structuring of changes arising from analysis of the existing A320-100 aircraft towards production of its successor, the A320-200.

[23] Note: a rule could specified to determine transitive dependencies between Impacts associations in order to support analysis.

Episode 5 - Describing the A320-200 Derivative

Let us now assume development of the A320-100 is complete and that engineers are in the process of modifying the existing design in order to produce an extended range and increased takeoff weight derivative, the A320-200. In Episode 4 we described how tracing across Impacts associations within the Product Data Synthesis has revealed that range affects fuel-capacity, thereby increasing the weight of the aircraft and that this impacts transitively on its safe operational envelope. In particular, conditions triggering release of the Inhibit Slat Retraction sub-functions ISR-Low Speed (shown) and ISR-High Angle of Attack (not shown, but based on the same principles of investigation).

Therefore having identified the need for change and established new event conditions using various analyses (again not shown) - the CAS threshold is modified to > 171 knots from 154, while CAoA becomes < 7.6 degrees from 7.1- engineers are in a position to express this information within the Product Data Synthesis. Firstly, a new Version object for the A320-200 aircraft (A320-200) is introduced, followed by new events (build elements) for the CAS and CAoA parameter conditions (figure 5.20).

Here, the changes are relatively small. But while at a low level of decomposition, the fact an intertwined model underpins our approach means original elements representing behaviour, as well as the functional and physical architecture, are largely retained. We simply introduce appropriate revisions to InputOutput and Condition elements and create a new configuration. In contrast, with a *version first* approach, new versions of all 'parent' build elements (direct and transitive) would need to be created.

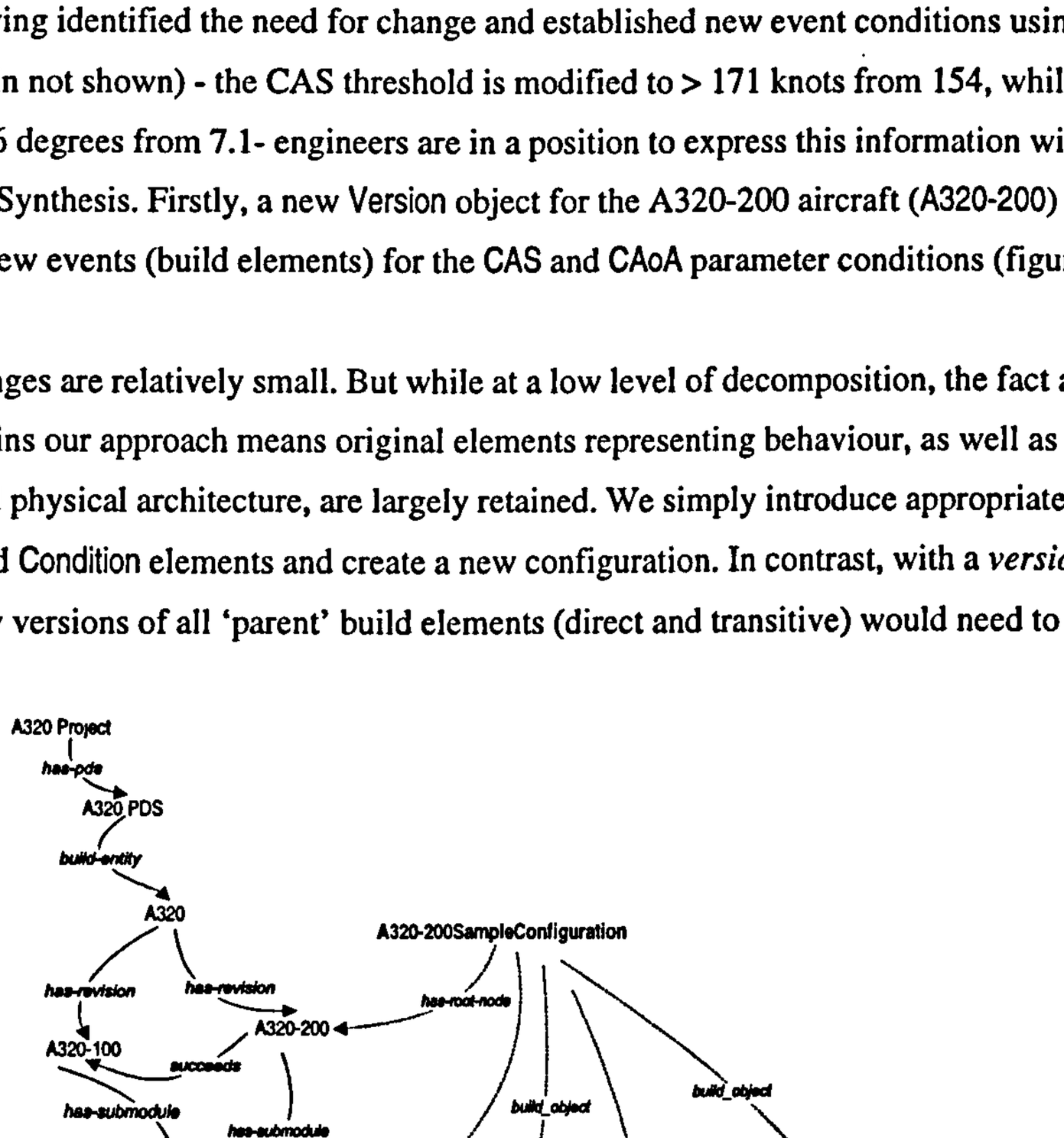


Figure 5.20 - 'Revising the A320-100 PDS (Including Partial Configuration Selection)'

Episode 6 - Updating Models of Behaviour for A320-200

While developing the revised aircraft, engineers must also update the Workspace. Therefore this episode considers traceability between structures capturing information from the existing and revised Statechart models. At a coarse granularity, this manifests as SucceedsAEO associations between successive models and at a finer level, as Removes and AddedTo associations (as described in 5.5.3.2.1).

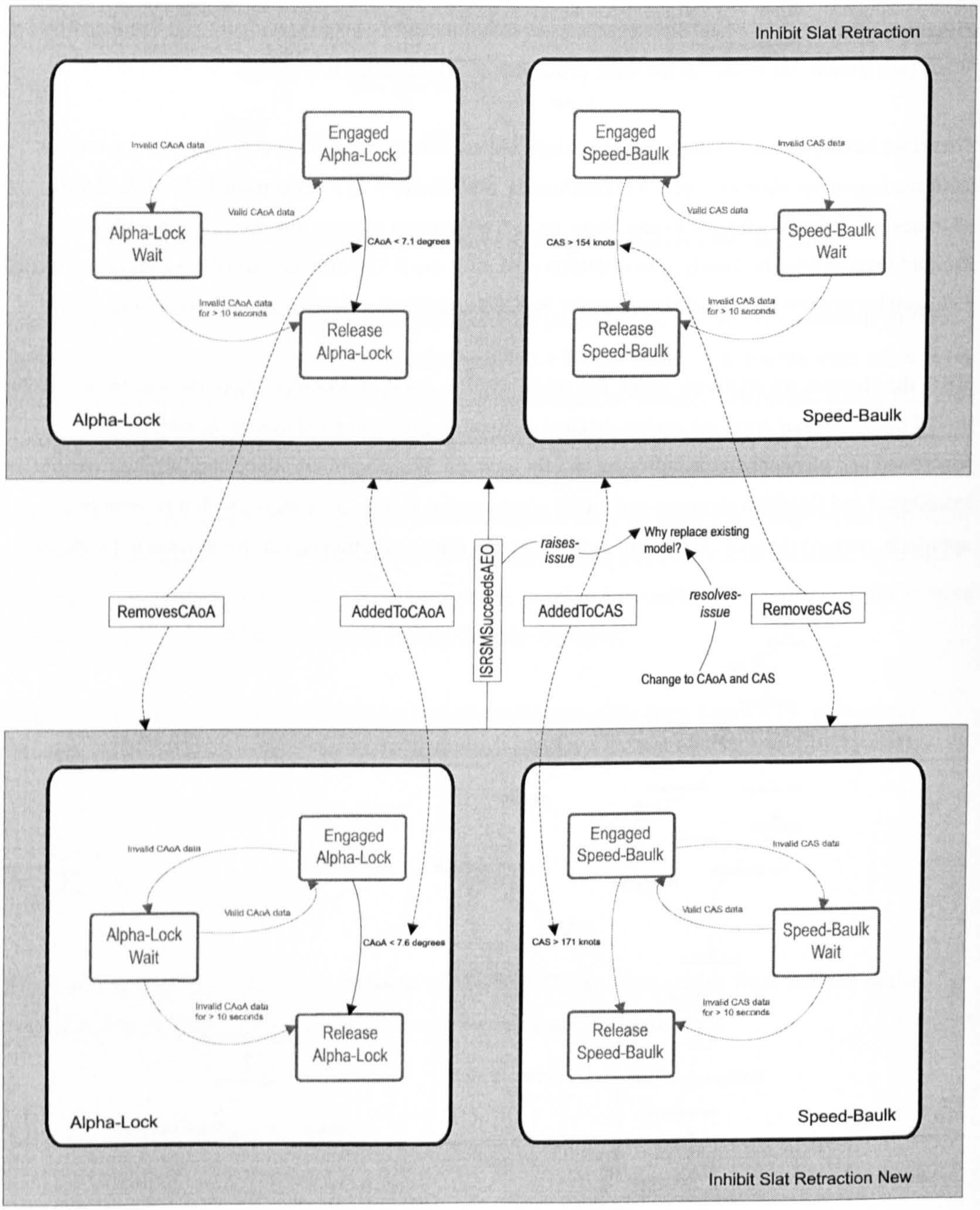


Figure 5.21 - 'Tracing Change Over SucceedsAEO, AddedTo and Removes Associations: A Statechart Example (Logical Level)'

In the context of our featured example, the original conditions triggering transitions from Engaged

Alpha-Lock to Release Alpha-Lock and Engaged Speed-Baulk to Release Speed-Baulk have been removed (i.e., are not present) in the new model, while their replacements (which of course were not present in the original) have been added. This concept is represented (again) at the logical level in figure 5.21:-

O-Telos code implementing the associations featured in figure 5.21 appears below:-

```
RemovesCAoA in Removes, Token with
from_entity
    fromEntity : InhibitSlatRetractionStateMachineNew
to_entity
    toEntity : EngagedToReleaseTriggerCAoA
end

AddedToCAoA in AddedTo, Token with
from_entity
    fromEntity : EngagedToReleaseTriggerCAoANew
to_entity
    toEntity : InhibitSlatRetractionStateMachine
end

RemovesCAS in Removes, Token with
from_entity
    fromEntity : InhibitSlatRetractionStateMachineNew
to_entity
    toEntity : EngagedToReleaseTriggerCAS
end

AddedToCAS in AddedTo, Token with
from_entity
    fromEntity : EngagedToReleaseTriggerCASNew
to_entity
    toEntity : InhibitSlatRetractionStateMachine
end

ISRSMSucceedsAEO in SucceedsAEO, Token with
from_entity
    fromEntity : InhibitSlatRetractionStateMachineNew
to_entity
    toEntity : InhibitSlatRetractionStateMachine
end
```

We also instantiate the Argumentation Structure (Appendix B, Part 2) with elements representing rationale attached to the 'ISRSMSucceedsAEO' association (from figure 5.21). In O-Telos, this is expressed as follows:-

```
ISRSMRaisesIssue in RaisesIssue, Token with
ate_source
    ateSource : ISRSMSucceedsAEO
issue_target
    issueTarget : ISRSMIssue
emd

ISRSMIssue in Issue, Token with
issue_text
    issueText : "Why replace existing model?"
end

ISRSMAssertionResolvesIssue in ResolvesIssue, Token with
assertion_source
    assertionSource: ISRSMAssertion
issue_target
    issueTarget : ISRSMIssue
end

ISRSMAssertion in Assertion, Token with
assertion_text
    assertionText : "Change to CAoA and CAS"
end
```

The final two episodes consider support for change deltas, both within the Product Data Synthesis (Episode 7) and the traceability Workspace (Episode 8).

Episode 7 - Configuration Delta for A320-100/A320-200

As indicated in subsection 5.5.2.1, a configuration delta provides engineers with a summary of the symmetric difference between two configurations. In Episode 3, we demonstrated a fragment of a configuration for the A320-100 aircraft; further configurations would be taken in developing its successor the A320-200. The O-Telos example below provides a partial configuration delta (instantiating ConfigurationDelta) based on the configuration from Episode 3 and an assumed configuration (based on hypothetical elements, and those selected in Episode 5) for the A320–200. Recall that derived population of ConfigurationDelta is achieved by appropriate implementation of the rule in 5.5.3.2.2(ii.1).

```
A320100A320200ConfigurationDelta in ConfigurationDelta, Token with
configuration_1
    _Configuration1 : A320100SampleConfiguration
configuration_2
    _Configuration2 : A320200SampleConfiguration
build_object
    buildObject1 : Dash100;
    buildObject2 : Dash200;
    buildObject3 : CAS154KtsEvent;
    buildObject4 : CAoA7Pt1Event;
    buildObject5 : CAS171KtsEvent;
    buildObject6 : CAoA7Pt6Event;
    buildObject7 : CAoAi;
    buildObject8 : CAoAii;
    buildObject9 : CASi;
    buildObject10 : CASii
end
```

Episode 8 - Aerospace Engineering Delta for Behavioural Models

Finally, we consider an aerospace engineering delta (instantiating AerospaceEngineeringDelta) expressing the symmetric difference between elements of our featured Statechart models derived (through appropriate implementation of the rule in 5.5.3.2.2(ii.3)) from the AddedTo and Removes associations in Episode 6. Again, only the O-Telos representation is provided.

```
ISRStateMachineAEODelta in AerospaceEngineeringDelta, Token with
model_1
    model1 : InhibitSlatRetractionStateMachine
model_2
    model2 : InhibitSlatRetractionStateMachineNew
delta_aeo
    deltaAEO1 : EngagedToReleaseTriggerCAoA;
    deltaAEO2 : EngagedToReleaseTriggerCAS;
    deltaAEO3 : EngagedToReleaseTriggerCAoANew;
    deltaAEO4 : EngagedToReleaseTriggerCASNew
end
```

5.5.4 Summary

Traceability of versions (subsuming revisions and variants) is essential to the aerospace industry as it supports continued evolution of existing aircraft, allowing manufacturers to keep pace with new technologies and changing markets.

This section proposed a novel structure for managing versions, and in particular revisions to both the Product Data Synthesis and traceability Workspace. The model encapsulates key concepts from configuration management literature, notably the *intertwined* versioning approach, as well as support for structuring configurations and change deltas.

Aspects of the model were demonstrated using a lengthy worked example, while a full evaluation again appears in Chapter Seven.

5.6 Chapter Summary

This chapter has presented novel meta-models (traceability structures) for well-defined and flexible notations used in *safety assessment* and *product management* throughout the aerospace industry; specifically, structures for Fault Tree Analysis and Failure Modes and Effects Analysis, together with a further structure based on the Programme Evaluation & Review Technique. Once more, we assume these are populated via the *tool2matra* transfer mechanism and where appropriate, verified for consistency against the Product Data Synthesis.

As in the previous chapter, we expressed key syntactic elements of each notation as a UML Class Diagram (using the System Engineering Notation Meta-model as a common basis), with well-formedness, usage and other constraints stated in OCL. Again the base classes were implemented in O-Telos (using ConceptBase) to provide a 'flavour' of automation, while consideration of the PERT structure also included a small worked example. Collectively these structures provide representative coverage of the *assessment* and *product management* Workspace viewpoints to complement the development perspective from Chapter Four.

The chapter concluded by demonstrating support for another aspect of product management, namely traceability of revisions and variants. In doing so we proposed the MATrA Configuration Model which is based on an established structuring technique from Configuration Management literature (the *intertwined* model), but which also incorporates means to represent change deltas and versioning related dependencies. Aspects of MCM were illustrated by a worked example.

In the following chapter we present two case studies based on material supplied by aerospace practitioners. The first of these exhibits the User Centred Requirements Structure (from Chapter Four) and the second, the Fault Tree and Failure Mode and Effects Analysis structures. Both case studies also feature the MATrA Natural Language Structure.

6 Tracing Development and Assessment Artifacts

6.1 Introduction

This chapter presents two case studies that demonstrate proof of concept for the User Centred Requirements Structure (from section 4.3) and the Fault Tree and Failure Modes and Effects Analysis structures (from sections 5.2 and 5.3).

Reader attention is drawn to the fact that featured artifacts are interleaved with O-Telos instantiations of the appropriate structures. Every effort has been made to maintain flow, with large amounts of code appearing in the appendices (C, Part 1 and D). However, traceability is essentially a practical topic and so representative examples are exhibited within the text. In view of these considerations, two paths are proposed which readers may follow depending on their interests, as shown in table 6.1.

Chapter 6: Suggested Reading Paths	
section	*title*
6.2	**Case Study I : A Hypothetical Mission Planning System for the Hawk 100 and 200 Series Aircraft**
6.2.1	Mission Planning System Overview
6.2.2	BASE Control Software Requirements and MATrA Representation
6.2.2.1	Use Case View
6.2.2.1.1	Instantiation of Use Case View
6.2.2.2	Interaction View
6.2.2.2.1	Erase Cartridge - Normal Path
6.2.2.2.2	Erase Cartridge - No Cartridge Present
6.2.2.2.3	Erase Cartridge - No Data on Cartridge
6.2.2.2.4	Erase Cartridge - Pilot Chooses Not to Erase Data
6.2.2.2.5	Retrieve from Cartridge - Normal Path (Timing Fragment)
6.2.2.2.6	Choose Mission and Aircraft (Event Group Fragment)
6.2.3	Trace Relations
6.2.3.1	Instantiation of Trace Relations
6.2.4	Summary
6.3	**Case Study II : A Brake System Control Unit for a Wheel Braking System of a Hypothetical Aircraft**
6.3.1	Scope of Case Study
6.3.2	Overview of S18 Wheel Braking System and Brake System Control Unit
6.3.3	Preliminary System Safety Assessment - Brake System Control Unit
6.3.3.1	Background on BSCU Design
6.3.3.2	Fault Tree Analysis - Preliminary
6.3.3.2.1	Instantiation of Fault Tree Analysis Meta-model - Preliminary Fault Tree
6.3.4	System Safety Assessment - Brake System Control Unit
6.3.4.1	Background on BSCU Power Supply Design
6.3.4.2	Failure Modes and Effects Analysis
6.3.4.2.1	Functional Failure Modes and Effects Analysis
6.3.4.2.2	Instantiation of Functional Failure Modes and Effects Analysis Meta-model
6.3.4.2.3	Piece-Part Failure Modes and Effects Analysis
6.3.4.2.4	Instantiation of Piece-Part Failure Modes and Effects Analysis Meta-model
6.3.4.3	Fault Tree Analysis - Updated
6.3.4.3.1	Instantiation of Fault Tree Analysis Meta-model - Updated Fault Tree

6.3.5	Trace Relations
6.3.5.1	Instantiation of Trace Relations
6.3.6	Summary
6.4	Chapter Summary

	Application-Engineering Path (Systems Engineer)
	Method-Engineering Path (Tool Developer)

Table 6.1 - 'Chapter 6: Suggested Reading Paths'

The *Application-Engineering* path (i.e., omitting the shaded subsections in table 6.1) should be taken by those interested in traceability from a user perspective. Alternatively, readers concerned with tool development, and hence implementation of the featured structures may wish to concentrate on the *Method-Engineering* path (i.e., focusing on the O-Telos subsections shaded in table 6.1).

6.2 Case Study I : A Hypothetical Mission Planning System for the Hawk 100 and 200 Series Aircraft

In this section, we present a case study based on a Mission Planning System (MPS) for the Hawk 100 and 200 series of trainer/lead-in-fighter aircraft produced by BAE SYSTEMS (BAe, 1999). Its purpose is to demonstrate features of the User Centred Requirements Structure (subsection 4.3) and to show support for traceability across development artifacts within the (intra-micro) horizontal dimension.

6.2.1 Mission Planning System Overview

The Mission Planning System (MPS) supports mission planning and rehearsal and the transfer of data (stored on a Data Transfer Cartridge - DTC) to and from the aircraft environment. Its components include a Data Transfer Module (DTM) which provides a receptacle for, and facilitates supporting, the loading and unloading of data to and from the DTC; DTCs are inserted into the aircraft for the transfer and retrieval of data from aircraft avionics systems (BAe, ibid.)

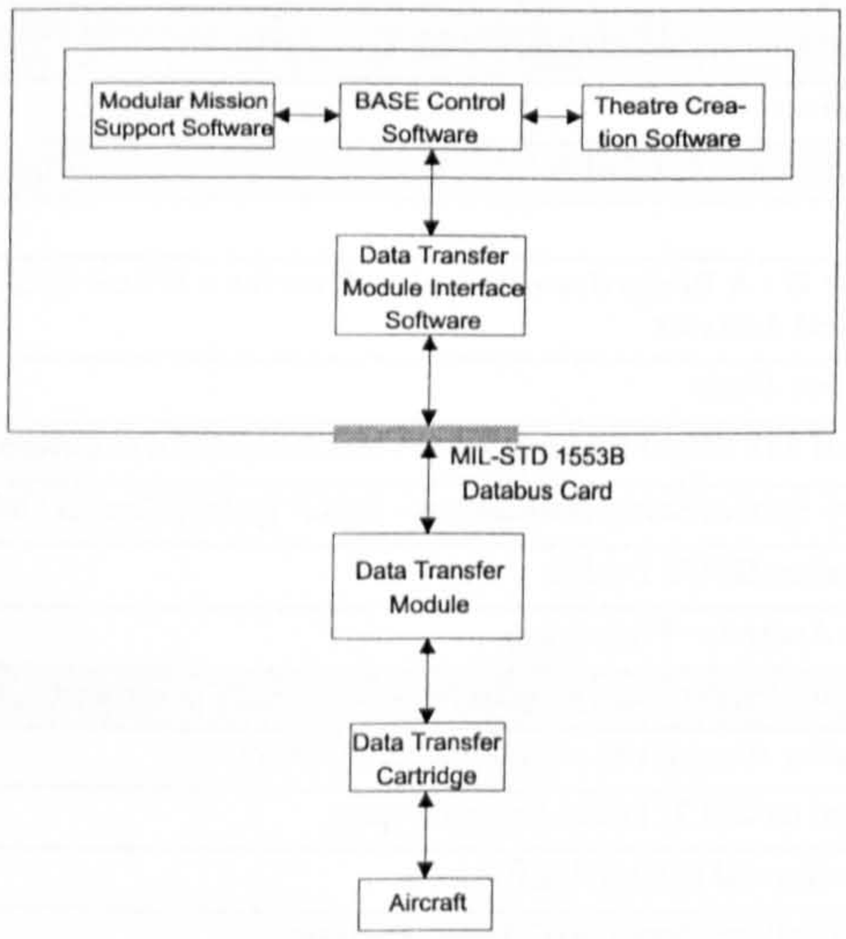


Figure 6.1 - 'Mission Planning System - Software Interaction'

MPS features four software modules, as shown in figure 6.1 - the BASE Control Software (BCS), Data Transfer Module Interface Software (DTMIS), Modular Mission Support Software (MMSS) and Theatre Creation Software (TCS). In this case study, we concentrate on the BASE Control Software.

6.2.2 BASE Control Software Requirements and MATrA Representation

The BASE Control Software provides an integrated mechanism for down loading missions to a DTC, for retrieving data from a DTC and for the display and editing of data stored on a DTC. In this subsection we introduce a subset of user centred requirements for the BASE Control Software expressed as Use Case Diagrams, Scenarios and Message Sequence Charts.

6.2.2.1 Use Case View

Hypothetical 'transactions' available to a pilot through the BCS shall include the ability to:- i) erase a cartridge; ii) retrieve (data) from a cartridge; and iii) choose a mission and aircraft (to work on). We now systematically consider details of these transactions, the service(s) to which they belong, their combination (through includes and extends), pre and post conditions and alternative paths[1].

i. Erase Cartridge

Overview	The purpose of this use case is to erase all current data from a Cartridge. Before proceeding with the erase process, checks are made to confirm that a Cartridge is present in the DTM and that the Cartridge contains data.
Services	Cartridge Administration
Includes	Check for Cartridge, Check Cartridge for Data, Erase Data from Cartridge (see figure 6.2).
Post-Conditions	The data on the Cartridge has been erased (assumes Normal Path scenario).
Scenarios	Normal Path, No Cartridge Present, No Data on Cartridge, Pilot Chooses Not to Erase Cartridge.

As indicated, constituent use cases of Erase Cartridge (i.e., combined through «includes» associations) are Check for Cartridge, Check Cartridge for Data and Erase Data from Cartridge. These may be described as follows:-

Check for Cartridge

Overview	This is a utility transaction 'called' from other high-level use cases. Its purpose is to determine the presence or otherwise of a Cartridge in the hardware before processing operations (e.g., erase, load, etc.) are attempted.
Post-Conditions	The MPS has been informed that there is a Cartridge present in the hardware (assumes Normal Path scenario).
Scenarios	Normal Path, No Cartridge (Loaded in the Hardware).

Check Cartridge for Data

Overview	A utility transaction 'called' from other high-level use cases in order to determine whether there is data on the Cartridge before processing operations (such as erase) are attempted.
Pre-Conditions	There is a Cartridge present in the hardware.
Post-Conditions	The MPS has been informed whether or not there is data loaded on the Cartridge (assumes Normal Path scenario for Check for Cartridge).
Scenarios	Normal Path, No Data Present (on Cartridge).

[1] In doing so, we remain faithful to the content of the original case study document.

Erase Data from Cartridge

Overview	This utility transaction 'called' from high-level use cases deletes data stored on a Cartridge.
Pre-Conditions	The Pilot has confirmed that he wishes to erase data from the Cartridge.
	The Cartridge has to contain data.
Post-Conditions	Data has been erased from the Cartridge.
Scenarios	Normal Path.

A graphical use case model (based on the notation introduced in 4.3.2.1) depicting the combination of these utility use cases towards fulfilment of the Erase Cartridge transaction is shown in figure 6.2.

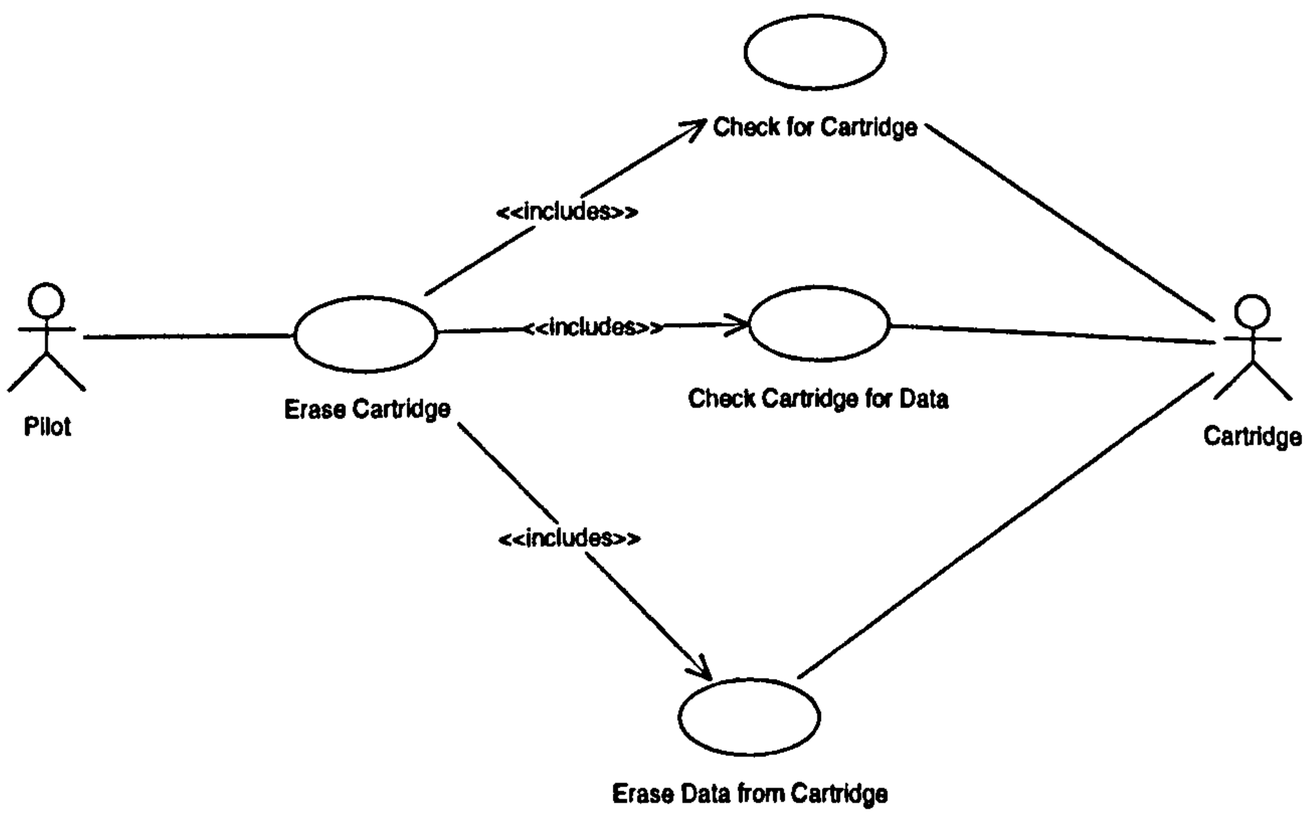


Figure 6.2 - 'Erase Cartridge Use Case Diagram'

ii. Retrieve from Cartridge

Overview	This use case is used to retrieve Cartridge data and store it on the MPS.
Services	Mission Administration.
Includes	Check for Cartridge, Check Cartridge for Data, Retrieve Data from Cartridge, Display Cartridge Data (see figure 6.3).
Post-Conditions	The data on the Cartridge has been copied onto the MPS.
	The data has been displayed to the Pilot (assumes Normal Path scenario).
Scenarios	Normal Path, No Cartridge Present, No Data on Cartridge, Pilot Retrieves a Subset of Data.

Retrieve from Cartridge is further 'extended' by Select Data to Retrieve, described as follows:-

Select Data to Retrieve

Overview	Allows the Pilot to define the data to be retrieved from the Cartridge.
Extends	Retrieve from Cartridge (see figure 6.3).
Post-Conditions	The data types to be retrieved have been defined (assumes Normal Path).
Scenarios	Normal Path, Pilot Chooses Not To Define Data Types To Retrieve.

The 'included' use cases for Retrieve from Cartridge not featured previously - namely Retrieve Data from Cartridge and Display Cartridge Data - may be described as follows:-

Retrieve Data from Cartridge

Overview	The purpose of this use case is to retrieve data that is on the Cartridge and store it on the MPS.
Pre-Conditions	A Cartridge containing data is present in the hardware.
Post-Conditions	The data on the Cartridge has been copied onto the MPS (assumes Normal Path scenario).
Scenarios	Normal Path, Data Type Requested Not Stored on the Cartridge.

Display Cartridge Data

Overview	The purpose of this use case is to allow the Pilot to view data on the Cartridge.
Pre-Conditions	Data has been retrieved from the Cartridge and stored on the MPS.
Post-Conditions	The data that is currently loaded onto the Cartridge is displayed for the Pilot (assumes Normal Path scenario).
Scenarios	Normal Path, System Has No Data Retrieved From the Cartridge Stored.

Display Cartridge Data is extended by Print Data, which is described as follows:-

Print Data

Overview	The purpose of this use case is to print data items of a particular type.
Extends	Display Cartridge Data (see figure 6.3).
Pre-Conditions	The data to be printed is being displayed.
Post-Conditions	The data item has been printed by the MPS Printer.
Scenarios	Normal Path.

Again, a graphical use case model showing combination of these use cases towards fulfilment of the Retrieve from Cartridge transaction is shown in figure 6.3.

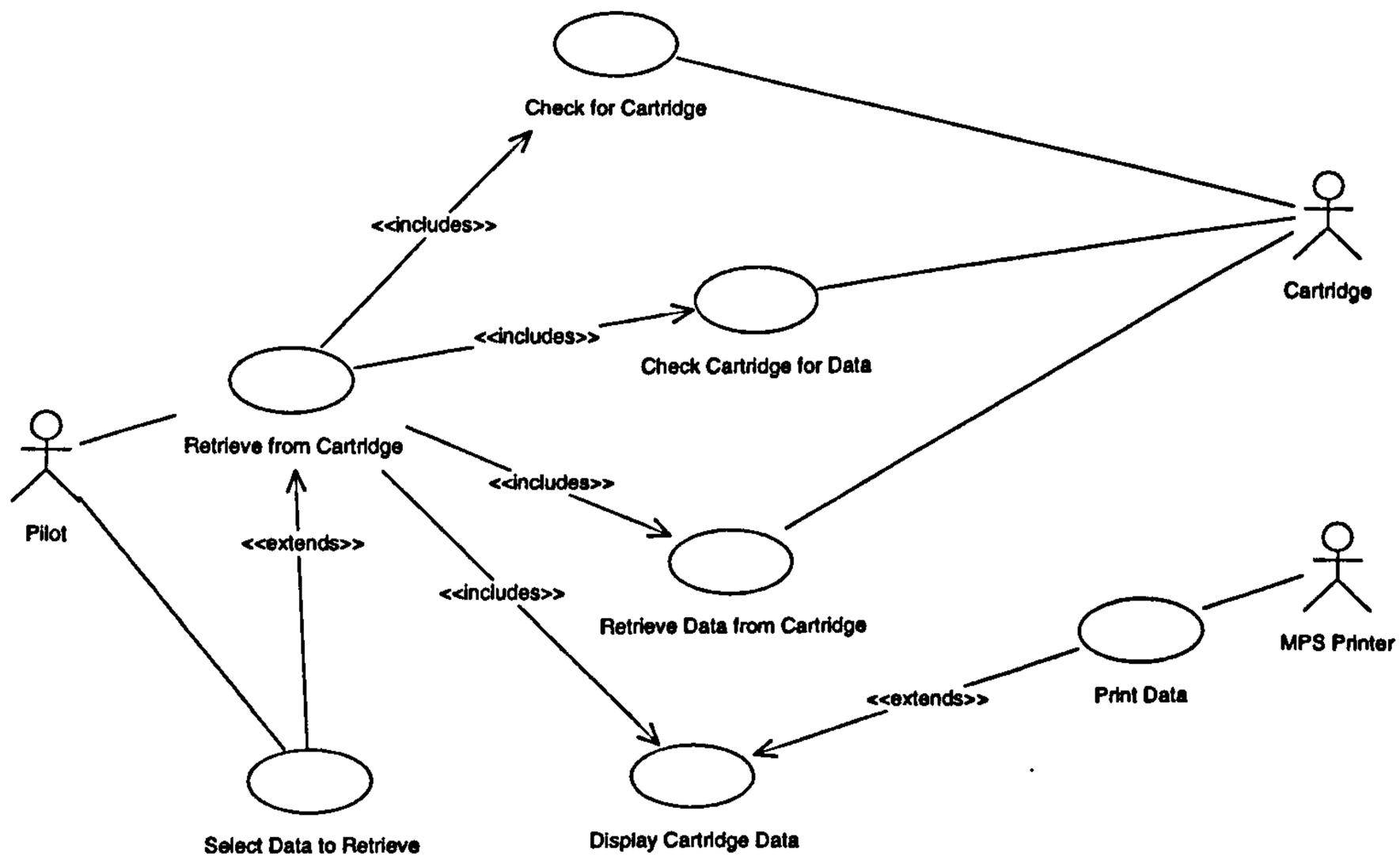


Figure 6.3 - 'Retrieve From Cartridge Use Case Diagram'

Iii. Choose Mission and Aircraft

Overview	The purpose of this use case is to allow the Pilot to select Mission and Aircraft Data to work on.
Services	Mission Administration.
Includes	Retrieve from Mission Plan (see figure 6.4).
Pre-Conditions	A database must be attached to the MPS.
Post-Conditions	A mission and aircraft have been selected. Data for the selected Mission Plan has been loaded onto the MPS.
Scenarios	New Mission From Open Missions, New Mission From All Missions, No Data for Selected Mission In Mission Plan, Pilot Does Not Initially Select an Aircraft or Mission.

We describe the 'included' use case for Choose Mission and Aircraft - Retrieve from Mission Plan - as follows:-

Retrieve from Mission Plan

Overview	A utility use case to retrieve Mission Plan data and store it on the Mission Planning System.
Pre-Conditions	A mission and aircraft have been defined.
Post-Conditions	The data on the Mission Plan for the selected mission and aircraft has been copied onto the MPS (assumes Normal Path).
Scenarios	Normal Path, No data for selected mission in Mission Plan.
Scenario Notes	The events involved in transferring data to the Mission Planning System are iterated according to the number of different types of data stored in the Mission Plan (see also subsection 6.2.2.2.6).

Figure 6.4 shows how Choose Mission and Aircraft and Retrieve from Mission Plan combine.

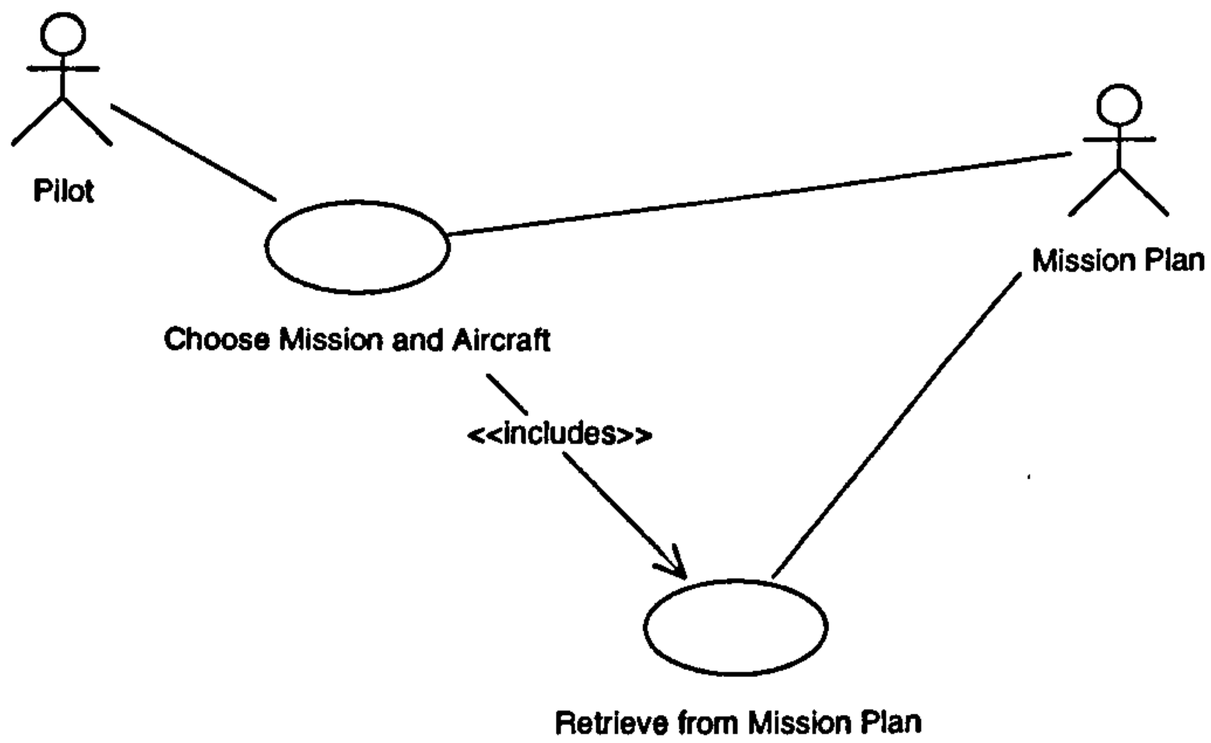


Figure 6.4 - 'Choose Mission and Aircraft Use Case Diagram'

A summary of services (according to the concepts discussed in subsection 4.3.3.1) to which the Erase Cartridge, Retrieve from Cartridge and Choose Mission and Aircraft use cases contribute appears in figure 6.5.

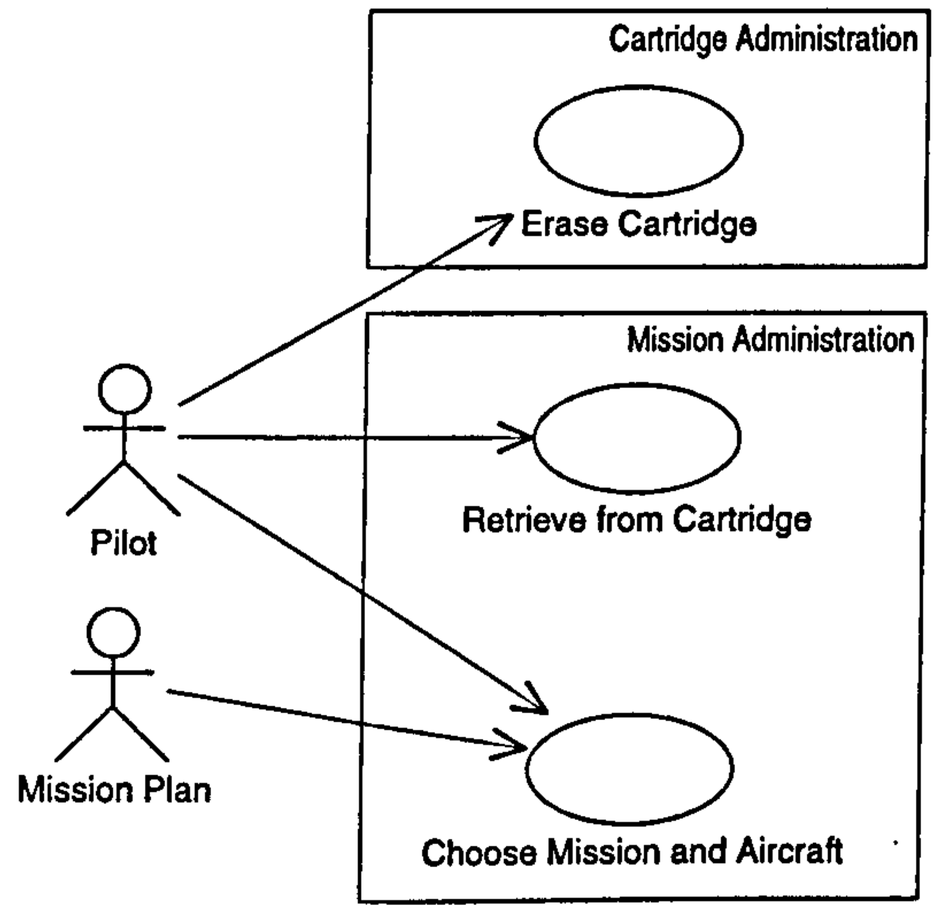


Figure 6.5 - 'Hawk MPS : Services'

6.2.2.1.1 Instantiation of Use Case View

In this subsection, we instantiate O-Telos classes from the Use Case View of the User Centred Requirements Structure introduced in section 4.3, with a subset of requirements data for the MPS of the Hawk aircraft introduced above. This will allow us to demonstrate support for the representation and traceability of use case artifacts within MATrA. Note, the complete O-Telos code for these artifacts appears in Appendix C, Part One.

Instantiation of UseCaseModel Elements

- **Actor Instances**

```
Pilot in Actor, Token with
actor_name
    actorName : "Pilot"
end

Cartridge in Actor, Token with
actor_name
    actorName : "Cartridge"
end

MPSPrinter in Actor, Token with
actor_name
    actorName : "MPS Printer"
end

MissionPlan in Actor, Token with
actor_name
    actorName : "Mission Plan"
end
```

- **Text Nodes (for specifying Pre and Post Conditions)**

```
CartridgeNode in ModuleNode, Token with
module_name
    moduleName : "Cartridge"
end

MissionPlanningSystemNode in ModuleNode,
Token with
module_name
    moduleName : "MPS"
end

-- Further Text Nodes in App.C, Pt.1
```

- **Use Case Instances**

Erase Cartridge

```
EraseCartridge in UseCase, Token with
use_case_name
    useCaseName : "Erase Cartridge"
sub_case
    subCase : False
post_condition
    postCondition1 : ECPost1NLS
end
```

Post Condition for Erase Cartridge

```
ECPost1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : ECPostC1
mnls_plain_text
    mnlsPlainText1 : ECPostPT1;
    mnlsPlainText2 : ECPostPT2
mnls_module
    mnlsModule1 : CartridgeNode
end

ECPostC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : ECPostPT1
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : ECPostPT2
end

ECPostPT1 in PlainTextNode, Token with
mnls_text
```

```
    mnlsText : "The data on the "
end

ECPostPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " has been erased."
end
```

Check for Cartridge

```
CheckforCartridge in UseCase, Token with
use_case_name
    useCaseName : "Check for Cartridge"
sub_case
    subCase : True
post_condition
    postCondition1 : CfCPost1NLS
end
```

Post Condition for Check for Cartridge

```
CfCPost1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : CfCPostC1;
    mnlsComposite2 : CfCPostC2
mnls_plain_text
    mnlsPlainText1 : CfCPostPT1;
    mnlsPlainText2 : CfCPostPT2;
    mnlsPlainText3 : CfCPostPT3
mnls_module
    mnlsModule1 :
MissionPlanningSystemNode;
    mnlsModule2 : CartridgeNode
end

CfCPostC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CfCPostPT1
subject_node
    subjectNode :
MissionPlanningSystemNode
following_fragment
    followingFragment : CfCPostC2
end

CfCPostPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

CfCPostC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CfCPostPT2
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : CfCPostPT3
end

CfCPostPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " has been informed that
there is a "
end

CfCPostPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " present in the
hardware."
end
```

Check Cartridge for Data

```
CheckCartridgeforData in UseCase, Token
with
use_case_name
    useCaseName : "Check Cartridge for
Data"
sub_case
    subCase : True
pre_condition
    preCondition1 : CCfDPre1NLS
post_condition
    postCondition1 : CCfDPost1NLS
end
```

PreCondition for Check Cartridge for Data

```
CCfDPre1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : CCfDPreC1
mnls_plain_text
    mnlsPlainText1 : CCfDPrePT1;
    mnlsPlainText2 : CCfDPrePT2
mnls_module
    mnlsModule1 : CartridgeNode
end

CCfDPreC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CCfDPrePT1
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : CCfDPrePT2
end

CCfDPrePT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "There is a "
end

CCfDPrePT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " present in the
hardware."
end
```

Post Condition for Check Cartridge for Data

```
CCfDPost1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : CCfDPostC1;
    mnlsComposite2 : CCfDPostC2
mnls_plain_text
    mnlsPlainText1 : CCfDPostPT1;
    mnlsPlainText2 : CCfDPostPT2;
    mnlsPlainText3 : CCfDPostPT3
mnls_module
    mnlsModule1 :
MissionPlanningSystemNode;
    mnlsModule2 : CartridgeNode
end

CCfDPostC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CCfDPostPT1
subject_node
    subjectNode :
MissionPlanningSystemNode
following_fragment
    followingFragment : CCfDPostC2
end

CCfDPostPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end
```

```
CCfDPostC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CCfDPostPT2
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : CCfDPostPT3
end

CCfDPrePT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " has been informed
whether or not there is data loaded on
the  "
end

CartridgeNode in ModuleNode, Token with
module_name
    moduleName : "Cartridge"
end

CCfDPrePT3 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

Erase Data from Cartridge

```
EraseDatafromCartridge in UseCase, Token
with
use_case_name
    useCaseName : "Erase Data from
Cartridge"
sub_case
    subCase : True
pre_condition
    preCondition1 : EDfCPre1NLS;
    preCondition2 : EDfCPre2NLS
post_condition
    postCondition1 : EDfCPost1NLS
end
```

Pre Conditions for Erase Data from Cartridge

Pre Condition 1

```
EDfCPre1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : EDfCPre1C1;
    mnlsComposite2 : EDfCPre1C2
mnls_plain_text
    mnlsPlainText1 : EDfCPre1PT1;
    mnlsPlainText2 : EDfCPre1PT2;
    mnlsPlainText3 : EDfCPre1PT3
mnls_module
    mnlsModule1 : PilotNode;
    mnlsModule2 : CartridgeNode
end

EDfCPre1C1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : EDfCPre1PT1
subject_node
    subjectNode : PilotNode
following_fragment
    followingFragment : EDfCPre1C2
end

EDfCPre1PT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

EDfCPre1C2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : EDfCPre1PT2
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : EDfCPre1PT3
end

EDfCPre1PT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " has confirmed that he
wishes to erase data from the "

end

EDfCPre1PT3 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

Pre Condition 2

```
EDfCPre2NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : EDfCPre2C1
mnls_plain_text
    mnlsPlainText1 : EDfCPre2PT1;
    mnlsPlainText2 : EDfCPre2PT2
mnls_module
    mnlsModule1 : CartridgeNode
end

EDfCPre2C1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : EDfCPre2PT1
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : EDfCPre2PT2
end

EDfCPre2PT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

EDfCPre2PT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " has to contain data."
end
```

Post Condition for Erase Data from Cartridge

```
EDfCPost1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : EDfCPostC1
mnls_plain_text
    mnlsPlainText1 : EDfCPostPT1;
    mnlsPlainText2 : EDfCPostPT2
mnls_module
    mnlsModule1 : CartridgeNode
end

EDfCPostC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : EDfCPostPT1
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : EDfCPostPT2
end

EDfCPostPT1 in PlainTextNode, Token with
mnls_text
```

```
    mnlsText : "Data has been erased from
               the "
end

EDfCPostPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

Retrieve from Cartridge

```
RetrievefromCartridge in UseCase, Token
with
use_case_name
    useCaseName : "Retrieve from
Cartridge"
sub_case
    subCase : False
post_condition
    postCondition1 : RfCPost1NLS;
    postCondition2 : RfCPost2NLS
end

-- All Pre and Post conditions for the
following Use Cases appear in App.C, Pt.1
```

Select Data to Retrieve

```
SelectDatatoRetrieve in UseCase, Token
with
use_case_name
    useCaseName : "Select Data to
Retrieve"
sub_case
    subCase : True
post_condition
    postCondition1 : SDtRPost1NLS
end
```

Retrieve Data from Cartridge

```
RetrieveDatafromCartridge in UseCase,
Token with
use_case_name
    useCaseName : "Retrieve Data from
    Cartridge"
sub_case
    subCase : True
pre_condition
    preCondition1 : RDfCPre1NLS
post_condition
    postCondition1 : RDfCPost1NLS
end
```

Display Cartridge Data

```
DisplayCartridgeData in UseCase, Token
with use_case_name
    useCaseName : "Display Cartridge
Data"
sub_case
    subCase : True
pre_condition
    preCondition1 : DCDPre1NLS
post_condition
    postCondition1 : DCDPost1NLS
end
```

Print Data

```
PrintData in UseCase, Token with
use_case_name
    useCaseName : "Print Data"
sub_case
    subCase : True
pre_condition
    preCondition1 : PDPre1NLS
post_condition
    postCondition1 : PDPost1NLS
end
```

Choose Mission and Aircraft

```
ChooseMissionandAircraft in UseCase,
Token with
use_case_name
    useCaseName : "Choose Mission and
Aircraft"
sub_case
    subCase : False
pre_condition
    preCondition1 : CMAPre1NLS
post_condition
    postCondition1 : CMAPost1NLS;
    postCondition2 : CMAPost2NLS
end
```

Retrieve from Mission Plan

```
RetrievefromMissionPlan in UseCase, Token
with
use_case_name
    useCaseName : "Retrieve from Mission
Plan"
sub_case
    subCase : True
pre_condition
    preCondition1 : RfMPPre1NLS
post_condition
    postCondition1 : RfMPPost1NLS
end
```

- **Interaction Instances**

```
PilotEraseCartridge in Interaction, Token
with
interactor_1
    interactor1 : Pilot
interactor_2
    interactor2 : EraseCartridge
end

CartridgeCheckforCartridge in
Interaction, Token with
interactor_1
    interactor1 : Cartridge
interactor_2
    interactor2 : CheckforCartridge
end

CartridgeCheckCartridgeforData in
Interaction, Token with
interactor_1
    interactor1 : Cartridge
interactor_2
    interactor2 : CheckCartridgeforData
end

CartridgeEraseDatafromCartridge in
Interaction, Token with
interactor_1
    interactor1 : Cartridge
interactor_2
    interactor2 : EraseDatafromCartridge
end

PilotRetrievefromCartridge in
Interaction, Token with
interactor_1
    interactor1 : Pilot
interactor_2
    interactor2 : RetrievefromCartridge
end
```

```
CartridgeRetrieveDatafromCartridge in
Interaction, Token with
interactor_1
    interactor1 : Cartridge
interactor_2
    interactor2 :
RetrieveDatafromCartridge
end

PilotSelectDatatoRetrieve in Interaction,
Token with
interactor_1
    interactor1 : Pilot
interactor_2
    interactor2 : SelectDatatoRetrieve
end

MPSPrinterPrintData in Interaction, Token
with
interactor_1
    interactor1 : MPSPrinter
interactor_2
    interactor2 : PrintData
end

PilotChooseMissionandAircraft in
Interaction, Token with
interactor_1
    interactor1 : Pilot
interactor_2
    interactor2 :
ChooseMissionandAircraft
end

MissionPlanRetrievefromMissionPlan in
Interaction, Token with
interactor_1
    interactor1 : MissionPlan
interactor_2
    interactor2 : RetrievefromMissionPlan
end

MissionPlanChooseMissionandAircraft in
Interaction, Token with
interactor_1
    interactor1 : MissionPlan
interactor_2
    interactor2 :
ChooseMissionandAircraft
end
```

- **Includes Instances**

```
EraseCartridgeCheckforCartridge in
Includes, Token with
includes_base
    includesBase : EraseCartridge
includes_include
    includesInclude : CheckforCartridge
end

EraseCartridgeCheckCartridgeforData in
Includes, Token with
includes_base
    includesBase : EraseCartridge
includes_include
    includesInclude :
CheckCartridgeforData
end

EraseCartridgeEraseDatafromCartridge in
Includes, Token with
includes_base
    includesBase : EraseCartridge
includes_include
    includesInclude :
EraseDatafromCartridge
end

RetrievefromCartridgeCheckforCartridge in
Includes, Token with
includes_base
    includesBase : RetrievefromCartridge
includes_include
    includesInclude : CheckforCartridge
end

RetrievefromCartridgeCheckCartridgeforData
in Includes, Token with
includes_base
    includesBase : RetrievefromCartridge
includes_include
    includesInclude :
CheckCartridgeforData
end

RetrievefromCartridgeRetrieveDatafromCart
ridgein Includes, Token with
includes_base
    includesBase : RetrievefromCartridge
includes_include
    includesInclude :
RetrieveDatafromCartridge
end

RetrievefromCartridgeDisplayCartridgeData
in Includes, Token with
includes_base
    includesBase : RetrievefromCartridge
includes_include
    includesInclude :
DisplayCartridgeData
end

ChooseMissionandAircraftRetrievefromMissi
onPlan in Includes, Token with
includes_base
    includesBase :
ChooseMissionandAircraft
includes_include
    includesInclude :
RetrievefromMissionPlan
end
```

- **Extends Instances**

```
PrintDataDisplayCartridgeData in Extends,
Token with
extends_base
    extendsBase : PrintData
extends_extend
    extendsExtend : DisplayCartridgeData
end

SelectDatatoRetrieveRetrievefromCartrdige
in Extends, Token with
extends_base
    extendsBase : SelectDatatoRetrieve
extends_extend
    extendsExtend : RetrievefromCartrdige
end
```

Erase Cartridge Use Case Model

```
EraseCartridgeModel in UseCaseModel,
Token with model_name
    modelName : "Erase Cartridge Model"
ucm_comments
    ucmComments : EraseCartridgeComments
ucm_use_case
    ucmUseCase1 : EraseCartridge;
    ucmUseCase2 : CheckforCartridge;
    ucmUseCase3 : CheckCartridgeforData;
    ucmUseCase4 : EraseDatafromCartridge
ucm_actor
    ucmActor1 : Pilot;
    ucmActor2 : Cartridge
```

```
ucm_interaction
    ucmInteraction1 :
PilotEraseCartridge;
    ucmInteraction2 :
    CartridgeCheckforCartridge;
    ucmInteraction3 :
CartridgeCheckCartridgeforData;
    ucmInteraction4 :
CartridgeEraseDatafromCartridge
ucm_includes
    ucmIncludes1 :
        EraseCartridgeCheckforCartridge;
    ucmIncludes2 :
    EraseCartridgeCheckCartridgeforData;
    ucmIncludes3 :
    EraseCartridgeEraseDatafromCartridge
ucm_pre_condition
    ucmPreCondition1 : CCfDPre1NLS;
    ucmPreCondition2 : EDfCPre1NLS;
    ucmPreCondition3 : EDfCPre2NLS
ucm_post_condition
    ucmPostCondition1 : ECPost1NLS;
    ucmPostCondition2 : CfCPost1NLS;
    ucmPostCondition3 : CCfDPost1NLS;
    ucmPostCondition4 : EDfCPost1NLS
end
```

Retrieve from Cartridge Use Case Model (Partial)

```
RetrievefromCartridgeModel in
UseCaseModel, Token with model_name
    modelName : "Retrieve from Cartridge
Model"
ucm_comments
    ucmComments :
RetrievefromCartridgeComments
ucm_use_case
    ucmUseCase1 : RetrievefromCartridge;
-- For complete model, see App.C, Pt.1
end
```

Choose Mission and Aircraft Use Case Model (Partial)

```
ChooseMissionandAircraftModel in
UseCaseModel, Token with model_name
    modelName : "Choose Mission and
Aircraft Model"
ucm_use_case
    ucmUseCase1 :
ChooseMissionandAircraft;
-- For complete model, see App.C, Pt.1
end
```

- **Service Instances**

```
MissionAdministration in Service, Token
with
service_name
    serviceName : "Mission
Administration"
service_use_case
    serviceUseCase1 :
RetrievefromCartridge;
    serviceUseCase2:
ChooseMissionandAircraft
end

CartridgeAdministration in Service, Token
with service_name
    serviceName : "Cartridge
Administration"
service_use_case
    serviceUseCase1 : EraseCartridge
end
```

- **Hawk MPS Use Case View (Partial)**

```
HawkMPSUseCaseView in UseCaseView, Token
with ucv_service
    ucvService1 : MissionAdministration;
    ucvService2 : CartridgeAdministration
use_case_model
    useCaseModel1 : EraseCartridgeModel;
    useCaseModel2 :
RetrievefromCartridgeModel;
    useCaseModel3 :
ChooseMissionandAircraftModel
end
```

- **Hawk MPS User Centred Requirements Structure**

```
HawkMPSUCRS in
UserCentredRequirementsStructure, Token
with subject_module
    subjectModule : "Mission Planning
System"
use_case_view
    useCaseView : HawkMPSUseCaseView
interaction_view
    interactionView :
    HawkMPSInteractionView
end
```

6.2.2.2 Interaction View

To show support for the representation and traceability of scenarios within MATrA, we present the UCRS Interaction View for the Erase Cartridge use case from 6.2.2.1(i). Featured paths include Normal Path, No Cartridge, No Data on Cartridge and Pilot Chooses Not To Erase the Data. In each case, we introduce logical (i.e., user) level representations in both textual and Message Sequence Chart forms (sections 6.2.2.2.1 through 6.2.2.2.4), along with their 'equivalent' O-Telos implementation. We further include fragments of scenarios (sections 6.2.2.2.5 and 6.2.2.2.6) for the Retrieve from Cartridge (Normal Path) and Choose Mission and Aircraft (New Mission from Open Missions) use cases to demonstrate features of UCRS not present in the above examples (the full scenarios appear in Appendix C, Part Two). Note, constituent (i.e. included) use cases of Erase Cartridge, such as Check for Cartridge and Check Cartridge for Data are modelled separately, with their O-Telos representations appearing in Appendix C, Part One.

6.2.2.2.1 Erase Cartridge - Normal Path

1. **C[SR]** The [sdr Pilot] selects the [msg Erase Cartridge option : Erase Cartridge Request] on the [rcr MPS] Main Screen.
2. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [msg is a cartridge present in the hardware? : Request Confirm Cartridge].
3. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is a cartridge present in the hardware : Confirm Cartridge].
4. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [is data on the cartridge? : Request Confirm Cartridge Data].
5. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is data on the cartridge : Confirm Cartridge Data].
6. **C[IP]** The [sdr MPS] informs the [rcr Pilot] that [msg there is data on the cartridge : Cartridge Data Found Notification] .
7. **C[SR]** The [sdr Pilot] indicates to the [rcr MPS] that it is [msg OK to proceed with Cartridge Erase : Proceed Erase Cartridge].
8. **C[SR]** The [sdr MPS] tells the [rcr Cartridge] to [msg erase the current data : Erase All].
9. **C[SP]** The [sdr Cartridge] indicates to the [rcr MPS] that [msg all current data has been deleted : Cartridge Erased].
10. **C[SP]** The [sdr MPS] indicates to the [rcr Pilot] that [msg all current data has been deleted : Cartridge Erased Notification].
11. **C[IP]** The [sdr Pilot] sends an [msg acknowledgement : Acknowledge Erase] to the [rcr MPS].
12. **C[IP]** The [sdr MPS] displays to the [rcr Pilot] the [msg Main Screen MainScreen_1].

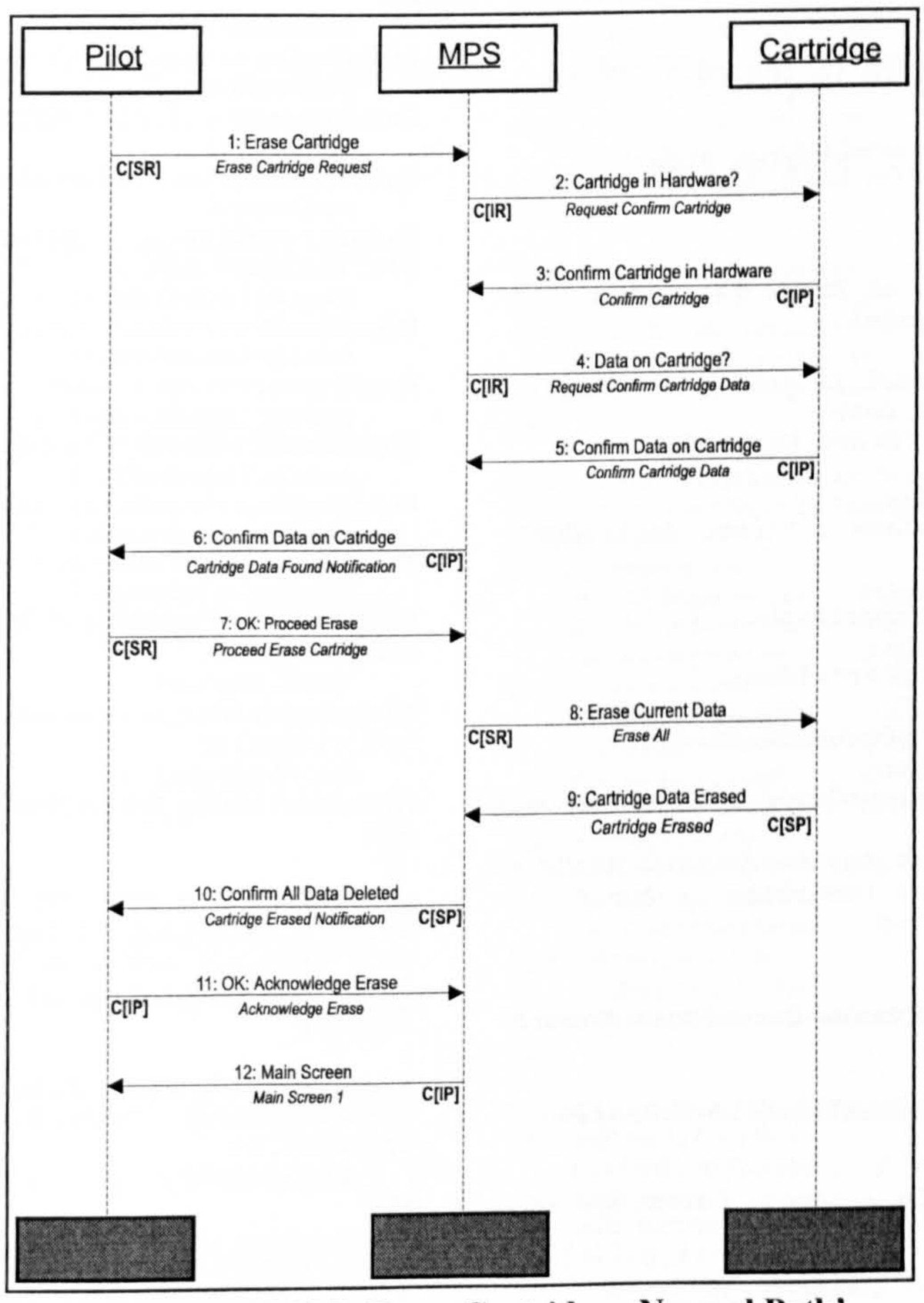


Figure 6.6 - 'MSC: Erase Cartridge - Normal Path'

- **Instantiation of Interaction View**

```
HawkMPSInteractionView in
InteractionView, Token with
interaction_model
    interactionModel1 :
CheckforCartridgeModel;
    interactionModel2 :
CheckCartridgeforDataModel;
    interactionModel3 :
EraseDatafromCartridgeModel;
    interactionModel4 :
EraseCartridgeModel
.....
end
```

- **Instantiation of Featured Instance Definitions**

```
MPSInstance in Instance, Token with
instance_name
    instanceName : "MPS"
end

CartridgeInstance in Instance, Token with
instance_name
    instanceName : "Cartridge"
end

PilotInstance in Instance, Token with
instance_name
    instanceName : "Pilot"
end

MissionPlanInstance in Instance, Token
with
instance_name
    instanceName : "Mission Plan"
end
```

- **Instantiation of Erase Cartridge Interaction Model**

```
EraseCartridgeModel in InteractionModel,
Token with model_name
    modelName : "Erase Cartridge
Descriptions"
describes_use_case
    describesUseCase : "Erase Cartridge"
inm_scenario
    inmScenario1 :
EraseCartridge_NormalPath;
    inmScenario2 :
EraseCartridge_NoCartridge;
    inmScenario3 :
EraseCartridge_NoDataOnCartridge;
    inmScenario4 :
EraseCartridge_PilotChoosesNotToEraseData
.....
-- other elements may be derived using an
implementation of the rules in App.A,
Pt.2 (xi).
end
```

Instantiation of Erase Cartridge: Normal Path (Partial)

```
EraseCartridge_NormalPath in Scenario,
Token with
scenario_title
    scenarioTitle : "Erase Cartridge -
Normal Path"
is_exception
    isException : False
scenario_event
    scenarioEvent1 :
EraseCartridgeRequest;
    scenarioEvent2 :
ConfirmDataPresentonCartridge;
    scenarioEvent3 :
ProceedCartridgeEraseRequest;
    scenarioEvent4 :
DataErasedNotification;
    scenarioEvent5 :
DataErasedAcknowledgement;
    scenarioEvent6 : MainScreenDisplay_1
includes_scenario
    includesScenario1 :
CheckforCartridge_NormalPath;
    includesScenario2 :
CheckCartridgeforData_NormalPath;
    includesScenario3 :
EraseDatafromCartridge
included_event
    includedEvent1 :
CheckforCartridgeRequest;
    includedEvent2 :
ConfirmCartridgePresent;
    includedEvent3 :
CheckCartridgeforDataRequest;
    includedEvent4 :
ConfirmCartridgeDataPresent;
    includedEvent5 :
EraseCurrentDataRequest;
    includedEvent6 :
CurrentDataErasedNotification
scn_seq_no
    scnSeqNo1 :
EraseCartridgeRequest_NormalPathSSN;
    scnSeqNo2 :
ConfirmDataPresentonCartridge_NormalPathS
SN;
    scnSeqNo3 :
ProceedCartridgeEraseRequestSSN;
    scnSeqNo4 :
DataErasedNotificationSSN;
    scnSeqNo5 :
DataErasedAcknowledgementSSN;
    scnSeqNo6 :
MainScreenDisplay_1_NormalPathSSN
scn_included_seq_no
    scnIncludedSeqNo1 :
CheckforCartridgeRequest_EC_NP_ISN;
    scnIncludedSeqNo2 :
ConfirmCartridgePresent_EC_NP_ISN;
    scnIncludedSeqNo3 :
CheckCartridgeforDataRequest_EC_NP_ISN;
    scnIncludedSeqNo4 :
ConfirmCartridgeDataPresent_EC_NP_ISN;
    scnIncludedSeqNo5 :
EraseCurrentDataRequest_EC_NP_ISN;
    scnIncludedSeqNo6 :
CurrentDataErasedNotification_EC_NP_ISN
tsn_viewpoint
    tsnViewpoint :
EraseCartridge_NormalPathTSV
msc_viewpoint
    mscViewpoint :
EraseCartridge_NormalPathMSV
end

-- 'included_event' may be instantiated
using a variation of the rule in App.A,
Pt.2 (vii.c); see also App.C, Pt.1 for O-
Telos implementation of included_event
classes

EraseCartridgeRequest_NormalPathSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 1
end

ConfirmDataPresentonCartridge_NormalPathS
SN in SequenceNumber, Token with
sequence_no
    sequenceNo : 6
end
```

```
ProceedCartridgeEraseRequestSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 7
end

DataErasedNotificationSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 10
end

DataErasedAcknowledgementSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 11
end

MainScreenDisplay_1_NormalPathSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 12
end

CheckforCartridgeRequest_EC_NP_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 2
end

ConfirmCartridgePresent_EC_NP_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 3
end

CheckCartridgeforDataRequest_EC_NP_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 4
end

ConfirmCartridgeDataPresent_EC_NP_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 5
end

EraseCurrentDataRequest_EC_NP_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 8
end

CurrentDataErasedNotification_EC_NP_ISN
in SequenceNumber, Token with
sequence_no
    sequenceNo : 9
end

EraseCartridge_NormalPathTSV in
TsnScenarioViewpoint, Token
with
tsv_tsn_comm
    tsvTsnComm1 :
EraseCartridgeRequestTextDescription;
    tsvTsnComm2 :
ConfirmDataPresentonCartridgeTextDescript
ion;
    tsvTsnComm3 :
ProceedCartridgeEraseRequestTextDescripti
on;
    tsvTsnComm4 :
DataErasedNotificationTextDescription;
    tsvTsnComm5 :
DataErasedAcknowledgementTextDescription;
    tsvTsnComm6 :
MainScreenDisplay_1TextDescription
end

EraseCartridge_NormalPathMSV in
MscScenarioViewpoint, Token
with
msv_msc_comm
    msvMscComm1 :
EraseCartridgeRequestMSCDescription;
    msvMscComm2 :
ConfirmDataPresentonCartridgeMSCDescripti
on;
    msvMscComm3 :
ProceedCartridgeEraseRequestMSCDescription;
    msvMscComm4 :
DataErasedNotificationMSCDescription;
    msvMscComm5 :
DataErasedAcknowledgementMSCDescription;
    mscMscComm6 :
MainScreenDisplay_1MSCDescription
end
```

Erase Cartridge Request Event Instantiation

```
EraseCartridgeRequest in
CommunicationEvent, Token with
interaction_type
    interactionType : "SR"
sequence_no
    sequenceNo1 :
EraseCartridgeRequest_NormalPathSSN;
    sequenceNo2 :
EraseCartridgeRequest_NoCartridgeSSN;
    sequenceNo3 :
EraseCartridgeRequest_NoDataOnCartridgeSSN;
    sequenceNo4 :
EraseCartridgeRequest_PilotChoosesNotToEr
aseDataSSN
tsn_communication_event
    tsnCommunicationEvent :
EraseCartridgeRequestTextDescription
msc_communication_event
    mscCommunicationEvent :
EraseCartridgeRequestMSCDescription
end

EraseCartridgeRequestTextDescription in
TsnCommunication, Token with
communication_description
    communicationDescription :
EraseCartridgeRequestEventText
end

EraseCartridgeRequestEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : ECREC1;
    mnlsComposite2 : ECREC2;
    mnlsComposite3 : ECREC3
mnls_plain_text
    mnlsPlainText1 : ECREPT1;
    mnlsPlainText2 : ECREPT2;
    mnlsPlainText3 : ECREPT3;
    mnlsPlainText4 : ECREPT4
tsn_sender_node
    tsnSenderNode : PilotInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode :
EraseCartridgeRequest
end

ECREC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : ECREPT1
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : ECREC2
end

ECREC2 in MatraNLSComposite, Token with
```

```
preceding_fragment
    precedingFragment : ECREPT2
subject_node
    subjectNode : EraseCartridgeRequest
following_fragment
    followingFragment : ECREC3
end

ECREC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : ECREPT3
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : ECREPT4
end

ECREPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

ECREPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " selects the "
end

ECREPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " on the "
end

ECREPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : " Main Screen."
end

EraseCartridgeRequest in Message, Token
with
message_name
    messageName : "Erase Cartridge
Request"
tsn_msg_parameter
    tsnMsgParameter :
EraseCartridgeRequestTsnParameter
msc_msg_parameter
    mscMsgParameter :
EraseCartridgeRequestMscParameter
end

EraseCartridgeRequestTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "Erase Cartridge
option"
end

EraseCartridgeRequestMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "Erase Cartridge"
end

EraseCartridgeRequestMSCDescription in
MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : PilotInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : EraseCartridgeRequest
end
```

Confirm Data Present on Cartridge Event Instantiation

```
ConfirmDataPresentonCartridge in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
ConfirmDataPresentonCartridge_NormalPathS
SN;
    sequenceNo2 :
ConfirmDataPresentonCartridge_PilotChoose
sNotToEraseDataSSN
follows_from
    followsFrom :
ConfirmCartridgeDataPresent
tsn_communication_event
    tsnCommunicationEvent :
ConfirmDataPresentonCartridgeTextDescript
ion
msc_communication_event
    mscCommunicationEvent :
ConfirmDataPresentonCartridgeMSCDescription
end

ConfirmDataPresentonCartridgeTextDescript
ion in TsnCommunication, Token with
communication_description
    communicationDescription :
ConfirmDataPresentonCartridgeEventText
end

ConfirmDataPresentonCartridgeEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : CDPoCEC1;
    mnlsComposite2 : CDPoCEC2;
    mnlsComposite3 : CDPoCEC3
mnls_plain_text
    mnlsPlainText1 : CDPoCEPT1;
    mnlsPlainText2 : CDPoCEPT2;
    mnlsPlainText3 : CDPoCEPT3;
    mnlsPlainText4 : CDPoCEPT4
tsn_sender_node
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : PilotInstance
tsn_message_node
    tsnMessageNode :
CartridgeDataFoundNotification
end

CDPoCEC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : CDPoCEPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : CDPoCEC2
end

CDPoCEC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : CDPoCEPT2
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : CDPoCEC3
end

CDPoCEC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : CDPoCEPT3
subject_node
    subjectNode :
CartridgeDataFoundNotification
following_fragment
    followingFragment : CDPoCEPT4
end
```

```
CDPoCEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

CDPoCEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " indicates to the "
end

CDPoCEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that "
end

CDPoCEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

CartridgeDataFoundNotification in
Message, Token with
message_name
    messageName : "Cartridge Data Found
Notification"
tsn_msg_parameter
    tsnMsgParameter :
CartridgeDataFoundNotificationTsnParameter
msc_msg_parameter
    mscMsgParameter :
CartridgeDataFoundNotificationMscParameter
end

CartridgeDataFoundNotificationTsnParameter
in MessageDescription, Token with
msg_parameter
    msgParameter : "there is data on the
cartridge"
end

CartridgeDataFoundNotificationMscParameter
in MessageDescription, Token with
msg_parameter
    msgParameter : "Confirm Data on
Cartridge"
end

ConfirmDataPresentonCartridgeMSCDescripti
on in MscCommunication, Token
with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance : PilotInstance
msc_message
    mscMessage :
CartridgeDataFoundNotification
end
```

Proceed Cartridge Erase Request Event Instantiation

```
ProceedCartridgeEraseRequest in
CommunicationEvent, Token
with
interaction_type
    interactionType : "SR"
sequence_no
    sequenceNo1 :
ProceedCartridgeEraseRequestSSN
follows_from
    followsFrom :
ConfirmDataPresentonCartridge
tsn_communication_event
    tsnCommunicationEvent :
ProceedCartridgeEraseRequestTextDescripti
on
msc_communication_event
    mscCommunicationEvent :
ProceedCartridgeEraseRequestMSCDescription
end

ProceedCartridgeEraseRequestTextDescripti
on in TsnCommunication, Token
with
communication_description
    communicationDescription :
ProceedCartridgeEraseRequestEventText
end

ProceedCartridgeEraseRequestEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : PCEREC1;
    mnlsComposite2 : PCEREC2;
    mnlsComposite3 : PCEREC3
mnls_plain_text
    mnlsPlainText1 : PCEREPT1;
    mnlsPlainText2 : PCEREPT2;
    mnlsPlainText3 : PCEREPT3;
    mnlsPlainText4 : PCEREPT4
tsn_sender_node
    tsnSenderNode : PilotInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode :
ProceedEraseCartridge
end

PCEREC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : PCEREPT1
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : PCEREC2
end

PCEREC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : PCEREPT2
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : PCEREC3
end

PCEREC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : PCEREPT3
subject_node
    subjectNode : ProceedEraseCartridge
following_fragment
    followingFragment : PCEREPT4
end

PCEREPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

PCEREPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " indicates to the "
end

PCEREPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that it is "
end
```

```
PCEREPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

ProceedEraseCartridge in Message, Token
with
message_name
    messageName : "Proceed Erase
Cartridge"
tsn_msg_parameter
    tsnMsgParameter :
ProceedEraseCartridgeTsnParameter
msc_msg_parameter
    mscMsgParameter :
ProceedEraseCartridgeMscParameter
end

ProceedEraseCartridgeTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "OK to proceed with
Cartridge Erase"
end

ProceedEraseCartridgeMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "OK: Proceed Erase"
end

ProceedCartridgeEraseRequestMSCDescription
in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : PilotInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : ProceedEraseCartridge
end
```

Data Erased Notification Event Instantiation

```
DataErasedNotification in
CommunicationEvent, Token with
interaction_type
    interactionType : "SP"
sequence_no
    sequenceNo1 :
DataErasedNotificationSSN
follows_from
    followsFrom :
CurrentDataErasedNotification
tsn_communication_event
    tsnCommunicationEvent :
DataErasedNotificationTextDescription
msc_communication_event
    mscCommunicationEvent :
DataErasedNotificationMSCDescription
end

DataErasedNotificationTextDescription in
TsnCommunication, Token with
communication_description
    communicationDescription :
DataErasedNotificationEventText
end

DataErasedNotificationEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : DENEC1;
    mnlsComposite2 : DENEC2;
    mnlsComposite3 : DENEC3
mnls_plain_text
    mnlsPlainText1 : DENEPT1;
    mnlsPlainText2 : DENEPT2;
    mnlsPlainText3 : DENEPT3;
    mnlsPlainText4 : DENEPT4
tsn_sender_node
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : PilotInstance
tsn_message_node
    tsnMessageNode :
CartridgeErasedNotification
end

DENEC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : DENEPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : DENEC2
end

DENEC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DENEPT2
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : DENEC3
end

DENEC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DENEPT3
subject_node
    subjectNode :
CartridgeErasedNotification
following_fragment
    followingFragment : DENEPT4
end

DENEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

DENEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " indicates to the "
end

DENEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that "
end

DENEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

CartridgeErasedNotification in Message,
Token with
message_name
    messageName : "Cartridge Erased
Notification"
tsn_msg_parameter
    tsnMsgParameter :
CartridgeErasedNotificationTsnParameter
msc_msg_parameter
    mscMsgParameter :
CartridgeErasedNotificationMscParameter
end

CartridgeErasedNotificationTsnParameter
in MessageDescription, Token with
```

```
msg_parameter
    msgParameter : "all current data has
been deleted"
end

CartridgeErasedNotificationMscParameter
in MessageDescription, Token with
msg_parameter
    msgParameter : "Confirm All Data
Deleted"
end

DataErasedNotificationMSCDescription in
MscCommunication, Token
with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance : PilotInstance
msc_message
    mscMessage :
CartridgeErasedNotification
end
```

Data Erased Acknowledgement Event Instantiation

```
DataErasedAcknowledgement in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
DataErasedAcknowledgementSSN
follows_from
    followsFrom : DataErasedNotification
tsn_communication_event
    tsnCommunicationEvent :
DataErasedAcknowledgementTextDescription
msc_communication_event
    mscCommunicationEvent :
DataErasedAcknowledgementMSCDescription
end

DataErasedAcknowledgementTextDescription
in TsnCommunication, Token with
communication_description
    communicationDescription :
DataErasedAcknowledgementEventText
end

DataErasedAcknowledgementEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : DEAEC1;
    mnlsComposite2 : DEAEC2;
    mnlsComposite3 : DEAEC3
mnls_plain_text
    mnlsPlainText1 : DEAEPT1;
    mnlsPlainText2 : DEAEPT2;
    mnlsPlainText3 : DEAEPT3;
    mnlsPlainText4 : DEAEPT4
tsn_sender_node
    tsnSenderNode : PilotInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode : AcknowledgeErase
end

DEAEC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DEAEPT1
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : DEAEC2
end

DEAEC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DEAEPT2
subject_node
    subjectNode : AcknowledgeErase
following_fragment
    followingFragment : DEAEC3
end

DEAEC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DEAEPT3
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : DEAEPT4
end

DEAEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

DEAEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " sends an "
end

DEAEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " to the "
end

DEAEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

AcknowledgeErase in Message, Token
with
message_name
    messageName : "Acknowledge Erase"
tsn_msg_parameter
    tsnMsgParameter :
AcknowledgeEraseTsnParameter
msc_msg_parameter
    mscMsgParameter :
AcknowledgeEraseMscParameter
end

AcknowledgeEraseTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "acknowledgement"
end

AcknowledgeEraseMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "OK: Acknowledge
Erase"
end

DataErasedAcknowledgementMSCDescription
in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
```

```
    mscSenderInstance : PilotInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : AcknowledgeErase
end
```

Main Screen Display (from Erase Cartridge) Event Instantiation

```
MainScreenDisplay_1 in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
MainScreenDisplay_1_NormalPathSSN;
    sequenceNo2 :
MainScreenDisplay_1_NoCartridgeSSN;
    sequenceNo3 :
MainScreenDisplay_1_NoDataOnCartridgeSSN;
    sequenceNo4 :
MainScreenDisplay_1_PilotChoosesNotToEras
eDataSSN
follows_from
    followsFrom1 :
DataErasedAcknowledgement;
    followsFrom2 :
NoCartridgeAcknowledgement;
    followsFrom3 :
NoCartridgeDataPresentAcknowledgement;
    followsFrom4 : CancelEraseRequest
tsn_communication_event
    tsnCommunicationEvent :
MainScreenDisplay_1TextDescription
msc_communication_event
    mscCommunicationEvent :
MainScreenDisplay_1MSCDescription
end

MainScreenDisplay_1TextDescription in
TsnCommunication, Token with
communication_description
    communicationDescription :
MainScreenDisplay_1EventText
end

MainScreenDisplay_1EventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : MSD_1EC1;
    mnlsComposite2 : MSD_1EC2;
    mnlsComposite3 : MSD_1EC3
mnls_plain_text
    mnlsPlainText1 : MSD_1EPT1;
    mnlsPlainText2 : MSD_1EPT2;
    mnlsPlainText3 : MSD_1EPT3;
    mnlsPlainText4 : MSD_1EPT4
tsn_sender_node
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : PilotInstance
tsn_message_node
    tsnMessageNode : MainScreen_1
end

MSD_1EC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : MSD_1EPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : MSD_1EC2
end

MSD_1EC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : MSD_1EPT2
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : MSD_1EC3
end

MSD_1EC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : MSD_1EPT3
subject_node
    subjectNode : MainScreen_1
following_fragment
    followingFragment : MSD_1EPT4
end

MSD_1EPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

MSD_1EPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " displays to the "
end

MSD_1EPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " the "
end

MSD_1EPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

MainScreen_1 in Message, Token with
message_name
    messageName : "Main Screen"
end

MainScreenDisplay_1MSCDescription in
MscCommunication, Token
with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance : PilotInstance
msc_message
    mscMessage : MainScreen_1
end
```

6.2.2.2.2 Erase Cartridge - No Cartridge Present

1. **C[SR]** The [sdr Pilot] selects the [msg Erase Cartridge option : Erase Cartridge Request] on the [rcr MPS] Main Screen.
2. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [msg is a cartridge present in the hardware? : Request Confirm Cartridge].
3. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is no cartridge present in the hardware : No Data].
4. **C[IP]** The [sdr MPS] informs the [rcr Pilot] that there is [msg no cartridge is present in the hardware : No Cartridge Notification].
5. **C[IP]** The [sdr Pilot] sends an [msg acknowledgement : Acknowledge No Cartridge] to the [rcr MPS].
6. **C[IP]** The [sdr MPS] displays to the [rcr Pilot] the [msg Main Screen MainScreen_1].

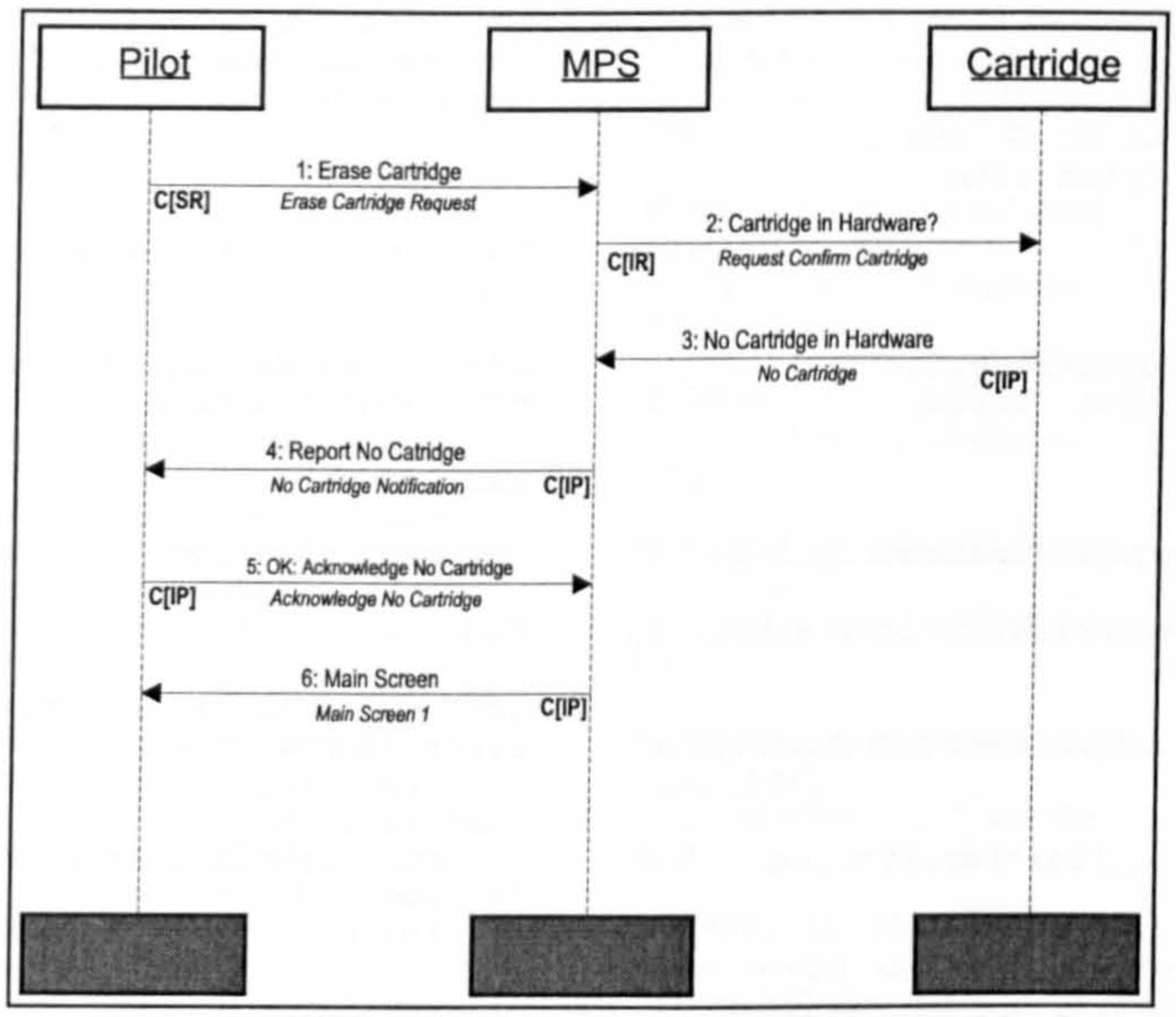


Figure 6.7 - 'MSC: Erase Cartridge - No Cartridge'

Instantiation of Erase Cartridge: No Cartridge Present

```
EraseCartridge_NoCartridge in Scenario,
Token with
scenario_title
    scenarioTitle : "Erase Cartridge - No
Cartridge Present"
is_exception
    isException : True
scenario_event
    scenarioEvent1 :
EraseCartridgeRequest;
    scenarioEvent2 :
NoCartridgePresentNotification;
    scenarioEvent3 :
NoCartridgeAcknowledgement;
    scenarioEvent4 : MainScreenDisplay_1
includes_scenario
    includesScenario1 :
CheckforCartridge_NoCartridge
included_event
    includedEvent1 :
CheckforCartridgeRequest;
    includedEvent2 : NoCartridgePresent
scn_seq_no
    scnSeqNo1 :
EraseCartridgeRequest_NoCartridgeSSN;
    scnSeqNo2 :
NoCartridgePresentNotificationSSN;
    scnSeqNo3 :
NoCartridgeAcknowledgementSSN;
    scnSeqNo4 :
MainScreenDisplay_1_NoCartridgeSSN
scn_included_seq_no
    scnIncludedSeqNo1 :
CheckforCartridgeRequest_EC_NC_ISN;
    scnIncludedSeqNo2 :
NoCartridgePresent_EC_NC_ISN
tsn_viewpoint
    tsnViewpoint :
EraseCartridge_NoCartridgeTSV
msc_viewpoint
    mscViewpoint :
EraseCartridge_NoCartridgeMSV
end

-- again, 'included_event' may be
instantiated using a variation of the
rule in App. A, Pt.2 (vii.c); see also
App.C, Pt.1 for O-Telos implementation of
included_event classes

EraseCartridgeRequest_NoCartridgeSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 1
end

NoCartridgePresentNotificationSSN in
```

```
SequenceNumber, Token with
sequence_no
    sequenceNo : 4
end

NoCartridgeAcknowledgementSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 5
end

MainScreenDisplay_1_NoCartridgeSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 6
end

CheckforCartridgeRequest_EC_NC_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 2
end

NoCartridgePresent_EC_NC_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 3
end

EraseCartridge_NoCartridgeTSV in
TsnScenarioViewpoint, Token
with
tsv_tsn_comm
    tsvTsnComm1 :
EraseCartridgeRequestTextDescription;
    tsvTsnComm2 :
NoCartridgePresentNotificationTextDescrip
tion;
    tsvTsnComm3 :
NoCartridgeAcknowledgementTextDescription
;
    tsvTsnComm4 :
MainScreenDisplay_1TextDescription
end

EraseCartridge_NoCartridgeMSV in
MscScenarioViewpoint, Token
with
msv_msc_comm
    msvMscComm1 :
EraseCartridgeRequestMSCDescription;
    msvMscComm2 :
NoCartridgePresentNotificationMSCDescript
ion;
    msvMscComm3 :
NoCartridgeAcknowledgementMSCDescription;
    msvMscComm4 :
MainScreenDisplay_1MSCDescription
end
```

No Cartridge Present Notification Event Instantiation

```
NoCartridgePresentNotification in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
NoCartridgePresentNotificationSSN
follows_from
    followsFrom : NoCartridgePresent
tsn_communication_event
    tsnCommunicationEvent :
NoCartridgePresentNotificationTextDescrip
tion
msc_communication_event
    mscCommunicationEvent :
NoCartridgePresentNotificationMSCDescript
ion
end

NoCartridgePresentNotificationTextDescrip
tion in TsnCommunication, Token with
communication_description
    communicationDescription :
NoCartridgePresentNotificationEventText
end

NoCartridgePresentNotificationEventText
in ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : NCPNEC1;
    mnlsComposite2 : NCPNEC2;
    mnlsComposite3 : NCPNEC3
mnls_plain_text
    mnlsPlainText1 : NCPNEPT1;
    mnlsPlainText2 : NCPNEPT2;
    mnlsPlainText3 : NCPNEPT3;
    mnlsPlainText4 : NCPNEPT4
tsn_sender_node
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : PilotInstance
tsn_message_node
    tsnMessageNode :
NoCartridgeNotification
end

NCPNEC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCPNEPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : NCPNEC2
end

NCPNEC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCPNEPT2
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : NCPNEC3
end

NCPNEC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCPNEPT3
subject_node
    subjectNode : NoCartridgeNotification
following_fragment
    followingFragment : NCPNEPT4
end

NCPNEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

NCPNEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " informs the "
end

NCPNEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that there is "
end

NCPNEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

NoCartridgeNotification in Message, Token
with
message_name
    messageName : "No Cartridge
Notification"
```

```
tsn_msg_parameter
    tsnMsgParameter :
NoCartridgeNotificationTsnParameter
msc_msg_parameter
    mscMsgParameter :
NoCartridgeNotificationMscParameter
end

NoCartridgeNotificationTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "no cartridge present
in the hardware"
end

NoCartridgeNotificationMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "Report No Cartridge"
end

NoCartridgePresentNotificationMSCDescript
ion in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance : PilotInstance
msc_message
    mscMessage : NoCartridgeNotification
end
```

No Cartridge Acknowledgement Event Instantiation

```
NoCartridgeAcknowledgement in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
NoCartridgeAcknowledgementSSN
follows_from
    followsFrom :
NoCartridgePresentNotification
tsn_communication_event
    tsnCommunicationEvent :
NoCartridgeAcknowledgementTextDescription
msc_communication_event
    mscCommunicationEvent :
NoCartridgeAcknowledgementMSCDescription
end

NoCartridgeAcknowledgementTextDescription
in TsnCommunication, Token with
communication_description
    communicationDescription :
NoCartridgeAcknowledgementEventText
end

NoCartridgeAcknowledgementEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : NCAEC1;
    mnlsComposite2 : NCAEC2;
    mnlsComposite3 : NCAEC3
mnls_plain_text
    mnlsPlainText1 : NCAEPT1;
    mnlsPlainText2 : NCAEPT2;
    mnlsPlainText3 : NCAEPT3;
    mnlsPlainText4 : NCAEPT4
tsn_sender_node
    tsnSenderNode : PilotInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode :
AcknowledgeNoCartridge
end

NCAEC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCAEPT1
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : NCAEC2
end

NCAEC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCAEPT2
subject_node
    subjectNode : AcknowledgeNoCartridge
following_fragment
    followingFragment : NCAEC3
end

NCAEC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCAEPT3
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : NCAEPT4
end

NCAEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

NCAEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " sends an "
end

NCAEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " to the "
end

NCAEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

AcknowledgeNoCartridge in Message, Token
with
message_name
    messageName : "Acknowledge No
Cartridge"
tsn_msg_parameter
    tsnMsgParameter :
AcknowledgeNoCartridgeTsnParameter
msc_msg_parameter
    mscMsgParameter :
AcknowledgeNoCartridgeMscParameter
end

AcknowledgeNoCartridgeTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "acknowledgement"
end

AcknowledgeNoCartridgeMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "OK: Acknowlege No
Cartridge"
end

NoCartridgeAcknowledgementMSCDescription
```

```
in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : PilotInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : AcknowledgeNoCartridge
end
```

6.2.2.2.3 Erase Cartridge - No Data on Cartridge

1. **C[SR]** The [sdr Pilot] selects the [msg Erase Cartridge option : Erase Cartridge Request] on the [rcr MPS] Main Screen.
2. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [msg is a cartridge present in the hardware? : Request Confirm Cartridge].
3. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is a cartridge present in the hardware : Confirm Cartridge].
4. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [is data on the cartridge? : Request Confirm Cartridge Data].
5. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is no data on the cartridge : No Cartridge Data].
6. **C[IP]** The [sdr MPS] informs the [rcr Pilot] that there is [msg no data on the cartridge: No Cartridge Data Notification].
7. **C[IP]** The [sdr Pilot] sends an [msg acknowledgement : Acknowledge No Data] to the [rcr MPS].
8. **C[IP]** The [sdr MPS] displays to the [rcr Pilot] the [msg Main Screen MainScreen_1].

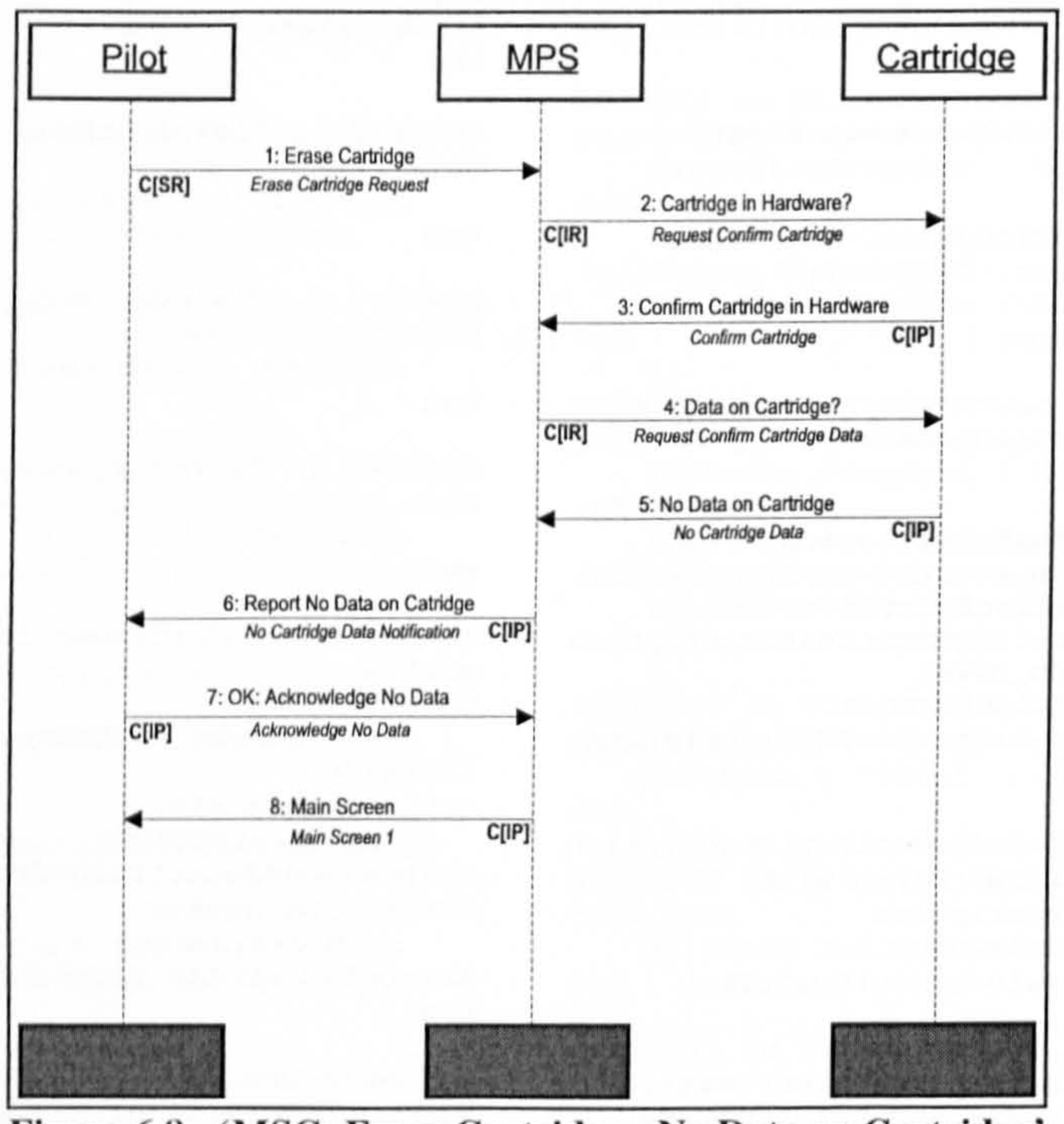


Figure 6.8 - 'MSC: Erase Cartridge - No Data on Cartridge'

Instantiation of Erase Cartridge: No Data on Cartridge

```
EraseCartridge_NoDataOnCartridge in
Scenario, Token with
scenario_title
    scenarioTitle : "Erase Cartridge - No
Data on Cartridge"
is_exception
    isException : True
scenario_event
    scenarioEvent1 :
EraseCartridgeRequest;
    scenarioEvent2 :
NoCartridgeDataPresentNotification;
    scenarioEvent3 :
NoCartridgeDataPresentAcknowledgement;
    scenarioEvent4 : MainScreenDisplay_1
```

```
includes_scenario
    includesScenario1 :
CheckforCartridge_NormalPath;
    includesScenario2 :
CheckCartridgeforData_NoData
included_event
    includedEvent1 :
CheckforCartridgeRequest;
    includedEvent2 :
ConfirmCartridgePresent;
    includedEvent3 :
CheckCartridgeforDataRequest;
    includedEvent4 :
NoCartridgeDataPresent
scn_seq_no
    scnSeqNo1 :
EraseCartridgeRequest_NoDataOnCartridgeSSN;
    scnSeqNo2 :
NoCartridgeDataPresentNotificationSSN;
    scnSeqNo3 :
NoCartridgeDataPresentAcknowledgementSSN;
    scnSeqNo4 :
MainScreenDisplay_1_NoDataOnCartridgeSSN
scn_included_seq_no
    scnIncludedSeqNo1 :
CheckforCartridgeRequest_EC_ND_ISN;
    scnIncludedSeqNo2 :
ConfirmCartridgePresent_EC_ND_ISN;
    scnIncludedSeqNo3 :
CheckCartridgeforDataRequest_EC_ND_ISN;
    scnIncludedSeqNo4 :
NoCartridgeDataPresent_EC_ND_ISN
tsn_viewpoint
    tsnViewpoint :
EraseCartridge_NoDataOnCartridgeTSV
msc_viewpoint
    mscViewpoint :
EraseCartridge_NoDataOnCartridgeMSV
end
```

-- again 'included_event' may be instantiated using a variation of the rule in App.A, Pt2 (vii.c); see also App. C, Pt.1 for O-Telos implementation of included_event classes

```
EraseCartridgeRequest_NoDataOnCartridgeSS
N in SequenceNumber, Token with
sequence_no
    sequenceNo : 1
end

NoCartridgeDataPresentNotificationSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 6
end

NoCartridgeDataPresentAcknowledgementSSN
in SequenceNumber, Token with
sequence_no
    sequenceNo : 7
end

MainScreenDisplay_1_NoDataOnCartridgeSSN
in SequenceNumber, Token with
sequence_no
    sequenceNo : 8
end

CheckforCartridgeRequest_EC_ND_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 2
end

ConfirmCartridgePresent_EC_ND_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 3
end

CheckCartridgeforDataRequest_EC_ND_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 4
end

NoCartridgeDataPresent_EC_ND_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 5
end

EraseCartridge_NoDataOnCartridgeTSV in
TsnScenarioViewpoint, Token
with
tsv_tsn_comm
    tsvTsnComm1 :
EraseCartridgeRequestTextDescription;
    tsvTsnComm2 :
NoCartridgeDataPresentNotificationTextDes
cription;
    tsvTsnComm3 :
NoCartridgeDataPresentAcknowledgementText
Description;
    tsvTsnComm4 :
MainScreenDisplay_1TextDescription
end

EraseCartridge_NoDataOnCartridgeMSV in
MscScenarioViewpoint, Token
with
msv_msc_comm
    msvMscComm1 :
EraseCartridgeRequestMSCDescription;
    msvMscComm2 :
NoCartridgeDataPresentNotificationMSCDesc
ription;
    msvMscComm3 :
NoCartridgeDataPresentAcknowledgementMSCD
escription;
    msvMscComm4 :
MainScreenDisplay_1MSCDescription
end
```

No Cartridge Data Present Notification Event Instantiation

```
NoCartridgeDataPresentNotification in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
NoCartridgeDataPresentNotificationSSN
follows_from
    followsFrom : NoCartridgeDataPresent
tsn_communication_event
    tsnCommunicationEvent :
NoCartridgeDataPresentNotificationTextDes
cription
msc_communication_event
    mscCommunicationEvent :
NoCartridgeDataPresentNotificationMSCDesc
ription
end

NoCartridgeDataPresentNotificationTextDes
cription in TsnCommunication, Token with
communication_description
    communicationDescription :
NoCartridgeDataPresentNotificationEventTe
xt
end

NoCartridgeDataPresentNotificationEventTe
xt in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : NCDPNEC1;
```

```
    mnlsComposite2 : NCDPNEC2;
    mnlsComposite3 : NCDPNEC3
mnls_plain_text
    mnlsPlainText1 : NCDPNEPT1;
    mnlsPlainText2 : NCDPNEPT2;
    mnlsPlainText3 : NCDPNEPT3;
    mnlsPlainText4 : NCDPNEPT4
tsn_sender_node
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : PilotInstance
tsn_message_node
    tsnMessageNode :
NoCartridgeDataNotification
end

NCDPNEC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCDPNEPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : NCDPNEC2
end

NCDPNEC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCDPNEPT2
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : NCDPNEC3
end

NCDPNEC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCDPNEPT3
subject_node
    subjectNode :
NoCartridgeDataNotification
following_fragment
    followingFragment : NCDPNEPT4
end

NCDPNEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

NCDPNEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " informs the "
end

NCDPNEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that there is "
end

NCDPNEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

NoCartridgeDataNotification in Message,
Token with
message_name
    messageName : "No Cartridge Data
Notification"
tsn_msg_parameter
    tsnMsgParameter :
NoCartridgeDataNotificationTsnParameter
msc_msg_parameter
    mscMsgParameter :
NoCartridgeDataNotificationMscParameter
end

NoCartridgeDataNotificationTsnParameter
in MessageDescription, Token with
msg_parameter
    msgParameter : "no data on the
cartridge"
end

NoCartridgeDataNotificationMscParameter
in MessageDescription, Token with
msg_parameter
    msgParameter : "Report No Data on
Cartridge"
end

NoCartridgeDataPresentNotificationMSCDesc
ription in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance : PilotInstance
msc_message
    mscMessage :
NoCartridgeDataNotification
end
```

No Cartridge Data Acknowledgment Event Instantiation

```
NoCartridgeDataPresentAcknowledgement in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
NoCartridgeDataPresentAcknowledgementSSN
follows_from
    followsFrom :
NoCartridgeDataPresentNotification
tsn_communication_event
    tsnCommunicationEvent :
NoCartridgeDataPresentAcknowledgementText
Description
msc_communication_event
    mscCommunicationEvent :
NoCartridgeDataPresentAcknowledgementMSCD
escription
end

NoCartridgeDataPresentAcknowledgementText
Description in TsnCommunication, Token
with
communication_description
    communicationDescription :
NoCartridgeDataPresentAcknowledgementEven
tText
end

NoCartridgeDataPresentAcknowledgementEven
tText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : NCDPAEC1;
    mnlsComposite2 : NCDPAEC2;
    mnlsComposite3 : NCDPAEC3
mnls_plain_text
    mnlsPlainText1 : NCDPAEPT1;
    mnlsPlainText2 : NCDPAEPT2;
    mnlsPlainText3 : NCDPAEPT3;
    mnlsPlainText4 : NCDPAEPT4
tsn_sender_node
    tsnSenderNode : PilotInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode : AcknowledgeNoData
end
```

```
NCDPAEC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCDPAEPT1
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : NCDPAEC2
end

NCDPAEC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCDPAEPT2
subject_node
    subjectNode : AcknowledgeNoData
following_fragment
    followingFragment : NCDPAEC3
end

NCDPAEC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCDPAEPT3
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : NCDPAEPT4
end

NCDPAEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

NCDPAEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " sends an "
end

NCDPAEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " to the "
end

NCDPAEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

AcknowledgeNoData in Message, Token with
message_name
    messageName : "Acknowledge No Data"
tsn_msg_parameter
    tsnMsgParameter :
AcknowledgeNoDataTsnParameter
msc_msg_parameter
    mscMsgParameter :
AcknowledgeNoDataMscParameter
end

AcknowledgeNoDataTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "acknowledgement"
end

AcknowledgeNoDataMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "OK: Acknowledge No
Data"
end

NoCartridgeDataPresentAcknowledgementMSCD
escription in MscCommunication, Token
with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : PilotInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : AcknowledgeNoData
end
```

6.2.2.2.4 Erase Cartridge - Pilot Chooses Not to Erase Data

1. **C[SR]** The [$_{sdr}$ Pilot] selects the [$_{msg}$ Erase Cartridge option : Erase Cartridge Request] on the [$_{rcr}$ MPS] Main Screen.
2. **C[IR]** The [$_{sdr}$ MPS] asks the [$_{rcr}$ Cartridge] whether there [$_{msg}$ is a cartridge present in the hardware? : Request Confirm Cartridge].
3. **C[IP]** The [$_{sdr}$ Cartridge] responds to the [$_{rcr}$ MPS] that [$_{msg}$ there is a cartridge present in the hardware : Confirm Cartridge].
4. **C[IR]** The [$_{sdr}$ MPS] asks the [$_{rcr}$ Cartridge] whether there [is data on the cartridge? : Request Confirm Cartridge Data].
5. **C[IP]** The [$_{sdr}$ Cartridge] responds to the [$_{rcr}$ MPS] that [$_{msg}$ there is data on the cartridge : Confirm Cartridge Data].
6. **C[IP]** The [$_{sdr}$ MPS] informs the [$_{rcr}$ Pilot] that [$_{msg}$ there is data on the cartridge : Cartridge Data Found Notification] .
7. **C[IP]** The [$_{sdr}$ Pilot] indicates to the [$_{rcr}$ MPS] that he wishes to [$_{msg}$ cancel the Erase Cartridge request : Cancel Erase Cartridge].
8. **C[IP]** The [$_{sdr}$ MPS] displays to the [$_{rcr}$ Pilot] the [$_{msg}$ Main Screen $_{MainScreen\_1}$].

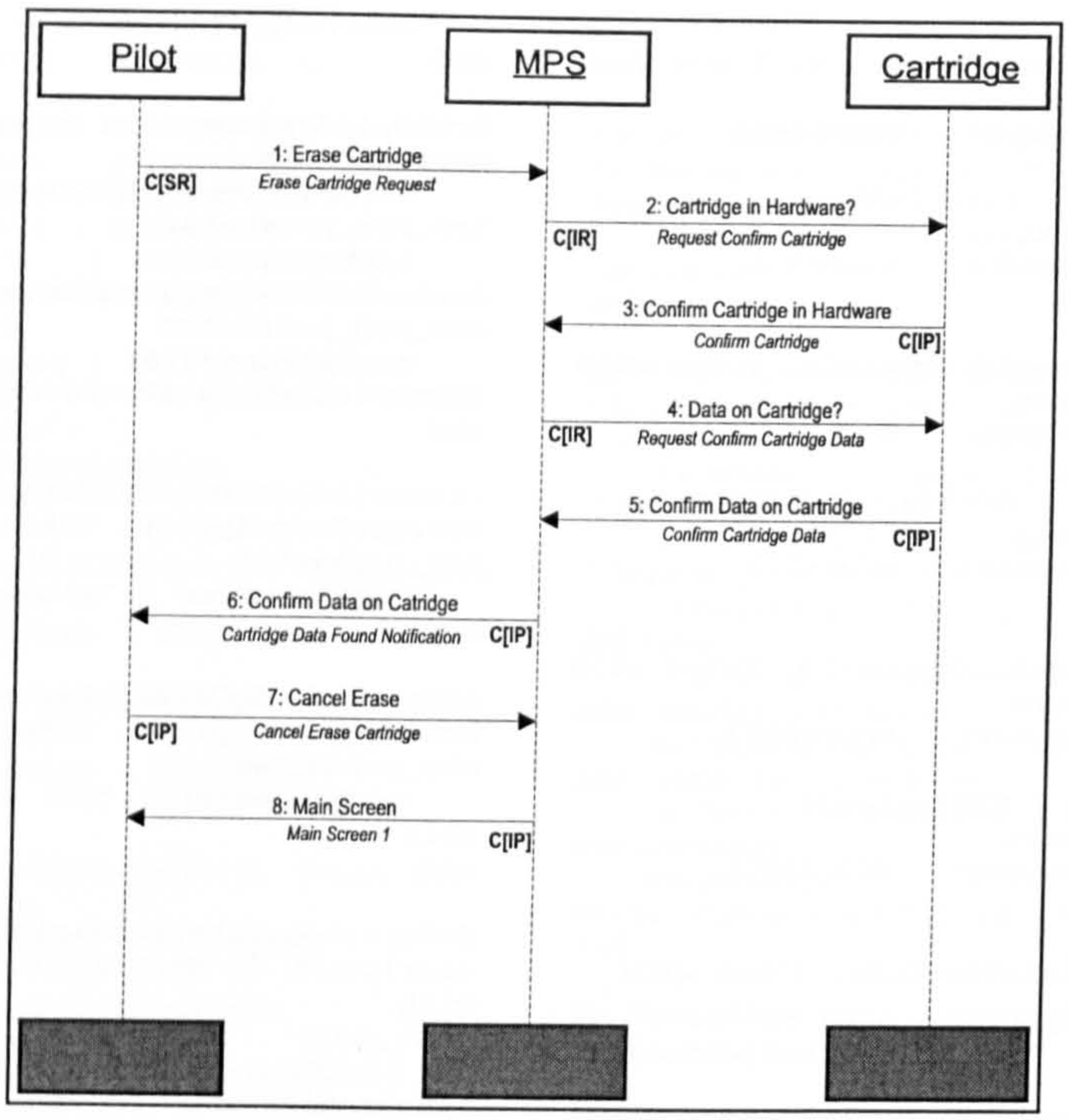


Figure 6.9 - 'MSC: Erase Cartridge - Pilot Chooses Not To Erase Data'

```
Instantiation of Erase Cartridge: Pilot
Chooses Not to Erase Data

EraseCartridge_PilotChoosesNotToEraseDa
ta in Scenario, Token with
scenario_title
    scenarioTitle : "Erase Cartridge -
Pilot Chooses Not to Erase Data"
is_exception
    isException : True
scenario_event
    scenarioEvent1 :
EraseCartridgeRequest;
    scenarioEvent2 :
ConfirmDataPresentonCartridge;
    scenarioEvent3 :
CancelEraseRequest;
    scenarioEvent4 :
MainScreenDisplay_1
includes_scenario
    includesScenario1 :
CheckforCartridge_NormalPath;
    includesScenario2 :
CheckCartridgeforData_NormalPath
included_event
    includedEvent1 :
CheckforCartridgeRequest;
    includedEvent2 :
ConfirmCartridgePresent;
    includedEvent3 :
CheckCartridgeforDataRequest;
    includedEvent4 :
ConfirmCartridgeDataPresent
scn_seq_no
    scnSeqNo1 :
EraseCartridgeRequest_PilotChoosesNotTo
EraseDataSSN;
    scnSeqNo2 :
ConfirmDataPresentonCartridge_PilotChoo
sesNotToEraseDataSSN;
    scnSeqNo3 : CancelEraseRequestSSN;
    scnSeqNo4 :
MainScreenDisplay_1_PilotChoosesNotToEr
aseDataSSN
scn_included_seq_no
    scnIncludedSeqNo1 :
CheckforCartridgeRequest_EC_PCNTED_ISN;
    scnIncludedSeqNo2 :
ConfirmCartridgePresent_EC_PCNTED_ISN;
    scnIncludedSeqNo3 :
CheckCartridgeforDataRequest_EC_PCNTED_
ISN;
    scnIncludedSeqNo4 :
ConfirmCartridgeDataPresent_EC_PCNTED_I
SN
tsn_viewpoint
    tsnViewpoint :
EraseCartridge_PilotChoosesNotToEraseDa
taTSV
msc_viewpoint
    mscViewpoint :
EraseCartridge_PilotChoosesNotToEraseDa
taMSV
end

-- again 'included_event' may be
instantiated using a variation of the
rule in App.A, Pt.2 (vii.c); see also
App.C, Pt.1 for O-Telos implementation
of included_event classes

EraseCartridgeRequest_PilotChoosesNotTo
EraseDataSSN in SequenceNumber, Token
with
sequence_no
    sequenceNo : 1
end

ConfirmDataPresentonCartridge_PilotChoo
sesNotToEraseDataSSN in SequenceNumber,
Token with
sequence_no
    sequenceNo : 6
end

CancelEraseRequestSSN in
SequenceNumber, Token with
sequence_no
```

```
    sequenceNo : 7
end

MainScreenDisplay_1_PilotChoosesNotToEr
aseDataSSN in SequenceNumber, Token
with
sequence_no
    sequenceNo : 8
end

CheckforCartridgeRequest_EC_PCNTED_ISN
in SequenceNumber, Token with
sequence_no
    sequenceNo : 2
end

ConfirmCartridgePresent_EC_PCNTED_ISN
in SequenceNumber, Token with
sequence_no
    sequenceNo : 3
end

CheckCartridgeforDataRequest_EC_PCNTED_
ISN in SequenceNumber, Token with
sequence_no
    sequenceNo : 4
end

ConfirmCartridgeDataPresent_EC_PCNTED_I
SN in SequenceNumber, Token with
sequence_no
    sequenceNo : 5
end

EraseCartridge_PilotChoosesNotToEraseDa
taTSV in TsnScenarioViewpoint, Token
with tsv_tsn_comm
    tsvTsnComm1 :
EraseCartridgeRequestTextDescription;
    tsvTsnComm2 :
ConfirmDataPresentonCartridgeTextDescri
ption;
    tsvTsnComm3 :
CancelEraseRequestTextDescription;
    tsvTsnComm4 :
MainScreenDisplay_1TextDescription
end

EraseCartridge_PilotChoosesNotToEraseDa
taMSV in MscScenarioViewpoint, Token
with msv_msc_comm
    msvMscComm1 :
EraseCartridgeRequestMSCDescription;
    msvMscComm2 :
ConfirmDataPresentonCartridgeMSCDescrip
tion;
    msvMscComm3 :
CancelEraseRequestMSCDescription;
    msvMscComm4 :
MainScreenDisplay_1MSCDescription
end
```

Cancel Erase Request Event Instantiation

```
CancelEraseRequest in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 : CancelEraseRequestSSN
follows_from
    followsFrom :
ConfirmDataPresentonCartridge
tsn_communication_event
    tsnCommunicationEvent :
CancelEraseRequestTextDescription
msc_communication_event
    mscCommunicationEvent :
CancelEraseRequestMSCDescription
end

CancelEraseRequestTextDescription in
TsnCommunication, Token with
communication_description
    communicationDescription :
CancelEraseRequestEventText
end

CancelEraseRequestEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : CEREC1;
    mnlsComposite2 : CEREC2;
    mnlsComposite3 : CEREC3
mnls_plain_text
    mnlsPlainText1 : CEREPT1;
    mnlsPlainText2 : CEREPT2;
    mnlsPlainText3 : CEREPT3;
    mnlsPlainText4 : CEREPT4
tsn_sender_node
    tsnSenderNode : PilotInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode :
CancelEraseCartridge
end

CEREC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : CEREPT1
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : CEREC2
end

CEREC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : CEREPT2
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : CEREC3
end

CEREC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : CEREPT3
subject_node
    subjectNode : CancelEraseCartridge
following_fragment
    followingFragment : CEREPT4
end

CEREPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

CEREPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " indicates to the "
end

CEREPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that he wishes to "
end

CEREPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

CancelEraseCartridge in Message, Token
with
message_name
    messageName : "Cancel Erase
Cartridge"
tsn_msg_parameter
```

```
    tsnMsgParameter :
CancelEraseCartridgeTsnParameter
msc_msg_parameter
    mscMsgParameter :
CancelEraseCartridgeMscParameter
end

CancelEraseCartridgeTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "cancel the Erase
Cartridge request"
end

CancelEraseCartridgeMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "Cancel Erase"
end
```

```
CancelEraseRequestMSCDescription in
MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : PilotInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : CancelEraseCartridge
end
```

6.2.2.2.5 Retrieve from Cartridge - Normal Path (Timing Fragment)

From Retrieve from Cartridge (Normal Path), we consider the following additional scenario fragment to demonstrate instantiation of timer-set, time-out and internal action events (the full logical level representation appears in Appendix C, Part Two).

.....

11. **T** The [timer-set MPS] sets the [timer DataTimer] to [duration 10 seconds].
12. **C[SP]** The [sdr MPS] informs the [rcr Pilot] that [msg type_1 data has been retrieved : Type_1 Retrieved Notification].
13. **T** The [host-on-timeout MPS] [timer DataTimer] times-out.
14. **A** The [sdr/rcr MPS] [act stores type_1 data : Store Type_1 Data].

.....

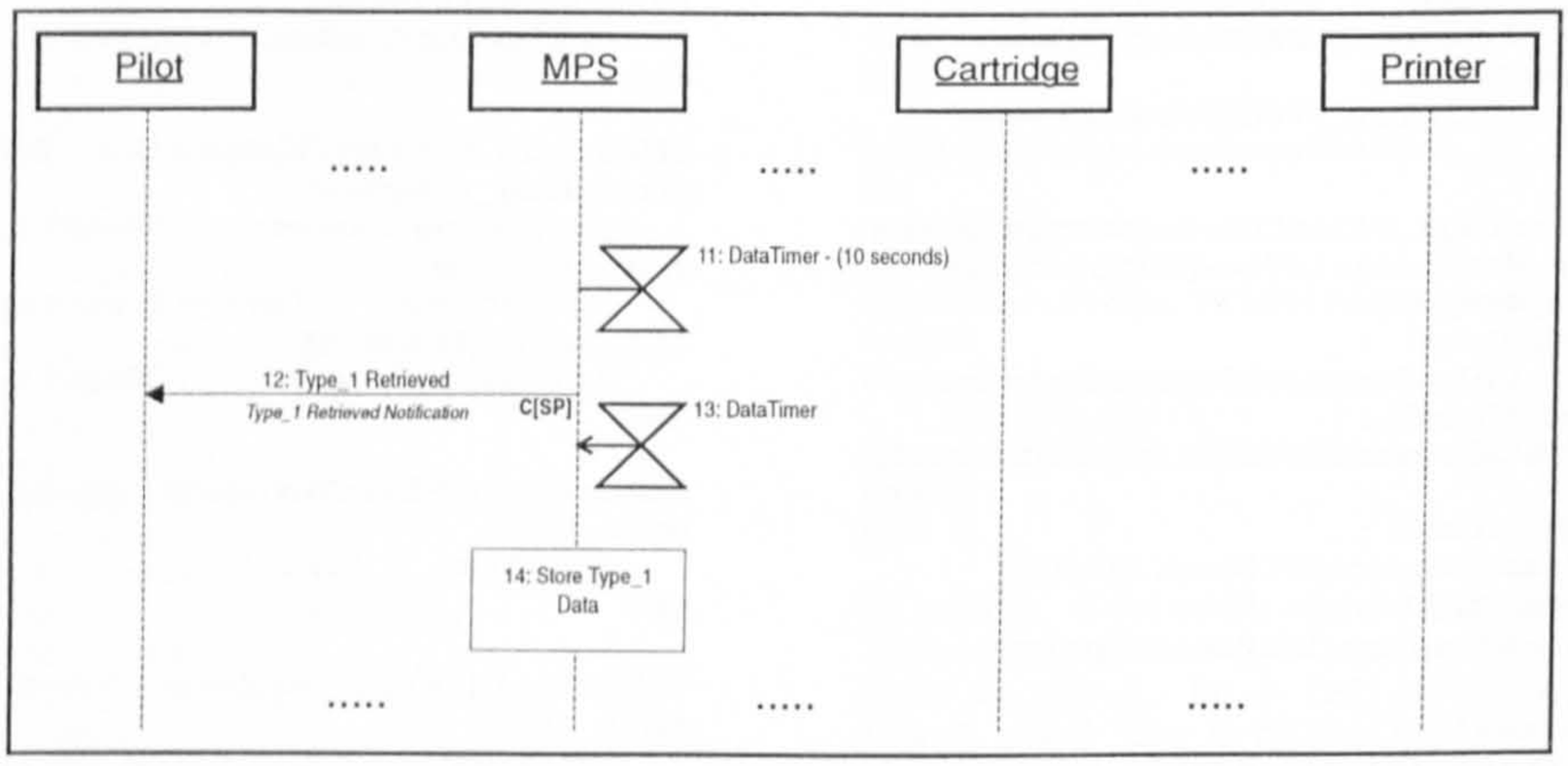


Figure 6.10 - 'Retrieve from Cartridge - Normal Path (Timing Fragment)'

Set Data Timer (Event # 11) Instantiation

```
SetDataTimer1 in TimingEvent, Token with
    .....
tsn_timing_event
    tsnTimingEvent :
SetDataTimer1TextDescription
msc_timing_event
    mscTimingEvent :
SetDataTimer1MSCDescription
end

SetDataTimer1TextDescription in
TsnTiming, Token with
timing_description
    timingDescription :
SetDataTimer1EventText
end

SetDataTimer1EventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : SDT1EC1;
    mnlsComposite2 : SDT1EC2;
    mnlsComposite3 : SDT1EC3
mnls_plain_text
    mnlsPlainText1 : SDT1EPT1;
    mnlsPlainText2 : SDT1EPT2;
```

```
    mnlsPlainText3 : SDT1EPT3;
    mnlsPlainText4 : SDT1EPT4
tsn_timer_set_node
    tsnTimerSetNode : MPSInstance
tsn_timer_instance_node
    tsnTimerInstanceNode : DataTimer
tsn_timer_duration
    tsnTimerDuration :
SetDataTimer1Duration
end

SDT1EC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : SDT1EPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : SDT1EC2
end

SDT1EC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : SDT1EPT2
subject_node
    subjectNode : DataTimer
following_fragment
    followingFragment : SDT1EC3
end

SDT1EC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : SDT1EPT3
subject_node
    subjectNode : SetDataTimer1Duration
following_fragment
    followingFragment : SDT1EPT4
end

SDT1EPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

SDT1EPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " sets the "
end

SDT1EPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " to "
end

SDT1EPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

DataTimer in Timer, Token with
timer_name
    timerName : "DataTimer"
timer_duration
    timerDuration1 :
SetDataTimer1Duration
end

SetDataTimer1Duration in TimerDuration,
Token with
duration
    _Duration : "10 Seconds"
end

SetDataTimer1MSCDescription in MscTiming,
Token with
msc_timer_set_instance
    mscTimerSetInstance : MPSInstance
msc_timer_instance
    mscTimerInstance : DataTimer
msc_timer_duration
    mscTimerDuration :
SetDataTimer1Duration
end
```

Type_1 (Data) Retrieved Notification (Event # 12) Instantiation

```
RetrievedType1Notification in
CommunicationEvent, Token with
interaction_type
    interactionType : "SP"
    .....
tsn_communication_event
    tsnCommunicationEvent :
RetrievedType1NotificationTextDescription
msc_communication_event
    mscCommunicationEvent :
RetrievedType1NotificationMSCDescription
end

RetrievedType1NotificationTextDescription
in TsnCommunication, Token with
communication_description
    communicationDescription :
RetrievedType1NotificationEventText
end

RetrievedType1NotificationEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : RT1NEC1;
    mnlsComposite2 : RT1NEC2;
    mnlsComposite3 : RT1NEC3
mnls_plain_text
    mnlsPlainText1 : RT1NEPT1;
    mnlsPlainText2 : RT1NEPT2;
    mnlsPlainText3 : RT1NEPT3;
    mnlsPlainText4 : RT1NEPT4
tsn_sender_node
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : PilotInstance
tsn_message_node
    tsnMessageNode :
Type_1RetrievedNotification
end

RT1NEC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : RT1NEPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : RT1NEC2
end

RT1NEC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : RT1NEPT2
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : RT1NEC3
end

RT1NEC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : RT1NEPT3
subject_node
    subjectNode :
Type_1RetrievedNotification
following_fragment
    followingFragment : RT1NEPT4
end

RT1NEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

RT1NEPT2 in PlainTextNode, Token with
```

```
mnls_text
    mnlsText : " informs the "
end

RT1NEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that "
end

RT1NEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

Type_1RetrievedNotification in Message,
Token with
message_name
    messageName : "Type_1 Retrieved
Notification"
tsn_msg_parameter
    tsnMsgParameter :
RetrievedType1NotificationTsnParameter
msc_msg_parameter
    mscMsgParameter :
RetrievedType1NotificationMscParameter
end

RetrievedType1NotificationTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "type_1 data has been
retrieved"
end

RetrievedType1NotificationMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "Type_1 Retrieved"
end

RetrievedType1NotificationMSCDescription
in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance : PilotInstance
msc_message
    mscMessage :
Type_1RetrievedNotification
end
```

Time-out Data Timer (Event # 13) Instantiation

```
TimeoutDataTimer1 in TimingEvent, Token
with
    .......
tsn_timing_event
    tsnTimingEvent :
TimeoutDataTimer1TextDescription
msc_timing_event
    mscTimingEvent :
TimeoutDataTimer1MSCDescription
end

TimeoutDataTimer1TextDescription in
TsnTiming, Token with
timing_description
    timingDescription :
TimeoutDataTimer1EventText
end

TimeoutDataTimer1EventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : TODT1EC1;
    mnlsComposite2 : TODT1EC2
mnls_plain_text
    mnlsPlainText1 : TODT1EPT1;
    mnlsPlainText2 : TODT1EPT2
mnls_null
    mnlsNull : TODT1ENull1
tsn_host_on_timeout_node
    tsnHostOnTimeoutNode : MPSInstance
tsn_timer_instance_node
    tsnTimerInstanceNode : DataTimer
end

TODT1EC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : TODT1EPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : TODT1EC2
end

TODT1EC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : TODT1ENull1
subject_node
    subjectNode : DataTimer
following_fragment
    followingFragment : TODT1EPT2
end

TODT1EPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

TODT1EPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " times-out."
end

TimeoutDataTimer1MSCDescription in
MscTiming, Token with
msc_host_on_timeout_instance
    mscHostOnTimeoutInstance :
MPSInstance
msc_timer_instance
    mscTimerInstance : DataTimer
end
```

Storage Type_1 Data (Event # 14) Instantiation

```
StorageType1 in InternalActionEvent,
Token with
    .......
tsn_action_event
    tsnActionEvent :
StorageType1TextDescription
msc_action_event
    mscActionEvent :
StorageType1MSCDescription
end

StorageType1TextDescription in TsnAction,
Token with
action_description
    actionDescription :
StorageType1EventText
end

StorageType1EventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : ST1EC1;
    mnlsComposite2 : ST1EC2
```

```
mnls_plain_text
    mnlsPlainText1 : ST1EPT1;
    mnlsPlainText2 : ST1EPT2
mnls_null
    mnlsNull : ST1ENull1
tsn_sdr_rcr_node
    tsnSdrRcrNode : MPSInstance
tsn_action_node
    tsnActionNode : StoreType_1Data
end

ST1EC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : ST1EPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : ST1EC2
end

ST1EC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : ST1ENull1
subject_node
    subjectNode : StoreType_1Data
following_fragment
    followingFragment : ST1EPT2
end

ST1EPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

ST1EPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

StoreType_1Data in Action, Token with
action_name
    actionName : "Store Type_1 Data"
tsn_act_parameter
    tsnActParameter :
StoreType1TsnParameter
end

StoreType1TsnParameter in
MessageDescription, Token with
action_parameter
    actionParameter : "stores type_1
data"
end

StorageType1MSCDescription in MscAction,
Token with
msc_sdr_rcr_instance
    mscSdrRcrInstance : MPSInstance
msc_system_action
    mscSystemAction : StoreType_1Data
end
```

6.2.2.2.6 Choose Mission and Aircraft (Event Group Fragment)

Finally, from Choose Mission and Aircraft (New Mission from Open Missions), we consider the following fragment to demonstrate elements for event grouping and upper and lower bounds on iteration.

ITERATION: Lower Bound = 1 : Upper Bound = *card* data types Mission Plan()

11. **C[IR]** The [sdr MPS] asks the [rcr Mission Plan] to [msg supply a data item : Request Data Item].
12. **C[IP]** The [sdr Mission Plan] supplies the [msg data item for the selected Mission and Aircraft : Mission&AC Data Item] to the [rcr MPS].
13. **A** The [sdr/rcr MPS] [act stores the data item for the selected Mission and Aircraft : Store Selected Mission&AC Data].

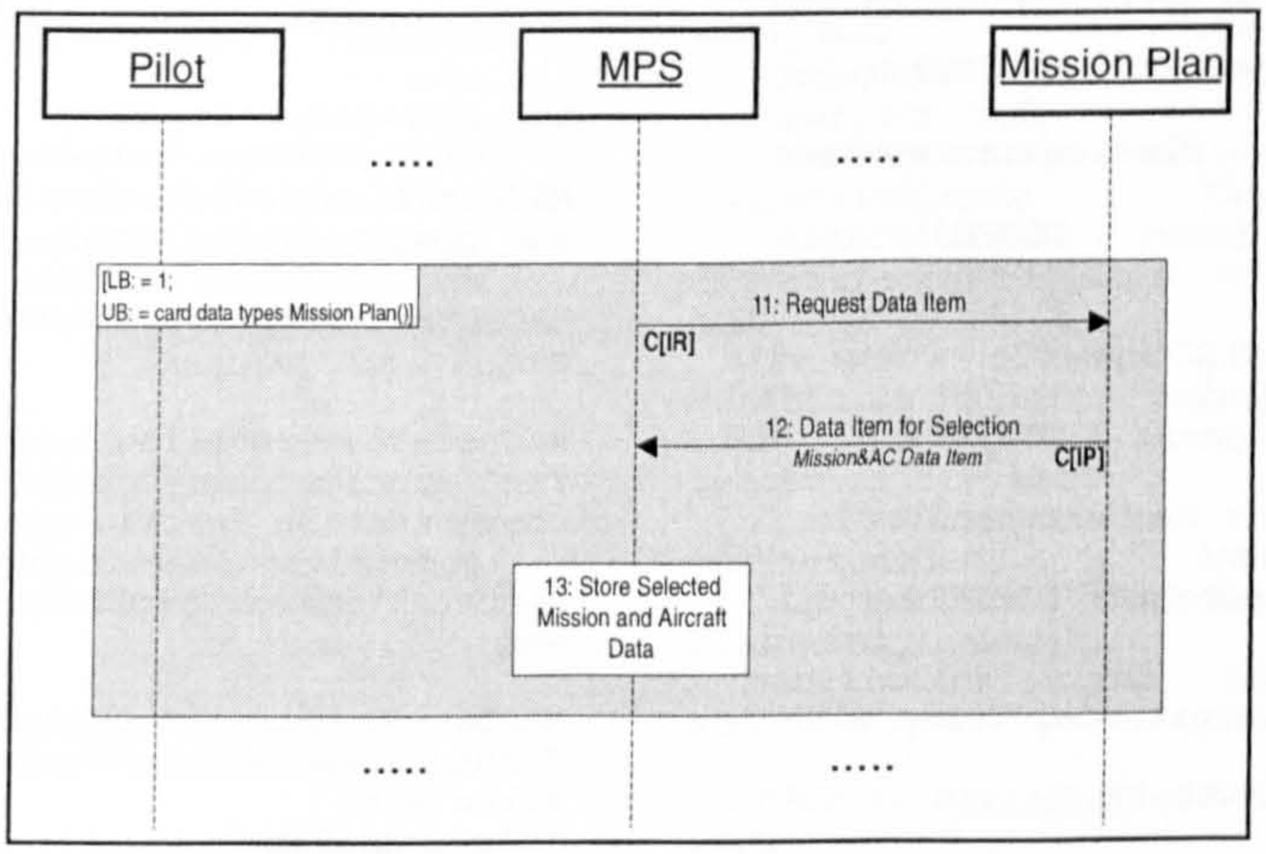


Figure 6.11 - 'Choose Mission and Aircraft - New Mission from Open Missions (Event Group Fragment)'

Data Item Request (Event # 11) Instantiation

```
DataItemRequest in CommunicationEvent,
Token with
interaction_type
    interactionType : "IR"
    .....
tsn_communication_event
    tsnCommunicationEvent :
DataItemRequestTextDescription
msc_communication_event
    mscCommunicationEvent :
DataItemRequestMSCDescription
end

DataItemRequestTextDescription in
TsnCommunication, Token with
communication_description
    communicationDescription :
DataItemRequestEventText
end

DataItemRequestEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : DIREC1;
    mnlsComposite2 : DIREC2;
    mnlsComposite3 : DIREC3
mnls_plain_text
    mnlsPlainText1 : DIREPT1;
    mnlsPlainText2 : DIREPT2;
    mnlsPlainText3 : DIREPT3;
    mnlsPlainText4 : DIREPT4
tsn_sender_node
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : MissionPlanInstance
tsn_message_node
    tsnMessageNode : RequestDataItem
end

DIREC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DIREPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : DIREC2
end

DIREC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DIREPT2
subject_node
    subjectNode : MissionPlanInstance
following_fragment
    followingFragment : DIREC3
end

DIREC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DIREPT3
subject_node
    subjectNode : RequestDataItem
following_fragment
    followingFragment : DIREPT4
end

DIREPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

DIREPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " asks the "
end

DIREPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " to "
end

DIREPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

RequestDataItem in Message, Token
with
message_name
    messageName : "Request Data Item"
tsn_msg_parameter
    tsnMsgParameter :
RequestDataItemTsnParameter
end

RequestDataItemTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "supply a data item"
end

DataItemRequestMSCDescription in
MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance :
MissionPlanInstance
msc_message
    mscMessage : RequestDataItem
end
```

Mission And Aircraft Data Item Provision (Event #12) Instantiation

```
MACDataItemProvision in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
    .....
tsn_communication_event
    tsnCommunicationEvent :
MACDataItemProvisionTextDescription
msc_communication_event
    mscCommunicationEvent :
MACDataItemProvisionMSCDescription
end

MACDataItemProvisionTextDescription in
TsnCommunication, Token with
communication_description
    communicationDescription :
MACDataItemProvisionEventText
end

MACDataItemProvisionEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : MACDIPEC1;
    mnlsComposite2 : MACDIPEC2;
    mnlsComposite3 : MACDIPEC3
mnls_plain_text
```

```
    mnlsPlainText1 : MACDIPEPT1;
    mnlsPlainText2 : MACDIPEPT2;
    mnlsPlainText3 : MACDIPEPT3;
    mnlsPlainText4 : MACDIPEPT4
tsn_sender_node
    tsnSenderNode : MissionPlanInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode : Mission&ACDataItem
end

MACDIPEC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : MACDIPEPT1
subject_node
    subjectNode : MissionPlanInstance
following_fragment
    followingFragment : MACDIPEC2
end

MACDIPEC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : MACDIPEPT2
subject_node
    subjectNode : Mission&ACDataItem
following_fragment
    followingFragment : MACDIPEC3
end

MACDIPEC3 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : MACDIPEPT3
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : MACDIPEPT4
end

MACDIPEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

MACDIPEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " supplies the "
end

MACDIPEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " to the "
end

MACDIPEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

Mission&ACDataItem in Message, Token
with
message_name
    messageName : "Mission&AC Data Item"
tsn_msg_parameter
    tsnMsgParameter :
Mission&ACDataItemTsnParameter
msc_msg_parameter
    mscMsgParameter :
Mission&ACDataItemMscParameter
end

Mission&ACDataItemTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "data item for the
selected Mission and Aircraft"
end

Mission&ACDataItemMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "Data Item for
Selection"
end

MACDataItemProvisionMSCDescription in
MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance :
MissionPlanInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : Mission&ACDataItem
end
```

Storage Mission and Aircraft Data (Event #13) Instantiation

```
StorageMAC in InternalActionEvent, Token
with
    .....
tsn_action_event
    tsnActionEvent :
StorageMACTextDescription
msc_action_event
    mscActionEvent :
StorageMACMSCDescription
end

StorageMACTextDescription in TsnAction,
Token with
action_description
    actionDescription :
StorageMACEventText
end

StorageMACEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : SMACEC1;
    mnlsComposite2 : SMACEC2
mnls_plain_text
    mnlsPlainText1 : SMACEPT1;
    mnlsPlainText2 : SMACEPT2
mnls_null
    mnlsNull : SMACENull1
tsn_sdr_rcr_node
    tsnSdrRcrNode : MPSInstance
tsn_action_node
    tsnActionNode :
StoreSelectedMission&ACData
end

SMACEC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : SMACEPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : SMACEC2
end

SMACEC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : SMACENull1
subject_node
```

```
    subjectNode :
StoreSelectedMission&ACData
following_fragment
    followingFragment : SMACEPT2
end

SMACEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

SMACEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

StoreSelectedMission&ACData in Action,
Token
with
action_name
    actionName : "Store Selected
Mission&AC Data"
tsn_act_parameter
    tsnActParameter :
StoreSelectedMission&ACDataTsnParameter
msc_act_parameter
    mscActParameter :
StoreSelectedMission&ACDataMscParameter
end

StoreSelectedMission&ACDataTsnParameter
in MessageDescription, Token
with
action_parameter
    actionParameter :
"stores the data item for the selected
Mission and Aircraft"
end

StoreSelectedMission&ACDataMscParameter
in MessageDescription, Token
with
action_parameter
    actionParameter :
"Store Selected Mission and Aircraft
Data"
end

StorageMACMSCDescription in MscAction,
Token
with
msc_sdr_rcr_instance
    mscSdrRcrInstance : MPSInstance
msc_system_action
    mscSystemAction :
StoreSelectedMission&ACData
end
```

Grouping for Events 11-13

```
Events11To13Group in EventGroup, Token
with
group_event
    groupEvent1 : DataItemRequest;
    groupEvent2 : MACDataItemProvision;
    groupEvent3 : StorageMAC
grp_lb
    grpLb : Events11To13GroupLB
grp_ub
    grpUb : Events11To13GroupUB
end

Events11To13GroupLB in LowerBound, Token
with
lower_bound
    lowerBound : "1"
end

Events11To13GroupUB in UpperBound, Token
with
upper_bound
    upperBound :
    "card data types Mission Plan()"
end
```

6.2.3 Trace Relations

This subsection will demonstrate how, given the meta-model representations in subsection 6.2.2.1.1 and in subsections 6.2.2.2.1 through 6.2.2.2.6, the MATrA workspace is able to support traceability of user centred requirements artifacts within (in this case) the intra-micro horizontal dimension. In doing so, we instantiate a subset of trace relations introduced in subsection 3.3.6.3.2. These relations are illustrated at a logical level in figure 6.12 (and summarised in table 6.2).

It should be noted that the featured examples are fairly arbitrary. Indeed, as Chapter Three indicated, a thorough investigation (combining literature review and practitioner consultation) is deemed necessary to develop a comprehensive set of associations for linking different artifact types used throughout the aerospace industry; this is earmarked as a future work item in subsection 7.4.3. The investigation would need to consider a wide variety of notations and techniques as potential source and targets of these associations - including requirements, design, implementation, safety assessment and product management. Those for requirements could potentially build on the taxonomy proposed by project NATURE (Pohl, 1996) referred to in subsection 3.2.1.

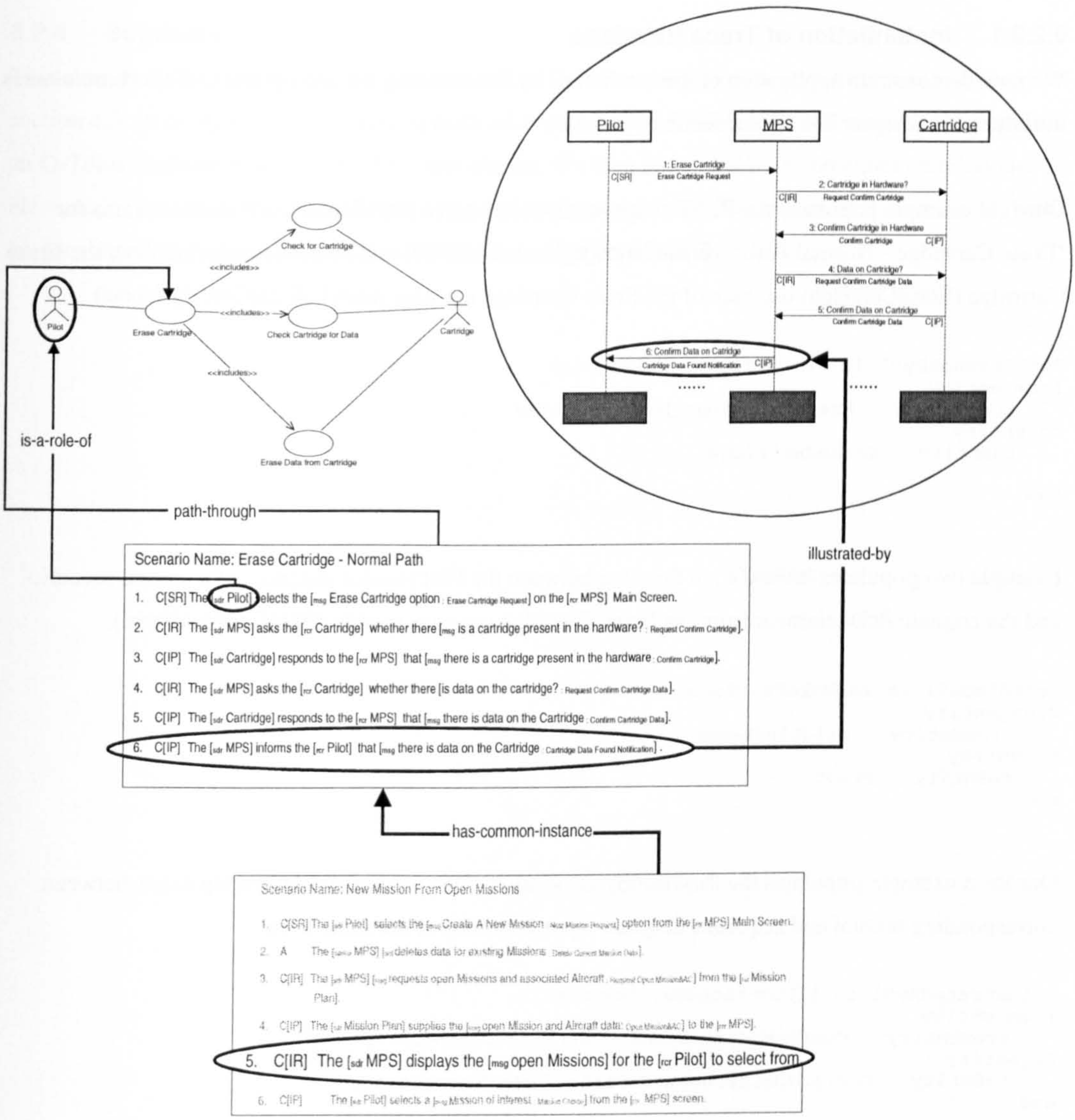


Figure 6.12 - 'Exemplar Intra-Micro Horizontal Traceability Relations'

SOURCE		RELATION TYPE	TARGET	
Model	**Element**		**Model**	**Element**
Interaction Model	'Erase Cartridge' (Scenario)	Path-Through	Use Case Model	'Erase Cartridge' (Use Case)
Interaction Model	Pilot (message sender) Instance ('Erase Cartridge' - Event #1)	Is-A-Role-Of	Use Case Model	Pilot (Actor)
Interaction Model	'Erase Cartridge' (Event #6 - Textual View)	Illustrated-By	Interaction Model	'Erase Cartridge' (Event #6 - MSC View)
Interaction Model	'New Mission from Open Missions' (Scenario)	Has-Common-Instance	Interaction Model	'Erase Cartridge' (Scenario)

Table 6.2 - 'Summary of Traceability Relations' (from figure 6.12)

6.2.3.1 Instantiation of Trace Relations

We now demonstrate application of these relations by instantiating the appropriate O-Telos base classes introduced in Chapter Three (subsection 3.3.6.3.2).

Our first example populates the PathThrough relation; its source (fromEntity) is a textual scenario for 'Erase Cartridge - Normal Path[2]' (EraseCartridge_NormalPathTSV) and its destination (toEntity), the Erase Cartridge (EraseCartridge) use case of the Erase Cartridge use case model (EraseCartridgeModel).

```
PathThroughBy01 in PathThrough, Token with
from_entity
    fromEntity : EraseCartridge_NormalPathTSV
to_entity
    toEntity : EraseCartridge

end
```

Example two populates IsARoleOf , in this case between the Pilot (sender instance) of a textual scenario[3] and the cognate Actor element from the Erase Cartridge use case model (EraseCartridgeModel).

```
IsARoleOf01 in IsARoleOf, Token with
from_entity
    fromEntity : PilotInstance
to_entity
    toEntity : Pilot
end
```

Our third example populates the IllustratedBy association. This particular relationship exists between corresponding textual and sequence diagram representations of the same event.

```
IllustratedBy01 in IllustratedBy, Token with
from_entity
    fromEntity : ConfirmDataPresentonCartridgeTextDescription
to_entity
    toEntity : ConfirmDataPresentonCartridgeMSCDescription
end
```

Our final example populates the HasCommonInstance association linking two scenarios, 'Erase Cartridge - Normal Path' and 'New Mission from Open Missions', both of which include Pilot and MPS instances (one such event for the 'New Mission from Open Missions' scenario is highlighted in figure 6.12).

```
HasCommonInstance01 in HasCommonInstance, Token with
from_entity
    fromEntity : EraseCartridge_NormalPath
to_entity
    toEntity : NewMissionfromOpenMissions
end
```

Note the source element of HasCommonInstance01, EraseCartridge_NormalPath, comes from instantiation of the Interaction View in 6.2.2.2.1 (EraseCartridgeModel), while its target NewMissionfromOpenMissions is introduced purely to support the example.

---

[2] A corresponding PathThrough association would also exist between the MSC (EraseCartridge_NormalPathMSV) representation and EraseCartridge.

[3] Recall that textual and MSC scenario representations share common Instance objects such that figure 6.12 could show a similar logical-level association from the corresponding Sequence Diagram element.

6.2.4 Summary

This case study has demonstrated application of the User Centred Requirements Structure introduced in section 4.3. In doing so, a commercial specification supplied by BAE SYSTEMS was used to populate an O-Telos implementation of (UCRS) base classes. We then illustrated how constituent models and elements of the structure may be linked using various trace relations. The results of this case study will be considered as part of our overall thesis evaluation in Chapter Seven.

6.3 Case Study II : A Brake System Control Unit for a Wheel Braking System of a Hypothetical Aircraft

This section presents a case study based on extracts from a contiguous example in ARP 4761 (Appendix L). We use a subset of artifacts featured in that example describing assessment of a hypothetical aircraft - the S18 - to demonstrate aspects of the Fault Tree and Failure Modes and Effects Analysis structures introduced in sections 5.2 and 5.3. We also show how elements of these structures may be linked using trace relations, again based on the approach shown in 3.3.6.3.2.

6.3.1 Scope of Case Study

The case study concentrates on a subset of activities from the ARP 4761 assessment process and in doing so, on one particular component (item) of the S18 aircraft. Specifically, we consider identification and verification of quantitative (safety) requirements for the Brake System Control Unit (BSCU) computer, a sub-module of the S18 Wheel Braking System (WBS). Requirements identification forms part of Preliminary System Safety Assessment (PSSA) of the BSCU and verification, part of System Safety Assessment (SSA). This is placed in context by the following diagram fragment (figure 6.13); note readers are referred back to figure 1.6 in subsection 1.4.6.2.2 for the complete diagram and a description of the ARP 4761 assessment process.

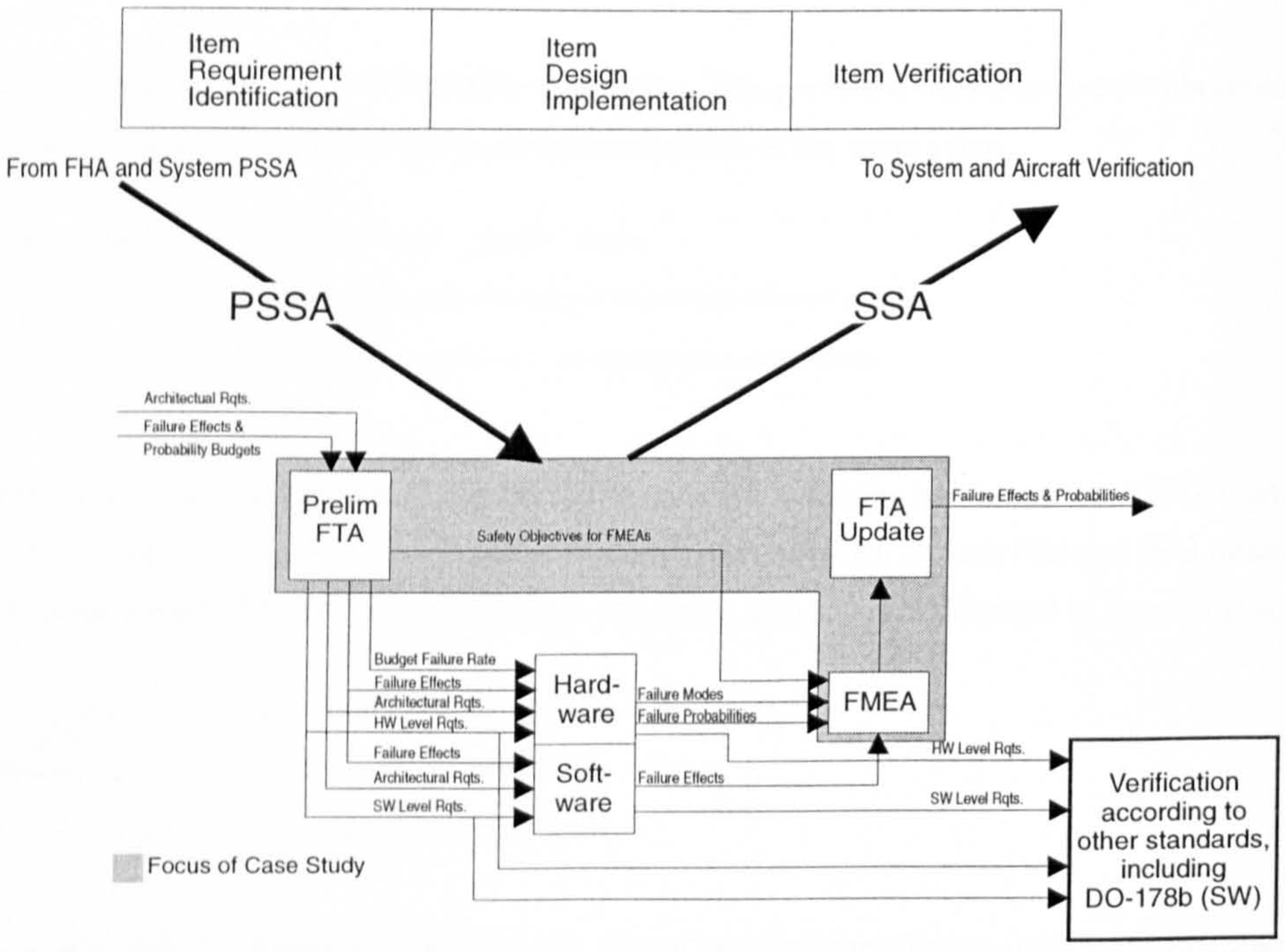


Figure 6.13 - 'ARP Assessment Process (Partial)'

6.3.2 Overview of S18 Wheel Braking System and Brake System Control Unit

The Wheel Braking System is installed on the main landing gears, its purpose to decelerate aircraft on the ground (without the tyres skidding) during taxi and landing phases and in the event of rejected take-off. Braking is automatically performed on landing, or when manually activated by the pilot.

Each wheel brake assembly is operated by two independent sets of hydraulic pistons. One set operates from the Green hydraulic supply and is used in Normal Braking mode. The Alternate mode which uses the Blue hydraulic supply is on standby and is selected automatically when the Normal system fails. An Emergency braking mode is also available, although designers take the decision that all safety requirements shall be met without regard to this system. In the Normal mode, all wheels are individually braked from their own servo valves according to commands received from one of two Braking System Control Unit computers - normally BSCU1 or, if system 1 reports a failure, BSCU2.

Failure conditions relating to this function include 'Loss of all Wheel Braking' (shown by the fault tree in figure 5.1, subsection 5.2.2.1) and 'Inadvertent Wheel Braking' - the focus of this case study. Such events are established by a (Braking System) Functional Hazard Assessment (FHA), with budget probabilities allocated according to severity. These requirements provide inputs to the (Braking System) PSSA; to determine causality, catastrophic and hazardous conditions form top events of fault trees (an example of this relationship is shown at aircraft level in figure 1.5 of Chapter One). In turn, basic events of the system PSSA trees derive requirements that feed into an item level PSSA. This is the point at which we join the example from ARP 4761.

6.3.3 Preliminary System Safety Assessment - Brake System Control Unit

For the purpose of this case study, we assume a fault tree (not shown) developed as part of the Wheel Braking System PSSA has a basic event imposing the following item level requirement over the component BSCU:-

- The probability of 'BSCU commands braking in absence of braking commands and causes inadvertent braking' shall be less that 2.5E-9 per flight.

Preliminary System Safety Assessment of the BSCU subsequently serves to complete safety requirements for this particular component. These include quantitative requirements, again derived using fault trees - one of which will now be used to demonstrate instantiation of 'preliminary' elements of the Fault Tree Analysis structure.

6.3.3.1 Background on BSCU Design

The BSCU design consists of two independent systems (referred to previously as BSCU1 and BSCU2). Both generate necessary voltages from their respective power supplies; out of specification voltages are detected within each system by a power supply monitor (described in 6.3.4.1).

According to the design proposal considered here, each system will also contain a command and monitor channel which computes braking commands based on brake pedal inputs. The commands generated by each channel are compared, with a failure reported when a disparity is detected.

Results of the power supply monitor and comparator are then provided to a system validity monitor; a failure reported by either BSCU causes that system to disable its outputs and set the system validity

monitor to invalid. Each system validity monitor is provided to an overall BSCU validity monitor; failure of both BSCU1 and BSCU2 causes the selector valve to switch to the Alternate Braking System.

In normal operation, BSCU1 provides the braking commands. When a failure is reported (via its system validity monitor), the output of BSCU2 (if valid) is switched in to allow braking. If system 2 also fails, all BSCU outputs are disabled and the BSCU validity monitor set to invalid.

6.3.3.2 Fault Tree Analysis - Preliminary

The fault tree in figures 6.14i to 6.14iii considers inadvertent wheel braking attributable to the BSCU (with requirement 2.5E-9 per flight hour as stated in subsection 6.3.3) to determine feasibility of the design outlined above. In the interests of readability, transfer-in/transfer-out symbols (denoted by a triangle with a horizontal line from its side) are employed allowing the two main fault tree branches to be shown as separate figures.

In addition to safety requirements from the previous assessment phase, PSSA also takes into account operational considerations. Those relevant to this analysis include average flight length (5 hours), average power-up interval (100 hours), estimated aircraft life (100,000 hours) and time between V1and VR (0.004167 hour)[4]. These provide exposure times and are used (together with failure rates based on design data and service experience) in calculating probabilities for basic fault tree events.

It can be seen from figure 6.14i that the tree assumes no undetected BSCU failures can lead to inadvertent braking (BSCUUNDF); such an assumption must be proved correct through Failure Modes and Effects Analysis and/or Common Mode Analysis. The other branch of the fault tree (developed in figures 6.14ii and 6.14iii) addresses combinations of monitored BSCU failures and monitor failures[5].

The fault tree in 6.14ii describes analysis of the BSCU1 detectable failures causing bad data event (BSCU1DETD). In summary, this event can occur if the power supply monitor is stuck valid (BS1PSMOFV) and the power supply failure causes bad data (BSCU1PSF). An alternative path to the event is if the monitor channel always reports valid due to hardware failure (BSCU1MOFV) and command channel I/O failure causes bad data (BSCU1I/OF) or, command channel CPU hardware failure causes bad data (BSCU1CPUF).

The fault tree in figure 6.14iii contains the same failure information relative to BSCU2. However, this system is only applied to the brakes upon activation of the monitor/select switch. Thus the event of the switch being in position 2 (SWITCH2) is And-ed with BSCU2 failures. Two conditions may result in switch activation, a previously detected failure of BSCU1 (BSCU1TF), or an independent monitor switch failure (SWIFAIL2).

---

[4] V1 is the take off decision speed at which it is possible to take off safely following engine failure. It is also the speed whereby, if take off were abandoned, then the aircraft may be brought to a safe stop within the remaining runway. VR is the speed where the aircraft begins to rotate to lift off attitude and climb.

[5] Note event labels in figures 6.14i-6.14iii contain the subject entity (preceded by an optional qualifying entity enclosed in square brackets) and a condition, separated by a period.

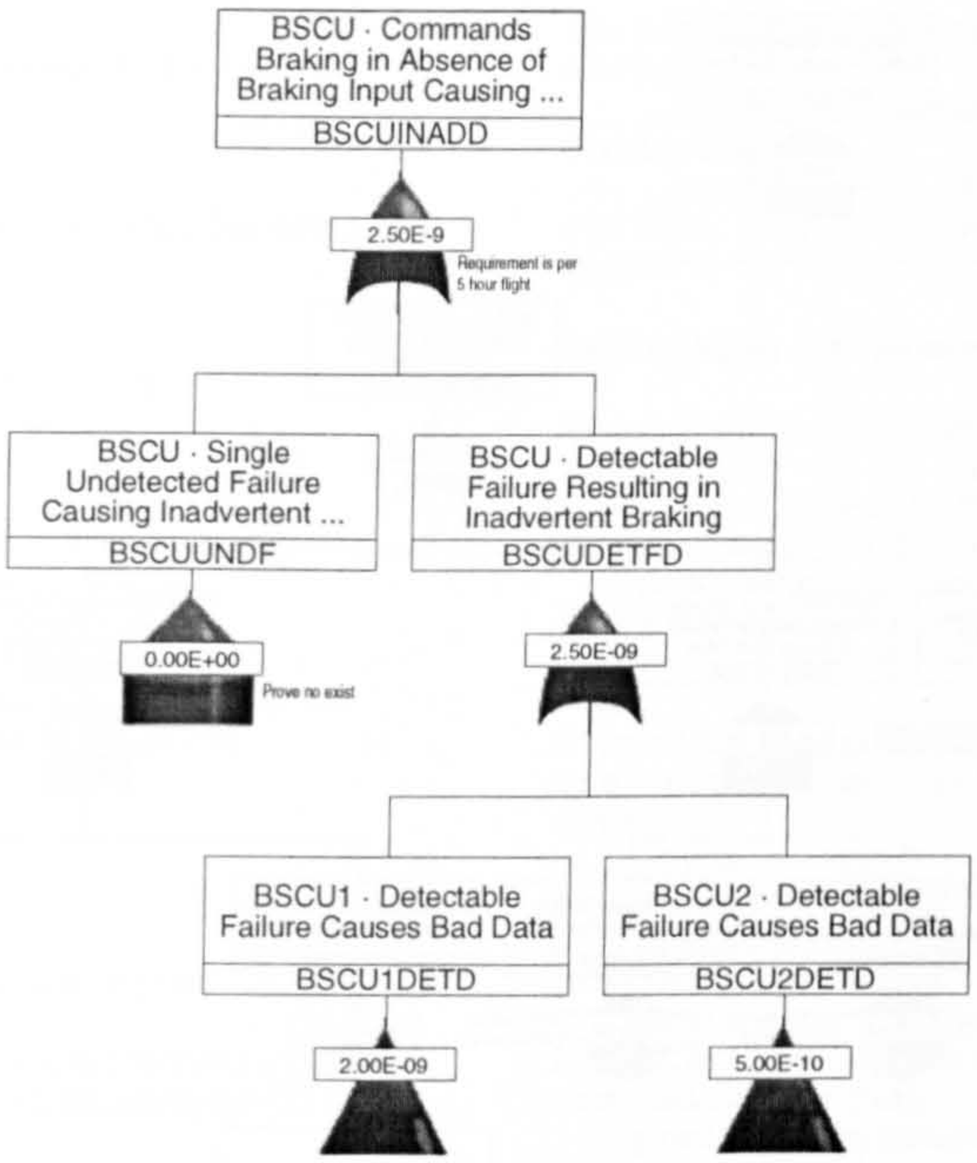


Figure 6.14i - 'BSCU Commands Braking in Absence of Brake Input Causing Inadvertent Braking - Preliminary Fault Tree (page 1)'

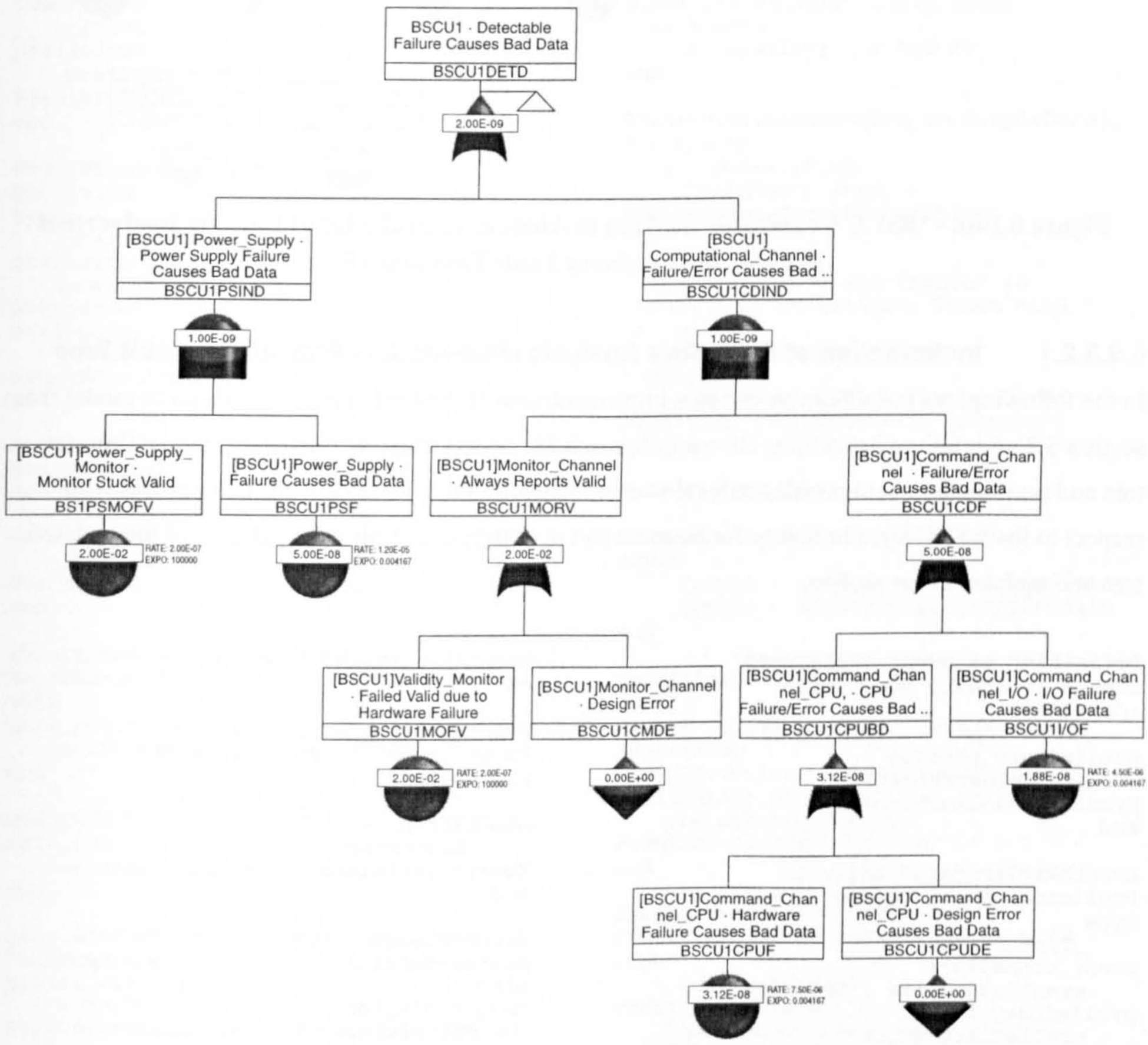


Figure 6.14ii - 'BSCU Commands Braking in Absence of Brake Input Causing Inadvertent Braking - Preliminary Fault Tree (page 2)'

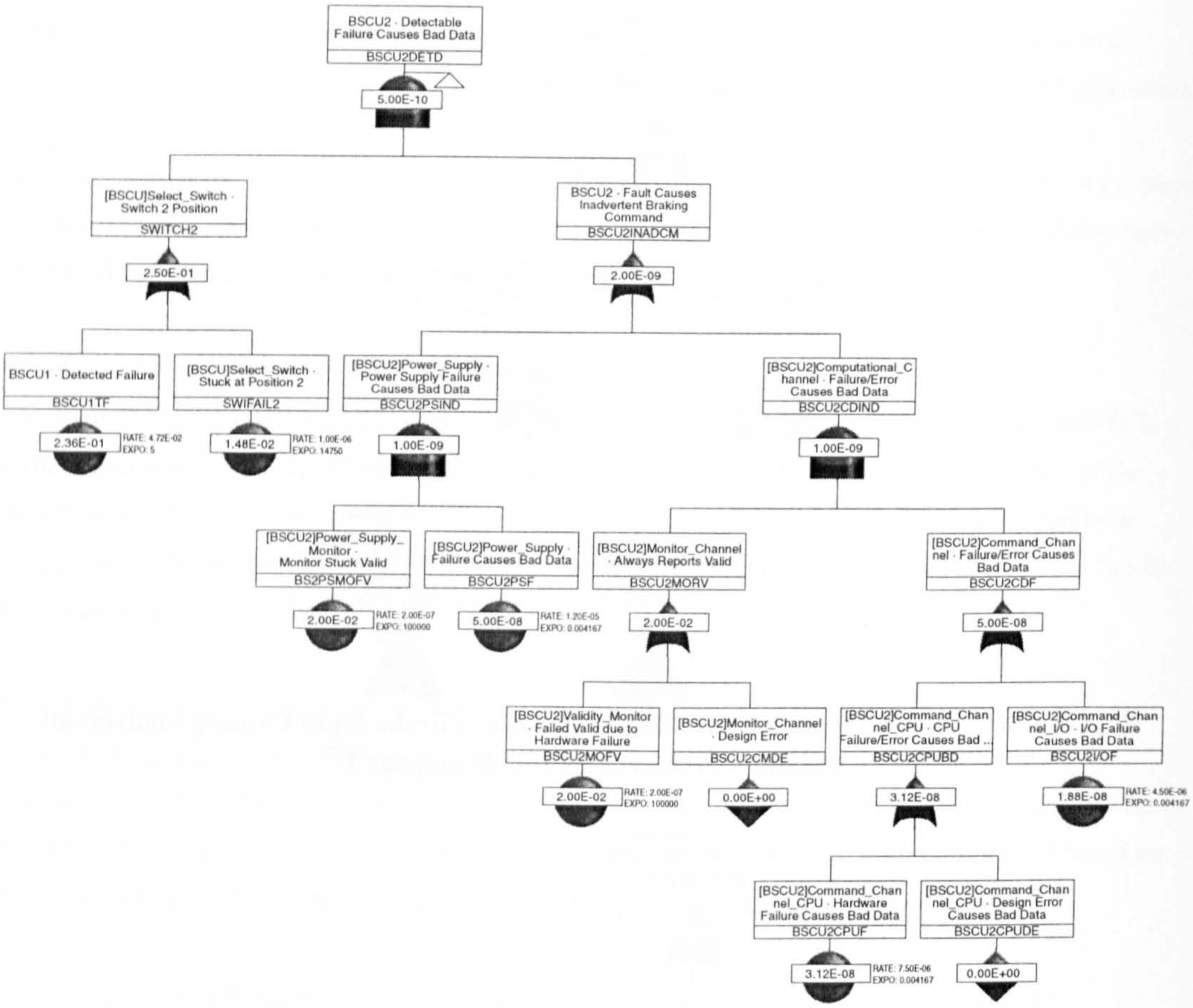


Figure 6.14iii - 'BSCU Commands Braking in Absence of Brake Input Causing Inadvertent Braking - Preliminary Fault Tree (page 3)'

6.3.3.2.1 Instantiation of Fault Tree Analysis Meta-model - Preliminary Fault Tree

In the following, we instantiate an O-Telos implementation of the Fault Tree Analysis meta-model from section 5.2 with failure behaviours shown in figure 6.14. At this stage, we instantiate the preliminary tree and preliminary event profiles only. However, subsection 6.3.4.3 revisits the meta-model with respect to the BSCU System Safety Assessment and in doing so, completes population of the updated tree and updated event profiles.

```
Definition of Event 'BSCUINADD'
EventA in Event, Token with
identifier
    _Identifier : "BSCUINADD"
preliminary_profile
    preliminaryProfile :
EventAPreliminaryProfile
end

EventAPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "top"
event_connective
    eventConnective : OrGate1P
preliminary_budget
    preliminaryBudget :
EventAPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventAPreliminaryLabel
end

EventAPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 2.50E-09
annotation
    _Annotation :
EventAPreliminaryBudgetMNLS
end

EventAPreliminaryBudgetMNLS in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : EventAPBPT1
end

EventAPBPT1 in PlainTextNode, Token with
```

```
mnls_text
    mnlsText : "Requirement is per 5
hour flight."
end

EventAPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventASimpleEventDescription
end

EventASimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "BSCU"
condition
    _Condition : "Commands Braking in
Absence of Braking Input Causing
Inadvertent Braking"
end
```

Gate definitions

```
OrGate1P in OrGate, Token with
input
    _Input1 : EventBPreliminaryProfile;
    _Input2 : EventCPreliminaryProfile
end
```

Definition of Event 'BSCUUNDF'

```
EventB in Event, Token with
identifier
    _Identifier : "BSCUUNDF"
preliminary_profile
    preliminaryProfile :
EventBPreliminaryProfile
end

EventBPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "ext"
preliminary_budget
    preliminaryBudget :
EventBPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventBPreliminaryLabel
end

EventBPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 0.00E+00
annotation
    _Annotation :
EventBPreliminaryBudgetMNLS
end

EventBPreliminaryBudgetMNLS in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : EventBPBPT1
end

EventBPBPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "Prove no exist"
end

EventBPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventBPreliminarySimpleEventDescription
end

EventBPreliminarySimpleEventDescription
in SimpleEventDescription, Token with
entity
    _Entity : "BSCU"
condition
    _Condition : "Single Undetected
Failure Causing Inadvertent Braking"
end
```

Definition of Event 'BSCUDETFD'

```
EventC in Event, Token with
identifier
    _Identifier : "BSCUDETFD"
preliminary_profile
    preliminaryProfile :
EventCPreliminaryProfile
end

EventCPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "int"
event_connective
    eventConnective : OrGate2P
preliminary_budget
    preliminaryBudget :
EventCPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventCPreliminaryLabel
end

EventCPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 2.50E-09
end

EventCPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventCSimpleEventDescription
end

EventCSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "BSCU"
condition
    _Condition : "Detectable Failure
Resulting in Inadvertent Braking"
end
```

Gate definitions

```
OrGate2P in OrGate, Token with
input
    _Input1 : EventDPreliminaryProfile;
    _Input2 : EventEPreliminaryProfile
end
```

Definition of Event 'BSCU1DETD'

```
EventD in Event, Token with
identifier
    _Identifier : "BSCU1DETD"
preliminary_profile
    preliminaryProfile :
EventDPreliminaryProfile
end

EventDPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : OrGate3P
preliminary_budget
    preliminaryBudget :
EventDPreliminaryBudget
```

```
preliminary_label
    preliminaryLabel :
EventDPreliminaryLabel
end

EventDPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 2.00E-09
end

EventDPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventDSimpleEventDescription
end

EventDSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "BSCU1"
condition
    _Condition : "Detectable Failure
Causes Bad Data"
end
```

Definition of Event 'BSCU2DETD'

```
EventE in Event, Token with
identifier
    _Identifier : "BSCU2DETD"
preliminary_profile
    preliminaryProfile :
EventEPreliminaryProfile
end

EventEPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : AndGate3P
preliminary_budget
    preliminaryBudget :
EventEPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventEPreliminaryLabel
end

EventEPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 5.00E-10
end

EventEPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventESimpleEventDescription
end

EventESimpleEventDescription in
SimpleEventEDescription, Token with
entity
    _Entity : "BSCU2"
condition
    _Condition : "Detectable Failure
Causes Bad Data"
end
```

Gate definitions

```
OrGate3P in OrGate, Token with
input
    _Input1 : EventFPreliminaryProfile;
    _Input2 : EventGPreliminaryProfile
end
```

Definition of Event 'BSCU1PSIND'

```
EventF in Event, Token with
identifier
    _Identifier : "BSCU1PSIND"
preliminary_profile
    preliminaryProfile :
EventFPreliminaryProfile
end

EventFPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : AndGate1P
preliminary_budget
    preliminaryBudget :
EventFPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventFPreliminaryLabel
end

EventFPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 1.00E-09
end

EventFPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventFSimpleEventDescription
end

EventFSimpleEventDescription in
SimpleEventFDescription, Token with
entity
    _Entity : "Power_Supply"
qualifiying_entity
    qualifyingEntity : "BSCU1"
condition
    _Condition : "Power Supply Failure
Causes Bad Data"
end
```

Definition of Event 'BSCU1CDIND'

```
EventG in Event, Token with
identifier
    _Identifier : "BSCU1CDIND"
preliminary_profile
    preliminaryProfile :
EventGPreliminaryProfile
end

EventGPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : AndGate2P
preliminary_budget
    preliminaryBudget :
EventGPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventGPreliminaryLabel
end

EventGPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 1.00E-09
end

EventGPreliminaryLabel in SimpleLabel,
Token with
simple_description
```

```
    simpleDescription :
EventGSimpleEventDescription
end

EventGSimpleEventDescription in
SimpleEventGDescription, Token with
entity
    _Entity : "Computational_Channel"
qualifiying_entity
    qualifyingEntity : "BSCU1"
condition
    _Condition : "Failure/Error Causes
Bad Data"
end
```

Gate definitions

```
AndGate1P in AndGate, Token with
input
    _Input : HIEventSetP
end

AndGate2P in AndGate, Token with
input
    _Input : JKEventSetP
end

HIEventSetP in EventSet, Token with
event_profile
    eventProfile1 :
EventHPreliminaryProfile;
    eventProfile2 :
EventIPreliminaryProfile
end

JKEventSetP in EventSet, Token with
event_profile
    eventProfile1 :
EventJPreliminaryProfile;
    eventProfile2 :
EventKPreliminaryProfile
end
```

Definition of Event 'BS1PSMOFV'

```
EventH in Event, Token with
identifier
    _Identifier : "BS1PSMOFV"
preliminary_profile
    preliminaryProfile :
EventHPreliminaryProfile
end

EventHPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "bas"
preliminary_budget
    preliminaryBudget :
EventHPreliminaryBudget
preliminary_rate
    preliminaryRate :
EventHPreliminaryRate
preliminary_exposure
    preliminaryExposure :
EventHPreliminaryExposure
preliminary_label
    preliminaryLabel :
EventHPreliminaryLabel
end

EventHPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 2.00E-02
end

EventHPreliminaryRate in Rate, Token
with
failure_rate
    failureRate : 2.00E-07
end

EventHPreliminaryExposure in Exposure,
Token with
period
    _Period : 100000.00
end

EventHPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventHSimpleEventDescription
end

EventHSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Power_Supply_Monitor"
qualifiying_entity
    qualifyingEntity : "BSCU1"
condition
    _Condition : "Monitor Stuck Valid"
end
```

Definition of Event 'BSCU1PSF'

```
EventI in Event, Token with
identifier
    _Identifier : "BSCU1PSF"
preliminary_profile
    preliminaryProfile :
EventIPreliminaryProfile
end

EventIPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "bas"
preliminary_budget
    preliminaryBudget :
EventIPreliminaryBudget
preliminary_rate
    preliminaryRate :
EventIPreliminaryRate
preliminary_exposure
    preliminaryExposure :
EventIPreliminaryExposure
preliminary_label
    preliminaryLabel :
EventIPreliminaryLabel
end

EventIPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 5.00E-08
end

EventIPreliminaryRate in Rate, Token
with
failure_rate
    failureRate : 1.20E-05
end

EventIPreliminaryExposure in Exposure,
Token with
period
    _Period : 0.004167
end

EventIPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventISimpleEventDescription
end

EventISimpleEventDescription in
SimpleEventDescription, Token with
entity
```

```
    _Entity : "Power_Supply"
qualifiying_entity
    qualifyingEntity : "BSCU1"
condition
    _Condition : "Failure Causes Bad
Data"
end
```

Definition of Event 'BSCU1MORV'

```
EventJ in Event, Token with
identifier
    _Identifier : "BSCU1MORV"
preliminary_profile
    preliminaryProfile :
EventJPreliminaryProfile
end

EventJPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : OrGate4P
preliminary_budget
    preliminaryBudget :
EventJPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventJPreliminaryLabel
end

EventJPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 2.00E-02
end

EventJPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventJSimpleEventDescription
end

EventJSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Monitor_Channel"
qualifiying_entity
    qualifyingEntity : "BSCU1"
condition
    _Condition : "Always Reports Valid"
end
```

Definition of Event 'BSCU1CDF'

```
EventK in Event, Token with
identifier
    _Identifier : "BSCU1CDF"
preliminary_profile
    preliminaryProfile :
EventKPreliminaryProfile
end

EventKPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : OrGate5P
preliminary_budget
    preliminaryBudget :
EventKPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventKPreliminaryLabel
end

EventKPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 5.00E-08
end

EventKPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventKSimpleEventDescription
end

EventKSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Command_Channel"
qualifiying_entity
    qualifyingEntity : "BSCU1"
condition
    _Condition : "Failure/Error Causes
Bad Data"
end
```

Gate definitions

```
OrGate4P in OrGate, Token with
input
    _Input1 : EventLPreliminaryProfile;
    _Input2 : EventMPreliminaryProfile
end

OrGate5P in OrGate, Token with
input
    _Input1 : EventNPreliminaryProfile;
    _Input2 : EventOPreliminaryProfile
end
```

Definition of Event 'BSCU1MOFV'

```
EventL in Event, Token with
identifier
    _Identifier : "BSCU1MOFV"
preliminary_profile
    preliminaryProfile :
EventLPreliminaryProfile
end

EventLPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "bas"
preliminary_budget
    preliminaryBudget :
EventLPreliminaryBudget
preliminary_rate
    preliminaryRate :
EventLPreliminaryRate
preliminary_exposure
    preliminaryExposure :
EventLPreliminaryExposure
preliminary_label
    preliminaryLabel :
EventLPreliminaryLabel
end

EventLPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 2.00E-02
end

EventLPreliminaryRate in Rate, Token
with
failure_rate
    failureRate : 2.00E-07
end

EventLPreliminaryExposure in Exposure,
Token with
period
    _Period : 100000
end
```

```
EventLPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventLSimpleEventDescription
end

EventLSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Validity_Monitor"
qualifiying_entity
    qualifyingEntity : "BSCU1"
condition
    _Condition : "Failed Valid due to
Hardware Failure"
end
```

Definition of Event 'BSCU1CMDE'

```
EventM in Event, Token with
identifier
    _Identifier : "BSCU1CMDE"
preliminary_profile
    preliminaryProfile :
EventMPreliminaryProfile
end

EventMPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "und"
preliminary_budget
    preliminaryBudget :
EventMPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventMPreliminaryLabel
end

EventMPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 0.00E+00
end

EventMPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventMSimpleEventDescription
end

EventMSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Monitor_Channel"
qualifiying_entity
    qualifyingEntity : "BSCU1"
condition
    _Condition : "Design Error"
end
```

Definition of Event 'BSCU1CPUBD'

```
EventN in Event, Token with
identifier
    _Identifier : "BSCU1CPUBD"
preliminary_profile
    preliminaryProfile :
EventNPreliminaryProfile
end

EventNPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : OrGate6P
preliminary_budget
    preliminaryBudget :
EventNPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventNPreliminaryLabel
end

EventNPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 3.12E-08
end

EventNPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventNSimpleEventDescription
end

EventNSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Command_Channel_CPU"
qualifiying_entity
    qualifyingEntity : "BSCU1"
condition
    _Condition : "CPU Failure/Error
Causes Bad Data"
end
```

Definition of Event 'BSCU1I/OF'

```
EventO in Event, Token with
identifier
    _Identifier : "BSCU1I/OF"
preliminary_profile
    preliminaryProfile :
EventOPreliminaryProfile
end

EventOPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "bas"
preliminary_budget
    preliminaryBudget :
EventOPreliminaryBudget
preliminary_rate
    preliminaryRate :
EventOPreliminaryRate
preliminary_exposure
    preliminaryExposure :
EventOPreliminaryExposure
preliminary_label
    preliminaryLabel :
EventOPreliminaryLabel
end

EventOPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 1.88E-08
end

EventOPreliminaryRate in Rate, Token
with
failure_rate
    failureRate : 4.50E-06
end

EventOPreliminaryExposure in Exposure,
Token with
period
    _Period : 0.004167
end

EventOPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
```

```
EventOSimpleEventDescription
end

EventOSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Command_Channel_I/O"
qualifiying_entity
    qualifyingEntity : "BSCU1"
condition
    _Condition : "I/O Failure Causes Bad
Data"
end
```

Gate definitions

```
OrGate6P in OrGate, Token with
input
    _Input1 : EventPPreliminaryProfile;
    _Input2 : EventQPreliminaryProfile
end
```

Definition of Event 'BSCU1CPUF'

```
EventP in Event, Token with
identifier
    _Identifier : "BSCU1CPUF"
preliminary_profile
    preliminaryProfile :
EventPPreliminaryProfile
end

EventPPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "bas"
preliminary_budget
    preliminaryBudget :
EventPPreliminaryBudget
preliminary_rate
    preliminaryRate :
EventPPreliminaryRate
preliminary_exposure
    preliminaryExposure :
EventPPreliminaryExposure
preliminary_label
    preliminaryLabel :
EventPPreliminaryLabel
end

EventPPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 3.12E-08
end

EventPPreliminaryRate in Rate, Token
with
failure_rate
    failureRate : 7.50E-06
end

EventPPreliminaryExposure in Exposure,
Token with
period
    _Period : 0.004167
end

EventPPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventPSimpleEventDescription
end

EventPSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Command_Channel_CPU"
qualifiying_entity
    qualifyingEntity : "BSCU1"
condition
    _Condition : "Hardware Failure
Causes Bad Data"
end
```

Definition of Event 'BSCU1CPUDE'

```
EventQ in Event, Token with
identifier
    _Identifier : "BSCU1CPUDE"
preliminary_profile
    preliminaryProfile :
EventQPreliminaryProfile
end

EventQPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "und"
preliminary_budget
    preliminaryBudget :
EventQPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventQPreliminaryLabel
end

EventQPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 0.00E+00
end

EventQPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventQSimpleEventDescription
end

EventQSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Command_Channel_CPU"
qualifiying_entity
    qualifyingEntity : "BSCU1"
condition
    _Condition : "Design Error Causes
Bad Data"
end
```

Gate definitions

```
AndGate3P in AndGate, Token with
input
    _Input : RSEventSetP
end

RSEventSetP in EventSet, Token with
event_profile
    eventProfile1 :
EventRPreliminaryProfile;
    eventProfile2 :
EventSPreliminaryProfile
end
```

Definition of Event 'SWITCH2'

```
EventR in Event, Token with
identifier
    _Identifier : "SWITCH2"
preliminary_profile
    preliminaryProfile :
EventRPreliminaryProfile
end

EventRPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "int"
event_connective
```

```
    EventConnective : OrGate7P
preliminary_budget
    preliminaryBudget :
EventRPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventRPreliminaryLabel
end

EventRPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 2.50E-01
end

EventRPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventRSimpleEventDescription
end

EventRSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Select_Switch"
qualifiying_entity
    qualifyingEntity : "BSCU"
condition
    _Condition : "Switch 2 Position"
end
```

Definition of Event 'BSCU2INADCM'

```
EventS in Event, Token with
identifier
    _Identifier : "BSCU2INADCM"
preliminary_profile
    preliminaryProfile :
EventSPreliminaryProfile
end

EventSPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : OrGate8P
preliminary_budget
    preliminaryBudget :
EventSPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventSPreliminaryLabel
end

EventSPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 2.00E-09
end

EventSPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventSSimpleEventDescription
end

EventSSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "BSCU2"
condition
    _Condition : "Fault Causes
Inadvertent Braking Command"
end
```

Gate definitions

```
OrGate7P in OrGate, Token with
input
    _Input1 : EventTPreliminaryProfile;
    _Input2 : EventUPreliminaryProfile
end

OrGate8P in OrGate, Token with
input
    _Input1 : EventVPreliminaryProfile;
    _Input2 : EventWPreliminaryProfile
end
```

Definition of Event 'BSCU1TF'

```
EventT in Event, Token with
identifier
    _Identifier : "BSCU1TF"
preliminary_profile
    preliminaryProfile :
EventTPreliminaryProfile
end

EventTPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "bas"
preliminary_budget
    preliminaryBudget :
EventTPreliminaryBudget
preliminary_rate
    preliminaryRate :
EventTPreliminaryRate
preliminary_exposure
    preliminaryExposure :
EventTPreliminaryExposure
preliminary_label
    preliminaryLabel :
EventTPreliminaryLabel
end

EventTPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 2.36E-01
end

EventTPreliminaryRate in Rate, Token
with
failure_rate
    failureRate : 4.72E-02
end

EventTPreliminaryExposure in Exposure,
Token with
period
    _Period : 5.00
end

EventTPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventTSimpleEventDescription
end

EventTSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "BSCU1"
condition
    _Condition : "Detected Failure"
end
```

Definition of Event 'SWIFAIL2'

```
EventU in Event, Token with
identifier
    _Identifier : "SWIFAIL2"
preliminary_profile
    preliminaryProfile :
EventUPreliminaryProfile
end
```

```
EventUPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "bas"
preliminary_budget
    preliminaryBudget :
EventUPreliminaryBudget
preliminary_rate
    preliminaryRate :
EventUPreliminaryRate
preliminary_exposure
    preliminaryExposure :
EventUPreliminaryExposure
preliminary_label
    preliminaryLabel :
EventUPreliminaryLabel
end

EventUPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 1.48E-02
end

EventUPreliminaryRate in Rate, Token
with
failure_rate
    failureRate : 1.00E-06
end

EventUPreliminaryExposure in Exposure,
Token with
period
    _Period : 14750.00
end

EventUPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventUSimpleEventDescription
end

EventUSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Select_Switch"
qualifiying_entity
    qualifyingEntity : "BSCU"
condition
    _Condition : "Stuck at Position 2"
end
```

Definition of Event 'BSCU2PSIND'

```
EventV in Event, Token with
identifier
    _Identifier : "BSCU2PSIND"
preliminary_profile
    preliminaryProfile :
EventVPreliminaryProfile
end

EventVPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : AndGate4P
preliminary_budget
    preliminaryBudget :
EventVPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventVPreliminaryLabel
end

EventVPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 1.00E-09
end

EventVPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventVSimpleEventDescription
end

EventVSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Power_Supply"
qualifiying_entity
    qualifyingEntity : "BSCU2"
condition
    _Condition : "Power Supply Failure
Causes Bad Data"
end
```

Definition of Event 'BSCU2CDIND'

```
EventW in Event, Token with
identifier
    _Identifier : "BSCU2CDIND"
preliminary_profile
    preliminaryProfile :
EventWPreliminaryProfile
end

EventWPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : AndGate5P
preliminary_budget
    preliminaryBudget :
EventWPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventWPreliminaryLabel
end

EventWPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 1.00E-09
end

EventWPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventWSimpleEventDescription
end

EventWSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Computational_Channel"
qualifiying_entity
    qualifyingEntity : "BSCU2"
condition
    _Condition : "Failure/Error Causes
Bad Data"
end
```

Gate definitions

```
AndGate4P in AndGate, Token with
input
    _Input : XYEventSetP
end

AndGate5P in AndGate, Token with
input
    _Input : ZAAEventSetP
end
```

```
XYEventSetP in EventSet, Token with
event_profile
    eventProfile1 :
EventXPreliminaryProfile;
    eventProfile2 :
EventYPreliminaryProfile
end

ZAAEventSetP in EventSet, Token with
event_profile
    eventProfile1 :
EventZPreliminaryProfile;
    eventProfile2 :
EventAAPreliminaryProfile
end
```

Definition of Event 'BS2PSMOFV'

```
EventX in Event, Token with
identifier
    _Identifier : "BS2PSMOFV"
preliminary_profile
    preliminaryProfile :
EventXPreliminaryProfile
end

EventXPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "bas"
preliminary_budget
    preliminaryBudget :
EventXPreliminaryBudget
preliminary_rate
    preliminaryRate :
EventXPreliminaryRate
preliminary_exposure
    preliminaryExposure :
EventXPreliminaryExposure
preliminary_label
    preliminaryLabel :
EventXPreliminaryLabel
end

EventXPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 2.00E-02
end

EventXPreliminaryRate in Rate, Token
with
failure_rate
    failureRate : 2.00E-07
end

EventXPreliminaryExposure in Exposure,
Token with
period
    _Period : 100000.00
end

EventXPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventXSimpleEventDescription
end

EventXSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Power_Supply_Monitor"
qualifying_entity
    qualifyingEntity : "BSCU2"
condition
    _Condition : "Monitor Stuck Valid"
end
```

Definition of Event 'BSCU2PSF'

```
EventY in Event, Token with
identifier
    _Identifier : "BSCU2PSF"
preliminary_profile
    preliminaryProfile :
EventYPreliminaryProfile
end

EventYPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "bas"
preliminary_budget
    preliminaryBudget :
EventYPreliminaryBudget
preliminary_rate
    preliminaryRate :
EventYPreliminaryRate
preliminary_exposure
    preliminaryExposure :
EventYPreliminaryExposure
preliminary_label
    preliminaryLabel :
EventYPreliminaryLabel
end

EventYPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 5.00E-08
end

EventYPreliminaryRate in Rate, Token
with
failure_rate
    failureRate : 1.20E-05
end

EventYPreliminaryExposure in Exposure,
Token with
period
    _Period : 0.004167
end

EventYPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventYSimpleEventDescription
end

EventYSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Power_Supply"
qualifiying_entity
    qualifyingEntity : "BSCU2"
condition
    _Condition : "Failure Causes Bad
Data"
end
```

Definition of Event 'BSCU2MORV'

```
EventZ in Event, Token with
identifier
    _Identifier : "BSCU2MORV"
preliminary_profile
    preliminaryProfile :
EventZPreliminaryProfile
end

EventZPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : OrGate9P
preliminary_budget
    preliminaryBudget :
EventZPreliminaryBudget
```

```
preliminary_label
    preliminaryLabel :
EventZPreliminaryLabel
end

EventZPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 2.00E-02
end

EventZPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventZSimpleEventDescription
end

EventZSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Monitor_Channel"
qualifiying_entity
    qualifyingEntity : "BSCU2"
condition
    _Condition : "Always Reports Valid"
end
```

Definition of Event 'BSCU2CDF'

```
EventAA in Event, Token with
identifier
    _Identifier : "BSCU2CDF"
preliminary_profile
    preliminaryProfile :
EventAAPreliminaryProfile
end

EventAAPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : OrGate10P
preliminary_budget
    preliminaryBudget :
EventAAPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventAAPreliminaryLabel
end

EventAAPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 5.00E-08
end

EventAAPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventAASimpleEventDescription
end

EventAASimpleEventDescription in
SimpleEventDescription, Token
with
entity
    _Entity : "Command_Channel"
qualifiying_entity
    qualifyingEntity : "BSCU2"
condition
    _Condition : "Failure/Error Causes
Bad Data"
end
```

Gate definitions

```
OrGate9P in OrGate, Token with
input
    _Input1 : EventBBPreliminaryProfile;
    _Input2 : EventCCreliminaryProfile
end

OrGate10P in OrGate, Token with
input
    _Input1 : EventDDPreliminaryProfile;
    _Input2 : EventEEPreliminaryProfile
end
```

Definition of Event 'BSCU2MOFV'

```
EventBB in Event, Token with
identifier
    _Identifier : "BSCU2MOFV"
preliminary_profile
    preliminaryProfile :
EventBBPreliminaryProfile
end

EventBBPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "bas"
preliminary_budget
    preliminaryBudget :
EventBBPreliminaryBudget
preliminary_rate
    preliminaryRate :
EventBBPreliminaryRate
preliminary_exposure
    preliminaryExposure :
EventBBPreliminaryExposure
preliminary_label
    preliminaryLabel :
EventBBPreliminaryLabel
end

EventBBPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 2.00E-02
end

EventBBPreliminaryRate in Rate, Token
with
failure_rate
    failureRate : 2.00E-07
end

EventBBPreliminaryExposure in Exposure,
Token with
period
    _Period : 100000.00
end

EventBBPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventBBSimpleEventDescription
end

EventBBSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Validity_Monitor"
qualifiying_entity
    qualifyingEntity : "BSCU2"
condition
    _Condition : "Failed Valid due to
Hardware Failure"
end
```

Definition of Event 'BSCU2CMDE'

```
EventCC in Event, Token with
identifier
    _Identifier : "BSCU2CMDE"
preliminary_profile
    preliminaryProfile :
```

```
EventCCPreliminaryProfile
end

EventCCPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "und"
preliminary_budget
    preliminaryBudget :
EventCCPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventCCPreliminaryLabel
end

EventCCPreliminaryBudget in
BudgetProbability, Token
with
probability
    _Probability : 0.00E+00
end

EventCCPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventCCSimpleEventDescription
end

EventCCSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Monitor_Channel"
qualifiying_entity
    qualifyingEntity : "BSCU2"
condition
    _Condition : "Design Error"
end
```

Definition of Event 'BSCU2CPUBD'

```
EventDD in Event, Token with
identifier
    _Identifier : "BSCU2CPUBD"
preliminary_profile
    preliminaryProfile :
EventDDPreliminaryProfile
end

EventDDPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : OrGate11P
preliminary_budget
    preliminaryBudget :
EventDDPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventDDPreliminaryLabel
end

EventDDPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 3.12E-08
end

EventDDPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventDDSimpleEventDescription
end

EventDDSimpleEventDescription in
SimpleEventDescription, Token with
entity
    _Entity : "Command_Channel_CPU"
qualifiying_entity
    qualifyingEntity : "BSCU2"
condition
    _Condition : "CPU Failure/Error
Causes Bad Data"
end
```

Definition of Event 'BSCU2I/OF'

```
EventEE in Event, Token with
identifier
    _Identifier : "BSCU2I/OF"
preliminary_profile
    preliminaryProfile :
EventEEPreliminaryProfile
end

EventEEPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "bas"
preliminary_budget
    preliminaryBudget :
EventEEPreliminaryBudget
preliminary_rate
    preliminaryRate :
EventEEPreliminaryRate
preliminary_exposure
    preliminaryExposure :
EventEEPreliminaryExposure
preliminary_label
    preliminaryLabel :
EventEEPreliminaryLabel
end

EventEEPreliminaryBudget in
BudgetProbability, Token with
probability
    _Probability : 1.88E-08
end

EventEEPreliminaryRate in Rate, Token
with
failure_rate
    failureRate : 4.50E-06
end

EventEEPreliminaryExposure in Exposure,
Token with
period
    _Period : 0.004167
end

EventEEPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventEESimpleEventDescription
end

EventEESimpleEventDescription in
SimpleEventDescription, Token
with
entity
    _Entity : "Command_Channel_I/O"
qualifiying_entity
    qualifyingEntity : "BSCU2"
condition
    _Condition : "I/O Failure Causes Bad
Data"
end
```

Gate definitions

```
OrGate11P in OrGate, Token with
input
    _Input1 : EventFFPreliminaryProfile;
    _Input2 : EventGGreliminaryProfile
end
```

Definition of Event 'BSCU2CPUF'

```
EventFF in Event, Token
with
identifier
    _Identifier : "BSCU2CPUF"
preliminary_profile
    preliminaryProfile :
EventFFPreliminaryProfile
end

EventFFPreliminaryProfile in
PreliminaryEventProfile, Token with
type
    _Type : "bas"
preliminary_budget
    preliminaryBudget :
EventFFPreliminaryBudget
preliminary_rate
    preliminaryRate :
EventFFPreliminaryRate
preliminary_exposure
    preliminaryExposure :
EventFFPreliminaryExposure
preliminary_label
    preliminaryLabel :
EventFFPreliminaryLabel
end

EventFFPreliminaryBudget in
BudgetProbability, Token
with
probability
    _Probability : 3.12E-08
end

EventFFPreliminaryRate in Rate, Token
with
failure_rate
    failureRate : 7.50E-06
end

EventFFPreliminaryExposure in Exposure,
Token with
period
    _Period : 0.004167
end

EventFFPreliminaryLabel in SimpleLabel,
Token
with
simple_description
    simpleDescription :
EventFFSimpleEventDescription
end

EventFFSimpleEventDescription in
SimpleEventDescription, Token
with
entity
    _Entity : "Command_Channel_CPU"
qualifiying_entity
    qualifyingEntity : "BSCU2"
condition
    _Condition : "Hardware Failure
Causes Bad Data"
end
```

Definition of Event 'BSCU2CPUDE'

```
EventGG in Event, Token
with
identifier
    _Identifier : "BSCU2CPUDE"
preliminary_profile
    preliminaryProfile :
EventGGPreliminaryProfile
end

EventGGPreliminaryProfile in
PreliminaryEventProfile, Token
with
type
    _Type : "und"
preliminary_budget
    preliminaryBudget :
EventGGPreliminaryBudget
preliminary_label
    preliminaryLabel :
EventGGPreliminaryLabel
end

EventGGPreliminaryBudget in
BudgetProbability, Token
with
probability
    _Probability : 0.00E+00
end

EventGGPreliminaryLabel in SimpleLabel,
Token with
simple_description
    simpleDescription :
EventGGSimpleEventDescription
end

EventGGSimpleEventDescription in
SimpleEventDescription, Token
with
entity
    _Entity : "Command_Channel_CPU"
qualifiying_entity
    qualifyingEntity : "BSCU2"
condition
    _Condition : "Design Error Causes
Bad Data"
end
```

Instantiation of Preliminary Fault Tree

```
BscuPssaPrelimFT in
PreliminaryFaultTree, Token
with
ft_and_gate
    ftAndGate1 : AndGate1P;
    ftAndGate2 : AndGate2P;
    ftAndGate3 : AndGate3P;
    ftAndGate4 : AndGate4P;
    ftAndGate5 : AndGate5P
ft_or_gate
    ftOrGate1 : OrGate1P;
    ftOrGate2 : OrGate2P;
    ftOrGate3 : OrGate3P;
    ftOrGate4 : OrGate4P;
    ftOrGate5 : OrGate5P;
    ftOrGate6 : OrGate6P;
    ftOrGate7 : OrGate7P;
    ftOrGate8 : OrGate8P;
    ftOrGate9 : OrGate9P;
    ftOrGate10 : OrGate10P;
    ftOrGate11 : OrGate11P
ft_event_set
    ftEventSet1 : HIEventSetP;
    ftEventSet2 : JKEventSetP;
    ftEventSet3 : RSEventSetP;
    ftEventSet4 : XYEventSetP;
    ftEventSet5 : ZAAEventSetP
ft_event_profile
    ftEventProfile1 :
EventAPreliminaryProfile;
    ftEventProfile2 :
EventBPreliminaryProfile;
    ftEventProfile3 :
EventCPreliminaryProfile;
    ftEventProfile4 :
EventDPreliminaryProfile;
    ftEventProfile5 :
EventEPreliminaryProfile;
    .....

    ftEventProfile33 :
EventGGPreliminaryProfile
ft_budget
    ftBudget1 : EventAPreliminaryBudget;
```

```
    ftBudget2 : EventBPreliminaryBudget;
    ftBudget3 : EventCPreliminaryBudget;
    ftBudget4 : EventDPreliminaryBudget;
    ftBudget5 : EventEPreliminaryBudget;
    .....

    ftBudget33 : EventGGPreliminaryBudget
ft_rate
    ftRate1 : EventHPreliminaryRate;
    ftRate2 : EventIPreliminaryRate;
    ftRate3 : EventLPreliminaryRate;
    ftRate4 : EventOPreliminaryRate;
    ftRate5 : EventPPreliminaryRate;
    ftRate6 : EventTPreliminaryRate;
    ftRate7 : EventUPreliminaryRate;
    ftRate8 : EventXPreliminaryRate;
    ftRate9 : EventYPreliminaryRate;
    ftRate10 : EventBBPreliminaryRate;
    ftRate11 : EventEEPreliminaryRate;
    ftRate12 : EventFFPreliminaryRate
ft_exposure
    ftExposure1 :
EventHPreliminaryExposure;
    ftExposure2 :
EventIPreliminaryExposure;
    ftExposure3 :
EventLPreliminaryExposure;
    ftExposure4 :
EventOPreliminaryExposure;
    ftExposure5 :
EventPPreliminaryExposure;
    ftExposure6 :
EventTPreliminaryExposure;
    ftExposure7 :
EventUPreliminaryExposure;
    ftExposure8 :
EventXPreliminaryExposure;
    ftExposure9 :
EventYPreliminaryExposure;
    ftExposure10 :
EventBBPreliminaryExposure;
    ftExposure11 :
EventEEPreliminaryExposure;
    ftExposure12 :
EventFFPreliminaryExposure
ft_simple
    ftSimple1 : EventAPreliminaryLabel;
    ftSimple2 : EventBPreliminaryLabel;
    ftSimple3 : EventCPreliminaryLabel;
    ftSimple4 : EventDPreliminaryLabel;
    ftSimple5 : EventEPreliminaryLabel;
    .....

    ftSimple33 : EventGGPreliminaryLabel
ft_simple_desc
    ftSimpleDesc1 :
EventASimpleEventDescription;
    ftSimpleDesc2 :
EventBPreliminarySimpleEventDescription;
    ftSimpleDesc3 :
EventCSimpleEventDescription;
    ftSimpleDesc4 :
EventDSimpleEventDescription;
    ftSimpleDesc5 :
EventESimpleEventDescription;
    .....

    ftSimpleDesc33 :
EventGGSimpleEventDescription
ft_annotation
    ftAnnotation1 :
EventAPreliminaryBudgetMNLS;
    ftAnnotation2 :
EventBPreliminaryBudgetMNLS
end
```

Instantiation of Fault Tree Analysis

```
BscuFTA in FaultTreeAnalysis, Token
with
subject_module
    subjectModule "BSCU"
fta_preliminary_tree
    ftaPreliminaryTree :
BscuPssaPrelimFT
end
```

6.3.4 System Safety Assessment - Brake System Control Unit

At this point, we assume the PSSA is sufficiently developed to allow detailed design implementation to proceed. Therefore our example resumes post-implementation by considering System Safety Assessment of the BSCU towards verification of PSSA safety objectives. This includes Functional and Piece-Part FMEAs of the power supply and power supply monitor respectively, as well as updating of the preliminary fault tree introduced in 6.3.3.2. Artifacts produced by these activities will be used to demonstrate instantiation of the FMEA and Fault Tree Analysis structures, together with a partial population of the Circuit Diagram meta-model from Chapter Three.

6.3.4.1 Background on BSCU Power Supply Design

The BSCU1 and BSCU2 power supplies are identical in both their design and implementation and are located in physically remote areas of the BSCU circuit card assembly. Within each BSCU, the power supply and power supply monitor functions are physically independently located. Power supply design is depicted in the block diagram[6] in figure 6.15, whilst a detailed circuit schematic of the +5 volt monitor appears in figure 6.16.

---

[6] Failure rates in figure 6.15 are determined by the functional FMEA; e.g., +5 volt rate derived from the sum of failures shown in table 6.3 (subsection 6.3.4.2.1).

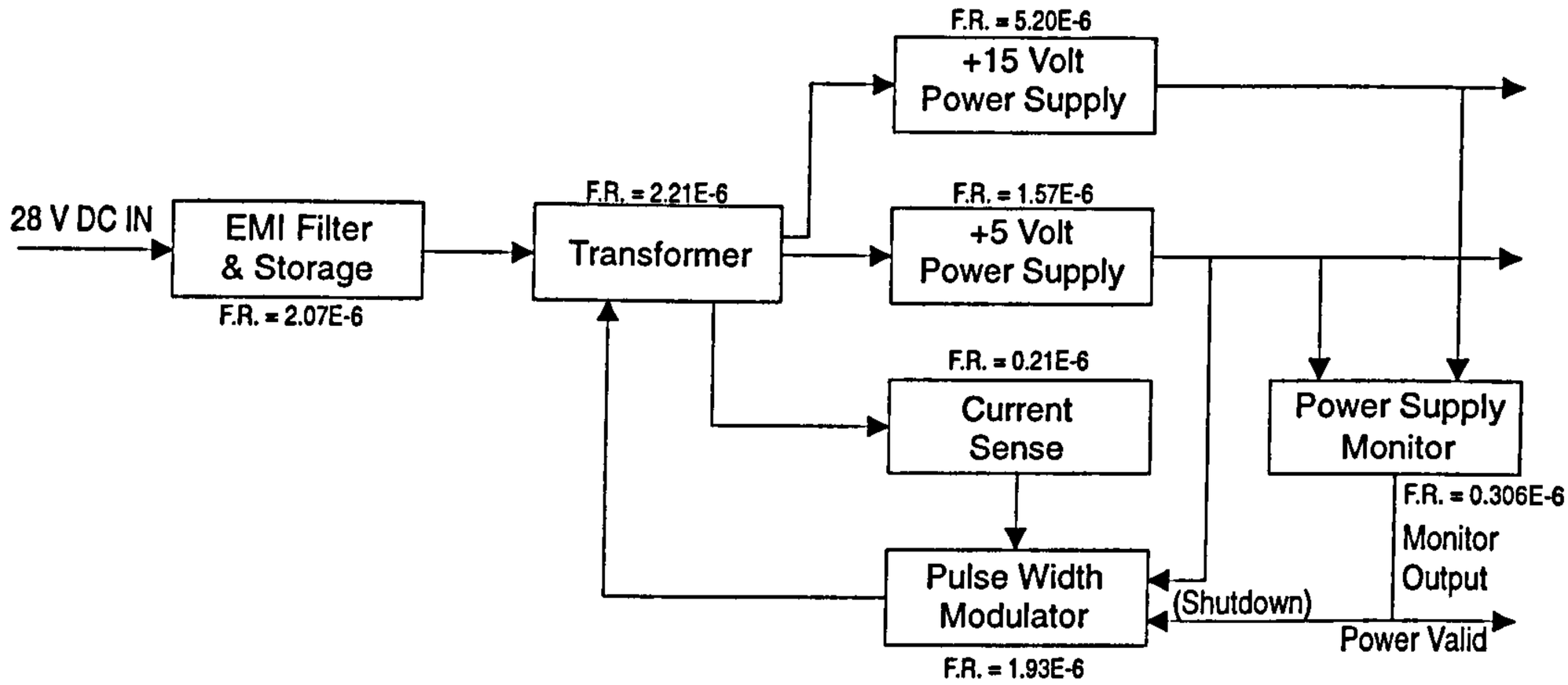


Figure 6.15 - 'BSCU Power Supply Block Diagram'

The power supply monitors are window comparators[7]. Both +5 volt and +15 volt (shown as 'Power Supply Monitor' in figure 6.15) are monitored for over and under voltage conditions and their outputs And-ed together such that if voltage exceeds the trip-point, high or low, monitor output is pulled low.

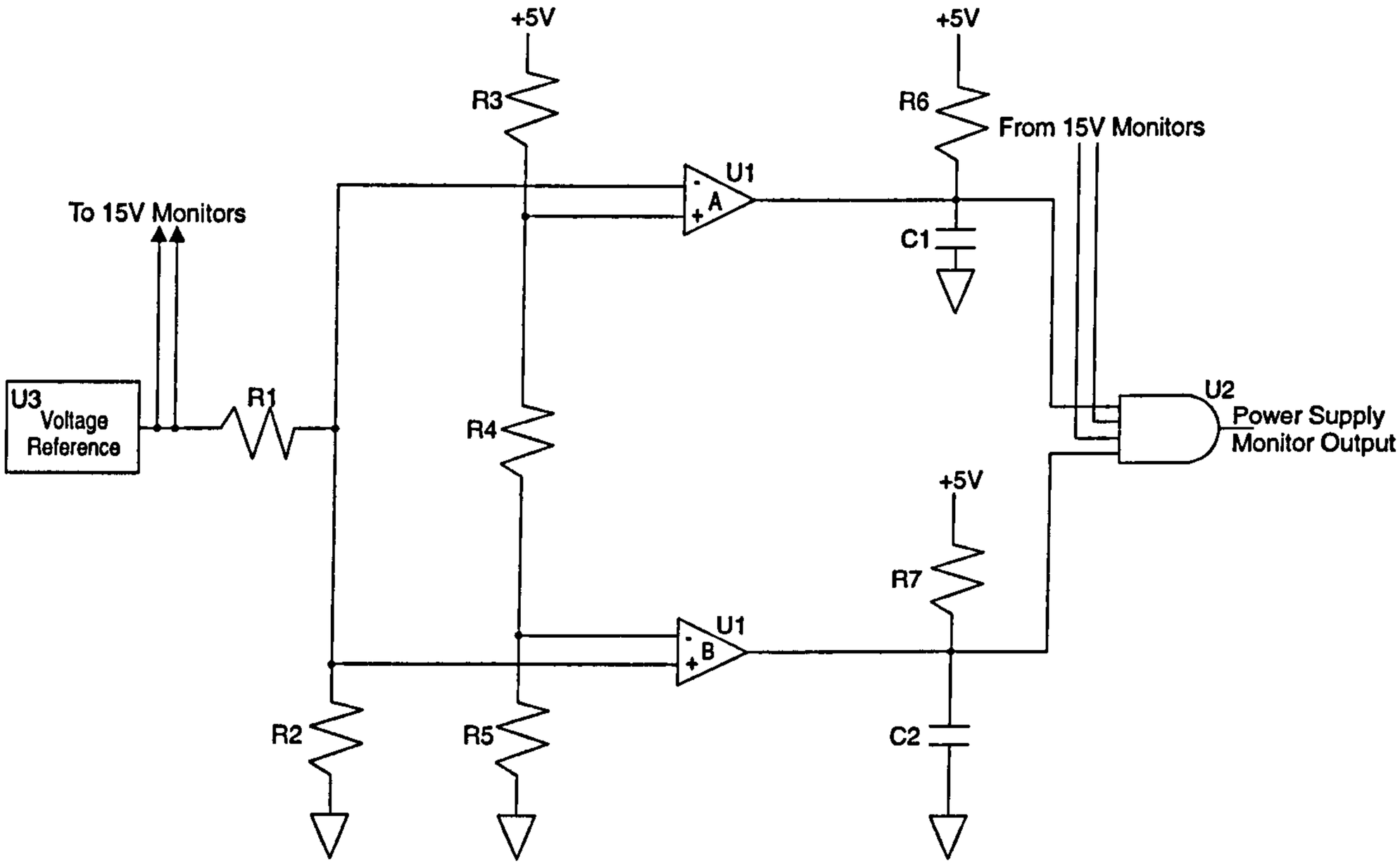


Figure 6.16 - 'BSCU + 5 Volt Power Supply Monitor Circuit Schematic'

We now introduce O-Telos code demonstrating partial population of the Circuit Diagram meta-model (from subsection 3.3.7) for the power supply monitor (figure 6.16); partial in the sense of identifying only those elements from the circuit relevant to the +5 volt power supply and without providing either their descriptions or inter-connections. Note that no meta-model definition of block diagrams is provided, although their inherent simplicity suggests the same approach can be applied as that used to represent other graphical notations demonstrated by this thesis.

[7] Window comparators monitor an output line and inform the controller when voltage moves outside specific settings.

Definition of Power Supply Monitor Circuit Schematic

```
CircuitDiagram in DevelopmentStructure, SimpleClass      -- base classes from 3.3.7.3.3
isA AerospaceEngineeringObject with has_property
    circuit_name : String
has_element
    resistor : Resistor;
    capacitor : Capacitor;
    comparator : Comparator;
    and_gate : AndGate;
    dc_source : DCSource
end


PowerSupplyMonitorCD in CircuitDiagram, Token with      -- elements from figure 6.16
circuit_name
    circuitName : "Power Supply Monitor"
resistor
    resistor1 : R1;
    resistor2 : R2;
    resistor3 : R3;
    resistor4 : R4;
    resistor5 : R5;
    resistor6 : R6;
    resistor7 : R7
capacitor
    capacitor1 : C1;
    capacitor2 : C2
comparator
    comparator1 : U1A;
    comparator2 : U1B
and_gate
    andGate : U2
dc_source
    dcSource : U3
end
```

We return to the Circuit Diagram meta-model in subsection 6.3.5 when demonstrating trace relations between development and assessment artifacts.

6.3.4.2 Failure Modes and Effects Analysis

This FMEA considers the BSCU power supply with respect to safety objectives for basic events in the 'inadvertent wheel braking' fault tree from 6.3.3.2. Basic events supported by this particular analysis are Power Supply • Failure Causes Bad Data and Power Supply Monitor • Monitor Stuck Valid.

The FMEA is performed in two parts: i) a *functional* analysis of the entire power supply; and ii) a *piece-part* analysis of the power supply monitor. For the purpose of this example, the latter is assumed to be necessary after results of the functional FMEA did not meet the safety objectives. Note, that the functional FMEA on the power supply monitor is superseded by the piece-part FMEA.

6.3.4.2.1 Functional Failure Modes and Effects Analysis

According to the scenario outlined in ARP 4761, initial analysis of the power supply was conducted by computing the total power supply failure rate based on parts counts and failure rates. Conservative analysis (details of which are not included) failed to meet the safety budget for Power Supply • Failure Causes Bad Data (namely 1.20E-05 as shown in figure 6.14) and so a functional FMEA was performed to provide better resolution to the failure rates of the various failure modes. This investigation concluded that the only failure that may cause bad data and may not be detected by a fully functioning power supply monitor is 'loss of filtering'. This failure can cause increased ripple on the output

voltages at such a level and frequency that it goes undetected by the monitor. Table 6.3 shows a partial results table for the BSCU power supply functional FMEA showing analysis of the +5 volt function.

Function Name	Failure Mode	Flight Phase	Failure Rate	Failure Effect	Detection Method	Comments
+5 Volt Power Supply	+5 volt out of spec	All	0.2143E-06	Power Supply shut down.	The Power Supply Monitor is tripped.	The BSCU channel fails.
	+5 volt short to ground	All	0.2857E-06	Power Supply shut down.	The Power Supply Monitor will pass invalid power supply to other BSCU.	
	loss of filtering	All	0.3571E-06	Increased Ripple.	May emit out of spec voltage if ripple is not detected by monitor.	May cause spurious trip.
	+ 5 volt open	All	0.5714E-06	Power Supply shut down.	The Power Supply Monitor will pass invalid power supply to other BSCU.	
	No Effect	All	0.1429E-06	No Effect.	None/No Effect.	No Effect.
.....	.....	.....	.....	.....	.....	.....

Table 6.3 - 'Functional FMEA (Partial) of BSCU Power Supply'

ARP 4761 states that the actual failure rate for Power Supply • Failure Causes Bad Data is 1.06E-05 (derivation not shown) which satisfies the requirement of 1.20E-05 failures per hour. This information will be used in subsection 6.3.4.3 to update the BSCU preliminary fault tree.

6.3.4.2.2 Instantiation of Functional Failure Modes and Effects Analysis Meta-model

We now instantiate the O-Telos representation of our Functional Failure Modes and Effects Analysis meta-model from section 5.3 with a subset of information from table 6.3.

```
+ 5 Volt Power Supply Function Failure
Mode Descriptions

+5voltpsFailureDescription in
FunctionFailureDescription, Token with
fnc_id
    fncId : "+ 5 Volt Power Supply"
fnc_fail_mode_description
    fncFailModeDescription1 :
VoltageOutofSpecFailureModeDescription;
    fncFailModeDescription2 :
ShortToGndFailureModeDescription;
    fncFailModeDescription3 :
LossOfFilteringFailureModeDescription;
    fncFailModeDescription4 :
VoltageOpenFailureModeDescription
end

VoltageOutofSpecFailureModeDescription in
FunctionFailureModeDescription, Token
with
fnc_fail_mode
    fncFailMode : "+5 volt out of spec"
fnc_flight_phase_desc
    fncFlightPhaseDesc1 :
VoltageOutofSpecFlightPhaseFailureDescrip
tion
fnc_detection
    fncDetection :
VoltageOutofSpecDetection
fnc_comment
    fncComment : VoltageOutofSpecComments
end

VoltageOutofSpecFlightPhaseFailureDescrip
tion in FlightPhaseFailureDescription,
Token with
fnc_flight_phase
    fncFlightPhase : "All"
fnc_fail_rate
    fncFailRate : 0.2143E-06
fnc_phase_fail_effect
    fncPhaseFailEffect : "Power Supply
shut down."
end

VoltageOutofSpecDetection in
MatraNaturalLanguageStructure, Token
with
mnls_composite
    mnlsComposite1 : VOoSDC1;
    mnlsComposite2 : VOoSDC2
mnls_plain_text
    mnlsPlainText1 : VOoSDPT1;
    mnlsPlainText2 : VOoSDPT2;
    mnlsPlainText3 : VOoSDPT3
mnls_module
    mnlsModule1 : PowerSupplyMonitorNode
mnls_condition
    mnlsCondition1 :
PowerSupplyMonitorTripNode
end

VOoSDC1 in MatraNLSComposite, Token with
```

```
preceding_fragment
    precedingFragment : VOoSDPT1
subject_node
    subjectNode : PowerSupplyMonitorNode
following_fragment
    followingFragment : VOoSDC2
end

VOoSDPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

PowerSupplyMonitorNode in ModuleNode,
Token with
module_name
    moduleName : "Power Supply Monitor"
end

VOoSDC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : VOoSDPT2
subject_node
    subjectNode :
PowerSupplyMonitorTripNode
following_fragment
    followingFragment : VOoSDPT3
end

VOoSDPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " is "
end

PowerSupplyMonitorTripNode in
ConditionNode, Token with
condition_name
    conditionName : "tripped"
end

VOoSDPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

VoltageOutofSpecComments in
MatraNaturalLanguageStructure, Token
with
mnls_composite
    mnlsComposite1 : VOoSCC1
mnls_plain_text
    mnlsPlainText1 : VOoSCPT1;
    mnlsPlainText2 : VOoSCPT2
mnls_condition_node
    mnlsConditionNode1 :
BSCUChannelFailNode
end

VOoSCC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : VOoSCPT1
subject_node
    subjectNode : BSCUChannelFailNode
following_fragment
    followingFragment : VOoSCPT2
end

VOoSCPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

BSCUChannelFailNode in ConditionNode,
Token with
condition_name
    conditionName : "channel fails"
qualified_by
    qualifiedBy : BSCUNode
end

BSCUNode in ModuleNode, Token with
module_name
    moduleName : "BSCU"
end

VOoSCPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

ShortToGndFailureModeDescription in
FunctionFailureModeDescription, Token
with
fnc_fail_mode
    fncFailMode : "+5 volt short to
ground"
fnc_flight_phase_desc
    fncFlightPhaseDesc1 :
ShortToGndFlightPhaseFailureDescription
fnc_detection
    fncDetection : ShortToGndDetection
end

ShortToGndFlightPhaseFailureDescription
in FlightPhaseFailureDescription, Token
with
fnc_flight_phase
    fncFlightPhase : "All"
fnc_fail_rate
    fncFailRate : 0.2857E-06
fnc_phase_fail_effect
    fncPhaseFailEffect : "Power Supply
shut down."
end

ShortToGndDetection in
MatraNaturalLanguageStructure, Token with
mnls_plain_text
    mnlsPlainText1 : StGDPT1
end

StGDPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The Power Supply Monitor
will pass invalid power supply to other
BSCU."
end
-- Note : primitives not demarcated in
this and following MNLS examples

LossOfFilteringFailureModeDescription in
FunctionFailureModeDescription, Token
with
fnc_fail_mode
    fncFailMode : "loss of filtering"
fnc_flight_phase_desc
    fncFlightPhaseDesc1 :
LossofFilteringFlightPhaseFailureDescript
ion
fnc_detection
    fncDetection :
LossofFilteringDetection
fnc_comment
    fncComment : LossofFilteringComments
end

LossofFilteringFlightPhaseFailureDescript
ion in FlightPhaseFailureDescription,
Token with
fnc_flight_phase
    fncFlightPhase : "All"
fnc_fail_rate
    fncFailRate : 0.3571E-06
fnc_phase_fail_effect
    fncPhaseFailEffect : "Increased
Ripple."
end

LossofFilteringDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
```

```
    mnlsPlainText1 : LoFDPT1
end

LoFDPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "May emit out of spec
voltage if ripple is not detected by
monitor."
end

LossofFilteringComments in
MatraNaturalLanguageStructure, Token with
mnls_plain_text
    mnlsPlainText1 : LoFCPT1
end

LoFCPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "May cause spurious trip."
end

VoltageOpenFailureModeDescription in
FunctionFailureModeDescription, Token
with
fnc_fail_mode
    fncFailMode : "+5 volt open"
fnc_flight_phase_desc
    fncFlightPhaseDesc1 :
VoltageOpenFlightPhaseFailureDescription
fnc_detection
    fncDetection : VoltageOpenDetection
end

VoltageOpenFlightPhaseFailureDescription
in FlightPhaseFailureDescription, Token
with
fnc_flight_phase
    fncFlightPhase : "All"
fnc_fail_rate
    fncFailRate : 0.5714E-06
fnc_phase_fail_effect
    fncPhaseFailEffect : "Power Supply
shut down."
end

VoltageOpenDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : VODPT1
end

VODPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The Power Supply Monitor
will pass invalid power supply to other
BSCU."
end
```

BSCU Power Supply FMEA Elements (Partial)

```
BSCUPowerSupplyFailureMode&EffectsAnalysis
in FunctionalFMEA, Token with
subject_module
    subjectModule : "BSCU Power Supply"
fmea_mode
    fmeaMode1 : "+5 volt out of spec";
    fmeaMode2 : "+5 volt short to
ground";
    fmeaMode3 : "loss of filtering";
    fmeaMode4 : "+5 volt open"
fmea_effect
    fmeaEffect1 : "Power Supply shut
down.";
    fmeaEffect2 : "Power Supply shut
down.";
    fmeaEffect3 : "Increased Ripple.";
    fmeaEffect4 : "Power Supply shut
down."
fmea_detection
    fmeaDetection1 :
VoltageOutofSpecDetection;
    fmeaDetection2 : ShortToGndDetection;
    fmeaDetection3 :
LossofFilteringDetection;
    fmeaDetection4 : VoltageOpenDetection
fmea_comment
    fmeaComment1 :
VoltageOutofSpecComments;
    fmeaComment2 :
LossofFilteringComments
fmea_function
    fmeaFunction1 : "+ 5 Volt Power
Supply";
fmea_rate
    fmeaRate1 : 0.2143E-06;
    fmeaRate2 : 0.2857E-06;
    fmeaRate3 : 0.3571E-06;
    fmeaRate4 : 0.5714E-06
fmea_phase
    fmeaPhase1 : "All";
    fmeaPhase2 : "All";
    fmeaPhase3 : "All";
    fmeaPhase4 : "All"
fmea_fnc_fail_desc
    fmeaFncFailDesc1 :
+5voltpsFailureDescription
fmea_fnc_fail_mode_desc
    fmeaFncFailModeDesc1 :
VoltageOutofSpecFailureModeDescription;
    fmeaFncFailModeDesc2 :
ShortToGndFailureModeDescription;
    fmeaFncFailModeDesc3 :
LossOfFilteringFailureModeDescription;
    fmeaFncFailModeDesc4 :
VoltageOpenFailureModeDescription
fmea_flight_phase_desc
    fmeaFlightPhaseDesc1 :
VoltageOutofSpecFlightPhaseFailureDescrip
tion;
    fmeaFlightPhaseDesc2 :
ShortToGndFlightPhaseFailureDescription;
    fmeaFlightPhaseDesc3 :
LossofFilteringFlightPhaseFailureDescript
ion;
    fmeaFlightPhaseDesc4 :
VoltageOpenFlightPhaseFailureDescription
end
```

6.3.4.2.3 Piece-Part Failure Modes and Effects Analysis

Turning to the other basic event under consideration, Monitor Stuck Valid; our scenario assumes initial analysis of the power supply monitor was part of the functional FMEA of the entire power supply. However, it was found that the total failure rate of the power supply monitor was 3.06E-7 failures per hour which does not comply with the budgeted requirement of 2.0E-7 (as shown in figure 6.14). Accordingly a detailed piece-part FMEA was conducted to provide better resolution into the probability of Monitor Stuck Valid. Partial results of this analysis are shown in table 6.4.

Component	Component Type	Failure Mode	Failure Rate	Failure Effect	Detection Method
C1	Ceramic Capacitor	short	0.0073E-06	Monitor stuck tripped	Power Supply shut down by Monitor.
		open	0.0013E-06	Loss of delay Spurious monitor trip	Power Supply shut down.
		low cap	0.0019E-06	Decrease delay to trip	
C2	Ceramic Capacitor	short	0.0073E-06	Monitor stuck tripped	Power Supply shut down by Monitor.
		open	0.0013E-06	Loss of delay Spurious monitor trip	Power Supply shut down.
		low cap	0.0019E-06	Decrease delay to trip	
U1A	Comparator IC	output open	0.0124E-06	Monitor stuck valid	Bench test.
		output grounded	0.0056E-06	Monitor trip	Power Supply shut down.
		high offset voltage	0.0062E-06	Loss of monitor sensitivity	Bench test.
U1B	Comparator IC	output open	0.0124E-06	Monitor stuck valid	Bench test.
		output grounded	0.0056E-06	Monitor trip	Power Supply shut down.
		high offset voltage	0.0062E-06	Loss of monitor sensitivity	Bench test.
R1	Film Resistor	open	0.0009E-06	Monitor trip	Power Supply shut down.
		increase resistance	0.0005E-06	Trip window shifts down	
		decrease resistance	0.0004E-06	Trip window shifts up	
R2	Film Resistor	open	0.0009E-06	Monitor trip	Power Supply shut down.
		increase resistance	0.0005E-06	Trip window shifts up	
		decrease resistance	0.0004E-06	Trip window shifts down	
R3	Film Resistor	open	0.0009E-06	Monitor trip	Power Supply shut down.
		increase resistance	0.0005E-06	Trip window shifts up	
		decrease resistance	0.0004E-06	Trip window shifts down	
R4	Film Resistor	open	0.0009E-06	Monitor stuck valid	Bench test.
		increase resistance	0.0005E-06	Trip window tightens	Bench test.
		decrease resistance	0.0004E-06	Trip window widens Monitor stuck valid	Bench test.
R5	Film Resistor	open	0.0009E-06	Monitor trip	Power Supply shut down.
		increase resistance	0.0005E-06	Trip window shifts down	
		decrease resistance	0.0004E-06	Trip window shifts up	

Component	Component Type	Failure Mode	Failure Rate	Failure Effect	Detection Method
R6	Film Resistor	open	0.0009E-06	Monitor stuck tripped	Power Supply shut down.
R7	Film Resistor	open	0.0009E-06	Monitor stuck tripped	Power Supply shut down.
U2	AND Gate	stuck high	0.0108E-06	Monitor stuck valid	Bench test.
		stuck low	0.0054E-06	Monitor stuck tripped	Power Supply shut down.
U3	Voltage Reference	inop	0.0110E-06	Monitor trip	Power Supply shut down.
		out of spec	0.0058E-06	Window shift	
		short	0.0026E-06	Monitor trip	Power Supply shut down.
		open	0.0245E-06	Monitor trip	Power Supply shut down.

Table 6.4 - 'Piece-Part FMEA (Partial) of BSCU Power Supply Monitor'

Examination of table 6.4 reveals several potential failure modes that may cause a monitor to become 'stuck valid', namely U1A • output open, U1B • output open, R4 • open, R4 • decrease resistance and U2 • stuck high. Summed rates (including those not shown in the above) for contributing failures yield an actual failure rate of 1.429E-07, which satisfies the budget of 2.00E-07. This information will also be used in subsection 6.3.4.3 to update the BSCU preliminary fault tree.

6.3.4.2.4 Instantiation of Piece-Part Failure Modes and Effects Analysis Meta-model

We now instantiate elements from the O-Telos representation of our Piece-Part Failure Modes and Effects Analysis meta-model with information from table 6.4.

```
Power Supply Monitor Component Failure
Mode Descriptions

Definition of component C1 failure
description

C1FailureDescription in
ComponentFailureDescription, Token
with
com_name
    comName : "C1"
com_type
    comType : "Ceramic Capacitor"
com_fail_mode_description
    comFailModeDescription1 :
C1ShortFailModeDescription;
    comFailModeDescription2 :
C1OpenFailModeDescription;
    comFailModeDescription3 :
C1LowCapFailModeDescription
end

C1ShortFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "short"
com_fail_rate
    comFailRate : 0.0073
com_fail_effect
    comFailEffect1 : "Monitor stuck
tripped"
com_detection
    comDetection : C1ShortDetection
end

C1ShortDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : C1ShortDPT1
end

C1ShortDPT1 in PlainTextNode, Token
with
mnls_text
    mnlsText : "Power Supply shut down by
Monitor."
end
-- Note : MNLS primitives not demarcated


C1OpenFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "open"
com_fail_rate
    comFailRate : 0.0013E-06
com_fail_effect
    comFailEffect1 : "Loss of delay";
    comFailEffect2 : "Spurious monitor
trip"
com_detection
```

```
    comDetection : C1OpenDetection
end

C1OpenDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : C1OpenDPT1
end

C1OpenDPT1 in PlainTextNode, Token
with
mnls_text
    mnlsText : "Power Supply shut down."
end

C1LowCapFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "low cap"
com_fail_rate
    comFailRate : 0.0019E-06
com_fail_effect
    comFailEffect1 : "Decrease delay to
trip"
end
```

Definition of component C2 failure description

```
C2FailureDescription in
ComponentFailureDescription, Token
with
com_name
    comName : "C2"
com_type
    comType : "Ceramic Capacitor"
com_fail_mode_description
    comFailModeDescription1 :
C2ShortFailModeDescription;
    comFailModeDescription2 :
C2OpenFailModeDescription;
    comFailModeDescription3 :
C2LowCapFailModeDescription
end

C2ShortFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "short"
com_fail_rate
    comFailRate : 0.0073E-06
com_fail_effect
    comFailEffect1 : "Monitor stuck
tripped"
com_detection
    comDetection : C2ShortDetection
end

C2ShortDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : C2ShortDPT1
end

C2ShortDPT1 in PlainTextNode, Token
with
mnls_text
    mnlsText : "Power Supply shut down by
monitor."
end

C2OpenFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "open"
com_fail_rate
    comFailRate : 0.0013E-06
com_fail_effect
    comFailEffect1 : "Loss of delay";
    comFailEffect2 : "Spurious monitor
trip"
com_detection
    comDetection : C2OpenDetection
end

C2OpenDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : C2OpenDPT1
end

C2OpenDPT1 in PlainTextNode, Token
with
mnls_text
    mnlsText : "Power Supply shut down."
end

C2LowCapFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "low cap"
com_fail_rate
    comFailRate : 0.0019E-06
com_fail_effect
    comFailEffect1 : "Decrease delay to
trip"
end
```

Definition of component U1A failure description

```
U1AFailureDescription in
ComponentFailureDescription, Token
with
com_name
    comName : "U1A"
com_type
    comType : "Comparator IC"
com_fail_mode_description
    comFailModeDescription1 :
U1AOutputOpenFailModeDescription;
    comFailModeDescription2 :
U1AOutputGroundedFailModeDescription;
    comFailModeDescription3 :
U1AHighOffsetVoltageFailModeDescription
end

U1AOutputOpenFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "output open"
com_fail_rate
    comFailRate : 0.0124E-06
com_fail_effect
    comFailEffect1 : "Monitor stuck
valid"
com_detection
    comDetection : U1AOutputOpenDetection
end

U1AOutputOpenDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : U1AOutputOpenDPT1
end

U1AOutputOpenDPT1 in PlainTextNode, Token
with
mnls_text
    mnlsText : "Bench test."
end
```

```
U1AOutputGroundedFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "output grounded"
com_fail_rate
    comFailRate : 0.0056E-06
com_fail_effect
    comFailEffect1 : "Monitor trip"
com_detection
    comDetection :
U1AOutputGroundedDetection
end

U1AOutputGroundedDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 :
U1AOutputGroundedDPT1
end

U1AOutputGroundedDPT1 in PlainTextNode,
Token with
mnls_text
    mnlsText : "Power Supply shut down."
end

U1AHighOffsetVoltageFailModeDescription
in ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "high offset voltage"
com_fail_rate
    comFailRate : 0.0062E-06
com_fail_effect
    comFailEffect1 : "Loss of monitor
sensitivity"
com_detection
    comDetection :
U1AHighOffsetVoltageDetection
end

U1AHighOffsetVoltageDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 :
U1AHighOffsetVoltageDPT1
end

U1AHighOffsetVoltageDPT1 in
PlainTextNode, Token with
mnls_text
    mnlsText : "Bench test."
end
```

Definition of component U1B failure description

```
U1BFailureDescription in
ComponentFailureDescription, Token
with
com_name
    comName : "U1B"
com_type
    comType : "Comparator IC"
com_fail_mode_description
    comFailModeDescription1 :
U1BOutputOpenFailModeDescription;
    comFailModeDescription2 :
U1BOutputGroundedFailModeDescription;
    comFailModeDescription3 :
U1BHighOffsetVoltageFailModeDescription
end

U1BOutputOpenFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "output open"
com_fail_rate
    comFailRate : 0.0124E-06
com_fail_effect
    comFailEffect1 : "Monitor stuck
valid"
com_detection
    comDetection : U1BOutputOpenDetection
end

U1BOutputOpenDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : U1BOutputOpenDPT1
end

U1BOutputOpenDPT1 in PlainTextNode, Token
with
mnls_text
    mnlsText : "Bench test."
end

U1BOutputGroundedFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "output grounded"
com_fail_rate
    comFailRate : 0.0056E-06
com_fail_effect
    comFailEffect1 : "Monitor trip"
com_detection
    comDetection :
U1BOutputGroundedDetection
end

U1BOutputGroundedDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 :
U1BOutputGroundedDPT1
end

U1BOutputGroundedDPT1in PlainTextNode,
Token with
mnls_text
    mnlsText : "Power Supply shut down."
end

U1BHighOffsetVoltageFailModeDescription
in ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "high offset voltage"
com_fail_rate
    comFailRate : 0.0062E-06
com_fail_effect
    comFailEffect1 : "Loss of monitor
sensitivity"
com_detection
    comDetection :
U1BHighOffsetVoltageDetection
end

U1BHighOffsetVoltageDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 :
U1BHighOffsetVoltageDPT1
end

U1BHighOffsetVoltageDPT1in PlainTextNode,
Token with
mnls_text
    mnlsText : "Bench test."
end
```

Definition of component R1 failure description

```
R1FailureDescription in
ComponentFailureDescription, Token
with
com_name
    comName : "R1"
com_type
    comType : "Film Resistor"
com_fail_mode_description
    comFailModeDescription1 :
R1OpenFailModeDescription;
    comFailModeDescription2 :
R1IncreaseResistanceFailModeDescription;
    comFailModeDescription3 :
R1DecreaseResistanceFailModeDescription
end

R1OpenFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "open"
com_fail_rate
    comFailRate : 0.0009E-06
com_fail_effect
    comFailEffect1 : "Monitor trip"
com_detection
    comDetection : R1OpenDetection
end

R1OpenDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : R1OpenDPT1
end

R1OpenDPT1 in PlainTextNode, Token
with
mnls_text
    mnlsText : "Power Supply shut down."
end

R1IncreaseResistanceFailModeDescription
in ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "increase resistance"
com_fail_rate
    comFailRate : 0.0005E-06
com_fail_effect
    comFailEffect1 : "Trip window shifts
down"
end

R1DecreaseResistanceFailModeDescription
in ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "decrease resistance"
com_fail_rate
    comFailRate : 0.0004E-06
com_fail_effect
    comFailEffect1 : "Trip window shifts
up"
end
```

Definition of component R2 failure description

```
R2FailureDescription in
ComponentFailureDescription, Token
with
com_name
    comName : "R2"
com_type
    comType : "Film Resistor"
com_fail_mode_description
    comFailModeDescription1 :
R2OpenFailModeDescription;
    comFailModeDescription2 :
R2IncreaseResistanceFailModeDescription;
    comFailModeDescription3 :
R2DecreaseResistanceFailModeDescription
end

R2OpenFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "open"
com_fail_rate
    comFailRate : 0.0009E-06
com_fail_effect
    comFailEffect1 : "Monitor trip"
com_detection
    comDetection : R2OpenDetection
end

R2OpenDetection in
MatraNaturalLanguageStructure, Token with
mnls_plain_text
    mnlsPlainText1 : R2OpenDPT1
end

R2OpenDPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "Power Supply shut down."
end

R2IncreaseResistanceFailModeDescription
in ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "increase resistance"
com_fail_rate
    comFailRate : 0.0005E-06
com_fail_effect
    comFailEffect1 : "Trip window shifts
up"
end

R2DecreaseResistanceFailModeDescription
in ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "decrease resistance"
com_fail_rate
    comFailRate : 0.0004E-06
com_fail_effect
    comFailEffect1 : "Trip window shifts
down"
end
```

Definition of component R3 failure description

```
R3FailureDescription in
ComponentFailureDescription, Token
with
com_name
    comName : "R3"
com_type
    comType : "Film Resistor"
com_fail_mode_description
    comFailModeDescription1 :
R3OpenFailModeDescription;
    comFailModeDescription2 :
R3IncreaseResistanceFailModeDescription;
    comFailModeDescription3 :
R3DecreaseResistanceFailModeDescription
end

R3OpenFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
```

```
    comFailMode : "open"
com_fail_rate
    comFailRate : 0.0009E-06
com_fail_effect
    comFailEffect1 : "Monitor trip"
com_detection
    comDetection : R3OpenDetection
end

R3OpenDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : R3OpenDPT1
end

R3OpenDPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "Power Supply shut down."
end
R3IncreaseResistanceFailModeDescription
in ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "increase resistance"
com_fail_rate
    comFailRate : 0.0005E-06
com_fail_effect
    comFailEffect1 : "Trip window shifts
up"
end

R3DecreaseResistanceFailModeDescription
in ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "decrease resistance"
com_fail_rate
    comFailRate : 0.0004E-06
com_fail_effect
    comFailEffect1 : "Trip window shifts
down"
end
```

Definition of component R4 failure description

```
R4FailureDescription in
ComponentFailureDescription, Token
with
com_name
    comName : "R4"
com_type
    comType : "Film Resistor"
com_fail_mode_description
    comFailModeDescription1 :
R4OpenFailModeDescription;
    comFailModeDescription2 :
R4IncreaseResistanceFailModeDescription;
    comFailModeDescription3 :
R4DecreaseResistanceFailModeDescription
end

R4OpenFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "open"
com_fail_rate
    comFailRate : 0.0009E-06
com_fail_effect
    comFailEffect1 : "Monitor stuck
valid"
com_detection
    comDetection : R4OpenDetection
end

R4OpenDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : R4OpenDPT1
end

R4OpenDPT1 in PlainTextNode, Token
with
mnls_text
    mnlsText : "Bench test."
end

R4IncreaseResistanceFailModeDescription
in ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "increase resistance"
com_fail_rate
    comFailRate : 0.0005E-06
com_fail_effect
    comFailEffect1 : "Trip window
tightens"
com_detection
    comDetection :
R4IncreaseResistanceDetection
end

R4IncreaseResistanceDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 :
R4IncreaseResistanceDPT1
end

R4IncreaseResistanceDPT1 in
PlainTextNode, Token with
mnls_text
    mnlsText : "Bench test."
end

R4DecreaseResistanceFailModeDescription
in ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "decrease resistance"
com_fail_rate
    comFailRate : 0.0004E-06
com_fail_effect
    comFailEffect1 : "Trip window
widens";
    comFailEffect2 : "Monitor stuck
valid"
com_detection
    comDetection :
R4DecreaseResistanceDetection
end

R4DecreaseResistanceDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 :
R4DecreaseResistanceDPT1
end

R4DecreaseResistanceDPT1 in
PlainTextNode, Token with
mnls_text
    mnlsText : "Bench test."
end
```

Definition of component R5 failure description

```
R5FailureDescription in
ComponentFailureDescription, Token
with
com_name
    comName : "R5"
com_type
    comType : "Film Resistor"
```

```
com_fail_mode_description
    comFailModeDescription1 :
R5OpenFailModeDescription;
    comFailModeDescription2 :
R5IncreaseResistanceFailModeDescription;
    comFailModeDescription3 :
R5DecreaseResistanceFailModeDescription
end

R5OpenFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "open"
com_fail_rate
    comFailRate : 0.0009E-06
com_fail_effect
    comFailEffect1 : "Monitor trip"
com_detection
    comDetection : R5OpenDetection
end

R5OpenDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : R5OpenDPT1
end

R5OpenDPT1 in PlainTextNode, Token
with
mnls_text
    mnlsText : "Power Supply shut down."
end

R5IncreaseResistanceFailModeDescription
in ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "increase resistance"
com_fail_rate
    comFailRate : 0.0005E-06
com_fail_effect
    comFailEffect1 : "Trip window shifts
down"
end

R5DecreaseResistanceFailModeDescription
in ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "decrease resistance"
com_fail_rate
    comFailRate : 0.0004E-06
com_fail_effect
    comFailEffect1 : "Trip window shifts
up"
end
```

Definition of component R6 failure description

```
R6FailureDescription in
ComponentFailureDescription, Token
with
com_name
    comName : "R6"
com_type
    comType : "Film Resistor"
com_fail_mode_description
    comFailModeDescription1 :
R6OpenFailModeDescription
end

R6OpenFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "open"
com_fail_rate
    comFailRate : 0.0009E-06
com_fail_effect
    comFailEffect1 : "Monitor stuck
tripped"
com_detection
    comDetection : R6OpenDetection
end

R6OpenDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : R6OpenDPT1
end

R6OpenDPT1 in PlainTextNode, Token
with
mnls_text
    mnlsText : "Power Supply shut down."
end
```

Definition of component R7 failure description

```
R7FailureDescription in
ComponentFailureDescription, Token
with
com_name
    comName : "R7"
com_type
    comType : "Film Resistor"
com_fail_mode_description
    comFailModeDescription1 :
R7OpenFailModeDescription
end

R7OpenFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "open"
com_fail_rate
    comFailRate : 0.0009E-06
com_fail_effect
    comFailEffect1 : "Monitor stuck
tripped"
com_detection
    comDetection : R7OpenDetection
end

R7OpenDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : R7OpenDPT1
end

R7OpenDPT1 in PlainTextNode, Token
with
mnls_text
    mnlsText : "Power Supply shut down."
end
```

Definition of component U2 failure description

```
U2FailureDescription in
ComponentFailureDescription, Token
with
com_name
    comName : "U2"
com_type
    comType : "AND Gate"
com_fail_mode_description
    comFailModeDescription1 :
U2StuckHighFailModeDescription;
    comFailModeDescription2 :
U2StuckLowFailModeDescription
```

```
end

U2StuckHighFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "stuck high"
com_fail_rate
    comFailRate : 0.0108E-06
com_fail_effect
    comFailEffect1 : "Monitor stuck
valid"
com_detection
    comDetection : U2StuckHighDetection
end

U2StuckHighDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : U2StuckHighDPT1
end

U2StuckHighDPT1 in PlainTextNode, Token
with
mnls_text
    mnlsText : "Bench test."
end
U2StuckLowFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "stuck low"
com_fail_rate
    comFailRate : 0.0054E-06
com_fail_effect
    comFailEffect1 : "Monitor stuck
tripped"
com_detection
    comDetection : U2StuckLowDetection
end

U2StuckLowDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : U2StuckLowDPT1
end

U2StuckLowDPT1 in PlainTextNode, Token
with
mnls_text
    mnlsText : "Power Supply shut down."
end
```

Definition of component U3 failure description

```
U3FailureDescription in
ComponentFailureDescription, Token
with
com_name
    comName : "U3"
com_type
    comType : "Voltage Reference"
com_fail_mode_description
    comFailModeDescription1 :
U3InopFailModeDescription;
    comFailModeDescription2 :
U3OutofSpecFailModeDescription;
    comFailModeDescription3 :
U3ShortFailModeDescription;
    comFailModeDescription4 :
U3OpenFailModeDescription
end

U3InopFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "inop"
com_fail_rate
    comFailRate : 0.0110E-06
com_fail_effect
    comFailEffect1 : "Monitor trip"
com_detection
    comDetection : U3InopDetection
end

U3InopDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : U3InopDPT1
end

U3InopDPT1in PlainTextNode, Token
with
mnls_text
    mnlsText : "Power Supply shut down."
end

U3OutofSpecFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "out of spec"
com_fail_rate
    comFailRate : 0.0058E-06
com_fail_effect
    comFailEffect1 : "Window shift"
end

U3ShortFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "short"
com_fail_rate
    comFailRate : 0.0026E-06
com_fail_effect
    comFailEffect1 : "Monitor trip"
com_detection
    comDetection : U3ShortDetection
end

U3ShortDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : U3ShortDPT1
end

U3ShortDPT1 in PlainTextNode, Token
with
mnls_text
    mnlsText : "Power Supply shut down."
end

U3OpenFailModeDescription in
ComponentFailureModeDescription, Token
with
com_fail_mode
    comFailMode : "open"
com_fail_rate
    comFailRate : 0.0245E-06
com_fail_effect
    comFailEffect1 : "Monitor trip"
com_detection
    comDetection : U3OpenDetection
end

U3OpenDetection in
MatraNaturalLanguageStructure, Token
with
mnls_plain_text
    mnlsPlainText1 : U3OpenDPT1
end
```

```
U3OpenDPT1 in PlainTextNode, Token
with
mnls_text
    mnlsText : "Power Supply shut down."
end
```

BSCU Power Supply Monitor FMEA Elements (Partial)

```
BSCUPowerSupplyMonitorFailureMode&Effects
Analysis in PiecePartFMEA, Token
with
subject_module
    subjectModule : "BSCU Power Supply
Monitor"
fmea_mode
    fmeaMode1 : "short";
    fmeaMode2 : "open";
    fmeaMode3 : "low cap"
    fmeaMode4 : "short";
    fmeaMode5 : "open";
    ..........

    fmeaMode35 : "open"
fmea_effect
    fmeaEffect1 : "Monitor stuck tripped";
    fmeaEffect2 : "Loss of delay";
    fmeaEffect3 : "Spurious monitor trip";
    fmeaEffect4 : "Decrease delay to trip";
    fmeaEffect5 : "Monitor stuck tripped";
    ..........

    fmeaEffect38 : "Monitor trip"
fmea_detection
    fmeaDetection1 : C1ShortDetection;
    fmeaDetection2 : C1OpenDetection;
    fmeaDetection3 : C2ShortDetection;
    fmeaDetection4 : C2OpenDetection;
    fmeaDetection5 :
U1AOutputOpenDetection;
    ..........

    fmeaDetection24 : U3OpenDetection
fmea_component
    fmeaComponent1 : "C1";
    fmeaComponent2 : "C2";
    fmeaComponent3 : "U1A";
    fmeaComponent4 : "U1B";
    ..........

    fmeaComponent13 : "U3"
fmea_comp_type
    fmeaCompType1 : "Ceramic Capacitor";
    fmeaCompType2 : "Ceramic Capacitor";
    fmeaCompType3 : "Comparator IC";
    fmeaCompType4 : "Comparator IC";
    fmeaCompType5 : "Film Resistor";
    ..........

    fmeaCompType13 :"Voltage Reference"
fmea_mode_rate
    fmeaModeRate1 : 0.0073E-06;
    fmeaModeRate2 : 0.0013E-06;
    fmeaModeRate3 : 0.0019E-06;
    fmeaModeRate4 : 0.0073E-06;
    fmeaModeRate5 : 0.0013E-06;
    ..........

    fmeaModeRate35 : 0.0245E-06
fmea_com_fail_desc
    fmeaComFailDesc1 :
C1FailureDescription;
    fmeaComFailDesc2 :
C2FailureDescription;
    fmeaComFailDesc3 :
U1AFailureDescription;
    fmeaComFailDesc4 :
U1BFailureDescription;
    fmeaComFailDesc5 :
R1FailureDescription;
    ..........

    fmeaComFailDesc13 :
U3FailureDescription
fmea_com_fail_mode_desc
    fmeaComFailModeDesc1 :
C1ShortFailModeDescription;
    fmeaComFailModeDesc2 :
C1OpenFailModeDescription;
    fmeaComFailModeDesc3 :
C1LowCapFailModeDescription;
    fmeaComFailModeDesc4 :
C2ShortFailModeDescription;
    fmeaComFailModeDesc5 :
C2OpenFailModeDescription;
    ..........

    fmeaComFailModeDesc35 :
U3OpenFailModeDescription
end
```

6.3.4.3 Fault Tree Analysis - Updated

The results of Failure Modes & Effects Analyses, together with those of other techniques such as Common Mode Analysis are used to update the fault trees developed as part of Preliminary System Safety Assessment. In doing so, evidence is provided for certification demonstrating that safety requirements for undesirable top events have been met.

In this subsection we update failure rates and probabilities for the fault tree in 6.3.3.2, which recall considered as its top event inadvertent braking attributable to the BSCU, and which has a requirement of 2.5E-09. Note the description for this example is the same as given previously.

Rather than repeat what is essentially the same tree but with additional and revised quantitative data, we include a subset of events (figure 6.17) from its upper levels (down to the transfer gates), with the remainder appearing in Appendix D.

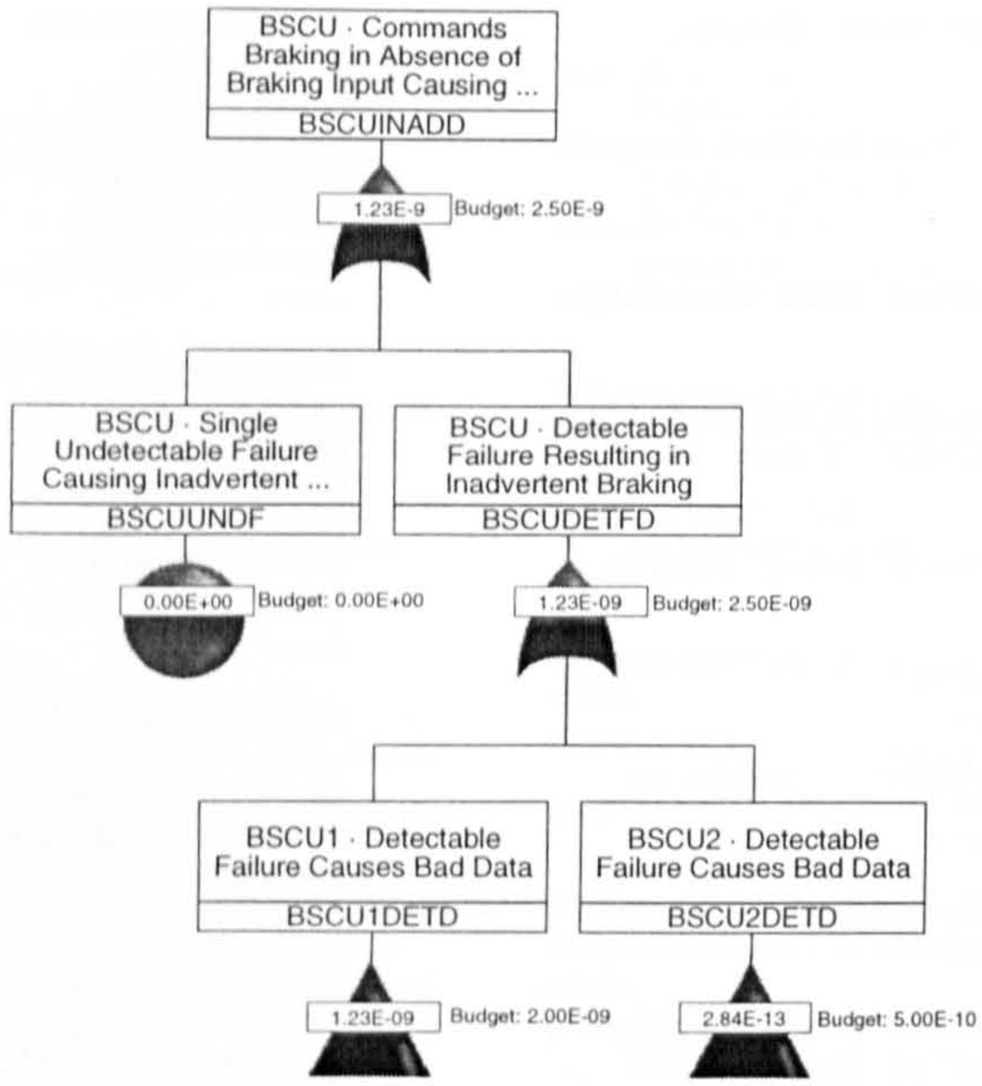


Figure 6.17 - 'BSCU Commands Braking in Absence of Brake Input Causing Inadvertent Braking - Updated Fault Tree (partial)'

Besides this additional and revised quantitative data, the label of event BSCUUNDF has been modified from 'single undetected .....' to 'single undetectable .....', and its type from external to basic. In the following subsection, we complete instantiation of the Fault Tree Analysis begun in 6.3.3.2.1 by creating updated profiles capturing these modifications for events shown in figure 6.17 (readers are again referred to Appendix D for the complete tree).

6.3.4.3.1 Instantiation of Fault Tree Analysis Meta-Model - Updated Fault Tree

Updated Event Definition 'BSCUINADD'

```
EventA in Event, Token with
updated_profile
    updatedProfile : EventAUpdatedProfile
end

EventAUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "top"
event_connective
    eventConnective : OrGate1U
actual_probability
    actualProbability :
EventAActualProbability
preliminary_budget
    preliminaryBudget :
EventAPreliminaryBudget
actual_label
    actualLabel : EventAPreliminaryLabel
end

EventAActualProbability in
ActualProbability, Token with
probability
    _Probability : 1.23E-09
end
```

Gate definitions

```
OrGate1U in OrGate, Token with
input
    _Input1 : EventBUpdatedProfile;
    _Input2 : EventCUpdatedProfile
end
```

Updated Event Definition 'BSCUUNDF'

```
EventB in Event, Token with
updated_profile
    updatedProfile : EventBUpdatedProfile
end

EventBUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "bas"
actual_probability
    actualProbability :
EventBActualProbability
preliminary_budget
    preliminaryBudget :
EventBPreliminaryBudget
actual_label
    actualLabel : EventBActualLabel
end

EventBActualProbability in
ActualProbability, Token with
probability
    _Probability : 0.00E+00
end

EventBActualLabel in SimpleLabel, Token
with
```

```
simple_description
    simpleDescription :
EventBActualSimpleEventDescription
end

EventBActualSimpleEventDescription in
SimpleEventDescription, Token
with
entity
    _Entity : "BSCU"
condition
    _Condition : "Single Undetectable
Failure Causing Inadvertent Braking"
end
```

Updated Event Definition 'BSCUDETFD'

```
EventC in Event, Token with
updated_profile
    updatedProfile : EventCUpdatedProfile
end

EventCUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    eventConnective : OrGate2U
actual_probability
    actualProbability :
EventCActualProbability
preliminary_budget
    preliminaryBudget :
EventCPreliminaryBudget
actual_label
    actualLabel : EventCPreliminaryLabel
end

EventCActualProbability in
ActualProbability, Token
with
probability
    _Probability : 1.23E-09
end
```

Gate definitions

```
OrGate2U in OrGate, Token with
input
    _Input1 : EventDUpdatedProfile;
    _Input2 : EventEUpdatedProfile
end
```

Updated Event Definition 'BSCU1DETD'

```
EventD in Event, Token with
updated_profile
    updatedProfile : EventDUpdatedProfile
end

EventDUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : OrGate3U
actual_probability
    actualProbability :
EventDActualProbability
preliminary_budget
    preliminaryBudget :
EventDPreliminaryBudget
actual_label
    actualLabel : EventDPreliminaryLabel
end

EventDActualProbability in
ActualProbability, Token
with
probability
    _Probability : 1.23E-09
end
```

Updated Event Definition 'BSCU2DETD'

```
EventE in Event, Token with
updated_profile
    updatedProfile : EventEUpdatedProfile
end

EventEUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : AndGate3U
actual_probability
    actualProbability :
EventEActualProbability
preliminary_budget
    preliminaryBudget :
EventEPreliminaryBudget
actual_label
    actualLabel : EventEPreliminaryLabel
end

EventEActualProbability in
ActualProbability, Token
with
probability
    _Probability : 2.84E-13
end
```

Failure effects and probabilities from the item level SSA are subsequently used to verify system level analyses (including fault trees), and thence aircraft level analyses. However, these are beyond the scope of this investigation; interested readers are again referred to EUROCAE (1996b) for more details.

6.3.5 Trace Relations

This case study has further demonstrated population of meta-models within the traceability Workspace. Trace relations may again be added to provide means of navigating between these models, and elements of these models, as we now illustrate.

From the artifacts represented, a number of possible associations can be established as shown in figure 6.18 (and summarised in table 6.5):-

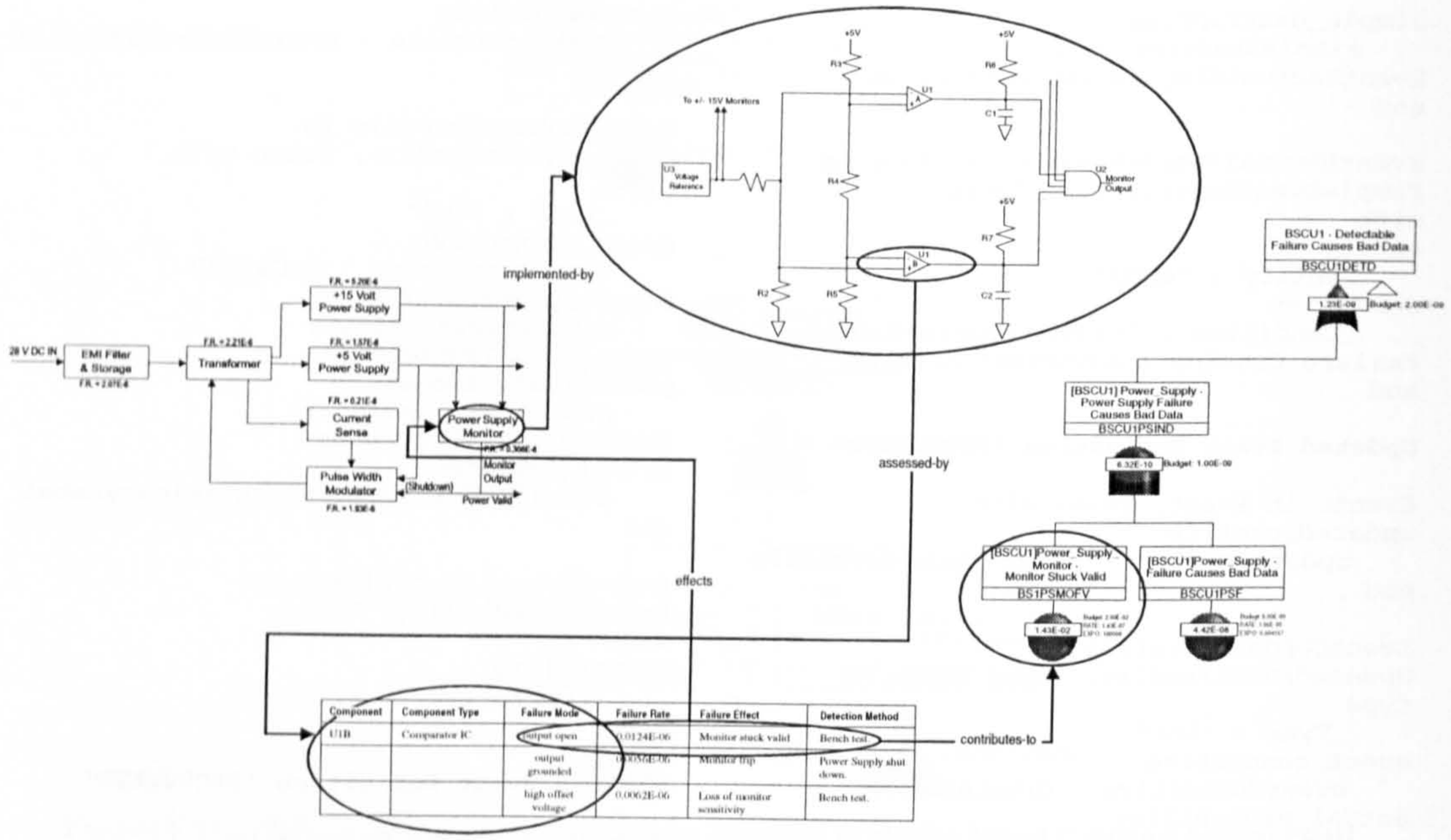


Figure 6.18 - 'Exemplar Intra-Micro Horizontal & Vertical Traceability Relations'

SOURCE		RELATION TYPE	TARGET	
Model	**Element**		**Model**	**Element**
Power Supply Function Block Diagram	Power Supply Monitor (Function)	Implemented-By	Power Supply Monitor Circuit Diagram	
Power Supply Monitor Circuit Diagram	U1B (Capacitor)	Assessed-By	Failure Modes & Effects Analysis Table	U1B Failure Description (Component, Type and Failure Modes)
Failure Modes & Effects Analysis Table	Monitor stuck valid (Failure Mode Description)	Effects	Power Supply Function Block Diagram	Power Supply Monitor (Function)
Failure Modes & Effects Analysis Table	output open (Failure Mode Description)	Contributes-to	Fault Tree Analysis	Power Supply Monitor • Monitor Stuck Valid (Event Profile)

Table 6.5 - 'Summary of Traceability Relations' (from figure 6.18)

To clarify the above relations according to the traceability axes from Chapter One (subsection 1.4.3): all are deemed intra-micro since - in ARP 4761 terminology - they describe various views within a single 'item' (BSCU) of the Wheel Braking System[8]. AssessedBy and Effects are vertical relations (from implementation to assessment artifacts and from assessment to design respectively), as is Implemented-By (assuming we regard the block diagram as a design artifact and the Circuit Diagram an implementation artifact). Finally, Contributes-to is a horizontal relation among SSA assessment artifacts.

Again, we reiterate that these associations are fairly arbitrary and that a literature survey together with practitioner consultation will be necessary to produce a comprehensive set relevant to the aerospace

[8] The BSCU may also be regarded as a system in its own right and hence components such as U1, as constituent items of that system.

industry and artifacts from that domain (see further work item in Chapter Seven, subsection 7.4.3).

6.3.5.1 Instantiation of Trace Relations

To demonstrate application of these relations, we instantiate the appropriate O-Telos base classes - specialisations of AerospaceEngineeringAssociation - introduced in Chapter Three (subsection 3.3.6.3.2).

Our first example populates the ImplementedBy relation; its source (fromEntity) is the Power Supply Monitor (PowerSupplyMonitor) function (element) of the Function Block Diagram, and its destination (toEntity), the Power Supply Monitor Circuit Diagram (PowerSupplyMonitorCD).

```
ImplementedBy01 in ImplementedBy, Token with
from_entity
    fromEntity : PowerSupplyMonitor
to_entity
    toEntity : PowerSupplyMonitorCD
end
```

Example two populates AssessedBy, in this case between U1B, a comparator element of the Power Supply Monitor Circuit Diagram - and the corresponding description of failures for that particular component (in terms of component, type and failure mode[9]) from the piece-part FMEA table (U1BFailureDescription).

```
AssessedBy01 in AssessedBy, Token with
from_entity
    fromEntity : U1B
to_entity
    toEntity : U1BFailureDescription
end
```

Our third example populates the Effects association; it occurs between an instance of failure effect details (i.e., mode, effect, rate, etc.) from the FMEA table (U1BOutputOpenFailModeDescription)[10], and the PowerSupplyMonitor function of the Function Block Diagram.

```
Effects01 in Effects, Token with
from_entity
    fromEntity : U1BOutputOpenFailModeDescription
to_entity
    toEntity : PowerSupplyMonitor
end
```

Our final example populates the ContributesTo association between details of a failure effect (again U1BOutputOpenFailModeDescription from example three) and a fault tree updated profile (EventHUpdatedProfile). Note, here, using aggregated objects as source and target (i.e., opting for a relatively coarse granularity) adds context to the association (as it does with examples two and three above) which in this case might otherwise simply link rates in the FMEA to those in the fault tree.

```
ContributesTo01 in ContributesTo, Token with
from_entity
    fromEntity : U1BOutputOpenFailModeDescription
to_entity
    toEntity : EventHUpdatedProfile

end
```

---

[9] This relates to the aggregated ComponentFailureDescription class from the FMEA meta-model in subsection 5.3.3.2.1.
[10] This relates to the aggregated ComponentFailureModeDescription class from the FMEA meta-model in subsection 5.3.3.2.1; similar Effects relations apply to the other FMEA failure descriptions shown in figure 6.18 as these also impact on the Monitor.

6.3.6 Summary

This section has demonstrated application of the Fault Tree Analysis and Failure Modes and Effects Analysis structures introduced in sections 5.2 and 5.3 respectively. In doing so, extracts of artifacts described in a case study from an aerospace industry standard (ARP 4761) were used to populate O-Telos implementations of both structures. We then illustrated how these models and their elements may be linked using various trace relations. The results of this case study will again be considered as part of our overall thesis evaluation in Chapter Seven.

6.4 Chapter Summary

This chapter has exhibited a number of traceability structures (meta-models) introduced in Chapters Four and Five using case studies supplied by aerospace practitioners. These, along with worked examples from the previous chapters, provide a flavour of one possible means of automation for MATrA.

Our first case study used specification documents for a Mission Planning System for the Hawk Aircraft to populate the User Centred Requirements Structure (incorporating the MATrA Natural Language Structure). Three Use Case Models were instantiated, along with textual Scenarios and Message Sequence Chart representations of paths through one particular use case. Two further path fragments were included to demonstrate population of model elements for timing events and event grouping. We also featured a small number of example trace associations to show potential ways in which UCRS elements may be linked using the AerospaceEngineeringAssociation concept (from subsection 3.3.6.3.2). The case study confirmed that UCRS is capable of representing commercial specifications expressed in it constituent notations and that traceability linkages can be established between its elements. While acknowledging the implementation yields a large number of O-Telos objects, readers are again reminded that these will be created automatically by the *tool2matra* function and 'concealed' from users by an appropriate interface.

The second case study used material from Appendix L of ARP 4761[11] (featuring a braking system for a hypothetical aircraft) to populate the Fault Tree and Failure Modes and Effects Analysis Structures (the latter again incorporating MNLS). Featured artifacts included preliminary and updated fault trees, as well as fragments of functional and piece-part FMEA tables. Again example associations demonstrating potential traceability paths between elements of these structures were also included. The study showed that both the Fault Tree and Failure Modes and Effects Analysis Structures are able to represent, and support traceability across, artifacts expressed in these notations.

We regard the benefits of using MATrA shown by these case studies to be twofold. The first is simply improved traceability; engineers are able to create links, both among elements of individual structures (as shown by the Hawk case study), but perhaps more importantly, between elements of different structures (as demonstrated by the ARP 4761 case study). Given that featured notations are likely to be supported by disparate tools, this was the main aim of the thesis.

The second benefit stems from rigour imposed on developers when encoding their specifications in the MATrA structures. This was particularly true for the Hawk case study which features structures for notations that are not rigorously defined (for instance, use cases and textual scenarios). Thus, given implementation of the well-formedness and PDS consistency checks featured throughout (see future work item 7.4.13), the richness and granularity at which the structures are represented can potentially lead to specifications that are not only more traceable, but also of better quality.

---

[11] Several deficiencies exist with the case study material presented in ARP 4761 (see Dawkins *et al.*, 1999). However it is acknowledged as the best published example from the safety literature and is often used for academic and training purposes.

Chapter 7 Conclusions

7.1 Introduction

This chapter summarises the dissertation, highlights its contributions and provides some directions for further work.

7.2 Concluding Remarks

It is useful to begin by revisiting the thesis argument from Chapter One (subsection 1.3) which stated the following:-

> Most notations for development, assessment and product management used by aerospace practitioners have (bespoke or commercial) tool support; however a lack of well-defined approaches to integration limits traceability between their respective data sets.
>
> We argue that traceability across tools can be achieved by exporting these data sets to an integrated environment consisting of: i) a *Workspace* comprising a set of structures or meta-models (literally, models describing models) capturing data elements for a representative set of development, assessment and product management notations; ii) a further structure capturing fundamental elements of the emerging product that maintains consistency within the Workspace (where 'fundamental elements' refers to system components, their functions and behaviour, etc.); iii) well-formedness constraints over these structures; and iv) associations and consistency constraints between the structures.
>
> We also argue that development and assessment information populates four traceability dimensions, of which three record links between project artifacts (conceptualised as a cube), while the fourth relates artifacts across different projects (i.e., cubes) and across product families within the same project. Hence, the structures must provide coverage across four dimensions.

This thesis has defined and demonstrated an approach supporting traceability for the development and assessment of complex aerospace (an in particular avionics) systems. Its contribution lies in five areas:-

- **A meta-framework defining traceability in the context of aerospace (avionics) systems engineering and a visual conceptualisation of the traceability 'dimensions'.**
- **Classification of traceability techniques.**
- **A concrete framework for traceability across artifacts from aerospace (avionics) systems engineering projects.**
- **Meta-models for a representative set of development notations.**
- **Meta-models for a representative set of safety assessment and product management notations, together with a structure for configuration (i.e. version) management.**

In the following sections we summarise the thesis and draw some conclusions from each of these elements of the research.

7.2.1 Traceability for Avionics: Definitions & Drivers

In Chapter One, we provided a context for the thesis by stating our motivation for investigating traceability for avionics. Essentially this was derived from observations on the characteristic nature of aerospace projects gleaned in part from the literature, but mainly from discussions with practitioners. Properties such as protracted life-cycles, the complexity of products and processes used to develop them, use of fault tolerant architectures and the need for certification collectively challenge the provision of effective traceability within that industry.

Most existing work on traceability stems from software engineering literature. This is evident from definitions of the term that are couched in a language which undermines their application to systems engineering. For instance, they are often hardwired to an implied 'waterfall' model, explicitly state artifact types with a software orientation and fail to address the issues involved in tracing across system and component descriptions.

Understanding of the term 'traceability' has moved on considerably in the last ten years. Most authors are now agreed that we can differentiate aspects of traceability by considering such factors as the direction and type of artifact being traced. It is therefore common to refer to forward and backward traceability in describing navigation to 'up-stream' and 'downstream' artifacts. Likewise the notion of horizontal and vertical traceability describes facilities for navigating between artifacts of the same and different types respectively.

While traceability must surely be a basic necessity for all but the most trivial of engineering endeavours, work investigating means for its realisation has mainly surfaced since the 1990s. We attributed this general growth to two factors, the emergence of requirements engineering as a topic of interest and increased use of compliance frameworks (specifically, process improvement models and standards and guidelines).

7.2.1.1 Contribution

From our observation that existing definitions of traceability do not reflect the complex structure of aerospace (including avionics) products and processes, we proposed an appropriate meta-framework. This was based on a definition taxonomy in which we refined the notion of horizontal and vertical traceability by introducing the qualifiers *micro* and *macro* to differentiate traceability within and across decomposition levels (e.g., system, sub-system, component), and the qualifiers *intra* and *inter* to distinguish traceability within and across system descriptions (i.e., systems that interact with one another). We also recognised traceability of revisions and variants through separate definitions in preference to overloading the horizontal definition (as is normally the case).

To provide a visual conceptualisation, horizontal, vertical and revision traceability were represented as dimensions of a cube. This novel idea was extended to variant traceability (i.e., the variant dimension) by depicting traceability between cubes. The cube abstraction intuitively conveys salient features of

traceability that are not well-characterised by existing two-dimensional images which tend to disregard revisions and variants, usually as a corollary of failing to distinguish them from the horizontal dimension.

7.2.2 Modelling Concepts, Techniques & Tools

Chapter Two provided an overview of traceability techniques which we considered from three perspectives, namely *structure* (e.g., support for typing of artifacts and relationships, and for abstraction concepts such as generalisation and aggregation), *integrity* (e.g., means to specify rules and constraints over constituent elements of artifacts) and *manipulation* (e.g., means for selective information retrieval). For reader orientation, an overview of the UML, OCL and O-Telos representation techniques employed in this thesis was also provided. The chapter concluded by investigating various proprietary and commercial tools supporting the techniques considered. These included DOORS which we noted is moving towards the MATrA Workspace approach of transferring data from CASE tools onto information models expressed in a common language (termed DOORS 'surrogate' modules) and creating links between these models to support traceability.

7.2.2.1 Contribution

A means for classifying traceability techniques according to their basis of representation was proposed. Specifically, we differentiated between approaches employing *higher-order* and *lower-order* cross referencing (both of which are founded on graphs and matrices) from those using a *data-modelling* approach. The key difference between this classification scheme and others stems from its starting point - the premise that set theory is the mathematical foundation of all traceability techniques and so the level of sophistication afforded by a particular technique depends on what additional concepts (in terms of facilities for structure, integrity and manipulation) it adds to basic set theoretic constructs. This contrast with other classifications such as Gotel (1995) which do not divorce the underlying principles from their means of realisation.

7.2.3 MATrA: Towards A Concrete Framework for Traceability

Chapter Three proposed a concrete traceability framework for avionics engineering (a realisation of the dimensions meta-framework). Several principles were identified as 'fundamental' to this framework, while a review of the literature revealed existing work that provided a 'foundation' for its development.

Framework principles included a *Workspace* of notation dependent structures (meta-models) representing project data transferred from CASE tools and linkages between this data; a *Meta-class model* providing a common underlying representation for Workspace meta-models; a mapping function (*tool2matra*) to allow data transfer from CASE tools to the Workspace; the *Product Data Synthesis*, a notation independent structure representing fundamental elements of the emerging system (e.g., components, functions, behaviour and means for their association) which maintains Workspace consistency by preventing bad data from entering via *tool2matra* (i.e., preventing data being mapped to a notation dependent structure) unless the PDS contains corresponding data elements, and by

preventing violations once the data is 'inside'; and the *Framework Model* that provides a basis for managing framework elements and their inter-relationships. The main foundations of these principles were ESPRIT project NATURE (Pohl, 1996), ESPRIT project SEDRES (Johnson, 1997) and the Design Rational Capture System (Klein, 1993a).

In particular, we were influenced by NATURE's use of a conceptual modelling language to structure object-based representations of requirements notations for IS Development. Accordingly, we adopted a similar approach to developing Workspace meta-models for design, implementation, safety analysis and product management notations; the aim being to provide a seamless environment for traceability that is unconstrained by tool boundaries. We were also influenced by NATURE partners use of a common meta-level structure as is evident in the MATrA *Meta-class model*, and by their approach to creating associations between the various meta-model representations.

SEDRES' main influence on MATrA was in providing evidence of the ability to map data from CASE tools onto information models. This enabled us to treat *Workspace* population as a 'black-box' through the interface to an undefined function (*tool2matra*) and to concentrate on other aspects of the traceability framework. The symmetry with DOORS' notion of surrogate modules was again cited as further evidence of feasibility.

The main influence of the Design Rational Capture System on MATrA has been development of the *Product Data Synthesis* which takes as its starting point the Artifact Synthesis structure component of DRCS. Extensions were necessary however as the Artifact Synthesis lacks elements to record functional architecture and behaviour. The literature provided a basis for developing these extensions, in particular, work by Oliver (1994).

Chapter Three also stressed that the emphasis of this thesis was to be on development and validation of Workspace meta-models for a representative and diverse set of notations. Selection was guided not only by their relevance to avionics engineering, but also by a desire to include different representation formats (textual, graphical, tabular and program code) and hence address the different modelling challenges presented by each. Featured notations therefore included a Natural Language Structure, a User Centred Requirements Structure, a Real-Time Network Specification Language (RTN-SL) Structure, a SPARK Ada Structure, a Fault Tree Analysis (FTA) Structure, a Failure Mode and Effects Analysis (FMEA) Structure and a Programme Evaluation & Review Technique (PERT) Structure. For reader orientation, we used a further notation (Circuit Diagrams) to show how work on these structures would be presented in Chapters Four and Five.

7.2.3.1 Contribution

MATrA has integrated and extended a number of existing works towards a concrete traceability framework for avionics engineering. What sets it apart from the majority is consideration of traceability between notations. Besides SEDRES (through its support for data exchange), NATURE and to some

extent SAM (Wilson & McDermid, 1995), no other approach has addressed this issue. Moreover, NATURE concentrates on the requirements phase, functions independently of CASE tools and ignores consistency between notations. SAM meanwhile has an even narrower focus, offering support for traceability as a by-product of structuring descriptions of safety arguments for critical systems.

In addition, we are unaware of any other work addressing all four traceability dimensions 'in concert' as MATrA does; the framework as introduced in Chapter Three provided support for horizontal and vertical traceability which we then extended in Chapter Five (see 7.25) for the revision and variant dimensions.

7.2.4 Meta-models for System Development

As per the stated emphasis of our work, Chapter Four proposed meta-models for representing artifacts expressed in Natural Language, as Use Case Models, Scenarios and Message Sequence Charts via the User Centred Requirements Structure, in the Real-Time Network Specification Language and in SPARK Ada. In each case we described factors motivating their inclusion, introduced the basic concepts, proposed a meta-model in UML with well-formedness and PDS consistency checks expressed in OCL and gave a 'flavour' of tool support by implementing the base classes in O-Telos (using ConceptBase). We further provided worked examples instantiating these base classes, or else committed to a more detailed case study in Chapter Six.

7.2.4.1 Contribution

The MATrA Natural Language Structure is based on an approach to representing textual artifacts proposed by project NATURE and supports fine grained traceability at a user-determined granularity. Its main role in this thesis has been to augment the design of other structures (e.g., to represent pre and post-conditions of the Use Case Model in subsection 4.3 and the detection column for FMEA tables in 5.3), the idea being to replace a standard String type with an MNLS wherever PDS elements embedded in a prose statement must be promoted to primitives for traceability purposes. The introduction of node typing to enable PDS consistency checks on these primitives makes MNLS fundamentally different to the NATURE structure, whilst adding to its practicality. It also differentiates our work from functionally similar facilities offered by the DOORS and RTM tools. MNLS was evaluated by case studies in Chapter Six (see 7.2.6).

The User Centred Requirements Structure captures syntactic elements of three complementary requirements elicitation, analysis and documentation notations: Use Case Models, Scenarios and Message Sequence Charts. UCRS is entirely novel and was devised from observations on usage of these notations in actual commercial specifications. Accordingly, the structure allows management of, including the sharing of elements across, multiple Use Case Models. Paths through each use case are described in terms of interactions using textual Scenarios and/or Message Sequence Charts (the former expressed using a specialisation of MNLS), both of which share a common underlying representation on the basis that they contain the same core elements (allowing generation of MSCs from Scenarios and

visa versa). Formal conditions were also defined to preserve PDS consistency, usage restrictions and well-formedness, as well as consistency within the UCRS itself (i.e., between the three constituent notations). Again, the User Centred Requirements Structure was evaluated by case study in Chapter Six (see 7.2.6).

To demonstrate application of meta-modelling to a graphical design notation, we developed a novel structure representing artifacts expressed using the Real-Time Network Specification Language (RTN-SL) in which concurrent processing components exchange information and synchronise through shared data in the connections. All key syntactic elements are represented by the structure, although we confined definition of constraints to the principal restrictions needed to ensure an RTN-SL specification is internally consistent; a number of PDS consistency checks were also stated. The RTN-SL structure was then evaluated by implementing a number of (mostly hypothetical) worked examples in O-Telos using ConceptBase. Whilst providing proof-of-concept in that the structure allows us to represent (and hence with the insertion of appropriate linkages, trace to and from) artifacts represented in this particular language, we concede that some further evaluation using actual commercial specifications is desirable simply to increase confidence in these findings and to determine scalability (see 7.4.8).

Finally, to demonstrate how meta-modelling can be applied to the representation of software source code, we presented a novel structure capturing a subset of the concrete (well-formedness) syntax for SPARK Ada, a programming language used to develop safety-critical systems. The structure was developed in parallel with a modelling philosophy - a set of guidelines for representing languages with a formal grammar - and was presented as a series of schemas showing the source BNF (Backus Naur Form) syntax, corresponding UML Class Diagram and its implementation in O-Telos. The structure was evaluated by expressing worked examples of two source code fragments in ConceptBase. These successfully showed the ability to represent our chosen SPARK Ada subset and hence with the insertion of appropriate linkages, trace to and from its constituent elements. While use of a larger subset and worked examples would have provided further proof of concept, we felt there is little to be gained from this other than perhaps in terms of assessing scalability (again see 7.4.8). Finally, to evaluate versatility of the above-mentioned guidelines, we successfully applied them to development of a further structure representing a small subset of the RTN-SL textual syntax. This showed that the guidelines can potentially be used in extending MATrA to support any formal language expressed in BNF.

7.2.5 Meta-models for Safety Assessment & Product Management

Continuing the theme of our emphasis, Chapter Five introduced meta-models for expressing results of Fault Tree Analysis and Failure Modes and Effects Analysis, as well as artifacts represented using the Programme Evaluation & Review Technique. Again, we described for each the factors motivating their inclusion, introduced the basic concepts, proposed a UML meta-model with rules and constraints expressed in OCL and provided a foundation for tool support by implementing the base classes in O-Telos using ConceptBase. We further included a worked example of each meta-model, or else resolved to do a more detailed case study in Chapter Six. Finally, to support traceability of revisions and variants

the MATrA Configuration Model was introduced.

7.2.5.1 Contribution

To demonstrate how meta-modelling can be applied to graphical safety analysis techniques, we developed a novel Fault Tree Structure which captures results of Fault Tree Analysis, a deductive approach to determining and relating all events which may lead to a failure condition. The structure was guided by observations on usage of fault trees, notably in the context of ARP 4761 guidelines for certification of civil aircraft. Therefore in addition to supporting the main concepts underpinning Fault Tree Analysis, the structure enables representation and management of preliminary trees expressing budget safety objectives, together with their updated counterparts showing realisation of these requirements. To remove duplication of data between the two trees whilst helping to maintain consistency and increase traceability, the Fault Tree Structure permits sharing of events (or more specifically, elements of their descriptions) through the notion of 'event profiles'. In addition, well-formedness constraints (building on earlier work in Mason & Saeed, 1998) were expressed over the logical tree structure, together with safety-criteria identifying common cause and single failures. We further introduced a 'light-weight' approach to the formalisation of event labels by typing events according to a taxonomy from the literature and by specifying their content at a level of granularity that allows for their verification against the PDS. The Fault Tree Structure was evaluated by case study in Chapter Six (see subsection 7.2.6).

To demonstrate how meta-modelling can also be applied to tabular safety analysis techniques, we developed a novel structure for expressing the results of Failure Modes and Effects Analysis, an inductive approach to tracking the effects of failures within a system and determining their consequences. The structure supports recording of results for both functional and piece-part (i.e. component) analyses, while its content is consistent with the suggested worksheet formats detailed in ARP 4761; a number of formal checks verifying FMEA elements against the Product Data Synthesis were also defined. Again, the Failure Modes and Effects Analysis Structure was evaluated by case study in Chapter Six (see 7.2.6).

Finally, (for completeness and) to demonstrate how meta-modelling can be applied to the representation of product management structures, we proposed a novel structure capturing the graphical notation for the Programme Evaluation & Review Technique which represents inter-relationships between the timing of events and project activities in the form of a network. Again we captured the main syntactic elements and principal well-formedness restrictions. The structure was evaluated using hypothetical worked examples implemented in O-Telos using ConceptBase, one of which we included in the main text and which provides proof of the ability to represent artifacts expressed in this notation.

To demonstrate another aspect of product management, the MATrA Configuration Model was proposed (and the Framework model from Chapter Three extended) to manage revisions and variants across the Workspace and Product Data Synthesis. The model is based on an *intertwined* approach (Conradi &

Westfechtel, 1998) and features elements to represent configurations and change deltas, as well as means to record various versioning related dependencies; rules were defined for deriving deltas and constraints to ensure correct instantiation of dependencies. A lengthy worked example successfully demonstrated aspects of the Configuration Model, including realisation of the intertwined approach: in particular, articulation of revisions to product structures within the PDS, the ability to establish dependencies between PDS and Workspace elements, to create configurations, perform impact analysis and to effect change based on this analysis. As previously stated, no other work has sought to address the four dimensions as a whole and hence to integrate configuration management and traceability as called for by Ramesh & Jarke (1999).

7.2.6 Application of the MATrA Framework

To evaluate aspects of the framework not demonstrated by worked example, Chapter Six featured two in depth case studies, both based on material supplied by aerospace practitioners.

Our first case study used data from a commercial specification supplied by BAE SYSTEMS to instantiate a ConceptBase implementation of base classes for the User Centred Requirements Structure. Specifically, we populated three Use Case Models, together with textual Scenario and Message Sequence Chart paths (both normal and exceptional) through one particular use case. In addition, fragments of two further paths were populated to show instantiation of additional concepts for representing timing events and event grouping. A small number of example associations between elements of the UCRS were also introduced to demonstrate traceability among the constituent notations (we return to this subject in subsection 7.4.3). The study therefore provided proof that UCRS is capable of representing commercial specifications expressed using its combination of notations, and of supporting traceability.

In the second case study, material from an example featured in Appendix L of ARP 4761 was used to populate ConceptBase implementations of the Fault Tree and Failure Modes and Effects Analysis Structures. Specifically, preliminary and updated fault trees were created, together with fragments of functional and piece part FMEA tables, with the latter expressed over elements instantiating the Circuit Diagram meta-model introduced in Chapter Three. Further examples of associations were also included to indicate traceability between elements of these structures (again, see subsection 7.4.3); the fact that the associations linked data originating from (potentially) disparate source tools underlines the seamless nature of the Workspace. Again, the study provided proof that the featured meta-models are able to represent and support traceability across data from commercial artifacts expressed in these notations.

In addition, both case studies showcased the MATrA Natural Language Structure, the former in representing pre and post-conditions of the Use Case Model and the latter, the comment and detection columns for FMEA tables. To demonstrate its versatility, a range of text strings were successfully converted to 'MNLS form', with significant primitives extracted accordingly.

7.2.7 Overall Contribution

As stated throughout, this thesis has concentrated on meta-modelling aspects of the MATrA framework. Aside from claims made in subsections 7.2.4.1 and 7.2.5.1 on the contribution made by these structures, discussions with practitioners indicates that the practice of developing such models can itself prove beneficial. That is, the investigative process involved in producing a MATrA meta-model can lead to better understanding of the notation it represents, or perhaps more importantly, the particular usage of the notation for a development or assessment activity. This is especially true for notations that are less rigorously defined but which offer flexibility as a result.

However, the main purpose of the thesis has been to provide an environment enabling traceability among the data sets of tools, along the dimensions introduced in Chapter One. Therefore the fundamental gain from the notation dependent meta-models is their ability to be linked to form navigable paths through the Workspace (note that 'dimension-wise', the type of traceability existing between two meta-models depends entirely on when and for what purpose they are being used relative to the development and assessment process). Furthermore, by identifying means by which to make CASE tools part of MATrA and by providing a way of increasing confidence in the consistency of data transferred from these tools (using a common set of typed primitives - e.g., module, function, condition, etc.), we have improved industrial practicality of the framework. Therefore, this thesis can justifiably claim to have maintained the argument stated by our position in section 1.3 (and re-iterated in 7.2).

7.3 Limitations

We are aware of certain limitations in our work, as well as in the confidence and validity of some claims made with respect to it. These are as follows:-

- Absence of a *tool2matra* function
- Duplication of CASE tool data in the Workspace
- Object proliferation

7.3.1 Absence of a *tool2matra* Function

The main limitation of work presented here relates to the fact we do not have in place a function to map data from CASE tool data structures onto MATrA Workspace meta-models. This potentially undermines confidence in the framework itself and material presented to support its validation.

However, given that DOORS, a leading commercial traceability tool now employs a similar (although less rigorous) approach and given that reputable public domain evidence from SEDRES partners has addressed the technical issues involved, we suggest the feasibility of this aspect of MATrA is beyond reasonable doubt.

7.3.2 Duplication of CASE Tool Data in Workspace

The fact that CASE tool data is replicated in the Workspace is potentially a further limitation, especially given the issue of scale alluded to throughout. Vendors of the DOORS tool (which is widely used in the aerospace domain) would claim that this is a price developers are prepared to pay in return for the

improved traceability across tools that results. Moreover, we are proposing to investigate as a future work item a possible alternative which restricts *persistent* storage of Workspace elements to trace associations (see subsection 7.4.11).

7.3.3 Object Proliferation

Related to the previous point, it has been suggested that instantiation of MATrA structures yields an overly large number of objects (*cf.* subsection 6.2 and 6.3.) To counter such claims, we assert that the relationship between elements of notation dependent (i.e. meta-model) and CASE tool data structures is linear rather than exponential, that population will be automated by means of *tool2matra* and that irrespective of these issues, all such objects will be concealed from users beneath a graphical interface.

7.4 Further Work

During the course of our research, several areas worthy of further investigation were identified. These include the following:-

- Extension of Workspace notations
- Application of MATrA to other safety-critical domains
- Survey of domain requirements for trace associations
- Enriching the Product Data Synthesis
- Specifying requirements using the MATrA Natural Language Structure
- Systems Engineering process issues for MATrA
- Investigation of an inverse mapping function (*matra2tool*)
- Contiguous case study across all dimensions
- Investigation of analysis objectives
- Use of *tool2matra* to optimise Workspace revisions
- Confinement of persistent Workspace to trace associations
- Incorporation of standards knowledge into MATrA
- Use of a commercial tool as a basis for implementing MATrA
- Re-expression of structures in EXPRESS

In the following sections we provide a brief introduction to possible directions of further work in the areas identified above.

7.4.1 Extension of Workspace Notations

To maintain a tractable scope, the Workspace only featured a small (if representative) subset of notations and techniques used by aerospace practitioners. Clearly, to provide a practical engineering environment this subset must be increased. For example we could include a formal notation such as VDM (Jones, 1990) or Z (Spivey, 1989), both of which can potentially be represented by applying the modelling philosophy alluded to in subsection 4.5.3.1.1. Other candidates (some of which were developed but omitted due to space limitations) are Viewpoints (Mullery, 1979) and Piping & Instrumentation Diagrams for development (Turton *et al.*, 1997), Event Tree Analysis (Villemeur,

1992) and Goal Structure Notation (Wilson *et al.*, 1995) for safety and Responsibility Modelling (Dobson & Strens, 1994) for product management. Moreover, given that we considered a diversity of notations, both in terms of purpose (requirements, design, implementation, safety and product management) and means of representation (natural language, tabular and graphical), the existing set of structures provides an instructive source of reference for anyone seeking to extend the Workspace.

7.4.2 Application of MATrA to Other Safety-Critical Domains

While development of MATrA has been oriented towards avionics engineering, some of the industry characteristics enumerated in Chapter One can be said to apply to other sectors. It would therefore be worthwhile investigating the potential application of MATrA to other domains utilising complex dependable systems, in particular the Nuclear and Rail industries. *Prima facie*, this is likely to involve expansion of notations supported by the Workspace, although specific requirements would need to be established through discussions with practitioners and a review of current literature, including standards and guidelines.

7.4.3 Survey of Domain Requirements for Trace Associations

Despite considering a mechanism for creating relationships between Workspace meta-models, only a small number of arbitrary examples were included in the thesis, their purpose being to demonstrate the mechanism itself, rather than any specific traceability gain. We did however highlight the need to compile (through literature review and practitioner consultation) a comprehensive set of associations for relating requirements, design, implementation and other artifact types. Factors to consider include the specific types of notations to be related and the processes that apply them. A useful starting point for the latter was provided in subsection 1.2 (C2); recall our heuristic that regards the process of transforming an input artifact to an output artifact as an abstraction of a traceability association between the two.

7.4.4 Enriching the Product Data Synthesis

To increase utility of the Product Data Synthesis, consideration should be given to enriching the structure. In particular, the following have been suggested to the author:-

- **Predefined Aerospace Types**

Following a SEDRES approach (Herzog & Scerri, 1998), benefits could be gained from separating PDS definitions from their instances. This would reduce the modelling workload of developers and ensure 'like' profiles are both consistent and complete. It could be accomplished through an additional layer of abstraction whereby build elements are promoted to meta-level classes whose instances define standard modelling components. This is perhaps best explained by example.

At present, the existing Module class could be instantiated as the object TrimTank, with properties such as Capacity and NormalWorkingPressure. We could also define an InnerTransferTank, an OuterTransferTank, a CentralTank and so on, each with the same set of properties, but with variances in their respective parameter values. However, such an approach means engineers would have to replicate the same basic

profile each time they introduced a new tank, with all the attendant risks of inconsistency that this form of action entails.

Alternatively, a generic FuelTank (with the properties previously stated) could be specified as an instance of the Module meta-class (and conceivably a specialisation of some Tank superclass) whose instances - TrimTank, OuterTransferTank and CentralTank - would automatically share a common definition profile. This principle could be extended to other 'standard' modules which continuing the fuel system theme, might include piping, valve and pump types.

Such an approach is only made possible by concentrating on a specific domain, and one which by nature is instinctively conservative. The resulting set of 'Predefined Aerospace Types' would enable MATrA to operate over standardised definitions, which in turn provides increased scope for analysis. Moreover, the cost of establishing such definitions could be offset against the benefits of reusability.

- **Spatial Relations**

The set of build associations introduced in subsection 3.3.5 may be extended to include spatial-relations. These would be used for example, to integrate MATrA with CAD tools and to define properties associated with fault tolerance, such as segregation (maintenance of independence through use of a physical barrier between components) and separation (maintenance of independence by means of physical distance between components). A preliminary literature survey suggests a number of spatial relations may be of use; these are shown in Appendix E.

7.4.5 Specifying Requirements using the MATrA Natural Language Structure

An obvious use of the MNLS not considered in this thesis concerns the specification of textual requirements. Initial thoughts suggest that with some minor modifications, the structure could be used to express and partially validate certain properties of such statements. For instance, that they contain an imperative (such as must or shall) and that the singularity condition holds; i.e., the requirement is unambiguously expressed over *one* build element, and that said build element exists in the Product Data Synthesis. Moreover, were we to enrich the PDS with Predefined Aerospace Types in the manner described in 7.4.4, then the validity of values assigned to certain properties could be range checked.

7.4.6 Systems Engineering Process Issues for MATrA

Any traceability framework will be ineffectual without a well-defined mechanism for putting it into practice. MATrA raises several issues pertaining to its integration within a systems engineering environment that such mechanisms need to address. For instance, *who* should be given 'design authority' for managing and maintaining the Product Data Synthesis, *when* and how often should *tool2matra* be used to synchronise the CASE tool and Workspace data-sets and *how* are exceptions arising from this synchronisation to be dealt with. It is important to remember that traceability cannot be treated as a 'bolt-on'; as such, these and other process issues must be addressed *before* MATrA can be put to practical use.

7.4.7 Investigation of an Inverse Mapping Function (*matra2tool*)

To further integrate MATrA with the tool environment, an inverse function (*matra2tool*) capable of mapping data from the Workspace onto CASE tool data structures could be investigated. This would allow for *limited* editing to be performed within the Workspace itself, with results uploaded to the corresponding tool.

Early thoughts on definition of the function suggest the interface would take as its input parameters, an un-populated CASE tool data structure (uCDS) with a corresponding populated notation dependent structure (pNDS) and the Product Data Synthesis (PDS), and return a populated CASE tool data structure (pCDS).

pCDS *matra2tool* (uCDS, pNDS, PDS)

Following our discussion in 7.4.6, it should be noted that that this facility raises a number of additional process issues which would also need to be considered (e.g., alignment of the CASE tool and Workspace data sets).

7.4.8 Contiguous Case Study Across All Dimensions

Each of the structures considered in this thesis has been validated either through worked examples, or else by a more in depth case study (mostly conducted using material provided by practitioners from the aerospace industry). However, for a more thorough test of its usefulness (particularly in terms of scalability) the MATrA framework needs exposure to a contiguous example spanning all the traceability dimensions. This would call for the representation and linking of requirements, design, implementation, safety assessment and product management artifacts (including revisions and variants) at aircraft, system, item and hardware/software levels for two or more interacting systems. Only then could we begin to gauge the potential for practical application of MATrA.

7.4.9 Investigation of Analysis Objectives

The traceability Workspace and Product Data Synthesis are both potentially rich sources of information; in order to realise this potential, means are required for its extraction. These may include for example, mechanisms supporting impact analysis to determine the effects of change. However, given that MATrA structures have a formal foundation and therefore offer such broad scope for analysis, it would be worthwhile conducting a practitioner consultation to identify precise analysis needs.

7.4.10 Use of *tool2matra* to Optimise Workspace Revisions

While introducing the Configuration Model in subsection 5.5, it was remarked upon that 'equivalent' elements across revisions to Workspace models are actually represented by different objects. This is due to the assumed mapping from CASE tools into MATrA, which because of its theoretical treatment throughout, is intentionally simplistic. Thus for two models M_1 and M_2 containing objects Ob_1 and Ob_2 respectively, where M_2 'succeeds' M_1 and Ob_2 represents the same build element as Ob_1 (without modification), there clearly exists some redundancy. However, consideration could be given to

development of a more sophisticated function capable of reusing the same object in more than one revision. Given the limitations discussed in subsection 7.3.3, this appears to be an area with potential for relieving the Workspace 'overhead'.

7.4.11 Confinement of Persistent Workspace to Trace Associations

Continuing the optimisation theme, it would be interesting to consider the possibility of restricting *persistent* storage of Workspace elements to trace associations. Such a possibility is motivated by observations that the additional trace data (i.e., dependencies among models and their elements) is what actually differentiates the CASE tool and Workspace data sets. First impressions suggest *tool2matra* would need to ensure that whenever the Workspace became active, 'existing' elements were recreated (by repeating the mapping of CASE tool data onto corresponding meta-models) using the original object identifiers. This would allow instances of AerospaceEngineeringAssociation subtypes to be 'reunited' with the correct from and to objects.

7.4.12 Incorporation of Standards Knowledge into MATrA

Adherence to development and assessment processes set out in various standards is an important issue within the acrospace domain as evidence supporting claims of compliance often forms part of the safety argument. It has therefore been suggested that the potential for managing such processes within MATrA be explored, in particular the ability to associate and (possibly) perform checks against, individual process steps, the requirements on the data they are to produce and the Workspace artifacts that satisfy these criteria. Moreover, where a standard mandates use of a particular design feature (e.g., dual independent channels), these requirements may be linked to the appropriate PDS elements discharging them.

7.4.13 Use of a Commercial Tool as a Basis for Implementing MATrA

The functionality provided by commercial traceability tools (e.g., DOORS) has moved on rapidly during the course of our research. Hence, while ConceptBase was used in this thesis to provide a 'flavour' of automation, it would be worth investigating use of commercial tools as a basis for developing MATrA further, notably to enable implementation of the rules and constraints stated in Chapters Three to Five. Therefore apart from being able to represent the structures themselves, the richness of set and boolean operators (or a procedural extension language capable of replicating them) provided by a tool is of particular interest; a lack of such facilities (relative to OCL) prevents many formal aspects of MATrA from being realised in ConceptBase.

7.4.14 Re-Expression of Structures in EXPRESS

A first step towards development of a *tool2matra* mapping function would be to re-express the structures described in this thesis using EXPRESS (see subsection 2.2.2.2.7). EXPRESS was developed as part of the STEP framework (introduced in subsection 3.2.2) which provides a tool neutral format for data representation and exchange. It would of course be necessary to determine means of translating data from the CASE tools into this neutral format and thence to a format interpretable by the target

MATrA tool. However, as work by Riddle (2000) demonstrates, the actual mechanics of re-expressing current object-based representations of the structures in EXPRESS is unlikely to pose a problem.

7.5 Epilogue

We conclude that work in this thesis has been shown to provide the basis for a framework enabling traceability between CASE tools used by avionics engineers. The framework supports traceability across four dimensions using an integrated set of structures whose development and evaluation formed the main strands of our research. These structures are among the core *principles* on which the framework is based; the other principle relates to a function for populating a subset of framework structures using data transferred from CASE tools. Work towards realisation of this principle was not possible within the confines of a Doctoral programme; instead we identified credible evidence from current literature to support its feasibility. It is hoped the framework presented will contribute to the furtherance of traceability, both generally and within the aerospace industry.

References

Airbus, 2001 — Airbus Industrie - AM2085 : Method for Common Airbus Requirements Engineering (CARE)

Alford & Burns, 1976 — Alford, M. W. & Burns, I. F. - R Nets: A Graph Model For Real-Time Software Requirements, Proc. Symposium on Computer Software Engineering, Apr., pp. 97-108

Alford, 1977 — Alford, M. W. - A Requirements Engineering Methodology For Real-Time Processing Requirements, IEEE Trans. on Software Engineering, Jan., pp. 60-69

Alford, 1994 — Alford, M. W. - Types of Traceability, Requirenautics Quarterly, Oct., pp. 4-5

Alvarez & Castell, 1996 — Alvarez, J. & Castell, N. - Knowledge-Based Techniques For Software Requirements Validation, Uni Politècnica de Catalunya TR: LSI-96-65-R

Ambras & O'Day, 1988 — Ambras, J. & O'Day, V. - Microscope: A Knowledge Based Programming Environment, IEEE Software, May, pp. 50-58

Anderson & Lee, 1991 — Anderson, T. & Lee, P. A. - Fault Tolerance: Principles & Practice, 2nd Edition, Springer-Verlag

Anderson, 1989 — Anderson, Evan E. - A Heuristic For Software Evaluation & Selection, Software Practice & Experience, Aug., pp. 707-716

ANSI/IEEE Std. 830-1984, 1984 — ANSI/IEEE Guide To Software Requirements Specifications

Arango *et al.*, 1991 — Arango, G., Bruneau, L. Cloarec, J. & Feroldi, A. - A Tool Shell for Tracking Design Decisions, IEEE Software, Mar., pp. 75-83

Armstrong, 1993 — Armstrong, James R. - Systems Engineering Methods Compared, Proc. Annual Int'l Symposium - National Council on Systems Engineering, VA, USA, Jul., pp. 181-187

Ascent, 1997 — Ascent Logic - RDD-100 Marketing Material, Ascent Logic Corporation, Trinity Court, Batchworth Island, Church Street, Rickmansworth, Hertfordshire WD3 1RT, UK; obtained from http://www.alc.com

Attipoe, 1996 — Attipoe, Alfred K. - Modelling Design Documentation for Knowledge Traceability, Proc. 1996 Knowledge Acquisition Workshop; obtained from http://ksi.cpsc.ucalgary.ca/KAW/KAW96/KAW96Abstracts.html

BAe, 1999 — British Aerospace Defence Limited : Military Aircraft & Aerostructures - Top Level Requirements for a Mission Planning System for the Hawk Aircraft, BAe-BSY-DR-HWK-000194

Bailin *et al.*, 1990 — Bailin, S. C., Moore, J. M., Bentz, R. & Bewtra, M. - KAPTUR: Knowledge Acquisition for Preservation of Tradeoffs and Underlying Rationales, Proc. 5th Conf. on Knowledge Based Software Assistant, Liverpool NY, Sep.

Balzer *et al.*, 1983 — Balzer, R., Cheatham, T. & Green, C. - Software Technology In The 1990's: Using A New Paradigm, IEEE Computer, Nov., pp. 39-45

Barbaste & Desmons, 1988 — Barbaste, L. & Desmons, J. P. - Software Quality Assurance and Certification: The A320 Experience, Proc. 1st European Seminar on Software Quality, Brussels, Belgium, Apr., pp. 135-147

Barbier, 1994 — Barbier, F. - Traceability in the Object-Oriented Software Life Cycle, Proc. 13th Int'l Conf. on Technology of Object-Oriented Languages, Versailles, France, pp. 293-301

Barja *et al.*, 1995 — Barja, M. L., Fernandes, A. A. A., Paton, N. W., Williams, M. H., Dinn, A., and Abdelmoty, A. I.. - Design and Implementation of ROCK & ROLL: A

	Deductive Object-Oriented Database System, Information Systems, 20(3), pp. 185-211
Barnes, 1996	Barnes, J. - Programming in Ada 95, Addison-Wesley
Barnes, 1997	Barnes, J. - High Integrity Ada: The Spark Approach, Addison Wesley
Belford & Taylor, 1976	Belford, P.C. & Taylor, D. S. - Specification Verification: A Key To Improving Software Reliability, Proc. Symposium on Computer Software Engineering, Apr., pp. 83-96
Bell *et al.*, 1977	Bell, T. E., Bixler, D. C. & Dyer, M. E. - An Extendable Approach To Computer-Aided Software Requirements Engineering, IEEE Trans. on Software Engineering, Jan pp. 49-59
Bellagamba *et al.*, 1993	Bellagamba, L., Gernand, J. & Tribble, A. - Case Studies: Applications of QFD In Accord With Military Standard 499B, Proc. Annual Int'l Symposium - National Council on Systems Engineering, VA, USA, Jul., pp. 483-490
Bersoff & Davis, 1991	Bersoff, E. H. & Davis, Alan M. - Impacts of Life Cycle Models on Software Configuration Management, Communications of the ACM, 34(8), pp. 104-117
Bhattacharyya, 1992	Bhattacharyya, K. C. - Configuration Management for Quality Avionic Systems, Proc. National Workshop on Reliability Engineering, Bombay, India, Nov., pp. 67-69
Bigelow, 1988	Bigelow, J. - Hypertext and CASE, IEEE Software, Mar., pp. 23-27
Boehm, 1976	Boehm, B. - Software Engineering, IEEE Trans. on Computers, Dec., pp. 1226-1241
Boehm, 1981	Boehm, B. - Software Engineering Economics, Prentice-Hall
Bohner, 1995	Bohner, Shawn Anthony - A Graph Traceability Approach For Software Change Impact Analysis, George Mason University, USA, Ph.D. Thesis
Booch, 1994	Booch, G. - Object-Oriented Analysis and Design with Applications, Benjamin/Cummings
Booth, 1993	Booth, Stuart - Risk Assessment and Mitigation Planning Early in the Development Life Cycle, Proc. Annual Int'l Symposium - National Council on Systems Engineering, Arlington, VA, USA, Jul., pp. 507-512
Börstler & Janning, 1992	Börstler, Jürgen & Janning, Thorsten - Traceability Between Requirements and Design: A Transformational Approach, Proc. 16th Annual Int'l Computer Software and Applications Conf., Chicago, IL, USA, Sep., pp. 362-368
Börstler, 1994	Börstler, Jürgen - IPSEN: An Integrated Environment To Support Development For & With Reuse, in Schäfer, W., Prieto-Diaz, R. & Matsumoto M. (eds.): Software Reusability, Ellis-Horwood
Börstler, 1996	Börstler, Jürgen - User Centered Requirements Engineering in RECORD - An Overview, Proc. Nordic Workshop on Programming Environment Research, Aalborg, Denmark, May
Bosch, 1998	Bosch, Jan - Design Patterns as Language Constructs, Journal of Object-Oriented Programming, 11(2), pp. 18-32
Boyd, 1993	Boyd, Joanne Lee - Designing Reactive Systems For Strong Traceability, Carleton University Ph.D. Thesis, Jan.
Brodie, 1984	Brodie, M. - On the Development of Data Models, in Brodie, M., Mylopoulos, J., and Schmidt, J. (editors), On Conceptual Modelling, Perspectives from Artificial Intelligence, Databases and Programming Languages, Springer-Verlag, pp. 19-48

Brooks, 1987 — Brooks jr., F. P. - Essence and Accidents of Software Engineering, IEEE Computer, Apr., pp. 10-19

Brouse, 1992 — Brouse, Peggy Sharleen Lane - A Process For Use of Multimedia Information In Requirements Identification & Traceability, George Mason University, USA, Ph.D. Thesis, Feb.

Brown, 1991 — Brown, P. G. - QFD: Echoing The Voice of the Customer, AT&T Technical Journal, Mar/Apr., pp. 18-32

Brown, 1993 — Brown, Dean D. - Implementation of a Requirements Verification Database, Proc. Annual Int'l Symposium - National Council on Systems Engineering, Arlington, VA, USA, Jul., pp. 623-629

Brown, 1999 — Brown, N. - Evaluation of a CASE Tool for Support of Requirements Traceability in Dependable Avionics Systems, Department of Computing Science, University of Newcastle upon Tyne, MSc. Dissertation, Sep.

Buhr, 1995 — Buhr, R. J. A. - Use Case Maps: A New Model to Bridge the Gap Between Requirements and Design, Contribution to the Use Case Workshop at OOPSLA '95, Austin, TX, USA, Oct.; obtained from http://www.sce.carleton.ca/ftp/pub/UseCaseMaps/

Bussolini, 1971 — Bussolini, J. J. - High Reliability Design Techniques applied to the Lunar Module, Lecture Series No. 47 on Avionics Systems, London, Sep.

Buus *et al.*, 1997 — Buus, H., McLees, R. Orgun, M. Pasztor, E. & Schultz, L. - 777 Flight Controls Validation, IEEE Trans. on Aerospace and Electronic Systems, 33(2), Apr., pp. 656-667

Buzan, 1989 — Buzan, T. - Use Your Head (Revised Edition). London: BBC Books

Canfora *et al.*, 1995 — Canfora, Gerado, Lanubile, F. & Visaggio, G. - IESEM: Integrated Environment for Software Evolution Management, Int'l Journal of Software Engineering and Knowledge Engineering, 5(1), pp. 49-71

Card, 1988 — Card, David N. - Software Product Assurance: Measurement and Control, Information & Software Technology, Jul./Aug., pp. 322-330

Carré *et al.*, 1990 — Carré, B. A., Jennings, T. J., Maclennan, F. J., Farrow, P. F., Garnsworthy, J. R. - SPARK - The Spade Ada Kernel - 3rd ed., Program Validation Limited

Casemore, 1998 — Casemore, K. J. - Study of a CASE Tool to Support Traceability for a Dependable Avionics System, Final Year Project Dissertation, Department of Computing Science, University of Newcastle upon Tyne

Chandrasekaran *et al.*, 1993 — Chandrasekaran, B., Goel, A. & Iwasaki, Y. - Functional Representation as Design Rationale, IEEE Computer, Jan., pp. 48-56

Chen *et al.*, 1993 — Chen, S., Drake, J. M. & Tsai, W. T. - Database Requirements For A Software Engineering Environment: Criteria & Empirical Evaluation, Information & Software Technology, Mar., pp. 149-161

Chen, 1976 — Chen, P. - The Entity-Relationship Model: Toward a Unifying View of Data, ACM Trans. on Database Systems, Mar., pp. 9-36

Choi & Scacchi, 1989 — Choi, Song C. & Scacchi, Walt - Assuring the Correctness of Configured Software Descriptions, Software Engineering Notes, Nov., pp. 66-75

Chudge & Fulton, 1994 — Chudge, J. & Fulton, D. - Trust and Co-operation In Systems Development: Applying Responsibility Modeling To The Problem of Changing Requirements, Papers of the Workshop on Requirements Elicitation For Software-Based Systems, University of Keele, Staffordshire, UK, Jul.

Chung *et al.*, 1995 — Chung, L., Nixon, B. & Yu, E. - Using Non-Functional Requirements to Systematically Support Change, Proc. 2nd Int'l Symposium on

Requirements Engineering, York, UK, Mar.

Cimitile *et al.* 1992 — Cimitile, A., Lanubile, F. & Visaggio, G. - Traceability Based on Design Decisions, Proc. 8th Conf. on Software Maintenance, Orlando, Florida, USA, Nov., pp. 309-317

Coallier, 1994 — Coallier, François - How ISO 9001 Fits into the Software World, IEEE Software, Jan., pp. 98-100

Cockram *et al.*, 1998 — Cockram, T., Parker, R., Tiley, D., Woodward, H., Smith, J. & Vickers, A. - A System Requirements Traceability Model: An Industrial Application, Proc. Safety Critical Systems Symposium (SSS '98): Industrial Perspectives of Safety-Critical Systems, Birmingham, UK, Feb.

Codd, 1970 — Codd, E. F. - A Relational Model of Data for Large Shared Data Banks, Communications of the ACM, 13(6), Jun., pp. 377-387

Cogdell, 1999 — Cogdell, J. R. - Foundations of Electric Circuits, Prentice Hall

Collofello & Vennergrund, 1987 — Collofello, J. S. & Vennergrund, D. A. - Ripple Effect Analysis Based on Semantic Information, AFIPS Conf. Proc. (NCC), Vol. 56, pp. 675-682

Conklin & Yakemovic, 1991 — Conklin, J. E. & Yakemovic, K. C. B. - A Process-Oriented Approach to Design Rationale, Human-Computer-Interaction, 6(3-4), pp. 357-391

Conklin, 1987 — Conklin, Jeff - Hypertext: An Introduction and Survey, IEEE Computer, Sep., pp. 17-41

Conradi & Westfechtel (1998) — Conradi, R. & Westfechtel, B. - Version Models for Software Configuration Management, ACM Computing Surveys, Vol. 30., No. 2, Jun. pp. 232-282

Cook & Daniels, 1994 — Cook, S. & Daniels, J. - Designing Object Systems: Object-Modelling with Syntropy, Prentice-Hall

Corriveau & Hayashi, 1994 — Corriveau, Jean-Pierre & Hayashi, Craig - A Strategy For Realizing Traceability In An Object-Oriented Design Environment, Proc. 4th Int'l Workshop on Computer Aided Systems Theory, Ottawa, May., pp. 191-204

Corriveau, 1996 — Corriveau, Jean-Pierre - Traceability For Large Object-Oriented Projects, IEEE Computer, Sep., pp. 63-68

Coyne, 1993 — Coyne, Bob - Requirements Change Process Development, Proc. Annual Int'l Symposium - National Council on Systems Engineering, Arlington, VA, USA, Jul., pp. 391-387

Cross, 1996 — Cross, Gary - Tracking the Changing Face of System Development, Real-Time Magazine, 96/1, pp. 10-12

Cullyer *et al.*, 1991 — Cullyer, W. J., Goodenough, S. J. & Wichmann, B. A. - The Choice of Programming Languages for use in Safety-Critical Systems, Software Engineering Journal, 6(2), pp.51-58

Curran *et al.*, 1994 — Curran, P., O' Donoghue, P. G., Jackson, K., Hull, M. E. C. & Griffiths, L. - BORIS-R Specification of the Requirements of Large Scale Software Intensive Systems, Papers of the Workshop on Requirements Elicitation For Software-Based Systems, University of Keele, Staffordshire, Jul.

Cybulski & Reed, 1992 — Cybulski, J. L. & Reed, K. - A Hypertext Based Software Engineering Environment, IEEE Software, March, pp. 62-68

Czejdo *et al.*, 1992 — Czejdo, B., Embley, D. W. & Rusinkiewicz, M. - View Updates for an Extended Entity-Relationship Model, Information Sciences, No. 62, pp. 41-64

Dardenne *et al.*, 1993 — Dardenne, A., van Lamsweerde, A. & Fickas, S. - Goal-Directed Requirements Acquisition, Science of Computer Programming, Vol. 20, pp. 3-50

Date, 1995 — Date, C. J. - An Introduction to Database Systems, 6th edition, Addison-Wesley

Davis & Vick, 1977 — Davis, C. G. & Vick, C. R. - The Software Development System, IEEE Trans. on Software Engineering, Jan., pp. 69-84

Davis, 1990 — Davis, Alan. M. - Software Requirements Analysis & Specification, Prentice-Hall Inc.

Dawkins & Riddle, 2000 — Dawkins, S. & Riddle, S. - Managing and Supporting the use of COTS, Proc. of the 8th Annual Safety Critical Systems Symposium, Southampton, UK

Dawkins *et al.*, 1999 — Dawkins, S., Kelly, T., McDermid, J., Murdoch, J. & Pumfrey, D. - Issues in the Conduct of PSSA, Proceedings of the 17th International Safety Conference, Florida, USA

de Lemos *et al.*, 1995 — de Lemos, R., Saeed, A. & Anderson, T. - Analyzing Safety Requirements for Process-Control Systems, IEEE Software, May, pp. 42-52

Dean, 1992 — Dean, Edwin B. - Quality Function Deployment for Large Systems, Proc. 1992 Int'l Engineering Management Conf., Eatontown, NJ, USA, Oct.

Devanbu *et al.*, 1991 — Devanbu, P., Brachman, R. J., Selfridge, P. G. & Ballard, B. W. - LaSSIE - A Knowledge Based Software Information System, Communications of the ACM, 34(5), pp. 34-49

Diagne & Kordon, 1996 — Diagne, Alioune & Kordon, Fabrice - A Multi-Formalisms Prototyping Approach From Formal Description to Implementation of Distributed Systems, Proc. 7th Int'l Workshop on Rapid Systems Prototyping, Thessaloniki, Greece, Jun., pp. 102-107

Dick, 1999 — Dick, J. - Rich Traceability, Telelogic Technical Paper; obtained from http://www.telelogic.com/resources/

Distaso *et al.*, 1980 — Distaso, J., Manley, J., Stucki, L. & Munson, J. - Software Technology: Key Issues of the '80s, in COMPCON, Feb., pp. 387-389

Dobson & Strens, 1994 — Dobson, J. E. D. & Strens, R. - Enterprise Modelling as a Technique for Organisational Requirements Definition, Intelligent Systems Engineering, Spring, pp. 20-26

DoD, 1992 — Department of Defense (US) - Systems Engineering, Draft Military Standard 499b, Oct.

DoD, 1994 — Department of Defense (US) - Software Development and Documentation Standard, Military Standard 498; obtained from http://diamond.spawar.navy.mil/498/

Dömges & Pohl, 1998 — Dömges, R. & Pohl, K. - Adapting Traceability to Project-Specific Needs, Communications of the ACM, 41(12), pp. 54-62

Dömges *et al.*, 1998 — Dömges, R., Pohl, K. & Schreck, K. - A Filter-Mechanism for Method-Driven Trace Capture, Proc. 10th Int'l Conf. on Advanced Information Systems Engineering, Pisa, Italy, Jun.

Dorfman & Flynn, 1984 — Dorfman, M. & Flynn, R. F. - Arts - An Automated Traceability System, Journal of Systems & Software, 4(1), pp. 63-74

Dubois, 1994 — Dubois, E. - ALBERT at the Age of Two, Position Papers of the Dagstuhl Seminar on System Requirements Analysis: Management and Exploitation, Dagstuhl, Germany

Duke & Harrison, 1995 — Duke, D. & Harrison, M. - Mapping User Requirements To Implementations, Software Engineering Journal, Jan., pp. 13-20

Duvall, 1997 — Duvall, S. - Tool Supported Traceability for Development & Certification, Dpt. of Comp. Sci., University of Newcastle upon Tyne, MSc. Dissertation

Easterbrook *et al.*, 1994	Easterbrook, S, Finkelstein, A. Kramer, J. & Nuseibeh, B. - Co-ordinated Distributed ViewPoints: The Anatomy of a Consistency Check, Imperial College of Science Technology & Medicine, University of London, UK, Technical Report, TR 94/7
Eberlein *et al.*, 1997	Eberlein, A., Crowther, M. & Halsall, F. - Development of New Telecomms Services Using An Expert System, BT Tech Journal, Jan., pp. 217-223
Ecklund *et al.*, 1996	Ecklund, E. F., Delcambre, L. M. L. & Freiling, M. J. - Change Cases: Use Cases that Identify Future Requirements, 11th Annual Conf. on Object-Oriented Programming Systems Languages and Applications, in SIGPLAN Notices, 31(10), San Jose, California, USA, Oct., pp. 342-358
Edwards & Bergstein, 1993	Edwards, Michael & Bergstein, David - A Look at the Current Automated Capabilities of Traceability, Real-Time Applications Workshop, New York, USA, May, pp. 204-206
Elmasri & Navathe, 1997	Elmasri, R. & Navathe, S. B. - Fundamentals of Database Systems, 3rd Edition, Addison-Wesley
Emmerich *et al.*, 1999	Emmerich, W., Finkelstein, A., Montangero, C., Antonelli, S., Armitage, S. & Stevens, R. - Managing Standards Compliance, IEEE Trans. on Software Engineering, 25(6)
ESA, 1991	European Space Agency - ESA Software Engineering Standards, ESA PSS-05, ESA Publications
Escudie *et al.*, 1994	Escudie, A. , Lambolez, P. Y., Queille, J. P., Sedes, F. & Voidrot, J. F. - A Traceability-Based Model For an Integrated Maintenance Environment, Proc. Intelligent Multimedia Information Retrieval Systems & Management Conf., Toulouse, France, pp. 358-363
EUROCAE, 1992	European Organization for Civil Aviation Electronics - Software Considerations in Airborne Systems and Equipment Certification, EUROCAE document ED-12B, Dec. (Issued in the United States by the Requirements and Technical Concepts for Aviation Inc. as RATC document SC167/D0-178B)
EUROCAE, 1996a	European Organization for Civil Aviation Electronics - Certification Considerations For Highly-Integrated or Complex Aircraft Systems, EUROCAE document ARP 4754, Nov. (Issued in the United States by the Society of Automotive Engineers)
EUROCAE, 1996b	European Organization for Civil Aviation Electronics - Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment, EUROCAE document ARP 4761, Dec. (Issued in the United States by the Society of Automotive Engineers)
Evans, 1989	Evans, M. W. - The Software Factory, John Wiley & Sons
FAA, 2001	Federal Aviation Administration - Transport Airplane Fuel Tank System Design Review, Flammability Reduction and Maintenance and Inspection Requirements, Federal Register, Vol. 66, No. 88
Fan & Yih, 1999	Fan, Chin-Feng & Yih, Swu - Safety Markup Language, in Felici, M., Kanoun, K. & Pasquini, A. (eds.), Proc. Conf. on Computer Safety, Reliability and Security (SafeComp), France, Sep., pp. 177-186
Favre, 1994	Favre, C. - Fly-by-Wire for Commercial Aircraft: The Airbus Experience, International Journal of Control, Vol. 59, No. 1, pp. 139-157
Feather, 1991	Feather, Martin S. - Requirements Engineering: Getting Right From Wrong, in van Lamsweerde, A. & Fugetta, A. (eds.), 3rd European Software Engineering Conf., Milan, Italy, Oct., pp. 485-488
Fickas & Finkelstein, 1993	Fickas, S. & Finkelstein, A. - Requirements Engineering 1993, Proc. 1st Int'l Symposium on Requirements Engineering, San Diego, California,

	USA, Jan., pp. v-vi
Fiksel & Hayes-Roth, 1993	Fiksel, Joseph & Hayes-Roth, Frederick - Computer-Aided Requirements Management, Concurrent Engineering: Research & Applications, Jan., pp. 83-92
FIPSP, 1993	Federal Information Processing Standards Publication - Announcing the Standard for Integration Definition for Information Modeling (IDEF1X); obtained from http://www.idef.com/
Fischer & Walker, 1979	Fischer, K. F. & Walker, M. G. - Improved Software Reliability Through Requirements Verification, IEEE Trans. on Reliability, Aug., pp. 233-240
Fischer, 1991	Fischer, Wolf E. - CASE Seen From Both Sides of the Fence, in van Lamsweerde, A. & Fugetta, A. (eds.), 3rd European Software Engineering Conf., Milan, Italy, Oct., pp. 509-511
Flynn & Dorfman, 1990	Flynn, R. & Dorfman, M. - The Automated Requirements Traceability System (ARTS): An Experience of Eight Years, in Thayer, R. & Dorfman, M. (eds.), System & Software Requirements Engineering, IEEE Computer Society Press, pp. 423-438
Fragola & Spahn, 1973	Fragola, J. R. & Spahn. J. F. - The Software Error Effects Analysis : A Qualitative Design Tool, Proc. IEEE Symposium on Comp. S/W Rel., pp. 90-93
Fraser *et al.*, 1991	Fraser, M. D., Kamax, K. & Vaishnavi, V. K. - Informal and Formal Requirements Specification Languages: Bridging the Gap, IEEE Trans. on Software Engineering, May, pp. 454-464
Freedman & Weinberg, 1981	Freedman, D. P. & Weinberg, G. M. - A Checklist for Potential Side Effects of a Maintenance Change, in Parikh, G. (ed.), Techniques of Program and System Maintenance, pp. 93-100
Fyson & Boldyreff, 1998	Fyson, M. J. & Boldyreff, C. - Using Application Understanding to Support Impact Analysis, Software Maintenance: Research & Practice, Vol. 10, No. 2, pp. 93-110
Galle, 1996	Galle, Johan - HOORA: Hierarchical Object-Oriented Requirements Analysis for the European Space Agency, Journal of Object-Oriented Programming, Jun., pp. 38-46, 75
Garcia, 1994	Garcia, Lucy H. - A Tool For Design Traceability, Proc. National Aerospace and Electronics Conf., Dayton, Ohio, USA, Apr., pp. 807-813
Gardner, 1994	Gardner, Forrest K. - RayTracer: Traceability For Software Engineering, Proc. 3rd Symposium on the Assessment of Quality Software Development Tools, Washington, DC, USA, Mar., pp. 224-232
Garg & Scacchi, 1989	Garg, P. K. & Scacchi, W. - ISHYS : Designing an Intelligent Software Hypertext System, IEEE Expert, Autumn, pp. 52-62,
Garg & Scacchi, 1990	Garg, P. K. & Scacchi, W. - Hypertext System To Manage Software Life-cycle Documents, IEEE Software, May, pp. 90-98
Gieszl, 1992	Gieszl, Louis R. - Traceability For Integration, Proc. 2nd Int'l Conf. on Systems Integration, Morristown, New Jersey, USA, Jun., pp. 220-228
Gladden, 1982	Gladden, G. R. - Stop The Life-Cycle I Want To Get Off, Software Engineering Notes, Apr., pp. 35-39
Gogolla & Hohenstein, 1991	Gogolla, M. & Hohenstein, U. - Towards a Semantic View of an Extended Entity-Relationship Model, ACM Transactions on Database Systems, 16(3), pp. 369-416
Gogolla, 1994	Gogolla, M. - An Extended Entity-Relationship Model - Fundamentals and Pragmatics, Springer, Berlin, LNCS 767.

Goguen, 1996a — Goguen, J. A. - Formality and Informality in Requirements Engineering, Proc. 2nd Int'l Conf. on Requirements Engineering, Orlando, Florida, USA, Apr., pp. 2-10

Goguen, 1996b — Goguen, J. A. - Paramaterized Programming & Software Architecture, Proc. 4th Int'l Conf. on Software Reuse, Apr., pp. 2-11

Górski & Wardziński (1995) — Górski, J. & Wardziński, A. - Formalising Fault Trees, Proc. Safety-Critical Systems Symposium, Brighton, UK, pp. 310-327

Gossain, 1995 — Gossain, Sanjiv - Tracking Requirements in Object Development, Object Expo '95, London, UK, Sep., pp. 86-102

Gotel, 1995 — Gotel, O. - Contribution Structures For Requirements Traceability, Imperial College of Science, Technology & Medicine, University of London, UK, Ph.D. Thesis, Aug.

Grønbaek & Trigg, 1994 — Grønbaek, K. & Trigg, R. - Design Issues For Dexter-Based Hypermedia System, Communications of the ACM, Feb., pp. 40-49

Grant & Minker, 1992 — Grant, J. & Minker, J. - The Impact of Logic Programming on Databases, Communications of the ACM, Mar., pp. 66-81

Greenspan & McGowan, 1978 — Greenspan, Sol & McGowan, Clement - Structuring Software Development for Reliability, Microelectronics & Reliability, 17(1), pp. 75-84

Gries, 1997 — Gries, Michael J. - System Engineering For the 777 Autopilot System, IEEE Trans. on Aerospace and Electronic Systems, 33(2), Apr., pp. 649-655

Grigg & Henderson, 2000 — Grigg, A. & Henderson, N. - A Systematic Method for Development of Real-Time Systems, TR710, Department of Computing Science, University of Newcastle upon Tyne

Halasz & Schwartz, 1994 — Halasz, F. & Schwartz, M. - The Dexter Hypertext Reference Model, Communications of the ACM, Feb., pp. 30-39

Halpin, 1998 — Halpin, T. - Object Role Modeling, Handbook on Architectures of Information Systems, in Bernus, P., Mertins, K. & Schmidt G. (eds), Springer-Verlag, Berlin, pp. 81-101

Hammer & McLeod, 1981 — Hammer, M. & McLeod, D. - Database Description with SDM: a Semantic Data Model, ACM Transactions on Database Systems, 6(3), pp. 351--386

Han, 1995 — Han, Jun - A Document Based Approach to Software Engineering Environments, Proc. 5th Int'l CASE Symposium, Changsha, Hunan, China, Oct./Nov., pp. 128-133

Han, 1996 — Han, Jun - Supporting Impact Analysis and Change Propagation In Software Engineering Environments, University of Monash, Victoria, Australia, TR-96-09, Oct.

Han, 1997a — Han, Jun - Designing For Increased Software Maintainability, Proc. Int'l Conf. on Software Maintenance, Bari, Italy, Sep./Oct., pp. 278-286

Han, 1997b — Han, Jun - Traceability and Consistency Support in Computer-Aided Design Environments, Proc. of 5th Int'l Conf. on Computer Aided Systems Theory & Technology, Las Palmas de Gran Canaria, Spain, Feb., pp. 11-15.

Hansford *et al.*, 2000 — Hansford, G., Harrison, A. & Vickers, A. - Digital Advanced Radio for Trains (DART): The Safety Management & Engineering Case, Proc. of the Safety-Critical Systems Symposium, Redmill, F. & Anderson, T. (eds.), Southampton, UK, Feb., pp. 187-205

Harel, 1988 — Harel, D. - On Visual Formalisms, Communications of the ACM, Vol. 31, No. 5, May, pp. 514 - 530

Harker & Eason, 1993 — Harker, S. & Eason, K. - The Change and Evolution of Requirements as a Challenge to the Practice of Software Engineering, Proc. 1st Int'l

Symposium on Requirements Engineering, San Diego, California, USA, Jan., pp. 266-272

Harris & Candy, 1999 — Harris, D. & Candy, L. - Evaluation in the SEDRES Project: Measuring the Effectiveness of Model Data Exchange between Systems Engineering Tools, Proc. 9th International Symposium of the International Council on Systems Engineering (INCOSE), Brighton, UK, Jun.

Hatley & Pirbhai, 1987 — Hatley, D. J. & Pirbhai, I. A. - Strategies For Real Time System Specification, New York: Dorset House

Haveman & Pearson, 1997 — Haveman, J. & Pearson, S. - Tracing Transactions, University of Newcastle upon Tyne/BAe Dependable Computing Systems Centre Technical Report, DCSC/TR/97/1, Jan.

Haveman *et al.*, 1997 — Haveman, J., Paynter, S. and Armstrong J. M. - A Transaction Model for Real-Time Systems. TR607, Department of Computing Science, University of Newcastle upon Tyne

Hermens, 1991 — Hermens, L. - A Software Specification Tool For Increased Requirements Traceability, University of Idaho, USA, MSc. Dissertation

Herzog & Scerri, 1998 — Herzog, E. & Scerri, P. -The SEDRES Draft Standard /2 Data Model, SEDRES Deliverable W.4.6.1, May

Herzog & Törne, 1999 — Herzog, E. & Törne, A. - A Seed for a STEP Application Protocol for Systems Engineering, Proc. Conference & Workshop on Engineering of Computer-Based Systems (ECBS '99), Nashville, TN, Mar. pp. 174-180

Hill, 1996 — Hill, Mike - Parasitic Languages For Requirements, Proc. 2nd Int'l Conf. on Requirements Engineering, Orlando, Florida, USA, Apr., pp. 69-75

Hodge, 1994 — Hodge, J. D. - Parametric Cost Estimating, in Readings in Program Control, Hoban, Francis T., Lawbaugh, William M. & Hoffman, Edward J. (eds.), NASA SP-6103

Hoffman, 1990 — Hoffman, Daniel - On Criteria For Module Interfaces, IEEE Trans. on Software Engineering,, May, pp. 537-542

Hoffnagle & Beregi, 1985 — Hoffnagle, G. & Beregi, W. - Automating the Software Development Process, IBM Systems Journal, 24(2), pp. 102-120

Horrowitz & Williamson, 1986 — Horrowitz, Ellis & Williamson, R. C. - SODOS: A Software Documentation Support Environment, IEEE Trans. on Software Engineering, Aug., pp. 849-859

Hsia *et al.*, 1994 — Hsia, P., Samuel, J., Gao, J. & Kung, D. - Formal Approaches to Scenario Analysis, IEEE Software, March

Hugge & Lang, 1995 — Hugge, P. B. & Lang, J. D. - Results of Implementing A Disciplined Avionic Development Process: Advanced Design for Quality Avionic Systems (ADQAS), Proc. of the National Aerospace & Electronics Conf., Ohio, USA, pp. 220-226

Hughes & Martin, 1998 — Hughes, T. & Martin, C. - Design Traceability of Complex Systems, Proc. 4th Annual Symposium on Human Interaction with Complex Systems, Ohio, USA, Mar., pp. 37-41

Hughes *et al.*, 1995 — Hughes, J., Rodden, T., Rouncefield, M. & Sommerville, I. - Presenting Ethnography in the Requirements Engineering Process, Proc. 2nd Int'l Symposium on Requirements Engineering, York, UK, Mar., pp. 27-34

Hull *et al.* (1991) — Hull, M. E. C., O'Donoghue, P. G. & Hagan, B. J. - Development Methods for Real-Time Systems, The Computer Journal, Vol. 34, No. 2, pp. 164-172

Humphrey, 1988 — Humphrey, Watts S. - Characterizing the Software Process: A Maturity Framework, IEEE Software, Mar., pp. 73-79

IEC, 1985 — International Electrical Commission - Analysis Techniques for System Reliability: Procedures for Failure Modes and Effects Analysis, International Standard 812, IEC

IEC, 1998 — International Electrical Commission - Functional Safety of Electrical/Electronic/Programmable Electronic Safety Related Systems, International Standard 61508

IEEE, 1977 — Institute of Electrical & Electronics Engineers - Special Issue on Requirements Analysis and Requirements Tools, IEEE Trans. on Software Engineering , Jan., SE-3, No. 1

IEEE, 1987 — Institute of Electrical & Electronics Engineers - Guide to Software Configuration Management, IEEE STD 1042-1987

IEEE, 1992 — Institute of Electrical & Electronics Engineers - Recommended Practice for the Evaluation and Selection of CASE Tools, IEEE Std 1209-1992, Dec.

IEEE, 1993a — Institute of Electrical & Electronics Engineers - Standard For Software Maintenance, Jun.

IEEE, 1993b — Institute of Electrical & Electronics Engineers - Systems Engineering of Computer Based Systems, Report of the IEEE Working Group on the State of Practice into Systems Engineering of Computer-Based Systems, IEEE Computer, 26(11), pp. 54-65

Ihme *et al.*, 1995 — Ihme, T., Niemelä, E., Salmela, M. & Seppanen, V. - Object-Oriented Re-engineering of Embedded Software, Mechatronics, 5(1), pp. 73-86

Ince *et al.*, 1993 — Ince, D., Sharp, H. & Woodman, M. - Introduction To Software Project Management and Quality Assurance, McGraw-Hill

Ince, 1994 — Ince, Darrel - ISO 9001 and Software Quality Assurance, McGraw-Hill

INCOSE, 1996 — International Council on Systems Engineering - Systems Engineering Capability Assessment Model (version 1.50), Jun

INCOSE, 1999 — International Council on Systems Engineering - Results of Requirements Tools Survey (Revised); obtained from http://www.incose.org/workgrps/tools/rqsrvifo.html

Integrated, 1997 — Integrated Chipware - Requirements Traceability Management, User Documentation

ITU-T, 1993 — International Telecommunications Union - Recommendation Z.120: Message Sequence Chart (MSC)

Jackson & Renton, 1993 — Jackson, Scott & Renton, Meg - First Order System Engineering: A Case Study, Proc. Annual Int'l Symposium - National Council on Systems Engineering, Arlington, VA, USA, Jul., pp. 55-61

Jackson, 1986 — Jackson, K. - Mascot 3 and Ada, Software Engineering Journal, May, pp. 121-135

Jackson, 1991 — Jackson, Justin - A Keyphrase Based Traceability Scheme, Tools and Techniques For Maintaining Traceability During Design, IEE Colloquium, UK Digest Number: 1991/180, Dec., pp. 2/1-2/4

Jacobs & Kethers, 1994 — Jacobs, Stephen & Kethers, Stefanie - Improving Communication & Decision Making within Quality Function Deployment, Proc. 1st Int'l Conf. on Concurrent Engineering, Research and Applications, Pennsylvania, USA

Jacobson *et al.*, 1993 — Jacobson, I., Christerson, M., Jonsson, P. & Overgaard, G. - Object-Oriented Software Engineering - A Use Case Driven Approach, Addison-Wesley

Jarke *et al.*, 1995 — Jarke, M., Gallersdörfer, R., Jeusfeld, M., Staudt, M. & Eherer, S. - ConceptBase - A Deductive Object Base for Meta Data, Journal of

	Intelligent Information Systems, Mar., pp. 167-192
Jayaratna, 1994	Jayaratna, N. - Understanding and Evaluating Methodologies, NIMSAD, A Systematic Framework, McGraw-Hill
Jenkins, 1994	Jenkins, D. - Designers Using Co-operative Knowledge, IEE Colloquium on Issues of Co-operative Working in Concurrent Engineering, Digest No. 1994/177, Oct., pp. 8/1- 8/3
Jenkins, *et al.*, 1997	Jenkins, D., Lees, B., Livingstone, D. & Reglinslki, A. - Managing the Safety Argument Using A Memory Prosthesis, Daniel, P. (ed.), Proc. 16th Int'l Conf. on Computer Safety, Reliability and Security, York, UK, pp. 98 -110
Johnson & Merrithew, 1978	Johnson, L. A. & Merrithew, P. B. - Requirements/Design Analysis and Traceability, Proc. National Aerospace and Electronics Conf., Dayton, Ohio, USA, May, pp. 1130
Johnson *et al.*, 1991	Johnson, W., Feather, M. & Harris, D. - Integrating Domain Knowledge, Requirements and Specifications, Journal of Systems Integration, Vol. 1, pp. 283-320
Johnson *et al.*, 1992	Johnson, W. L., Feather, M. S. & Harris, D. R. - Representation and Presentation of Requirements Knowledge, IEEE Trans. on Software Engineering, 18(10), Oct., pp. 853-869
Johnson *et al.*, 1999	Johnson, J. F. E. , Luise, F., Loeuillet, J-L., Inderst, M., Nilsson, B., Torne, A., Candy, L. & Harris, D. - The Future System Engineering Data Exchange Standard STEP AP-233: Sharing the Results of the SEDRES Project, Proc. of 9th INCOSE Symposium, Brighton, UK
Johnson, 1997	Johnson, J. F .E. - The SEDRES Project (Systems Engineering Data Representation & Exchange); Extending STEP from Structural Definition To Product Functionality, Proc. 8th Int'l Conf. on CALS & Electronic Commerce in Europe, Frankfurt, Germany, Sep., pp. 92-107
Johnson, 1998	Johnson, J. F. E. - The SEDRES Project: Producing a Data Exchange Standard Supporting Integrated Systems Engineering, Proc. of 8th INCOSE Symposium, Vancouver, Canada, pp. 367-374
Johnson, 2000	Johnson, J. F .E. - The Latest Developments in Design Data Exchange: Towards Fully Integrated Aerospace Design Environments, Proc. of 22nd International Congress of Aeronautical Sciences, Harrogate, UK
Jones, 1990	Jones, C. B. - Systematic Software Development Using VDM, Prentice-Hall
Kaindl, 1993	Kaindl, H. - The Missing Link In Requirements Engineering, Software Engineering Notes, Apr., pp. 30-39
Kalinsky *et al.*, 1989	Kalinsky, D., Shilo, R. & Avnur, A. - Sunk Without A Trace, Systems Int'l, Apr., pp. 71-74
Karat & Bennett, 1991	Karat, J. & Bennett, J. L. - Using Scenarios in Design Meetings - A Case Study Example. in Karat, J. (ed.), Taking Software Design Seriously: Practical Techniques for Human-Computer Interaction Design, Academic Press
Kelley, 1990	Kelley, C. - Does It Fit the Bill?, Systems International, Jun., pp. 32-34
Kelly & McDermid, 1997	Kelly, T. P. & McDermid, J. A. - Safety Case Construction and Reuse using Patterns, Proceedings of the 14th International Conference on Computer Safety, Reliability and Security (SafeComp '97), York, Sep. pp 55-69
Kelly & McDermid, 1999	Kelly, T. P. & McDermid, J. A. - A Systematic Approach to Safety Case Maintenance, Proceedings of the 16th International Conference on Computer Safety, Reliability and Security (SafeComp '99), Toulouse, France, Sep. pp 13-26

Kenny, 1996 — Kenny, Christy - Requirements Traceability; obtained from http://www.cs.usask.ca/grads/cab130/856/trace.ps

Keys, 1991 — Keys, Ellen - A Workbench Providing Traceability In Real-Time System Development, Tools and Techniques For Maintaining Traceability During Design, IEE Colloquium, UK Digest Number: 1991/180, Dec., pp. 3/1-3/2

King *et al.*, 2000 — King, S., Hammond, J., Chapman, R. & Pryor, A. - Is Proof More Cost-Effective Than Testing?, IEEE Transactions on Software Engineering, 26(8), pp. 675- 695

Klein, 1993a — Klein, Mark - Capturing Design Rationale In Concurrent Engineering Teams, IEEE Computer, Jan., pp. 39-47

Klein, 1993b — Klein, Mark - Supporting Conflict Management in Cooperative Design Teams, Journal of Group Decision & Negotiation, No. 2, pp. 259-278

Klein, 1997a — Klein, Mark - An Exception Handling Approach to Enhancing Consistency, Completeness and Correctness in Collaborative Requirements Capture, Journal of Concurrent Engineering: Research & Applications, Mar.

Klein, 1997b — Klein, Mark - Capturing Geometry Rationale for Collaborative Design, Proc. 6th Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE '97), Massachusetts, USA, Jun.

Kotonya & Sommerville, 1998 — Kotonya, G. & Sommerville, I. - Requirements Engineering - Processes and Techniques, John Wiley & Sons Ltd.

Kunz & Rittel, 1970 — Kunz, W. & Rittel, H. - Issues as Elements of Information Systems, Working Paper No. 131, University of Berkeley, California, USA, Center for Planning and Development Research

Kydd *et al.*, 1994 — Kydd, S. Dyke, A. & Jenkins D. - Hypermedia Version Support for the On-Line Design Journal, Proc. CSCW Workshop on Collaborative Hypermedia Systems, North Carolina, USA

Kyng, 1995 — Kyng, M. - Creating Contexts for Design, in Carroll, J. M. (ed.), Scenario-Based Design, Envisioning Work & Technology in System Development, Wiley-

Laitinen, 1992 — Laitinen, K. - Document Classification for Software Quality Systems, Software Engineering Notes, Oct., pp. 32-39

Landes & Studer, 1995 — Landes, D. & Studer, R. - The Treatment of Non-Functional Requirements In MIKE, Proc. 5th European Software Engineering Conf., Sitges, Spain, Sep., pp. 294-306

Lano, 1979 — Lano, R. J. A. - Techniques for Software & System Design, TRW Series on Software Technology, Vol. III, North-Holland

Lanubile & Visaggio, 1995 — Lanubile, F. & Visaggio, G. - Decision Driven Maintenance, Software Maintenance: Research & Practice, Vol. 7, pp. 91-115

Laprie, 1989 — Laprie, J. C. - Dependability: A Unifying Concept for Reliable Computing and Fault Tolerance, in Anderson, T. (ed.), Dependability of Resilient Computers, BSP Professional Books, pp. 1-28

Laubengayer & Spearman, 1994 — Laubengayer, R. C. & Spearman, J. S. - A Model of Pre-Requirements Specification Traceability in the Department of Defense, Naval Postgraduate School, Monterey, California, USA, MS Dissertation, Jun.

Lee & Yen, 1993 — Lee, J. & Yen, J. - Enhancing the Software Life-Cycle of Knowledge Based Systems Using A Task Based Specification Methodology, Int'l Journal of Software Engineering & Knowledge Engineering, 3(1), pp. 3-15

Lee, 1991 — Lee, J. - Extending the Potts and Bruns Model for Recording Design Rationale, Proc. 13th Int'l Conf. on Software Engineering, TX, USA, May,

pp. 114-125

Lefering, 1993 — Lefering, Martin - An Incremental Integration Tool Between Requirements Engineering and Programming in the Large, Proc. 1st Int'l Symposium on Requirements Engineering, San Diego, California, USA, Jan., pp. 82-89

Lehman & Belady, 1985 — Lehman, M. M. & Belady, L. A. - Program Evolution: Processes of Software Change, London: Academic Press

Leite *et al.*, 1997 — Leite, J., Rossi, G., Balaguer, F., Maiorana, V., Kaplan, G., Hadad, G. & Oliveros, A. - Enhancing A Requirements Baseline With Scenarios, Proc. 3rd Int'l Symp. on Requirements Engineering, MD, USA, Jan., pp. 44-53

Leveson & Harvey, 1983 — Leveson, N. G. & Harvey, P. R. - Software Fault Tree Analysis, Journal of Systems and Software, vol. 3, pp. 173-181

Leveson & Reese, 1998 — Leveson, N. & Reese, J. - SpecTRM: A Toolset to Support the Safeware Methodology, Proc. 16th Int'l System Safety Conf., Seattle, USA, Sep., pp. 256 - 262

Leveson, 1995 — Leveson, N. G. - Safeware: System Safety and Computers, Addison-Wesley

Lindsay & Traynor, 1998 — Lindsay, P. & Traynor, O. - Supporting Fine-Grained Traceability in Software Development Environments, University of Queensland Technical Report, No. 98-10, Jul.; obtained from http://svrc.it.uq.edu.au

Lindvall, 1997 — Lindvall, M. - An Empirical Study of Requirements-Driven Impact Analysis in Object-Oriented Software Evolution, Linköping University, Sweden, Ph.D. Thesis

Liu *et al.*, 1993 — Liu, L. Robson, D. & Ellis, R. - Regression Testing Database Model, Proc. 4th European Software Engineering Conf., Garmisch-Partenkirchen, Germany, Sep.

Lubars *et al.*, 1993 — Lubars, M., Potts, C. & Richter, C. A - Review of the State of the Art In Requirements Modelling, Proc. 1st Int'l Symposium on Requirements Engineering, California, USA, Jan., pp. 2-14

Lucey, 1992 — Lucey, T. - Quantitative Techniques: 4th Edition, DP Publications Ltd.

Lueders, 1984 — Lueders, G. - Verification Techniques for Improving Software Quality Through Automated Requirements Databases, Proc. 6th Digital Avionics Systems Conf., MD, USA, Dec., pp. 309-311

Luqi, 1990 — Luqi - A Graph Model For Software Evolution, IEEE Trans. on Software Engineering, Aug., pp. 917-927

Macaulay, 1992 — Macaulay, Linda - Requirements Capture As A Cooperative Activity, Proc. 1st Int'l Symposium on Requirements Engineering, San Diego, California, USA, pp. 174-181

MacLean *et al.*, 1991 — MacLean, A., Young, R., Bellotti, V. & Moran, T. - Questions, Options and Criteria: Elements of Design Space Analysis Human Computer Interaction, 6(3-4), pp. 201-250

Madhavji, 1992 — Madhavji, N. - Evolution Environment: The Prism Model of Changes, IEEE Trans. on Software Engineering, May, pp. 380-392

Maier, 1993 — Maier, M. - Integrated Modeling: An Avionics Case Study, Proc. Annual Int'l Symposium - National Council on Systems Engineering, VA, USA, Jul., pp. 151-158

Mair & Birdsall, 1992 — Mair, W. A. & Birdsall, D. L. - Aircraft Performance, Cambridge University Press

Martin *et al.*, 1993 — Martin, R., Proietto, A., Scardia, B. & Szymanski, J. - Heuristics Driven Real Time Software Design, IFIP Trans. Computer Science and Technology, Vol. 39, pp. 383-400

Mason & Saeed, 1998 — Mason, P. & Saeed, A. - Tracing Support for Safety Properties: An Object-Oriented and Deductive Approach, Proc. 16th Int'l System Safety Conference, Seattle, WA, Sept.

Mason, 1996 — Mason, P. - A Database Tool To Support Traceability For Dependable Avionic Systems, Department of Computing Science, University of Newcastle upon Tyne, MSc. Dissertation

Mattsson & Elmqvist, 1998 — Mattsson, S. E. & Elmqvist, H. - An Overview of the Modeling Language Modelica, Eurosim '98 Simulation Congress, Helsinki, Finland

Mays *et al.*, 1985 — Mays, R., Orzech, L., Ciarfella, W. & Phillips, R. - PDM A Requirements Methodology For Software System Enhancements, IBM Systems Journal, No. 2, pp. 134-149

McDermid & Pumfrey, 1994 — McDermid, J. A. & Pumfrey, D. J., A Development of Hazard Analysis to aid Software Design, COMPASS '94: Proc. of the Ninth Annual Conf. on Computer Assurance, Gaithersburg, MD, pp. 17-25

McFarland *et al.*, 1997 — McFarland, G., Rudmik, A., Lange, D. - Object-Oriented Database Management Systems Revisited, DoD Data & Analysis Centre for Software State-of-the-Art-Report (Revised), Dec. 1997

McKay *et al.*, 1996 — McKay, A., Erens, F. & Bloor, M. - Relating Product Definition and Product Variety, Research in Engineering Design, Vol. 63, No. 2, pp. 63-80

Mejzak, 1990 — Mejzak, R. - A Traceable Systems Engineering Methodology, Proc. 9th Digital Avionics Conf., Virginia Beach, VA, USA, Oct., pp. 474-479

Minker, 1988 — Minker, J. - Perspectives in Deductive Databases, Logic Programming, No. 5, pp. 33-60

MoD, 1985 — Ministry of Defense (UK) - Modular Approach to Software Construction, Operation and Test - MASCOT, Defence Standard 00-17, Oct.

MoD, 1996 — Ministry of Defense (UK) - Safety Management Requirements for Defence Systems Containing Programmable Electronics, Second Draft Defence Standard 00-56, Aug.

MoD, 1997 — Ministry of Defense (UK) - The Procurement of Safety Related Software in Defence Equipment, (Part 1: Requirements; Part 2: Guidance), Interim Defence Standard 00-55, Apr.

Monk *et al.*, 1995 — Monk, S., Sommerville, I., Pendaries, J. M. & Durin, B. - Supporting Design Rationale For System Evolution, Cooperative Systems Engineering Group, University of Central Lancashire, Technical Report TR/17/95

Moore, 1993 — Moore, K. G. - Tracing Requirements into Implementation Environments, Proc. 13th Structured Development Forum: Innovation in Software Engineering, Philadelphia, USA, Aug., pp. 303

Moores & Champion, 1994 — Moores, T. T. & Champion, R. E. M. - Software Quality Through the Traceability of Requirements Specifications, Proc. 1st Int'l Conf. on Software Testing, Reliability and Quality Assurance, New Delhi, India, Dec., pp. 100-104

Mordechai, 1994 — Mordechai, Ben-Manachem - Software Configuration, Management Guidebook, McGraw-Hill

Morris *et al.*, 1994 — Morris, P., Coombes, A. & McDermid, J. - Requirements and Traceability, Proc. 1st Int'l Workshop on Requirements Engineering: Foundation of Software Quality, Utrecht, The Netherlands, Jun., pp. 82-87

Morris *et al.*, 1995 — Morris, P., Masera, M., & Wilikens, M. - Industrial Workshop on Requirements Engineering, Ispra, Italy, Oct.

Mosley, 1992 — Mosley, Vicky - How To Assess Tools Efficiently and Quantitatively, IEEE

	Software, May, pp. 29-32
Muller, 1997	Muller, Pierre-Alain - Instant UML, Wrox Press Ltd.
Mullery, 1979	Mullery, G. - A Method for Controlled Requirements Specifications, Proc. International Conference on Software Engineering, Munich, Germany, pp. 126-135
Mylopoulos *et al.*, 1990	Mylopoulos, J., Borgida, A., Jarke, M. & Koubarakis, M. - TELOS: Representing Knowledge about Information Systems, ACM Trans. on Information Systems, 8(4), Oct., pp. 325-362
Mylopoulos *et al.*, 1992	Mylopoulos, J., Chung, L. & Nixon, B. - Representing and Using Non-functional Requirements: A Process Oriented Approach, IEEE Trans. on Software Engineering, 18(6), pp. 483-497
NASA, 1993	National Aeronautics and Space Administration - Software Formal Inspection Standard (NASA-Std-2202),
Neely & Hartley, 1993	Neely, M. & Hartley, J. - SYNERGE: A Tool for Managing System Engineering Information, Proc. Annual Int'l Symposium - National Council on Systems Engineering, VA, USA, Jul., pp. 231-238
Nejmeh *et al.*, 1989	Nejmeh, B. A., Dickey, T. E. & Wartik, S. P. - Traceability Technology at the Software Productivity Consortium, Proc. IFIP 11th World Computer Congress, San Francisco, CA, USA, Aug./Sep., pp. 981-984
Ni *et al.*, 1994	Ni, D. C., Martinez, J., Eccles, D., Thomas, D. & Lai, P. K. M. - Process Automation with Enumeration and Traceability Tools, Proc. Int'l Conf. on Industrial Technology, Canton, China, pp. 361-365
Nixon *et al.*, 1987	Nixon, B., Chung, L., Lauzon, D., Borgida, A., Mylopoulos, J. & Stanley, M. - Implementation of a Compiler for a Semantic Data Model: Experiences with Taxis. In Proc. of ACM/SIGMOD
Oliver, 1994	Oliver, D. - A Draft Integration of Information Models: Complement Model and Oliver Model, Proc. of Tutorial and Workshop on Systems Engineering of Computer-Based Systems, pp. 44-69
Palmer & Evans, 1994	Palmer, J. D. & Evans, R. P. - An Integrated Semantic and Syntactic Framework For Requirements Traceability, Proc. Complex Systems Engineering Synthesis and Assessment Technology Workshop, Washington, DC, USA, Jul., pp. 9-14
Palmer, 1997	Palmer, J. D. - Traceability, in Thayer, R. H. & Dorfman, M. (eds.), Software Requirements Engineering (2nd Edition), IEEE Computer Society Press Tutorial, pp. 364-373
Papaioannou & Theodoulidis, 1996	Papaioannou, V. & Theodoulidis, B. - Hypermedia Environment for Requirements Engineering, Proc. 7th Workshop on the Next Generation of CASE Tools, Heraklian, Crete, May.
Parent *et al.*, 1989	Parent, C., Rolin, H., Yetongnon, K. & Spaccapietra, S. - An ER Calculus for the Entity-Relationship Complex Model. In Frederick H. Lochovsky, (editor), Proc. 8th Int. Conf. on Entity-Relationship Approach, pp. 75-98
Patel *et al.*, 1993	Patel, B., Tamanaha, D. & Rudzik, L. - Real Time Systems/Software Methodologies For Large Aerospace Systems, Proc. Annual Int'l Symposium - National Council on Systems Engineering, Arlington, VA, USA, Jul., pp. 113-120
Paulk *et al.*, 1993	Paulk, M., Curtis, B., Chrissis, M., & Weber, C. - Capability Maturity Model, Version 1.1, IEEE Software, Jul., pp. 18-27
Paulk, 1995	Paulk, M. - How ISO 9001 Compares with the CMM, IEEE Software, Jan., pp. 74-83

Paynter, 1995 — Paynter, S. E. - Structuring the Semantic Definitions of Graphical Design Notations, Software Engineering Journal, May, pp. 105-115

Paynter, 2000 — Paynter, S. E. - RTN-SL: The Real-Time Network Specification Language, MBDA Technical Report DR 20656, Nov.

Pearson & Rowlands, 1996 — Pearson, S. & Rowlands, M. - Airbus Traceability Case Study, University of Newcastle upon Tyne/BAe Dependable Computing Systems Centre Technical Report, TR DCSC/TR/96/16, Jan.

Pearson & Saeed, 1995 — Pearson, S. & Saeed, A. - Information Structures For Traceability For Dependable Avionic Systems, University of Newcastle upon Tyne/BAe Dependable Computing Systems Centre Technical Report, TR DCSC/TR/95/10

Pearson & Saeed, 1996 — Pearson, S. & Saeed, A. - A Traceability Method - Preliminary Guidance, University of Newcastle upon Tyne/BAe Dependable Computing Systems Centre Technical Report, DCSC/TR/96/2, Feb.

Pearson *et al.*, 1998 — Pearson, S., Riddle, S. & Saeed, A. - Traceability for the Development & Assessment of Safe Avionic Systems". Proc. of 8th INCOSE Symposium, Vancouver, Canada

Pearson, 1996 — Pearson, Justin K. - Requirements, Traceability and Formal Software Development or a Further Analysis of Requirements Traceability, University of London, Oct.; obtained from ftp://ftp.dcs.rhbnc.ac.uk/pub/Justin.Pearson/traceability.ps

Peckham & Maryanski, 1988 — Peckham, J. & Maryanski, F. - Semantic Data Models, ACM Computing Surveys, Vol. 20., No. 3, pp.153-189

Pena-Mora, 1995 — Pena-Mora, F., Sriram, D. & Logcher, R. - Design Rationale for Computer-Supported Conflict Mitigation, Journal of Computing in Civil Engineering, Vol. 9, No. 1, pp. 57-72

Pierce, 1978 — Pierce, Robert A. - A Requirements Tracing Tool, ACM Software Engineering Notes, Nov., pp. 53-60

Pirnia & Hayek, 1981 — Pirnia, S. & Hayek, M. J. - Requirements Definition Approach for an Automated Requirements Traceability Tool, Proc. National Aerospace and Electronics Conf., Dayton, Ohio, USA, Vol. 1, May, pp. 389-394

Plant & Tsoumpas, 1995 — Plant, R. & Tsoumpas, P. - A Survey of Current Practice In Aerospace Software Development, Information & Software Technology, 37(11), pp. 623-636

Pohl & Haumer, 1995 — Pohl, K. & Haumer, P. - HYDRA: A Hypertext Model for Structuring Informal Requirements Representations, Proc. 2nd Int'l Workshop on Requirements Engineering: Foundation of Software Quality (REFSQ '95), Jyväskylä, Finland

Pohl & Jacobs, 1994 — Pohl, K. & Jacobs, S. - Concurrent Engineering: Enabling Traceability and Mutual Understanding, Concurrent Engineering: Research & Applications, 2(4), pp. 279-290

Pohl, 1996 — Pohl, K. - Process Centered Requirements Engineering, Research Studies Press

Polack, 1990 — Polack, A. - Practical Applications of CASE Tools on DoD Projects, ACM SIGSOFT Software Engineering Notes, Vol. 15, No. 1

Popov *et al.*, 2001 — Popov, P., Strigini, L., Riddle, S. & Romanovsky, A. - Protective Wrapping of OTS Components, Proc., 4th ICSE Workshop on Component-Based Software Engineering, Toronto, Canada

Potts & Bruns, 1988 — Potts, C. & Bruns, G. - Recording the Reasons for Design Decisions, Proc. 10th Int'l Conf. on Software Engineering, pp. 418-427

Potts *et al.* 1994	Potts, C., Takahashi, K. & Anton, A. - Inquiry-Based Requirements Analysis, IEEE Software, 2(11):21-32, March
Potts, 1994	Potts, Colin - Inquiry Based Requirements Analysis, IEEE Software, Mar., pp. 21-32
Premerlani, 1994	Premerlani, W. - Object Model Transformations, Proc. Object Expo Europe Conf., London, UK, Sep., pp. 237.240
Prowell & Poore, 1998	Prowell, S. & Poore, J. - Sequence-Based Software Specification of Deterministic Systems, Software Practice & Experience, Mar., pp. 329-344
Pyle *et al.*, 1993	Pyle, I., Hruschka, P., Lissandre, M. & Jackson, K. - Real-Time Systems: Investigating Industrial Practice, John Wiley Ltd
QSS, 1998	Quality Systems & Software - DOORS Reference Manual, v4.0
Queille *et al.*, 1994	Queille, J-P., Richermo, A., Voidrot, J. F. & Sedes, F. - Modelling and Exploiting Traceability Between Development Documents, 3rd Annual Symposium on Document Analysis and Information Retrieval, Las Vegas, NV, Apr., pp. 349-360
Quillian, 1968	Quillian, M. R. - Semantic Memory, in Minsky, M.(ed.), Semantic Information Processing, MIT Press, pp. 227-270.
Ramamoorthy *et al.*, 1986	Ramamoorthy, C., Garg, V. & Prakash, A. - Programming in the Large, IEEE Trans. on Software Engineering, 12(7), pp. 769-783
Ramamoorthy *et al.*, 1990	Ramamoorthy, C.V., Usuda, Y., Prakash, A. & Tsai, W. T. - The Evolution Support Environment System, IEEE Trans. on Software Engineering, 16(11), Nov., 1225-1234
Ramesh & Dhar, 1992	Ramesh, B. & Dhar, V. - Supporting Systems Development by Capturing Deliberations During Requirements Engineering, IEEE Trans. on Software Engineering, 18(6), pp. 498-510
Ramesh & Edwards, 1993	Ramesh, B. & Edwards, M. - Issues In the Development of a Requirements Traceability Model, Proc. 1st Int'l Symposium on Requirements Engineering, San Diego, California, USA, Jan., pp. 256-259
Ramesh & Jarke, 1999	Ramesh, B. & Jarke, M. - Towards Reference Models for Requirements Traceability, CREWS Technical Report-99-13; obtained from ftp://sunsite.informatik.rwth-aachen.de/pub/CREWS/CREWS-99-13.ps.gz
Ramesh *et al.*, 1995	Ramesh, B., Powers, T., Stubbs, C. & Edwards, M. - Implementing Requirements Traceability: A Case Study, Proc. 2nd Int'l Symposium on Requirements Engineering, York, UK, Mar., pp. 89-95
Ramesh, 1994	Ramesh, B. - Towards A Pre-Requirements Specification Traceability Model, Proc. Complex Systems Engineering Synthesis and Assessment Technology Workshop, Washington DC, USA, Jul., pp. 1-7
Ramsay & Bernsen, 1995	Ramsay, J. & Bernsen, J. - Traceability Support For Modelling In the Design Process, Oxford University Technical Report, IP/WP45, May
Rational Software Corporation, 1997a	Rational Software Corporation - The Unified Modelling Language, Version 1.3; obtained from http://www.rational.com
Rational Software Corporation, 1997b	Rational Software Corporation - Object Constraint Language Specification, Version 1.1; obtained from http://www.rational.com
Redden, 1999	Redden, L. E. - A Traceability Procedure to Support Project Management and the Development Process in Dependable Avionics Systems, Final Year Diss'n, Department of Comp. Sci., University of Newcastle upon Tyne
Regnell *et al.*, 1996	Regnell, B., Anderson, M. & Bergstrand, J. - A Hierarchical Use Case Model with Graphical Representation, Proc. Int. Sym. and Workshop on Engineering of Computer-Based Systems, Friedrichshafen, Germany

Reifer, 1979 — Reifer, D. J. - Software Failure Modes and Effects Analysis, IEEE Trans. on Reliability, 28(3), pp. 247-249, Aug.

Reubenstein & Waters, 1991 — Reubenstein, H. B. & Waters, Richard C. - The Requirements Apprentice: Automated Assistance For Requirements Acquisition, IEEE Trans. on Software Engineering, Mar pp. 226-240

Riddle & Saeed, 1997 — Riddle, S. & Saeed, A. - Implementation and Analysis of Traceability Structures Using A Deductive Database, University of Newcastle upon Tyne/BAe Dependable Computing Systems Centre Technical Report, DCSC/TR/97/11

Riddle & Saeed, 1998 — Riddle, S. & Saeed, A. - Tracing Support for Variants & Evolutionary Development, University of Newcastle upon Tyne/BAe Dependable Computing Systems Centre Technical Report, DCSC/TR/98/01

Riddle & Saeed, 1999a — Riddle, S. & Saeed, A. - Application of Traceability Structures, University of Newcastle upon Tyne/BAe Dependable Computing Systems Centre Technical Report, DCSC/TR/99/02

Riddle & Saeed, 1999b — Riddle, S. & Saeed, A. - Tool Support for Implementation and Analysis of Traceability Structures, Proc. 9th International Symposium of the International Council on Systems Engineering (INCOSE), Brighton, UK, Jun., pp. 1083-1090

Riddle & Saeed, 2000 — Riddle, S. & Saeed, A. - Optimisation of the Traceability Structures, University of Newcastle upon Tyne/BAE SYSTEMS Dependable Computing Systems Centre Technical Report, DCSC/TR/99/18

Riddle, 2000 — Riddle, S. - Traceability Structures: A Common Interchange Format, University of Newcastle upon Tyne/BAE SYSTEMS Dependable Computing Systems Centre Technical Report, DCSC/TR/2000/18

Rolland & Achour, 1998 — Rolland, C. & Camille Achour, B. - Guiding The Construction Of Textual Use Case Specifications, Data Knowledge Engineering, Vol. 25(1-2), pp. 125-160

Rolland, 1994a — Rolland, Colette - A Contextual Approach for the Requirements Engineering Process, Proc. 6th Int'l Conf. on Software Engineering and Knowledge Engineering, Jurmala, Latvia, Jun.

Rolland, 1994b — Rolland, C. - Modeling the Evolution of Artifacts, Proc. of the 1st Int'l Conf. on Requirements Engineering, Colorado, USA, Apr. pp. 216-219

Roman, 1985 — Roman, Gruia-Catalin - A Taxonomy of Current Issues in Requirements Engineering, IEEE Computer, Apr., pp. 14-21

Rothery, 1993 — Rothery, B. - ISO 9000 (2nd Edition), Gower Press

Rozman *et al.*, 1997 — Rozman, I., Horvat, R. V., Györkös, J. & Hericko, M. - PROCESSUS - Integration of SEI CMM into ISO Quality Models, Software Quality Journal, No. 6, pp. 37-63

Rubin & Goldberg, 1992 — Rubin, K. S. & Goldberg, A. - Object Behaviour Analysis, Communications of the ACM, 35(9), pp. 48-62

Rumbaugh *et al.*, 1991 — Rumbaugh, J., Blaha, M., Premerlani, W., Eddy, F. & Lorensen, W. - Object-Oriented Modelling and Design, Prentice-Hall

Rumbaugh, 1994 — Rumbaugh, J. - Getting Started: Using Use Cases to Capture Requirements, Journal of Object-Oriented Programming, Sep., pp. 8-12

Saeed *et al.*, 1995 — Saeed, A., de Lemos, R. & Anderson, T. - Safety Analysis for Requirements Specifications: Methods & Techniques, Proc. 14t Int'l Conf. on Computer Safety, Reliability & Security (SafeComp), Italy, Oct. pp. 27-41

Sawyer *et al.*, 1996 — Sawyer, P., Sommerville, I. & Viller, S. - PREview: Tackling the Real Concerns of Requirements Engineering, Lancaster University, Cooperative

	Systems Engineering Group, Technical Report CSEG/5/1996
Scalzo & Hugue, 1996	Scalzo, R. C. & Hugue, M. M. - A Framework for Dependability Specification, Proc. 2nd Int'l Conf. on Engineering of Complex Computer Systems, Montreal, Quebec, Canada, Oct., pp. 301-304
Schenk & Wilson, 1994	Schenk, D. & Wilson, P. - Information Modelling: The EXPRESS Way, Oxford University Press
Sciortino & Dunning, 1984	Sciortino, J. & Dunning, D. - Software Traceability, Requirements Testability and Auditing Model, Proc. 6th Digital Avionics Systems Conf., MD, USA, Dec., 159-166
SEDRES, 1999	Systems Engineering Data Representation & Exchange - Capability 2 Data Model, SEDRES Deliverable, available from authors
SEI, 1995	Software Engineering Institute - Systems Engineering Capability Maturity Model (version 1.1), Carnegie Mellon University
Selic *et al.*, 1994	Selic, B., Gullekson, G. & Ward, P. T. - Real-Time Object-Oriented Modelling, Wiley & Sons
Sheard, 1997	Sheard, A. - The Frameworks Quagmire, A Brief Look, Software Productivity Consortium; obtained from http://www.software.org
Shilling & Sweeney, 1989	Shilling, J. & Sweeney, P. - Three Steps To Views: Extending the Object-Oriented Paradigm, OOPSLA '89 Proc., Oct., pp. 353-361
Shipman, 1981	Shipman, D. W. - The Functional Data Model and the Data Language DAPLEX, ACM Transactions on Database Systems, 6(1), pp. 140-173
Silva & Agusta, 1998	Silva, Antonio & Agusta, Via G. - Across Version/Variant Requirement Traceability in Avionics Software Development and Testing, Proc. Conf. on Data Systems in Aerospace, Athens, Greece, May, pp. 215-221
Simpson, 1986	Simpson, H. R. - The Mascot Method, Software Engineering Journal, May, pp. 103-120
Simpson, 1994	Simpson, H. R. - Architecture for Computer Based Systems, Proc. IEEE Workshop on the Engineering of Computer Based Systems, Stockholm
Simpson, 2000a	Simpson, H. R. - Protocols for Process Interaction: Part 1: Specification and Rationale, MBDA Technical Report, Nov.
Simpson, 2000b	Simpson, H. R. - Protocols for Process Interaction: Part 2: Application, MBDA Technical Report, Nov.
Simpson, 2000c	Simpson, H. R. - Protocols for Process Interaction: Part 3: Realisation, MBDA Technical Report, Nov.
Singh & Han, 1996	Singh, H. & Han, J. - Modelling Software Artifacts & Their Relationship in Software Engineering Environments, TR96-06, Peninsula School of Computing and Information Technology, Monash University, Melbourne, Australia, May
Smith & Smith, 1977	Smith, J. M. & Smith, D. C. P. - Database Abstractions: Aggregation and Generalisation, ACM Transactions on Database Systems, March, pp. 105-133
Smith *et al.*, 1997	Smith, P. A., Newman, I. A., & Parks, L. M. - Virtual Hierarchies & Virtual Networks: Some Lessons from Hypermedia Usability Research Applied to the World Wide Web, International Journal of Human-Computer Studies, No. 47, pp. 67-95
Smith, 1993	Smith, T. J. - READS: A Requirements Engineering Tool, Proc. 1st Int'l Symposium on Requirements Engineering, San Diego, California, USA, Jan., pp. 94-97

Sodhi, 1991	Sodhi, Jag - Software Engineering: Methods, Management and CASE Tools, McGraw-Hill
Sommerville & Sawyer, 1997	Sommerville, I. & Sawyer, P. - Requirements Engineering: A Good Practice Guide, John Wiley Ltd.
Sommerville *et al.*, 1993	Sommerville, I., Rodden, T., Sawyer, P., Bentley, R. & Twidale, M. - Integrating Ethnography into the Requirements Engineering Process, Proc. 1st Int'l Symposium on Requirements Engineering, California, USA, Jan., pp. 165-173
Spivey, 1989	Spivey, J. M. - The Z Notation: A Reference Manual, Prentice-Hall
Srivastava *et al.* 1993	Srivastava, D., Ramakrishnan, R., Seshadri, P., & Sudarshan, S. - Coral++: Adding Object-Orientation to a Logic Database Language, in Proc. Int. Conf. on Very Large Databases, Dublin, Ireland
Stallman & Sussman, 1977	Stallman, R. & Sussman, G. - Forward Reasoning and Dependency-Directed Backtracking in a System for Computer-Aided Circuit Analysis, Artificial Intelligence, 9(2), pp. 135-196
Stephenson, 1997	Stephenson, P. - Study of a Deductive Database Tools to Support Traceability for a Safety Critical Avionics System, Final Year Project Dissertation, Department of Computing Science, University of Newcastle upon Tyne, Sep.
Storey, 1996	Storey, Neil - Safety-Critical Computer Systems, Addison-Wesley
Strens, 1995	Strens, R. - Risk, Sensitivity and Impact Analysis and Their Application to Changing Requirements, Proteus Project Document
Su, 1986	Su, S. Y. W. - Modeling Integrated Manufacturing Data with SAM*, IEEE Computer, Vol. 19, No. 1. pp. 34-49
Sugden & Strens, 1996	Sugden, R. C. & Strens, M. R. - Strategies, Tactics & Methods For Handling Change, Int'l Symposium and Workshop on the Engineering of Computer Based Systems, Friedrichshafen, Germany, Mar.
Sukamaran, 1999	Sukamaran, S. - A Graphical User Interface For a Traceability Tool, Department of Computing Science, University of Newcastle upon Tyne, MSc. Dissertation
Sutcliffe *et al.*, 1998	Sutcliffe, A., Maiden, N., Minocha., S. & Manuel, D. - Supporting Scenario-Based Requirements Engineering, IEEE Trans. on Software Engineering, 24(12), pp. 1072-1088
Takahashi & Yamamoto, 1995	Takahashi, K. & Yamamoto, S. - An Analysis of Traceability in Requirements Documents, IEICE Trans. on Information and Systems, 78(4), pp. 394-402
Takahashi *et al.*, 1996	Takahashi, K., Potts, C. Kumar, V., Ota, K. & Smith, J. D. - Hypermedia Support for Collaboration In Requirements Analysis, Proc. 2nd Int'l Conf. on Requirements Engineering, Orlando, Florida, USA, Apr., pp. 31-40
Takeda *et al.*, 1993	Takeda, N., Shiomi, A., Kawai, K. & Ohiwa, H. - Requirements Analysis by the KJ Editor, Proc. 1st Int'l Symposium on Requirements Engineering, San Diego, California, USA, Jan., pp. 98-101
Tamanaha *et al.*, 1989	Tamanaha, D., Wenjen, W. C. & Patel, B. K. - The Application of CASE in Large Aerospace Projects, IEEE Aerospace Applications Conf. Digest, Feb., pp. 282-300
Teichroew & Sayani, 1971	Teichroew, D. & Sayani, H. - Automation of System Building, Datamation, Aug., pp. 25-30
Telelogic, 2001	Telelogic - DOORS Reference Manual, v5.1
Theriault, 1991	Theriault, M. - The Requirements Traceability Tool on VSCS, Proc. 36th

Annual Fall Conf. on Realizing the Future ATC System, Arlington, VA, USA, Sep., pp. 431-438

Tiel, 1993 — Tiel, Richard, F. - Using Structured Process Improvement Techniques on the Systems Engineering Process, Proc. Annual Int'l Symposium - National Council on Systems Engineering, Arlington, VA, USA, Jul., pp. 301-307

Tilbury, 1989 — Tilbury, A. J. M. - Enabling Software Traceability, IEE Colloquium on the Application of Computer-Aided Software Engineering Tools, Digest No. 24, London, UK, Feb., pp. 7/1-7/4

Toulmin, 1958 — Toulmin, S. E. - The Uses of Argument, Cambridge University Press

Tran *et al.*, 1997 — Tran, M., Sherif, J. S., Mikulski, C. & Wang, M. - My-Star: A Methodology and System for Tracing and Analyzing Requirements, Microelectronics and Reliability, 37(2), pp. 297-303

Tryggeseth & Nytro, 1997 — Tryggeseth, E. & Nytro, O. - Dynamic Traceability Links Supported By A System Architecture, Proc. Int'l Conf. on Software Maintenance, Bari, Italy, pp. 180-187

Turton *et al.*, 1997 — Turton, R., Bailie, R. C., Whiting, W. B. & Shaeiwitz, J. A. - Analysis, Synthesis, and Design of Chemical Processes, Prentice-Hall

van Lamsweerde *et al.*, 1995 — van Lamsweerde, A., Dardenne, A. & Dubisy, F. - Goal Directed Elaboration of Requirements for a Meeting Scheduler: Problems & Lessons Learnt, Proc. 2nd Int'l Symposium on Requirements Engineering, York, UK, Mar., 194-203

Vesely *et al.*, 1981 — Vesely, W., Goldberg, F., Roberts, N. & Haasl, D. - Fault Tree Handbook, Nureg 0492, US Nuclear Regulatory Commission

Villemeur, 1992 — Villemeur, A. - Reliability, Availability, Maintainability & Safety Assessment, Vol.I/ II, Wiley

Warmer & Kleppe, 1999 — Warmer, J. & Kleppe, A. - The Object Constraint Language: Precise Modelling with UML, Addison-Wesley

Watkins & Neal, 1994 — Watkins, Robert & Neal, Mark - Why & How of Requirements Tracing, IEEE Software, Jul., 104-106

Weidenhaupt *et al.* (1998) — Weidenhaupt, K., Pohl, K., Jarke, M. & Haumer, P. - Scenarios in System Development: Current Practice, IEEE Software, March/April, pp. 34-45

Weir, 2001 — Weir, A. - Concorde Crash Raises Questions Without Answers, Journal of System Safety, Vol. 37, No. 2, pp. 19-22

West, 1991 — West, Martin - QFD In Software Development, IBM Systems Journal, Nov., pp. 5/1-5/7

Westfechtel, 1989 — Westfechtel, B. - Revision Control In An Integrated Development Environment, Software Engineering Notes, 14(7), pp. 96-105

White, 1993 — White, Stephanie - Distributed Design of Computer-Based Systems: Traceability, Proc. Annual Int'l Symposium - National Council on Systems Engineering, Arlington, VA, USA, Jul., pp. 691-692

White, 1994a — White, Stephanie - Tracing Product and Process Information When Developing Complex Systems, Proc. Complex Systems Engineering Synthesis and Assessment Technology Workshop, USA, Jul., pp. 45-50

White, 1994b — White, Stephanie - Traceability for Complex Systems Engineering, Proc. 4th Int'l Symposium on Systems Engineering, Sunnyvale, California, USA, Aug., pp. 49-55

White, 1997 — White, Stephanie - Requirements Capture and Analysis Prior to Modelling, Proc. of Conference and Workshop on Engineering of Computer-Based Systems (ECBS '97), Monterey; CA, Mar., pp. 10-17

Whitgift, 1991 — Whitgift, David - Software Configuration Management: Methods & Tools, John Wiley and Sons

Wichmann, 1997 — Wichmann, B. A. - High Integrity Ada, Proceedings of the 16th International Conference on Computer Safety, Reliability and Security (SafeComp '97), York, Sep. pp. 173 - 184

Wieringa, 1995 — Wieringa, R. - An Introduction To Requirements Traceability, Vrije University Technical Report TR-389, Nov.

Wieringa, 1996 — Wieringa, R. J. - Requirements Engineering: Frameworks for Understanding, Wiley

Wieringa, 1998 — Wieringa, R. - Traceability & Modularity in Software Design, Proc. 9th Int'l Workshop on Software Specification & Design, Japan, pp. 87- 95

Wilson & McDermid, 1995 — Wilson, S. P. & McDermid, J. A. - Integrated Analysis of Complex Safety Critical Systems, The Computer Journal, 38(10)

Wilson *et al.*, 1995 — Wilson, S. P., Kelly, T. P., & McDermid, J. A. - Safety Case Development: Current Practice, Future Prospects, Proc. 12th Annual CSR Workshop / 1st ENCRESS Conf., Bruges, Belgium

Wilson *et al.*, 1996 — Wilson, S., McDermid, J., Pygott, C. & Tombs, D. - Assessing Complex Computer Based Systems Using the Goal Structure Notation: Proc. of 2nd International Conference on the Engineering of Complex Computer Systems, Montreal, Canada, pp. 498-505, Oct.

Wilson *et al.*, 1997a — Wilson, S., McDermid, J., Kirkham, P., Pygott, C. & Tombs, D. - Computer Based Support for Standards and Processes in Safety Critical Systems, in Daniel, P. (ed.), Proc. Conf. on Computer Safety, Reliability and Security (SafeComp), Sep., pp. 197-209

Wilson *et al.*, 1997b — Wilson, W. M., Rosenberg, L. H. & Hyatt, L. E. - Automated Analysis of Requirement Specifications, Proc. 20th Int'l Conf. on Software Engineering, Boston, USA, May

Wood, 1995 — Wood, K. - Automated Requirements Traceability & Object-Oriented Analysis, Texas Instruments Technical Journal, 12(1), pp. 15-20

Wright, 1991 — Wright, Simon - Requirements Traceability - What? Why? & How?, Tools and Techniques For Maintaining Traceability During Design, IEE Colloquium, UK Digest Number: 1991/180, Dec., pp. 1/1-1/2

Yau & Tsai, 1987 — Yau, S. S. & Tsai, J. - Knowledge Representation of Software Component Interconnection Information for Large Scale Software Modifications, IEEE Trans. on Software Engineering, 13(3), pp. 335-361

Yau *et al.*, 1988 — Yau, S., Nichol, R., Tsai, J. & Liu S. - An Integrated Life-Cycle Model For Software Maintenance, IEEE Trans. on Software Engineering, 14(8), pp. 1128-1144

Yeh & Ng, 1990 — Yeh, R. T. & Ng, P. A. - Software Requirements: A Management Perspective, in Thayer, R. H. & Dorfman, M. (eds.), System and Software Requirements Engineering, Computer Society Press Tutorial, pp. 450-461

Yu, 1993 — Yu, Eric S. K. - Modelling Organisations For Information Systems Requirements Engineering, Proc. Int'l Symposium on Requirements Engineering, San Diego, California, USA, Jan., pp. 34-41

Yu, 1994 — Yu, Weider D. - Verifying Software Requirements: A Requirement Tracing Methodology & Its Tool RADIX, IEEE Journal on Selected Areas of Communications, Feb., pp. 234-239

Zaniolo, 1983 — Zaniolo, Carlo - The Database Language GEM, SIGMOD Conference, pp. 201-218

Glossary

2RARE	2 Real Applications for Requirements Engineering
ABE	Aerospace Build Entity
ADL	Activity Description Language
ADT	Abstract Data Type
AEA	Aerospace Engineering Association
AEE	Aerospace Engineering Entity
AEO	Aerospace Engineering Object
AEP	Aerospace Engineering Project
ALE	Aerospace Link Entity
AME	Aerospace Management Entity
ANSI	American National Standards Institute
API	Application Programming Interface
ARP	Aerospace Recommended Practice
ASM	Activity State-Machine
ATE	Aerospace Traceability Entity
BCET	Best-Case Execution Time
BCS	BASE Control Software/British Computer Society
BE	Build Element
BNF	Backus-Naur Form
BSCU	Brake System Control Unit
CAD	Computer-Aided Design
CAoA	Corrected Angle of Attack
CARE	Common Airbus Requirements Engineering
CAS	Computed Air Speed
CASE	Computer-Aided Systems/Software Engineering
CBQL	ConceptBase Query Language
CCA	Common Cause Analysis
CMA	Common Mode Analysis
CMM	Capability Maturity Model
COTS	Commercial Of The Shelf
CREWS	Co-operative Requirements Engineering With Scenarios
CSU	Command Sensor Unit
DCSC	Dependable Computing Systems Centre
DDS	Deductive Database System
DMS	Database Management System
DOODS	Deductive Object-Oriented Database System
DOORS	Dynamic Object-Oriented Requirements System

DORIS	Data-Oriented Requirements Implementation Scheme
DRCS	Design Rationale Capture System
DRL	Decision Representation Language
DTC	Data Transfer Cartridge
DTM	Data Transfer Module
DTMIS	Data Transfer Module Interface Software
DXL	DOORS eXtension Language
ELAC	ELevator and Aileron Computer
ELH	Entity Life History
ESA	European Space Agency
EST	Earliest Start Time
EUROCAE	EUROpean organisation for Civil Aviation Electronics
FAA	Federal Aviation Authority
FBD	Function Block Diagram
FCS	Flight Control System
FHA	Functional Hazard Assessment
FMEA	Failure Modes and Effects Analysis
FPPU	Feedback Position Pickoff Unit
FTA	Fault Tree Analysis
GEM	General Entity Manipulator
gIBIS	graphical Issue-Based Information System
GSN	Goal Structure Notation
HAZOP	HAZard and OPerability studies
HTML	Hypertext Markup Language
IBIS	Issue-Based Information System
IDA	Intercommunication Data Area
IDEF	ICAM (Integrated Computer Aided Manufacturing) DEFinition method
IEEE	Institute of Electrical & Electronics Engineers
INCOSE	INternational Council on Systems Engineering
IP	Information Provision
IR	Information Request
ISO	International Standards Organisation
ISR	Inhabit Slat Retraction
ISRE	Immersive Scenario-based Requirements Engineering
JAR	Joint Airworthiness Requirements
KARE	Knowledge Acquisition in Requirements Engineering
LDL	Logical Data Language
LESD	Linguistic Engineering for Software Design
LST	Latest Start Time

MASCOT	Modular Approach to Software, Construction, Operation and Test
MATrA	Meta-modelling Approach to Traceability for Avionics
MCM	MATrA Configuration Model
MMSS	Modular Mission Support Software
MNLS	MATrA Natural Language Structure
MPS	Mission Planning System
MSC	Message Sequence Chart
NATURE	Novel Approaches to Theories Underlying Requirements Engineering
OCL	Object Constraint Language
OMT	Object Modelling Technique
OODS	Object-Oriented Database System
ORM	Object-Role Modelling
pCDS	populated CASE tool Data Structure
PDS	Product Data Synthesis
PERT	Programme Evaluation and Review Technique
PIM	Process Improvement Model
pNDS	populated Notation Dependent Structure
PRA	Particular Risk Analysis
PSSA	Preliminary System Safety Assessment
QFD	Quality Function Deployment
QOC	Questions, Options and Criteria
RDD	Requirements-Driven Design
RDMS	Relational Database Management System
RE	Requirements Engineering
REAIMS	Requirements Engineering Adaptation for IMprovement for Safety
RIDL	Reference and IDea Language
RTM	Requirements & Traceability Management
RTN	Real-Time Network
RTN-SL	Real-Time Network Specification Language
RTN-SLg	Real-Time Network Specification Language graphical syntax
RTT	Real-Time Transaction
SAM	Safety Argument Manager
SAM*	Semantic Association Model
SDM	Semantic Database Model
SEC	Spoiler and Elevator Computer
SECAM	Systems Engineering Capability Assessment Model
SEDRES	System Engineering Data Representation & Exchange Standardisation
SEI	Software Engineering Institute
SENLS	Scenario Event Natural Language Structure

SENM	Systems Engineering Notation Meta-class model
SFCC	Slat and Flap Control Computer
SHM+	Semantic Hierarchy Model
SLATE	System Level Automation Tool for Engineers
SML	Safety Markup Language
SP	Service Provision
SQL	Structured Query Language
SR	Service Request
SRS	System/Software Requirements Specification
SSA	System Safety Assessment
STEFFIE	Systems Engineering Framework For Information and experience Exchange
STEP	Standard for The Exchange of Product data
TCS	Theatre Creation Software
UCRS	User Centred Requirements Structure
UML	Unified Modelling Language
uNDS	unpopulated Notation Dependent Structure
VDM	Vienna Development Method
WBS	Wheel Braking System
WCET	Worst-Case Execution Time
WCRT	Worst-Case Response Time
ZSA	Zonal Safety Analysis

Appendix - A

This page deliberately left blank

Appendix A (Part 1) - Additional Rules & Constraints for Use Case View & Models

The following rules and constraints provide an addendum to 4.3.3.3.2.

i. Constraint to prevent 'dangling' Actor instances (i.e., not attached to an interaction).

Actor **invariant**
self.allInstances->forall(a |
self.useCaseView->forall(v |
self.useCaseView.ucv_interaction->exists(i |
v.ucv_interaction->includes(i) and (i.interactor_1= a or i.interactor_2 = a))))

ii. Constraint to prevent a UseCase from extending itself.

Extends **invariant**
self.allInstances->forall(e | e.extends_base <> e.extends_extend)

iii. Constraint to ensure that at most one «extends» association exists between two Uses Cases.

Extends **invariant**
self.allInstances->forall(e1, e2 |
not (e1 <> e2 and e1.extends_base = e2 extends_base and e1.extends_extend = e2.extends_extend))

iv. Constraint to ensure that two Uses Cases cannot extend each other; i.e. not 'use case a' «extends» 'b' and 'use case b' «extends» 'a'.

Extends **invariant**
self.allInstances->forall(e1, e2 |
not (e1.extends_extend = e2.extends_ base and e1.extends_base = e2.extends_extend))

v. Constraint to prevent cycles within «extends» associations.

First, we define a rule to determine the transitive closure of «extends» associations.

UseCase
self.allInstances->forall(u2, u1 | self.extends->exists(e1 | e1.extends_extend = u2 and e1.extends_base = u1) or
self.allInstances->exists(u3 | self.extends->exists (e2 | e2.extends_ extend = u2 and e2.extends_base = u3 and
u3.transitive_extended_by->includes(u1)))) implies u2.transitive_extended_by->includes(u1)

This rule allows us to specify the following constraint.

UseCase **invariant**
self.allInstances->forall(u | not (u.transitive_extended_by->includes(u)))

vi. Rules to ensure that all elements associated with a particular model are also associated with the UseCaseView to which that model belongs.

a) Rule for deriving Actors.

UseCaseView
self.allInstances->forall (v |

```
self.use_case_model.ucm_actor->forall (a |
v.use_case_model.ucm_actor->includes(a)))
implies
v.ucv_actor->includes(a)
```

b) Rule for deriving Interactions.

```
UseCaseView
self.allInstances->forall (v |
self.use_case_model.ucm_interaction->forall (i |
v.use_case_model.ucm_interaction->includes(i)))
implies
v.ucv_interaction->includes(i)
```

c) Rule for deriving «includes» associations.

```
UseCaseView
self.allInstances->forall (v |
self.use_case_model.ucm_includes->forall (i |
v.use_case_model.ucm_includes->includes(i)))
implies
v.ucv_includes->includes(i)
```

d) Rule for deriving «extends» associations.

```
UseCaseView
self.allInstances->forall (v |
self.use_case_model.ucm_extends->forall (e |
v.use_case_model.ucm_extends->includes(e)))
implies
v.ucv_extends->includes(e)
```

e) Rule for deriving Pre-conditions.

```
UseCaseView
self.allInstances->forall (v |
self.use_case_model.ucm_pre_condition->forall (p |
v.use_case_model.ucm_pre_condition->includes(p)))
implies
v.ucv_pre_condition->includes(p)
```

f) Rule for deriving Post-conditions.

```
UseCaseView
self.allInstances->forall (v |
self.use_case_model.ucm_post_condition->forall (p |
v.use_case_model.ucm_post_condition->includes(p)))
implies
v.ucv_post_condition->includes(p)
```

vii. Rules to derive «includes» use cases (a) and associations (b) where a UseCase appears in more than one model.

a)

```
UseCaseModel
self.allInstances->forall(m |
self.useCaseView.ucv_includes->forall (i |
```

```
self.ucm_use_case->exists (u |
i.includes_base = u and m.useCaseView.ucv_includes->includes(i) and
m.ucm_use_case->includes(u))))
implies
m.ucm_use_case->includesAll(u.transitive_includes)
```

b)

```
UseCaseModel
self.allInstances->forall(m |
self.useCaseView.ucv_includes->forall(i |
m.useCaseView.ucv_includes->includes(i) and
m.ucm_use_case->includes(i.includes_base) and
m.ucm_use_case->includes(i.includes_include)))
implies
m.ucm_includes->includes(i)
```

viii. Rules to derive «extends» use cases (a) and associations (b) where a UseCase appears in more than one model.

a)

```
UseCaseModel
self.allInstances->forall(m |
self.useCaseView.ucv_extends->forall (e |
self.ucm_use_case->exists (u |
e.extends_extend = u and
m.useCaseView.ucv_extends->includes(e) and
m.ucm_use_case->includes(u))))
implies
m.ucm_use_case->includesAll(u.transitive_extended_by)
```

b)

```
UseCaseModel
self.allInstances->forall(m |
self.useCaseView.ucv_extends->forall(e |
m.useCaseView.ucv_extends->includes(e) and
m.ucm_use_case->includes(e.extends_base) and
m.ucm_use_case->includes(e.extends_extend)))
implies
m.ucm_extends->includes(e)
```

ix. The following rules are what we term 'spine' associations (e.g., ucm_interaction, ucm_includes, ucm_extends, etc.) that anchor elements to the UseCaseModel class.

a) Rule to populate ucm_interaction.

```
UseCaseModel
self.allInstances->forall (m |
self.ucm_use_case->forall(u |
self.ucm_actor->forall(a |
self.ucm_use_case.interaction->forall(i |
m.ucm_use_case->includes(u) and
m.ucm_actor->includes(a) and
(i.interactor_1->union(i.interactor_2))->includes(u) and
(i.interactor_1->union(i.interactor_2))->includes(a)))))
implies
m.ucm_interaction->includes(i)
```

b) Rule to populate ucm_includes.

```
UseCaseModel
self.allInstances->forall (m |
self.ucm_use_case->forall(u1, u2 |
self.ucm_use_case.includes->forall(i |
m.ucm_use_case->includes(u1) and
m.ucm_use_case->includes(u2) and
(i.includes_base->union(i.includes_include))->includes(u1) and
(i.includes_base->union(i.includes_include))->includes(u2))))
implies
m.ucm_includes->includes(i)
```

c) Rule to populate ucm_extends.

```
UseCaseModel
self.allInstances->forall (m |
self.ucm_use_case->forall(u1, u2 |
self.ucm_use_case.extends->forall(e |
m.ucm_use_case->includes(u1) and
m.ucm_use_case->includes(u2) and
(e.extends_base->union(e.extends_extend))->includes(u1) and
(e.extends_base->union(e.extends_extend))->includes(u2))))
implies
m.ucm_extends->includes(e)
```

Appendix A (Part 2) - Additional Rules & Constraints for Interaction View & Models

The following rules and constraints provide an addendum to 4.3.3.4.2.

i. Potential 'style rule' (expressed over textual perspective) ensuring that Communication Event types are compatible with PDS InputOutput flow types; i.e., service request and service provision flows are not recorded as non-triggering in the PDS. Similarly information requests and information provision are not recorded as triggering. Note that PDS flow types (particularly at the requirements stage may be as yet "undetermined"). Note also that this rule requires addition of an enumerated effect attribute (enumerators triggering and non_triggering) to the InputOutput class in the PDS.

CommunicationEvent
self.allInstances->forall(c |
self.tsn_communication_event.communication_description.tsn_message_node.
bEelementAEO.build_element->not exists(be |
c.tsn_communication_event.communication_description.tsn_message_node.message_name = be.flow_name
and
(be.effect="triggering" and (c.interaction_type = "IR" or c.interaction_type = "IP")) or
(be.effect="non_triggering" and (c.interaction_type = "SR" or c.interaction_type = "SP"))))

ii. Constraint to ensure that, for Message Sequence Chart perspectives, where a link_name is provided rather than using the default "unspecified" (a link is some form of connection between two instances), then there is a connection (Interface) of the same name specified in the PDS.

MscCommunication **invariant**
self.allInstances->forall(m|
not(
(m.msc_message.bEelementAEO.build_element.sentTo.target.connection.interface->intersection
(m.msc_message.bEelementAEO.build_element.receivedFrom.target.connection.interface)
->isEmpty and m.link_name <> "unspecified") or
(m.msc_message.bEelementAEO.build_element.sentTo.target.connection.interface->intersection
(m.msc_message.bEelementAEO.build_element.receivedFrom.target.connection.interface)
->notEmpty and m.link_name = "unspecified") or
(m.msc_message.bEelementAEO.build_element.sentTo.target.connection.interface.interface_name
<> m.link_name and
m.msc_message.bEelementAEO.build_element.receivedFrom.target.connection.interface.interface_name
<> m.link_name)))

iii. The following constraints ensure correct combination of TimingEvent constructs.

TimingEvent **invariant**
self.allInstances->forall(t |
(not
(t.tsn_timing_event.timing_description.tsn_host_on_timeout_node->size = 1 and
t.tsn_timing_event.timing_description.tsn_timer_duration->size = 1)
or
(t.msc_timing_event.msc_host_on_timeout_instance->size = 1 and
t.msc_timing_event.msc_timer_duration->size = 1)))

TimingEvent **invariant**
self.allInstances->forall(t |
(not

```
(t.tsn_timing_event.timing_description.tsn_timer_set_node->size = 1 and
t.tsn_timing_event.timing_description.tsn_timer_duration->size = 0)
or
(t.msc_timing_event.msc_timer_set_instance->size = 1 and
t.msc_timing_event.msc_timer_duration->size = 0)))
```

```
TimingEvent invariant
self.allInstances->forall(t |
(not
(t.tsn_timing_event.timing_description.tsn_timer_reset_node->size = 1 and
t.tsn_timing_event.timing_description.tsn_timer_duration->size = 1)
or
(t.msc_timing_event.msc_timer_reset_instance->size = 1 and
t.msc_timing_event.msc_timer_duration->size = 1)))
```

iv. This constraint (again expressed for the textual perspective) ensures that Instance elements in Timer Events correspond to the target system - i.e., are the same as the subject_module (as stated by the User Centred Requirements Structure).

```
TimingEvent invariant
self.allInstances->forall(t |
t.tsn_timing_event.timing_description.tsn_host_on_timeout_node.instance_name->union
(t.tsn_timing_event.timing_description.tsn_timer_set_node.instance_name->union
(t.tsn_timing_event.timing_description.tsn_timer_reset_node.instance_name))->includes
t.interactionModel.interactionView.userCentredRequirementsStructure.subject_module)
```

v. The following constraints apply to sequence numbers.

a) The set of events preceding an Event are recorded to ensure sequence numbers are correctly maintained (e.g., following insert operations). In order to do this, we first define a rule for population of transitive_follows_from.

```
Scenario
self.allInstances->forall(s |
self.scenario_event->union(self.included_event->union(self.extension_event))->forall(e1, e2 |
s.scenario_event->union(s.included_event->union(s.extension_event))->includes(e1) and
s.scenario_event->union(s.included_event->union(s.extension_event))->includes(e2) and
e1 <> e2 and
e2.follows_from->includes(e1))
or
self.scenario_event->union(self.included_event->union(self.extension_event))->exists(e' |
s.scenario_event->union(s.included_event->union(s.extension_event))->includes(e') and
e' <> e1 and e' <> e2 and
e2.follows_from->includes(e') and
e'.follows_from->includes(e1)))
implies
e2.transitive_follows_from->includes(e1)
```

b) Constraint to ensure 'normal sequence numbers' are correct. Note that in order to prevent repetition, an Event may in principle appear in all scenarios belonging to a use case and must therefore be capable of having several sequence numbers (potentially up to the number of scenarios describing that use case). These must be matched to the Scenario to which they apply.

```
Scenario invariant
self.allInstances->forall(s |
self.scenario_event->forall(e |
```

```
self.scenario_event.sequence_no->intersection(self.scn_seq_no)
->not exists(n |
(s.scenario_event->includes(e) and
e.sequence_no->intersection(s.scn_seq_no)->includes(n) and
n.sequence_no <>
(s.scenario_event->union(s.included_event->union(s.extension_event))
->intersection (e.transitive_follows_from))->size+1))))
```

c) Constraint to ensure 'included sequence numbers' are correct. Again these must be matched to the Scenario to which they apply, given that an event can be included in n > 1 scenarios and therefore has n > 1 'included sequence numbers'.

```
Scenario invariant
self.allInstances->forall(s |
self.included_event->forall(e |
self.included_event.included_seq_no->intersection(self.scn_included_seq_no)
->not exists(n |
(s.included_event->includes(e) and
e.included_seq_no->intersection(s.scn_included_seq_no)->includes(n) and
n.sequence_no <>
(s.scenario_event->union(s.included_event->union(s.extension_event))
->intersection (e.transitive_follows_from))->size+1))))
```

d) And similarly with 'extension sequence numbers'.

```
Scenario invariant
self.allInstances->forall(s |
self.extension_event->forall(e |
self.extension_event.extension_seq_no->intersection(self.scn_extension_seq_no)
->not exists(n |
(s.extension_event->includes(e) and
e.extension_seq_no->intersection(s.scn_extension_seq_no)->includes(n) and
n.sequence_no <>
(s.scenario_event->union(s.included_event->union(s.extension_event))
->intersection (e.transitive_follows_from))-size+1))))
```

e) The following constraint ensures that each Event has only one included or 'extension sequence number' per Scenario for which it is included in or extends.

```
Scenario invariant
self.allInstances->forall(s |
self.included_event->forall(e |
self.extension_event->forall(x |
not(
(s.included_event->includes(e) and
s.scn_included_seq_no->intersection(e.included_seq_no)->size <>1) or
(s.extension_event->includes(x) and
s.scn_extension_seq_no->intersection(x.extension_seq_no)->size <>1)) )))
```

vi. Constraint to ensure 'extends scenarios' are paths through different use cases.

```
InteractionModel invariant
self.allInstances->forall(m1, m2 |
self.inm_scenario->forall(s1, s2 |
not (m1.inm_scenario->includes(s1) and m2.inm_scenario->includes(s2) and
s1.extended_by_scenario->includes(s2) and m1 = m2)))
```

vii. The following rules populate associations for Scenario and Event elements of Interaction Models. They arise from the presence of «extends» associations in the Use Case Models they describe. Note similar rules may be defined for «includes».

a) To derive extension scenarios of a model (inm_extension_scenario), it is first necessary to define a rule for population of transitive_extended_by.

```
InteractionModel
self.allInstances->forall(m1, m2 |
self.inm_scenario->forall(s1, s2 |
m1.inm_scenario->includes(s1) and
m2.inm_scenario->includes(s2) and
s1.extended_by_scenario->includes(s2))
or
self.allInstances->exists(m' |
self.inm_secenario->exists(s' |
m'.inm_scenario->includes(s') and
(s1.extended_by_scenario->includes(s') or s1.includes_scenario->includes(s')) and
s'.transitive_extended_by_scenario->includes(s2))))
implies
s1.transitive_extended_by_scenario->includes(s2)
```

b) We can now define a rule for deriving «extends» scenarios.

```
InteractionModel
self.allInstances->forall(m1, m2 |
self.inm_scenario->forall(s1, s2 |
m1.inm_scenario->includes(s1) and
m2.inm_scenario->includes(s2) and
s1.extended_by_scenario->includes(s2) or
s1.transitive_extended_by_scenario->includes(s2)))
implies
m1.inm_extension_scenario->includes(s2)
```

c) In addition, the following populate the extension_event association between Scenario and Event.

```
Scenario
self.allInstances->forall(s |
self.transitive_extended_by_scenario->forall(e |
s.transitive_extended_by_scenario->includes(e)))
implies
s.extension_event->includesAll(e.scenario_event)
```

d) Also, the following populate the extension_event_group association between Scenario and EventGroup.

```
Scenario
self.allInstances->forall(s |
self.transitive_extended_by_scenario->forall(e |
s.transitive_extended_by_scenario->includes(e) and
e.event_group->size > 0))
implies
s.extension_event_group->includesAll(e.event_group)
```

viii. Constraint to ensure that for two Interaction Models (m1, m2) where the Use Case View contains an «extends» association in which the use case described in m1 is the base of this association and

the use case described in m2 is the extended part, then at least one Scenario forming m1 should appear in the extended scenarios of any Scenario in m2.

```
InteractionModel invariant
self.allInstances->forall(m1, m2 |
self.interactionView.userCentredRequirementsStructure.useCaseView.ucv_extends
->not exists(e |
m1.describes_use_case = e.extends_base.use_case_name and
m2.describes_use_case = e.extends_extend.use_case_name and
(m2.inm_scenario.extended_by_scenario->intersection(m1.inm_scenario))->isEmpty))
```

ix. The following constraints enforce uniqueness of Message (a), Action (b) and Timer (c) primitives throughout an InteractionView.

a)

```
InteractionView invariant
self.allInstances->forall(v |
self.interaction_model.inm_message->forall(m1, m2 |
not(
v.interaction_model.inm_message->includes(m1) and v.interaction_model.inm_message->includes(m2) and m1
<> m2 and m1.message_name = m2.message_name)))
```

b)

```
InteractionView invariant
self.allInstances->forall(v |
self.interaction_model.inm_action->forall(a1, a2 |
not(
v.interaction_model.inm_action->includes(a1) and v.interaction_model.inm_action->includes(a2) and a1 <> a2 and
a1.action_name = a2.action_name)))
```

c)

```
InteractionView invariant
self.allInstances->forall(v |
self.interaction_model.inm_timer->forall(t1, t2 |
not(
v.interaction_model.inm_timer->includes(t1) and v.interaction_model.inm_timer->includes(t2) and t1 <> t2 and
t1.timer_name = t2.timer_name)))
```

x. Rules to derive textual event representations from Message Sequence Charts (note derives primitives only, manual intervention is required to produce meaningful event statements).

a) Rule to derive Communication Events.

```
CommunicationEvent
self.allInstances->forall(c |
self.tsn_communication_event->exists(t |
c.msc_communication_event->notEmpty and c.tsn_communication_event->includes(t)))
implies
t.communication_description.tsn_sender_node->includes (c.msc_communication_event.msc_sender_instance)
and
t.communication_description.tsn_receiver_node->includes (c.msc_communication_event.msc_receiver_instance)
and
t.communication_description.tsn_message_node->includes (c.msc_communication_event.msc_message)
```

b) Rule to derive Internal Action Events.

```
InternalActionEvent
self.allInstances->forall(a |
self.tsn_action_event->exists(t |
a.msc_action_event->notEmpty
and
a.tsn_action_event->includes(t)))
implies
t.action_description.tsn_sdr_rcr_node->includes(a.msc_action_event.msc_sdr_rcr_instance) and
t.action_description.tsn_action_node->includes(a.msc_action_event.msc_system_action)
```

c) Rule to derive Timing Events.

```
TimingEvent
self.allInstances->forall(e |
self.tsn_timing_event->exists(t |
e.msc_timing_event->notEmpty and
e.tsn_timing_event->includes(t)))
implies
t.timing_description.tsn_host_on_timeout_node->union
(t.timing_description.tsn_timer_set_node->union
(t.timing_description.tsn_timer_reset_node))->includes
(e.msc_timing_event.msc_host_on_timeout_instance->union(e.msc_timing_event.msc_timer_set_instance->union
(e.msc_timing_event.msc_timer_reset_instance))) and
t.timing_description.tsn_timer_instance_node->includes(e.msc_timing_event.msc_timer_instance) and
t.timing_description.tsn_timer_duration->includes(e.msc_timing_event.msc_timer_duration)
```

xi. For more direct navigation, in particular between the Use Case and Interaction Views, a number of rules are used to populate InteractionModel 'spine' associations (e.g., inm_tsn_viewpoint, inm_tsn_action, etc.). A selection of these are defined as follows:-

a) Rule for population of Textual Viewpoints (a similar rule for MSC Viewpoints can also be defined).

```
InteractionModel
self.allInstances->forall(m |
self.inm_scenario.tsn_viewpoint->forall(t |
m.inm_scenario.tsn_viewpoint->includes(t))
implies
m.inm_tsn_viewpoint->includes(t)
```

b) Rule for population of Textual Viewpoints for each event type.

```
InteractionModel
self.allInstances->forall(m |
self.inm_tsn_viewpoint.tvp_tsn_comm->forall(c |
m.inm_tsn_viewpoint.tvp_tsn_comm->includes(c)))
implies
m.inm_tsn_communication->includes(c)

InteractionModel
self.allInstances->forall(m |
self.inm_tsn_viewpoint.tvp_tsn_act->forall(a |
m.inm_tsn_viewpoint.tvp_tsn_act->includes(a)))
implies
m.inm_tsn_action->includes(a)
```

InteractionModel
self.allInstances->forall(m |
self.inm_tsn_viewpoint.tvp_tsn_tim->forall(t |
m.inm_tsn_viewpoint.tvp_tsn_tim->includes(t)))
implies
m.inm_tsn_timing->includes(t)

c) Rule for population of the three event types.

InteractionModel
self.allInstances->forall(m |
self.inm_scenario.scenario_event->forall(c |
m.inm_scenario.scenario_event->includes(c) and m.oclType = CommunicationEvent))
implies
m.inm_communication_event->includes(c)

InteractionModel
self.allInstances->forall(m |
self.inm_scenario.scenario_event->forall(a |
m.inm_scenario.scenario_event->includes(a) and a. oclType = InternalActionEvent))
implies
m.inm_action_event->includes(a)

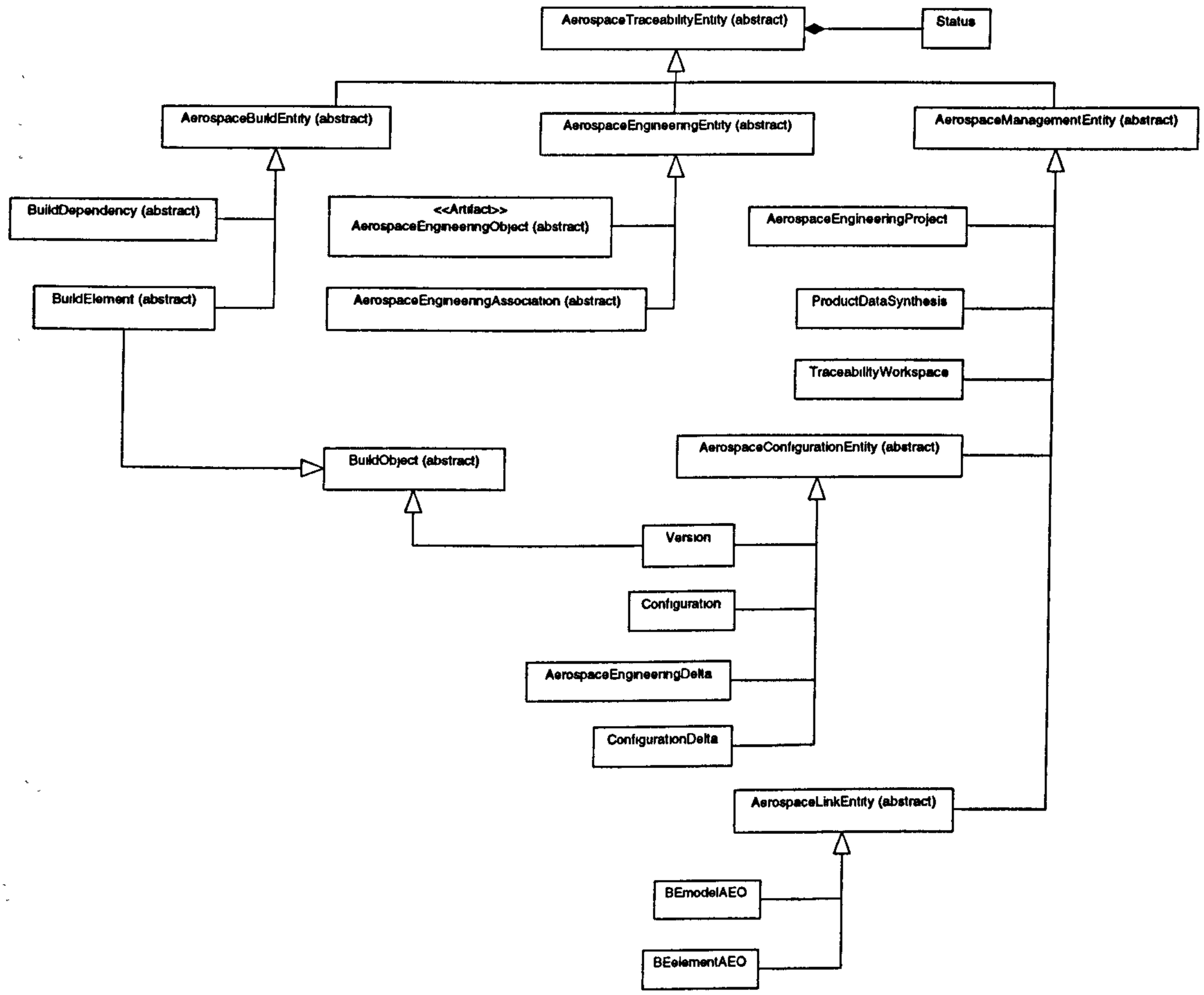
InteractionModel
self.allInstances->forall(m |
self.inm_scenario.scenario_event->forall(t |
m.inm_scenario.scenario_event->includes(t) and t.oclType = TimingEvent))
implies
m.inm_timing_event->includes(t)

This page deliberately left blank

Appendix - B

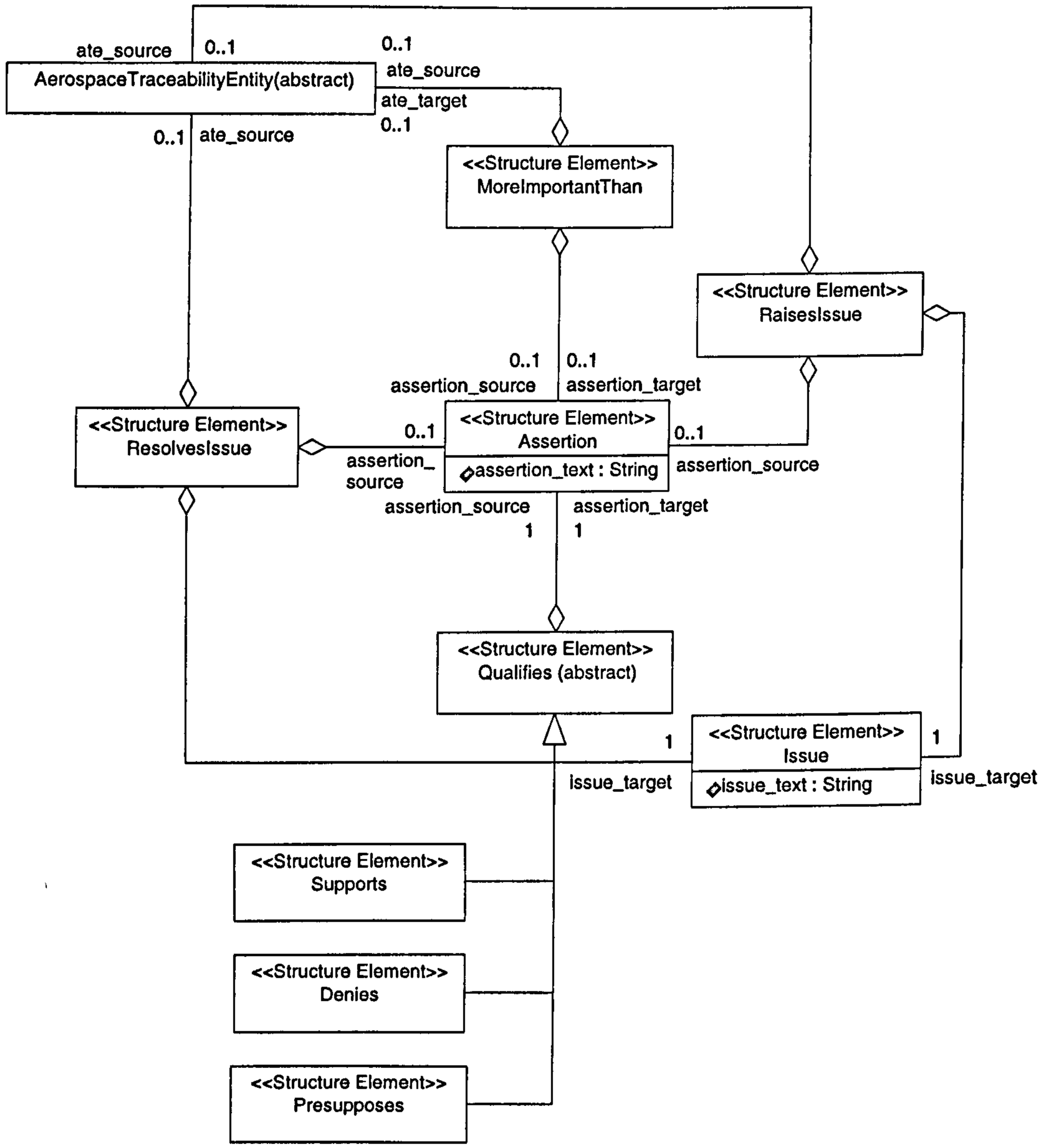
This page deliberately left blank

Appendix B (Part 1)



'MATrA Framework (Revised)'

Appendix B (Part 2)



'Argumentation Meta-model'

Appendix B (Part 3)

Complete O-Telos Representations for MATrA Configuration Model Worked Example

Instantiation of elements in figure 5.12

```
A320 in AerospaceEngineeringProject,
Token with
project_title
    projectTitle : "A320 Project"
has_pds
    hasPDS : A320PDS
end

A320PDS in ProductDataSynthesis, Token
with
build_entity
    buildEntity1 : AirbusA320;
    buildentity2 : GrossWingArea;
    buildEntity3 : LandingDistance;
    buildEntity4 : WingLoading;
    buildEntity5 : FuelCapacity;
    buildEntity6 :
MaximumLiftCoefficient;
    buildEntity7 : Payload;
    buildEntity8 :  Range;
    buildEntity9 : TouchDownSpeed;
    buildEntity10 : ApproachSpeed;
    buildEntity11 : StallingSpeed;
    buildEntity12 : MTOW
.....
end

AirbusA320 in Module, Token with
module_name
    moduleName : "A320"
end

A320HasVer100 in HasRevision, Token with
bd_source
    bdSource : AirbusA320
bd_target
    bdTarget : Dash100
end

Dash100 in Version , Token with
version_name
    versionName : "A320-100"
end

Dash100HasPropertyGrossWingArea in
HasProperty, Token with
bd_source
    bdSource : Dash100
bd_target
    bdTarget : GrossWingArea
end

GrossWingArea in Property, Token with
property_name
    propertyName : "Gross Wing Area"
end

Dash100HasPropertyLandingDistance in
HasProperty, Token with
bd_source
    bdSource : Dash100
bd_target
    bdTarget : LandingDistance
end

LandingDistance in Property, Token with
property_name
    propertyName : "Landing Distance"
end

Dash100HasPropertyWingLoading in
HasProperty, Token with
bd_source
    bdSource : Dash100
bd_target
    bdTarget : WingLoading
end

WingLoading in Property, Token with
property_name
    propertyName : "Wing Loading"
end

Dash100HasPropertyFuelCapacity in
HasProperty, Token with
bd_source
    bdSource : Dash100
bd_target
    bdTarget : FuelCapacity
end

FuelCapacity in Property, Token with
property_name
    propertyName : "Fuel Capacity"
end

Dash100HasPropertyMaximumLiftCoefficient
in HasProperty, Token with
bd_source
    bdSource : Dash100
bd_target
    bdTarget : MaximumLiftCoefficient
end

MaximumLiftCoefficient in Property, Token
with
property_name
    propertyName : "Maximum Lift
Coefficient"
end

Dash100HasPropertyPayload in HasProperty,
Token with
bd_source
    bdSource : Dash100
bd_target
    bdTarget : Payload
end

Payload in Property, Token with
property_name
    propertyName : "Payload"
end

Dash100HasPropertyRange in HasProperty,
Token with
bd_source
    bdSource : Dash100
bd_target
    bdTarget : Range
end

Range in Property, Token with
property_name
    propertyName : "Range"
end

Dash100HasPropertyTouchDownSpeed in
HasProperty, Token with
bd_source
    bdSource : Dash100
```

```
bd_target
    bdTarget : TouchDownSpeed
end

TouchDownSpeed in Property, Token with
property_name
    propertyName : "Touch Down Speed"
end

Dash100HasPropertyApproachSpeed in
HasProperty, Token with
bd_source
    bdSource : Dash100
bd_target
    bdTarget : ApproachSpeed
end

ApproachSpeed in Property, Token with
property_name
    propertyName : "Approach Speed"
end

Dash100HasPropertyStallingSpeed in
HasProperty, Token with
bd_source
    bdSource : Dash100
bd_target
    bdTarget : StallingSpeed
end

StallingSpeed in Property, Token with
property_name
    propertyName : "Stalling Speed"
end

Dash100HasPropertyMTOW in HasProperty,
Token with
bd_source
    bdSource : Dash100
bd_target
    bdTarget : MTOW
end

MTOW in Property, Token with
property_name
    propertyName : "Maximum Takeoff
Weight"
end

MTOWHasSpecificationSpec1 in
HasSpecification, Token with
bd_source
    bdSource : MTOW
bd_target
    bdTarget : MTOWSpec1
end

MTOWSpec1 in Specification, Token with
value_specification
    valueSpecification : "75 000 kg"
end

MTOWHasSpecificationSpec2 in
HasSpecification, Token with
bd_source
    bdSource : MTOW
bd_target
    bdTarget : MTOWSpec2
end

MTOWSpec2 in Specification, Token with
value_specification
    valueSpecification : "75 500 kg"
end

MTOWHasSpecificationSpec3 in
HasSpecification, Token with
bd_source
    bdSource : MTOW
bd_target
    bdTarget : MTOWSpec3
end

MTOWSpec3 in Specification, Token with
value_specification
    valueSpecification : "76 000 kg"
end

MTOWSpecSucceeds1 in Succeeds, Token with
bd_source
    bdSource : MTOWSpec2
bd_target
    bdTarget : MTOWSpec1
end

MTOWSpecSucceeds2 in Succeeds, Token with
bd_source
    bdSource : MTOWSpec3
bd_target
    bdTarget : MTOWSpec2
end
```

Instantiation of elements in figure 5.13

```
FlightControlSystem in Module, Token with
module_name
    moduleName : "FCS"
end

FCSHasVerDash100FCS in HasRevision, Token
with
bd_source
    bdSource : FlightControlSystem
bd_target
    bdTarget : Dash100FCS
end

Dash100FCS in Version , Token with
version_name
    versionName : "-100 FCS"
end

Dash100FCSHasFTsubmoduleSEC1 in
HasFTSubmodule, Token with
bd_source
    bdSource : Dash100FCS
bd_target
    bdTarget : SEC1
end

SEC1 in Module, Token with
module_name
    moduleName : "SEC1"
end

Dash100FCSHasFTsubmoduleSEC2 in
HasFTSubmodule, Token with
bd_source
    bdSource : Dash100FCS
bd_target
    bdTarget : SEC2
end

SEC2 in Module, Token with
module_name
    moduleName : "SEC2"
end

Dash100FCSHasFTsubmoduleELAC1 in
HasFTSubmodule, Token with
bd_source
    bdSource : Dash100FCS
bd_target
    bdTarget : ELAC1
end

ELAC1 in Module, Token with
module_name
    moduleName : "ELAC1"
end
```

```
Dash100FCSHasFTsubmoduleELAC2 in
HasFTSubmodule, Token with
bd_source
    bdSource : Dash100FCS
bd_target
    bdTarget : ELAC2
end

ELAC2 in Module, Token with
module_name
    moduleName : "ELAC2"
end

Dash100FCSHasFTsubmoduleSFCC1 in
HasFTSubmodule, Token with
bd_source
    bdSource : Dash100FCS
bd_target
    bdTarget : SFCC1
end

SFCC1 in Module, Token with
module_name
    moduleName : "SFCC1"
end

Dash100FCSHasFTsubmoduleSFCC2 in
HasFTSubmodule, Token with
bd_source
    bdSource : Dash100FCS
bd_target
    bdTarget : SFCC2
end

SFCC2 in Module, Token with module_name
    moduleName : "SFCC2"
end

SFCC1HasVerDash100SFCC1 in HasRevision,
Token with
bd_source
    bdSource : SFCC1
bd_target
    bdTarget : Dash100SFCC1
end

Dash100SFCC1 in Version , Token with
version_name
    versionName : "-100 SFCC1"
end

Dash100SFCC1HasSubmoduleFlapChannel in
HasSubmodule, Token with
bd_source
    bdSource : Dash100SFCC1
bd_target
    bdTarget : FlapChannel
end

FlapChannel in Module, Token with
module_name
    moduleName : "Flap Channel"
end

Dash100SFCC1HasSubmoduleSlatChannel in
HasSubmodule, Token with
bd_source
    bdSource : Dash100SFCC1
bd_target
    bdTarget : SlatChannel
end

SlatChannel in Module, Token with
module_name
    moduleName : "Slat Channel"
end

SlatChannelHasVerSlatChanneli in
HasRevision, Token with
bd_source
    bdSource : SlatChannel
bd_target
    bdTarget : SlatChanneli
end

SlatChanneli in Version , Token with
version_name
    versionName : "Slat Channel-i"
end

SlatChanneliHasFTsubmoduleSCLane1 in
HasFTSubmodule, Token with
bd_source
    bdSource : SlatChanneli
bd_target
    bdTarget : SlatChannelLane1
end

SlatChannelLane1 in Module, Token with
module_name
    moduleName : "SCLane1"
end

SlatChanneliHasFTsubmoduleSCLane2 in
HasFTSubmodule, Token with
bd_source
    bdSource : SlatChanneli
bd_target
    bdTarget : SlatChannelLane2
end

SlatChannelLane2  in Module, Token with
module_name
    moduleName : "SCLane2"
end

SlatChannelLane1HasVerSlatChannelLane1i
in HasRevision, Token with
bd_source
    bdSource : SlatChannelLane1
bd_target
    bdTarget : SlatChannelLane1i
end

SlatChannelLane1i in Version , Token with
version_name
    versionName : "SCLane1-i"
end

SlatChannelLane1iEncapsulatesInhibtSlatRe
traction in Encapsulates, Token with
bd_source
    bdSource : SlatChannelLane1i
bd_target
    bdTarget : InhibitSlatRetraction
end

InhibitSlatRetraction in Function, Token
with
function_name
    functionName : "Inhibit Slat
Retraction"
end

InhibitSlatRetractionHasVerInhibitSlatRet
ractioni in HasRevision, Token with
bd_source
    bdSource : InhibitSlatRetraction
bd_target
    bdTarget : InhibitSlatRetractioni
end

InhibitSlatRetractioni in Version , Token
with
version_name
    versionName : "Inhibit Slat
Retraction-i"
end

InhibitSlatRetractioniHasConditionDisable
d in HasCondition, Token with
bd_source
```

```
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : Disabled
end

Disabled in Condition, Token with
condition_label
    conditionLabel : "Disabled"
end

InhibitSlatRetractioniHasConditionNotEnga
ged in HasCondition, Token with
bd_source
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : NotEngaged
end

NotEngaged in Condition, Token with
condition_label
    conditionLabel : "Not-Engaged"
end

InhibitSlatRetractioniHasConditionSpeedBa
ulk in HasCondition, Token with
bd_source
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : SpeedBaulk
end

SpeedBaulk in Condition, Token with
condition_label
    conditionLabel : "Speed-Baulk"
end

InhibitSlatRetractioniHasConditionAlphaLo
ck in HasCondition, Token with
bd_source
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : AlphaLock
end

AlphaLock in Condition, Token with
condition_label
    conditionLabel : "Alpha-Lock"
end

InhibitSlatRetractioniHasSubfunctionISRLo
wSpeed in HasSubfunction, Token with
bd_source
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : ISRLowSpeed
end

ISRLowSpeed in Function, Token with
function_name
    functionName : "ISR-Low Speed"
end

InhibitSlatRetractioniHasSubfunctionISRHi
ghAoA in HasSubfunction, Token with
bd_source
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : ISRHighAoA
end

ISRHighAoA in Function, Token with
function_name
    functionName : "ISR-High Angle of
Attack"
end
```

Instantiation of elements in figure 5.14

```
ISRHighAoAHasVerISRHighAoAi in
HasRevision, Token with
bd_source
    bdSource : ISRHighAoA
bd_target
    bdTarget : ISRHighAoAi
end

ISRHighAoAi in Version , Token with
version_name
    versionName : "ISR-High Angle of
Attack-i"
end

AlphaLockHasVerAlphaLocki in HasRevision,
Token with
bd_source
    bdSource : AlphaLock
bd_target
    bdTarget : AlphaLocki
end

AlphaLocki in Version , Token with
version_name
    versionName : "Alpha-Lock-i"
end

AlphaLockiHasSubconditionEngagedAlphaLock
in HasSubcondition, Token with
bd_source
    bdSource : AlphaLocki
bd_target
    bdTarget : EngagedAlphaLock
end

EngagedAlphaLock in Condition, Token with
condition_label
    conditionLabel : "Engaged Alpha-Lock"
end

EngagedAlphaLockHasVerEngagedAlphaLocki
in HasRevision, Token with
bd_source
    bdSource : EngagedAlphaLock
bd_target
    bdTarget : EngagedAlphaLocki
end

EngagedAlphaLocki in Version , Token with
version_name
    versionName : "Engaged Alpha-Lock-i"
end

AlphaLockiHasSubconditionReleaseAlphaLock
in HasSubcondition, Token with
bd_source
    bdSource : AlphaLocki
bd_target
    bdTarget : ReleaseAlphaLock
end

ReleaseAlphaLock in Condition, Token with
condition_label
    conditionLabel : "Release Alpha-Lock"
end

ReleaseAlphaLockHasVerReleaseAlphaLocki
in HasRevision, Token with
bd_source
    bdSource : ReleaseAlphaLock
bd_target
    bdTarget : ReleaseAlphaLocki
end

ReleaseAlphaLocki in Version , Token with
version_name
    versionName : "Release Alpha-Lock-i"
end

ISRHAoAiConsumesCAoA in
ConsumesExternalIO, Token with
bd_source
    bdSource : ISRHighAoAi
```

```
bd_target
    bdTarget : CAoA
end

CAoA in InputOutput, Token with
flow_name
    flowName : "CAoA"
end

CAoAHasVerCAoAi in HasRevision, Token
with
bd_source
    bdSource : CAoA
bd_target
    bdTarget : CAoAi
end

CAoAi in Version, Token with
version_name
    versionName "CAoAi"
end

CAoAiCarriesConditionCAoA7Pt1Event in
CarriesCondition, Token
with
bd_source
        bdSource : CAoAi
bd_target
        bdTarget : CAoA7Pt1Event
end

CAoA7Pt1Event in Condition, Token with
condition_label
        conditionLabel : "CAoA < 7.1
degrees"
end

CAoA7Pt1EventOccurringInEngagedAlphaLock
in OccurringIn, Token
with
bd_source
        bdSource : CAoA7Pt1Event
bd_target
        bdTarget : EngagedAlphaLock
end

CAoA7Pt1EventLeadsToReleaseAlphaLock in
LeadsTo, Token
with
bd_source
        bdSource : CAoA7Pt1Event
bd_target
        bdTarget : ReleaseAlphaLock
end
```

Instantiation of elements in figure 5.15

```
ISRLowSpeedHasVerISRLowSpeedi in
HasRevision, Token with
bd_source
    bdSource : ISRLowSpeed
bd_target
    bdTarget : ISRLowSpeedi
end

ISRLowSpeedi in Version , Token with
version_name
    versionName : "ISR-Low Speed-i"
end

SpeedBaulkHasVerSpeedBaulki in
HasRevision, Token with
bd_source
    bdSource : SpeedBaulk
bd_target
    bdTarget : SpeedBaulki
end

SpeedBaulki in Version , Token with
version_name
    versionName : "Speed-Baulk-i"
end

SpeedBaulkiHasSubconditionEngagedSpeedBau
lk in HasSubcondition, Token with
bd_source
    bdSource : SpeedBaulki
bd_target
    bdTarget : EngagedSpeedBaulk
end

EngagedSpeedBaulk in Condition, Token
with
condition_label
    conditionLabel : "Engaged Speed-
Baulk"
end

EngagedSpeedBaulkHasVerEngagedSpeedBaulki
in HasRevision, Token with
bd_source
    bdSource : EngagedSpeedBaulk
bd_target
    bdTarget : EngagedSpeedBaulki
end

EngagedSpeedBaulki in Version , Token
with
version_name
    versionName : "Engaged Speed-Baulk-i"
end

SpeedBaulkiHasSubconditionReleaseSpeedBau
lk in HasSubcondition, Token with
bd_source
    bdSource : SpeedBaulki
bd_target
    bdTarget : ReleaseSpeedBaulk
end

ReleaseSpeedBaulk in Condition, Token
with
condition_label
    conditionLabel : "Release Speed-
Baulk"
end

ReleaseSpeedBaulkHasVerReleaseSpeedBaulki
in HasRevision, Token with
bd_source
    bdSource : ReleaseSpeedBaulk
bd_target
    bdTarget : ReleaseSpeedBaulki
end

ReleaseSpeedBaulki in Version , Token
with
version_name
    versionName : "Release Speed-Baulk-i"
end

ISRLowSpeediConsumesCAS in
ConsumesExternalIO, Token with
bd_source
    bdSource : ISRLowSpeedi
bd_target
    bdTarget : CAS
end

CAS in InputOutput, Token with
flow_name
    flowName : "CAS"
end

CASHasVerCASi in HasRevision, Token with
bd_source
    bdSource : CAS
bd_target
    bdTarget : CASi
end
```

```
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : Disabled
end

Disabled in Condition, Token with
condition_label
    conditionLabel : "Disabled"
end

InhibitSlatRetractioniHasConditionNotEnga
ged in HasCondition, Token with
bd_source
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : NotEngaged
end

NotEngaged in Condition, Token with
condition_label
    conditionLabel : "Not-Engaged"
end

InhibitSlatRetractioniHasConditionSpeedBa
ulk in HasCondition, Token with
bd_source
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : SpeedBaulk
end

SpeedBaulk in Condition, Token with
condition_label
    conditionLabel : "Speed-Baulk"
end

InhibitSlatRetractioniHasConditionAlphaLo
ck in HasCondition, Token with
bd_source
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : AlphaLock
end

AlphaLock in Condition, Token with
condition_label
    conditionLabel : "Alpha-Lock"
end

InhibitSlatRetractioniHasSubfunctionISRLo
wSpeed in HasSubfunction, Token with
bd_source
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : ISRLowSpeed
end

ISRLowSpeed in Function, Token with
function_name
    functionName : "ISR-Low Speed"
end

InhibitSlatRetractioniHasSubfunctionISRHi
ghAoA in HasSubfunction, Token with
bd_source
    bdSource : InhibitSlatRetractioni
bd_target
    bdTarget : ISRHighAoA
end

ISRHighAoA in Function, Token with
function_name
    functionName : "ISR-High Angle of
Attack"
end
```

Instantiation of elements in figure 5.14

```
ISRHighAoAHasVerISRHighAoAi in
HasRevision, Token with
bd_source
    bdSource : ISRHighAoA
bd_target
    bdTarget : ISRHighAoAi
end

ISRHighAoAi in Version , Token with
version_name
    versionName : "ISR-High Angle of
Attack-i"
end

AlphaLockHasVerAlphaLocki in HasRevision,
Token with
bd_source
    bdSource : AlphaLock
bd_target
    bdTarget : AlphaLocki
end

AlphaLocki in Version , Token with
version_name
    versionName : "Alpha-Lock-i"
end

AlphaLockiHasSubconditionEngagedAlphaLock
in HasSubcondition, Token with
bd_source
    bdSource : AlphaLocki
bd_target
    bdTarget : EngagedAlphaLock
end

EngagedAlphaLock in Condition, Token with
condition_label
    conditionLabel : "Engaged Alpha-Lock"
end

EngagedAlphaLockHasVerEngagedAlphaLocki
in HasRevision, Token with
bd_source
    bdSource : EngagedAlphaLock
bd_target
    bdTarget : EngagedAlphaLocki
end

EngagedAlphaLocki in Version , Token with
version_name
    versionName : "Engaged Alpha-Lock-i"
end

AlphaLockiHasSubconditionReleaseAlphaLock
in HasSubcondition, Token with
bd_source
    bdSource : AlphaLocki
bd_target
    bdTarget : ReleaseAlphaLock
end

ReleaseAlphaLock in Condition, Token with
condition_label
    conditionLabel : "Release Alpha-Lock"
end

ReleaseAlphaLockHasVerReleaseAlphaLocki
in HasRevision, Token with
bd_source
    bdSource : ReleaseAlphaLock
bd_target
    bdTarget : ReleaseAlphaLocki
end

ReleaseAlphaLocki in Version , Token with
version_name
    versionName : "Release Alpha-Lock-i"
end

ISRHAoAiConsumesCAoA in
ConsumesExternalIO, Token with
bd_source
    bdSource : ISRHighAoAi
```

```
bd_target
    bdTarget : CAoA
end

CAoA in InputOutput, Token with
flow_name
    flowName : "CAoA"
end

CAoAHasVerCAoAi in HasRevision, Token
with
bd_source
    bdSource : CAoA
bd_target
    bdTarget : CAoAi
end

CAoAi in Version, Token with
version_name
    versionName "CAoAi"
end

CAoAiCarriesConditionCAoA7Pt1Event in
CarriesCondition, Token
with
bd_source
        bdSource : CAoAi
bd_target
        bdTarget : CAoA7Pt1Event
end

CAoA7Pt1Event in Condition, Token with
condition_label
        conditionLabel : "CAoA < 7.1
degrees"
end

CAoA7Pt1EventOccurringInEngagedAlphaLock
in OccurringIn, Token
with
bd_source
        bdSource : CAoA7Pt1Event
bd_target
        bdTarget : EngagedAlphaLock
end

CAoA7Pt1EventLeadsToReleaseAlphaLock in
LeadsTo, Token
with
bd_source
        bdSource : CAoA7Pt1Event
bd_target
        bdTarget : ReleaseAlphaLock
end
```

Instantiation of elements in figure 5.15

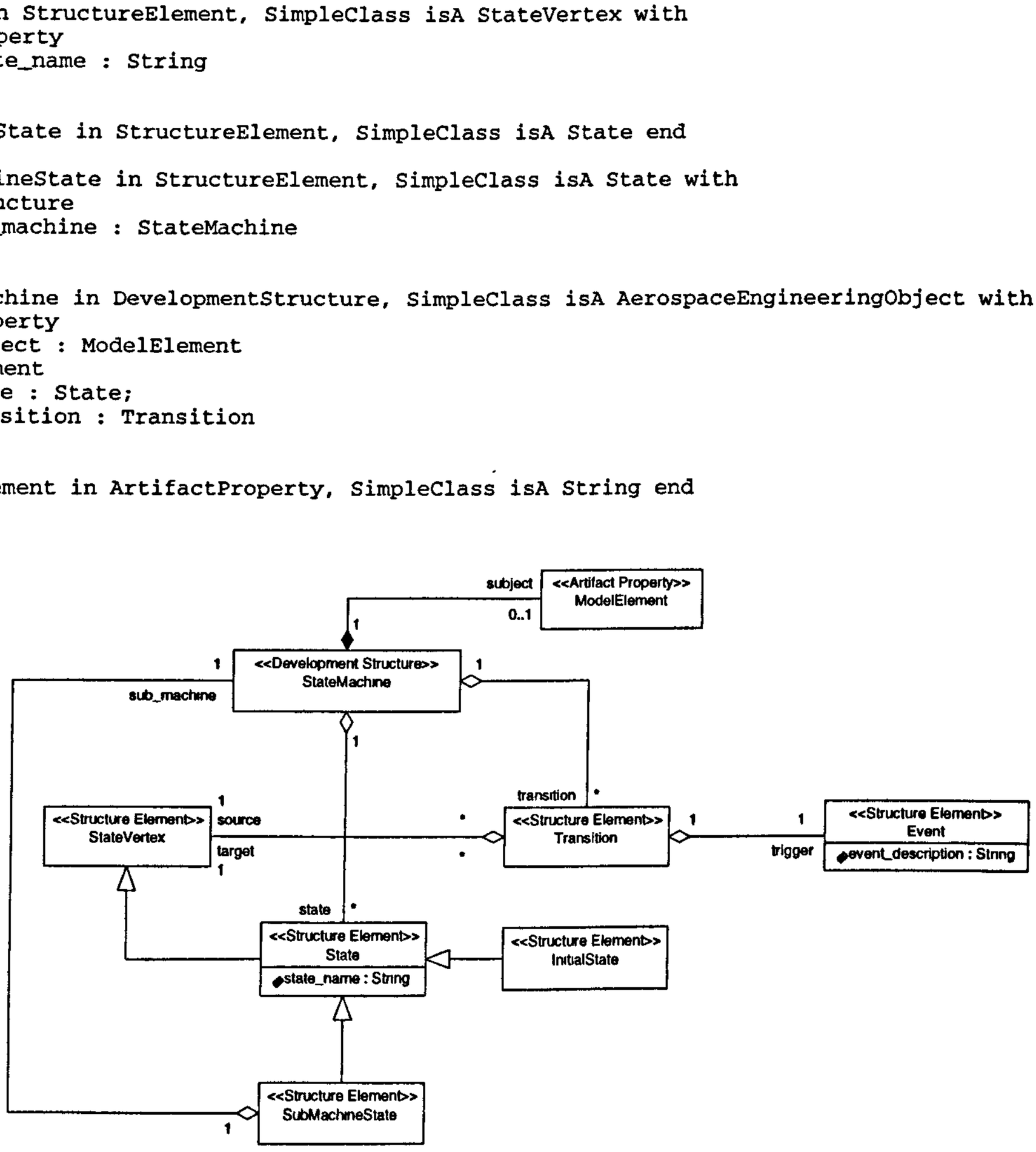
```
ISRLowSpeedHasVerISRLowSpeedi in
HasRevision, Token with
bd_source
    bdSource : ISRLowSpeed
bd_target
    bdTarget : ISRLowSpeedi
end

ISRLowSpeedi in Version , Token with
version_name
    versionName : "ISR-Low Speed-i"
end

SpeedBaulkHasVerSpeedBaulki in
HasRevision, Token with
bd_source
    bdSource : SpeedBaulk
bd_target
    bdTarget : SpeedBaulki
end

SpeedBaulki in Version , Token with
version_name
    versionName : "Speed-Baulk-i"
end

SpeedBaulkiHasSubconditionEngagedSpeedBau
lk in HasSubcondition, Token with
bd_source
    bdSource : SpeedBaulki
bd_target
    bdTarget : EngagedSpeedBaulk
end

EngagedSpeedBaulk in Condition, Token
with
condition_label
    conditionLabel : "Engaged Speed-
Baulk"
end

EngagedSpeedBaulkHasVerEngagedSpeedBaulki
in HasRevision, Token with
bd_source
    bdSource : EngagedSpeedBaulk
bd_target
    bdTarget : EngagedSpeedBaulki
end

EngagedSpeedBaulki in Version , Token
with
version_name
    versionName : "Engaged Speed-Baulk-i"
end

SpeedBaulkiHasSubconditionReleaseSpeedBau
lk in HasSubcondition, Token with
bd_source
    bdSource : SpeedBaulki
bd_target
    bdTarget : ReleaseSpeedBaulk
end

ReleaseSpeedBaulk in Condition, Token
with
condition_label
    conditionLabel : "Release Speed-
Baulk"
end

ReleaseSpeedBaulkHasVerReleaseSpeedBaulki
in HasRevision, Token with
bd_source
    bdSource : ReleaseSpeedBaulk
bd_target
    bdTarget : ReleaseSpeedBaulki
end

ReleaseSpeedBaulki in Version , Token
with
version_name
    versionName : "Release Speed-Baulk-i"
end

ISRLowSpeediConsumesCAS in
ConsumesExternalIO, Token with
bd_source
    bdSource : ISRLowSpeedi
bd_target
    bdTarget : CAS
end

CAS in InputOutput, Token with
flow_name
    flowName : "CAS"
end

CASHasVerCASi in HasRevision, Token with
bd_source
    bdSource : CAS
bd_target
    bdTarget : CASi
end
```

```
CASi in Version, Token with
version_name
    versionName "CASi"
end

CASiCarriesConditionCAS154KtsEvent in
CarriesCondition, Token with
bd_source
    bdSource : CASi
bd_target
    bdTarget : CAS154KtsEvent
end

CAS154KtsEvent in Condition, Token with
condition_label
    conditionLabel : "CAS > 154 knots"
end

CAS154KtsEventOccurringInEngagedSpeedBaulk
in OccurringIn, Token with
bd_source
    bdSource : CAS154KtsEvent
bd_target
    bdTarget : EngagedSpeedBaulk
end

CAS154KtsEventLeadsToReleaseSpeedBaulk in
LeadsTo, Token with
bd_source
    bdSource : CAS154KtsEvent
bd_target
    bdTarget : ReleaseSpeedBaulk
end
```

Appendix B (Part 4)

Statechart Meta-model : UML and O-Telos Base Classes

```
Event in StructureElement, SimpleClass isA AerospaceEngineeringObject with
has_property
    event_description : String

end

StateVertex in StructureElement, SimpleClass isA AerospaceEngineeringObject end

Transition in StructureElement, SimpleClass isA AerospaceEngineeringObject with
has_part
    source : StateVertex;
    target : StateVertex;
    trigger : Event
end

State in StructureElement, SimpleClass isA StateVertex with
has_property
    state_name : String
end

InitialState in StructureElement, SimpleClass isA State end

SubMachineState in StructureElement, SimpleClass isA State with
has_structure
    sub_machine : StateMachine
end

StateMachine in DevelopmentStructure, SimpleClass isA AerospaceEngineeringObject with
has_property
    subject : ModelElement
has_element
    state : State;
    transition : Transition
end

ModelElement in ArtifactProperty, SimpleClass isA String end
```



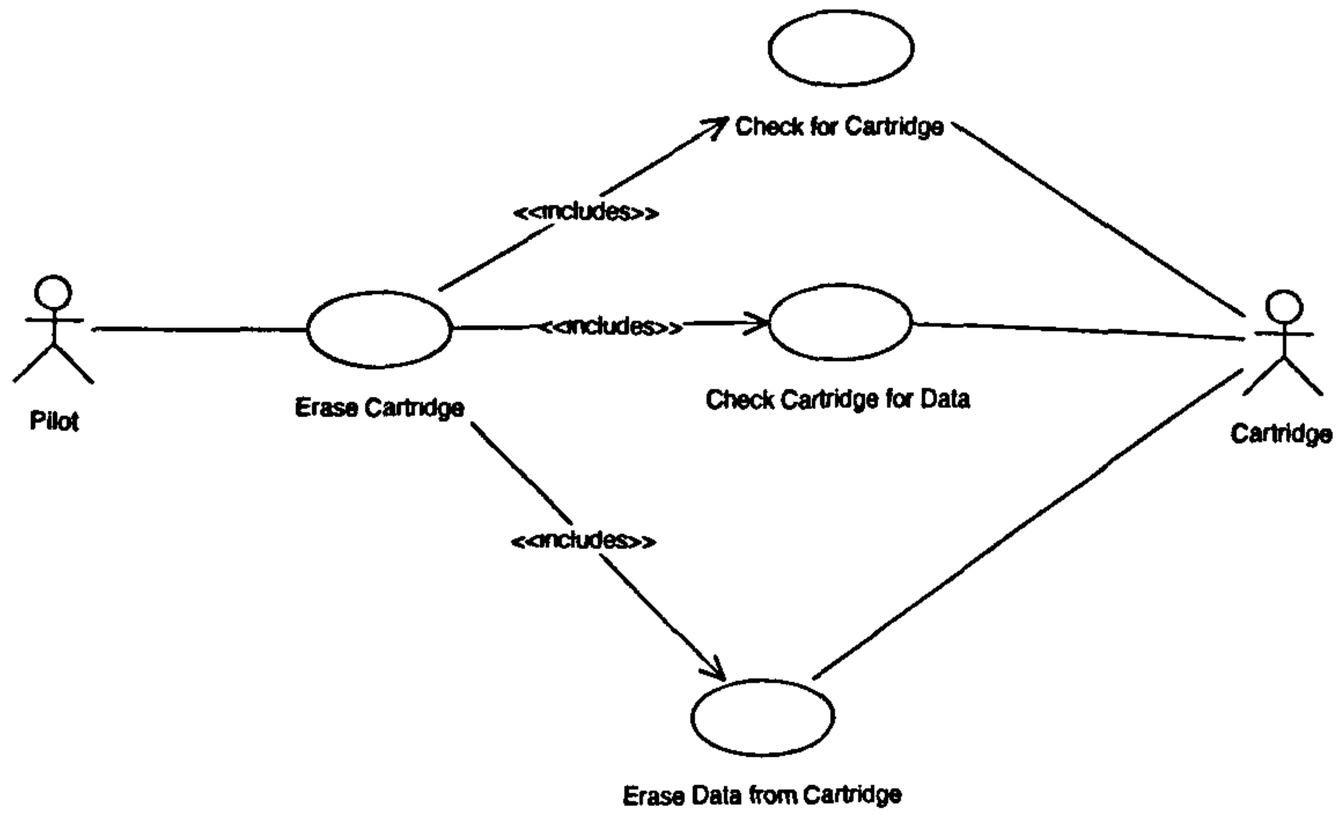
'State Machine Meta-model'

This page deliberately left blank

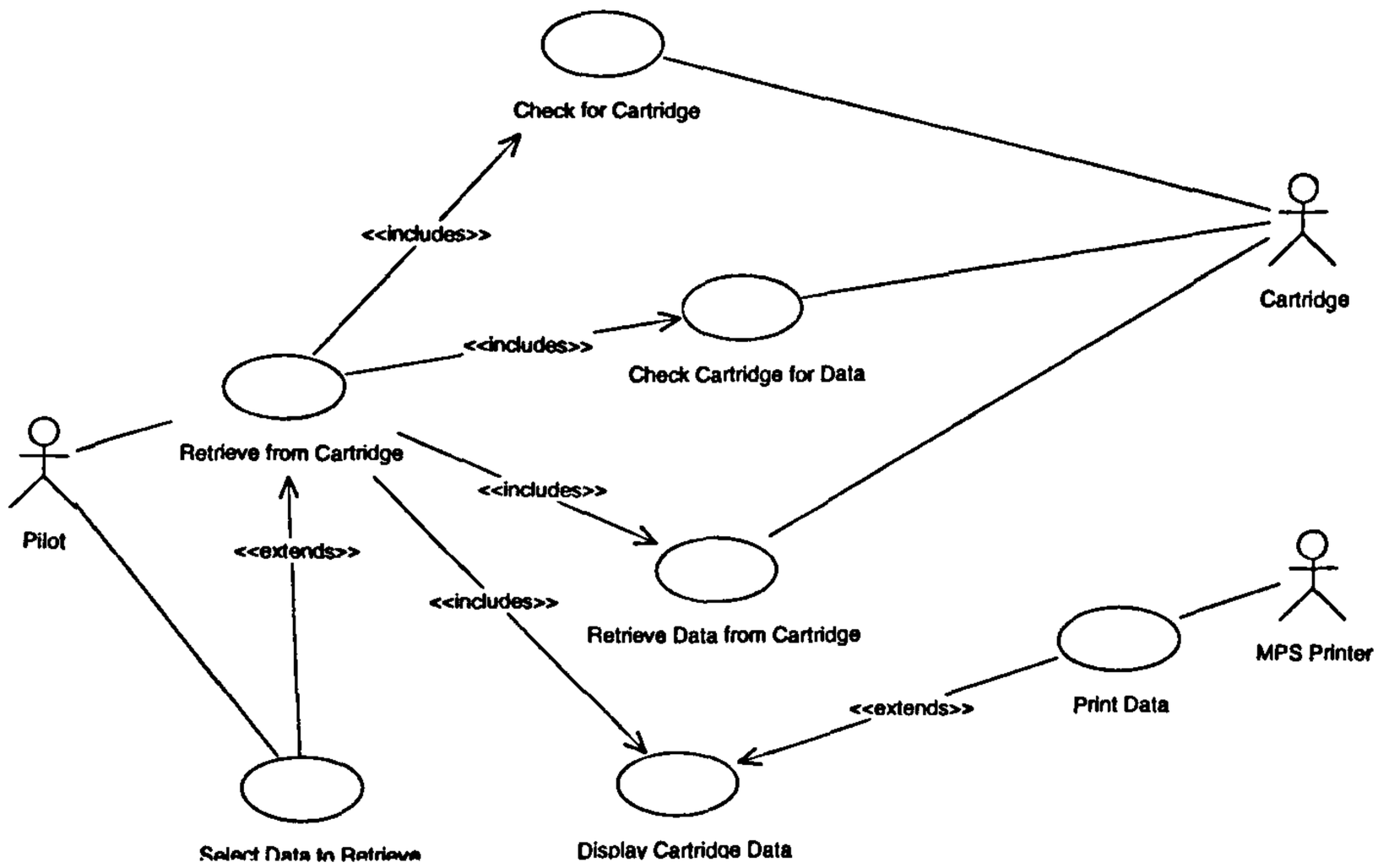
Appendix - C

This page deliberately left blank

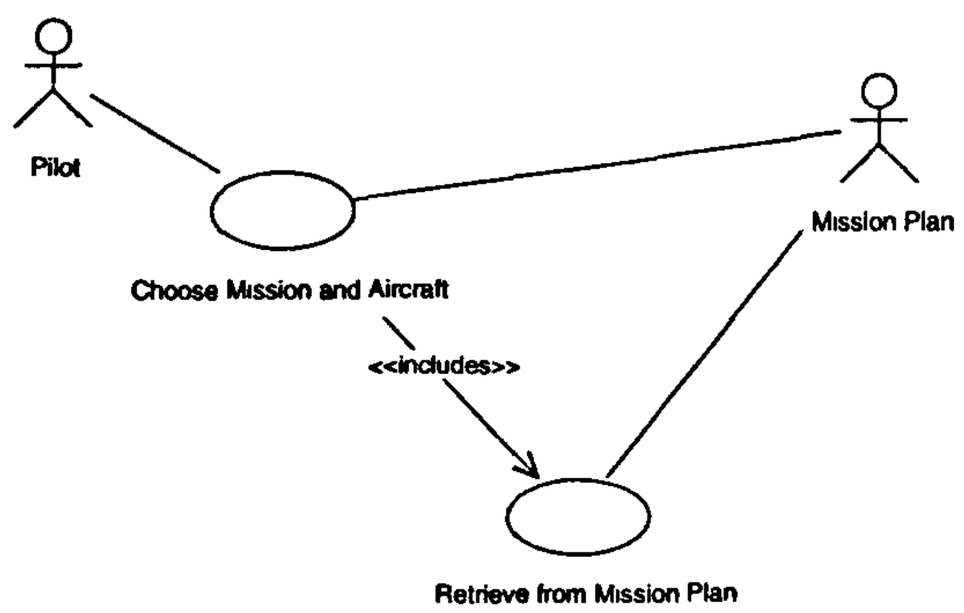
Appendix C (Part 1) - Case Study I : A Hypothetical Mission Planning System for the Hawk 100 and 200 Series Aircraft (Complete O-Telos Representation of Artifacts from 6.2)



'Erase Cartridge Use Case Diagram'



'Retrieve From Cartridge Use Case Diagram'



'Choose Mission and Aircraft Use Case Diagram'

I. Instantiation of Use Case View for Erase Cartridge, Retrieve from Cartridge and Choose Mission & Aircraft

Instantiation of UseCaseModel Elements

- **Actor Instances**

```
Pilot in Actor, Token with
actor_name
    actorName : "Pilot"
end

Cartridge in Actor, Token with
actor_name
    actorName : "Cartridge"
end

MPSPrinter in Actor, Token with
actor_name
    actorName : "MPS Printer"
end

MissionPlan in Actor, Token with
actor_name
    actorName : "Mission Plan"
end
```

- **Text Nodes (for specifying Pre and Post Conditions)**

```
CartridgeNode in ModuleNode, Token with
module_name
    moduleName : "Cartridge"
end

MissionPlanningSystemNode in ModuleNode,
Token with
module_name
    moduleName : "MPS"
end

PilotNode in ModuleNode, Token with
module_name
    moduleName : "Pilot"
end

MPSPrinterNode in ModuleNode, Token with
module_name
    moduleName : "MPS Printer"
end

MissionPlanNode in ModuleNode, Token with
module_name
    moduleName : "Mission Plan"
end

CheckforCartridgeNode in TransactionNode,
Token with
transaction_name
    transactionName : "Check for Cartridge"
end

CheckCartridgeforDataNode in
TransactionNode, Token with
transaction_name
    transactionName : "Check Cartridge
for Data"
end
```

- **Use Cases (including Pre & Post Conditions)**

Erase Cartridge

```
EraseCartridge in UseCase, Token with
use_case_name
    useCaseName : "Erase Cartridge"
sub_case
    subCase : False
post_condition
    postCondition1 : ECPost1NLS
end
```

Post Condition for Erase Cartridge

```
ECPost1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : ECPostC1
mnls_plain_text
    mnlsPlainText1 : ECPostPT1;
    mnlsPlainText2 : ECPostPT2
mnls_module
    mnlsModule1 : CartridgeNode
end

ECPostC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : ECPostPT1
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : ECPostPT2
end

ECPostPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The data on the "
end

ECPostPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " has been erased."
end
```

Check for Cartridge

```
CheckforCartridge in UseCase, Token with
use_case_name
    useCaseName : "Check for Cartridge"
sub_case
    subCase : True
post_condition
    postCondition1 : CfCPost1NLS
end
```

Post Condition for Check for Cartridge

```
CfCPost1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : CfCPostC1;
    mnlsComposite2 : CfCPostC2
mnls_plain_text
    mnlsPlainText1 : CfCPostPT1;
    mnlsPlainText2 : CfCPostPT2;
    mnlsPlainText3 : CfCPostPT3
mnls_module
    mnlsModule1 :
MissionPlanningSystemNode;
    mnlsModule2 : CartridgeNode
end

CfCPostC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CfCPostPT1
subject_node
    subjectNode :
MissionPlanningSystemNode
following_fragment
    followingFragment : CfCPostC2
end
```

```
CfCPostPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

CfCPostC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CfCPostPT2
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : CfCPostPT3
end

CfCPostPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " has been informed that
there is a "
end

CfCPostPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " present in the
hardware."
end
```

Check Cartridge for Data

```
CheckCartridgeforData in UseCase, Token
with
use_case_name
    useCaseName : "Check Cartridge for
Data"
sub_case
    subCase : True
pre_condition
    preCondition1 : CCfDPre1NLS
post_condition
    postCondition1 : CCfDPost1NLS
end
```

PreCondition for Check Cartridge for Data

```
CCfDPre1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : CCfDPreC1
mnls_plain_text
    mnlsPlainText1 : CCfDPrePT1;
    mnlsPlainText2 : CCfDPrePT2
mnls_module
    mnlsModule1 : CartridgeNode
end

CCfDPreC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CCfDPrePT1
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : CCfDPrePT2
end

CCfDPrePT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "There is a "
end

CCfDPrePT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " present in the
hardware."
end
```

Post Condition for Check Cartridge for Data

```
CCfDPost1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : CCfDPostC1;
    mnlsComposite2 : CCfDPostC2
mnls_plain_text
    mnlsPlainText1 : CCfDPostPT1;
    mnlsPlainText2 : CCfDPostPT2;
    mnlsPlainText3 : CCfDPostPT3
mnls_module
    mnlsModule1 :
MissionPlanningSystemNode;
    mnlsModule2 : CartridgeNode
end

CCfDPostC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CCfDPostPT1
subject_node
    subjectNode :
MissionPlanningSystemNode
following_fragment
    followingFragment : CCfDPostC2
end


CCfDPostPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

CCfDPostC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CCfDPostPT2
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : CCfDPostPT3
end

CCfDPrePT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " has been informed
whether or not there is data loaded on
the  "
end

CartridgeNode in ModuleNode, Token with
module_name
    moduleName : "Cartridge"
end

CCfDPrePT3 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

Erase Data from Cartridge

```
EraseDatafromCartridge in UseCase, Token
with
use_case_name
    useCaseName : "Erase Data from
Cartridge"
sub_case
    subCase : True
pre_condition
    preCondition1 : EDfCPre1NLS;
    preCondition2 : EDfCPre2NLS
post_condition
    postCondition1 : EDfCPost1NLS
end
```

Pre Conditions for Erase Data from Cartridge

Pre Condition 1

```
EDfCPre1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : EDfCPre1C1;
    mnlsComposite2 : EDfCPre1C2
mnls_plain_text
    mnlsPlainText1 : EDfCPre1PT1;
    mnlsPlainText2 : EDfCPre1PT2;
    mnlsPlainText3 : EDfCPre1PT3
mnls_module
    mnlsModule1 : PilotNode;
    mnlsModule2 : CartridgeNode
end

EDfCPre1C1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : EDfCPre1PT1
subject_node
    subjectNode : PilotNode
following_fragment
    followingFragment : EDfCPre1C2
end

EDfCPre1PT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

EDfCPre1C2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : EDfCPre1PT2
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : EDfCPre1PT3
end

EDfCPre1PT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " has confirmed that he
wishes to erase data from the "

end

EDfCPre1PT3 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

Pre Condition 2

```
EDfCPre2NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : EDfCPre2C1
mnls_plain_text
    mnlsPlainText1 : EDfCPre2PT1;
    mnlsPlainText2 : EDfCPre2PT2
mnls_module
    mnlsModule1 : CartridgeNode
end

EDfCPre2C1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : EDfCPre2PT1
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : EDfCPre2PT2
end

EDfCPre2PT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

EDfCPre2PT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " has to contain data."
end
```

Post Condition for Erase Data from Cartridge

```
EDfCPost1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : EDfCPostC1
mnls_plain_text
    mnlsPlainText1 : EDfCPostPT1;
    mnlsPlainText2 : EDfCPostPT2
mnls_module
    mnlsModule1 : CartridgeNode
end

EDfCPostC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : EDfCPostPT1
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : EDfCPostPT2
end

EDfCPostPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "Data has been erased from
                the "
end

EDfCPostPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

Retrieve from Cartridge

```
RetrievefromCartridge in UseCase, Token
with
use_case_name
    useCaseName : "Retrieve from
Cartridge"
sub_case
    subCase : False
post_condition
    postCondition1 : RfCPost1NLS;
    postCondition2 : RfCPost2NLS
end
```

Post Conditions for Retrieve from Cartridge

Post Condition 1

```
RfCPost1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : RfCPost1C1;
    mnlsComposite2 : RfCPost1C2
mnls_plain_text
    mnlsPlainText1 : RfCPost1PT1;
    mnlsPlainText2 : RfCPost1PT2;
    mnlsPlainText3 : RfCPost1PT3
mnls_module
    mnlsModule1 : CartridgeNode;
    mnlsModule2 :
MissionPlanningSystemNode
end

RfCPost1C1 in MatraNLSComposite, Token
with
```

```
preceding_fragment
    precedingFragment : RfCPost1PT1
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : RfCPost1C2
end

RfCPost1PT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The data on the "
end

RfCPost1C2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : RfCPost1PT2
subject_node
    subjectNode :
MissionPlanningSystemNode
following_fragment
    followingFragment : RfCPost1PT3
end

RfCPost1PT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " has been copied onto the
"
end

RfCPost1PT3 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

Post Condition 2

```
RfCPost2NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : RfCPost2C1
mnls_plain_text
    mnlsPlainText1 : RfCPost2PT1;
    mnlsPlainText2 : RfCPost2PT2
mnls_module
    mnlsModule1 : PilotNode
end

RfCPost2C1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : RfCPost2PT1
subject_node
    subjectNode : PilotNode
following_fragment
    followingFragment : RfCPost2PT2
end

RfCPost2PT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The data has been
displayed to the "
end

RfCPost2PT2 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

Select Data to Retrieve

```
SelectDatatoRetrieve in UseCase, Token
with
use_case_name
    useCaseName : "Select Data to
Retrieve"
sub_case
    subCase : True
post_condition
    postCondition1 : SDtRPost1NLS
end
```

Post Condition for Select Data to Retrieve

```
SDtRPost1NLS in
MatraNaturalLanguageStructure, Token with
mnls_plain_text
    mnlsPlainText1 : SDtRPostPT1
end

SDtRPostPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The data types to be
retrieved have been defined."

end
```

Retrieve Data from Cartridge

```
RetrieveDatafromCartridge in UseCase,
Token with
use_case_name
    useCaseName : "Retrieve Data from
    Cartridge"
sub_case
    subCase : True
pre_condition
    preCondition1 : RDfCPre1NLS
post_condition
    postCondition1 : RDfCPost1NLS
end
```

Pre Condition for Retrieve Data from Cartridge

```
RDfCPre1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : RDfCPreC1
mnls_plain_text
    mnlsPlainText1 : RDfCPrePT1;
    mnlsPlainText2 : RDfCPrePT2
mnls_module
    mnlsModule1 : CartridgeNode
end

RDfCPreC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : RDfCPrePT1
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : RDfCPrePT2
end

RDfCPrePT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "A "
end

RDfCPrePT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " containing data is
present in the hardware."

end
```

Post Condition for Retrieve Data from Cartridge

```
RDfCPost1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : RDfCPostC1;
    mnlsComposite2 : RDfCPostC2
```

```
mnls_plain_text
    mnlsPlainText1 : RDfCPostPT1;
    mnlsPlainText2 : RDfCPostPT2;
    mnlsPlainText3 : RDfCPostPT3
mnls_module
    mnlsModule1 : CartridgeNode;
    mnlsModule2 :
MissionPlanningSystemNode
end

RDfCPostC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : RDfCPostPT1
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : RDfCPostC2
end

RDfCPostPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The data on the "
end

RDfCPostC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : RDfCPostPT2
subject_node
    subjectNode :
MissionPlanningSystemNode
following_fragment
    followingFragment : RDfCPostPT3
end

RDfCPostPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " has been copied onto the
"
end

RDfCPostPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

Display Cartridge Data

```
DisplayCartridgeData in UseCase, Token
with
use_case_name
    useCaseName : "Display Cartridge
Data"
sub_case
    subCase : True
pre_condition
    preCondition1 : DCDPre1NLS
post_condition
    postCondition1 : DCDPost1NLS
end
```

Pre Condition for Display Cartridge Data

```
DCDPre1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : DCDPreC1;
    mnlsComposite2 : DCDPreC2
mnls_plain_text
    mnlsPlainText1 : DCDPrePT1;
    mnlsPlainText2 : DCDPrePT2;
    mnlsPlainText3 : DCDPrePT3
mnls_module
    mnlsModule1 : CartridgeNode;
    mnlsModule2 :
MissionPlanningSystemNode
end

DCDPreC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DCDPrePT1
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : DCDPreC2
end

DCDPrePT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "Data has been retrieved
    from the "
end

DCDPreC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DCDPrePT2
subject_node
    subjectNode :
MissionPlanningSystemNode
following_fragment
    followingFragment : DCDPrePT3
end

DCDPrePT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " and stored on the "
end

DCDPrePT3in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

Post Condition for Display Cartridge Data

```
DCDPost1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : DCDPostC1;
    mnlsComposite2 : DCDPostC2
mnls_plain_text
    mnlsPlainText1 : DCDPostPT1;
    mnlsPlainText2 : DCDPostPT2;
    mnlsPlainText3 : DCDPostPT3
mnls_module
    mnlsModule1 : CartridgeNode;
    mnlsModule2 : PilotNode
end

DCDPostC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : DCDPostPT1
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : DCDPostC2
end

DCDPostPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The data that is
currently loaded onto the "

end

DCDPostC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : DCDPostPT2
subject_node
    subjectNode : PilotNode
following_fragment
    followingFragment : DCDPostPT3
end

DCDPostPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " is displayed for the "
```

```
end

DCDPostPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

Print Data

```
PrintData in UseCase, Token with
use_case_name
    useCaseName : "Print Data"
sub_case
    subCase : True
pre_condition
    preCondition1 : PDPre1NLS
post_condition
    postCondition1 : PDPost1NLS
end
```

Pre Condition for Print Data

```
PDPre1NLS in
MatraNaturalLanguageStructure, Token with
mnls_plain_text
    mnlsPlainText1 : PDPrePT1
end

PDPrePT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The data to be printed is
being displayed."

end
```

Post Condition for Print Data

```
PDPost1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : PDPostC1
mnls_plain_text
    mnlsPlainText1 : PDPostPT1;
    mnlsPlainText2 : PDPostPT2
mnls_module
    mnlsModule1 : MPSPrinterNode
end


PDPostC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : PDPostPT1
subject_node
    subjectNode : MPSPrinterNode
following_fragment
    followingFragment : PDPostPT2
end

PDPostPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The data item has been
printed by the "
end

PDPostPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

Choose Mission and Aircraft

```
ChooseMissionandAircraft in UseCase,
Token with
use_case_name
    useCaseName : "Choose Mission and
Aircraft"
sub_case
    subCase : False
pre_condition
    preCondition1 : CMAPre1NLS
post_condition
    postCondition1 : CMAPost1NLS;
    postCondition2 : CMAPost2NLS
end
```

Pre Condition for Choose Mission and Aircraft

```
CMAPre1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : CMAPreC1
mnls_plain_text
    mnlsPlainText1 : CMAPrePT1;
    mnlsPlainText2 : CMAPrePT2
mnls_module
    mnlsModule1 :
MissionPlanningSystemNode
end

CMAPreC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : CMAPrePT1
subject_node
    subjectNode :
MissionPlanningSystemNode
following_fragment
    followingFragment : CMAPrePT2
end

CMAPrePT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "A database must be
attached to the "
end

CMAPrePT2 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

Post Conditions for Choose Mission and Aircraft

Post Condition 1

```
CMAPost1NLS in
MatraNaturalLanguageStructure, Token with
mnls_plain_text
    mnlsPlainText1 : CMAPost1PT1
end

CMAPost1PT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "A mission and aicraft
have been selected."
end
```

Post Condition 2

```
CMAPost2NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : CMAPost2C1;
    mnlsComposite2 : CMAPost2C2
mnls_plain_text
    mnlsPlainText1 : CMAPost2PT1;
    mnlsPlainText2 : CMAPost2PT2;
    mnlsPlainText3 : CMAPost2PT3
mnls_module
    mnlsModule1 : MissionPlanNode;
    mnlsModule2 :
MissionPlanningSystemNode
end
```

```
CMAPost2C1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CMAPost2PT1
subject_node
    subjectNode : MissionPlanNode
following_fragment
    followingFragment : CMAPost2C2
end

CMAPost2PT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "Data for the selected "
end

CMAPost2C2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CMAPost2PT2
subject_node
    subjectNode :
MissionPlanningSystemNode
following_fragment
    followingFragment : CMAPost2PT3
end

CMAPost2PT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " has been loaded onto the "
end

CMAPost2PT3 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

Retrieve from Mission Plan

```
RetrievefromMissionPlan in UseCase, Token
with
use_case_name
    useCaseName : "Retrieve from Mission
Plan"
sub_case
    subCase : True
pre_condition
    preCondition1 : RfMPPre1NLS
post_condition
    postCondition1 : RfMPPost1NLS
end
```

Pre Condition for Retrieve from Mission Plan

```
RfMPPre1NLS in
MatraNaturalLanguageStructure, Token with
mnls_plain_text
    mnlsPlainText1 : RfMPPrePT1;
end

RfMPPrePT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "A mission and aircraft
have been defined."

end
```

Post Condition for Retrieve from Mission Plan

```
RfMPPost1NLS in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : RfMPPostC1;
    mnlsComposite2 : RfMPPostC2
mnls_plain_text
    mnlsPlainText1 : RfMPPostPT1;
    mnlsPlainText2 : RfMPPostPT2;
    mnlsPlainText3 : RfMPPostPT3
mnls_module
    mnlsModule1 : MissionPlanNode;
    mnlsModule2 :
MissionPlanningSystemNode
end

RfMPPostC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : RfMPPostPT1
subject_node
    subjectNode : MissionPlanNode
following_fragment
    followingFragment : RfMPPostC2
end

RfMPPostPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The data on the "
end

RfMPPostC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : RfMPPostPT2
subject_node
    subjectNode :
MissionPlanningSystemNode
following_fragment
    followingFragment : RfMPPostPT3
end

RfMPPostPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " for the selected mission
and aircraft has been copied onto the "
end

RfMPPostPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

- **Interaction Instances**

```
PilotEraseCartridge in Interaction, Token
with
interactor_1
    interactor1 : Pilot
interactor_2
    interactor2 : EraseCartridge
end

CartridgeCheckforCartridge in
Interaction, Token with
interactor_1
    interactor1 : Cartridge
interactor_2
    interactor2 : CheckforCartridge
end

CartridgeCheckCartridgeforData in
Interaction, Token with
interactor_1
    interactor1 : Cartridge
interactor_2
    interactor2 : CheckCartridgeforData
end

CartridgeEraseDatafromCartridge in
Interaction, Token with
interactor_1
    interactor1 : Cartridge
interactor_2
    interactor2 : EraseDatafromCartridge
end

PilotRetrievefromCartridge in
Interaction, Token with
interactor_1
    interactor1 : Pilot
```

```
interactor_2
    interactor2 : RetrievefromCartridge
end

CartridgeRetrieveDatafromCartridge in
Interaction, Token with
interactor_1
    interactor1 : Cartridge
interactor_2
    interactor2 :
RetrieveDatafromCartridge
end

PilotSelectDatatoRetrieve in Interaction,
Token with
interactor_1
    interactor1 : Pilot
interactor_2
    interactor2 : SelectDatatoRetrieve
end

MPSPrinterPrintData in Interaction, Token
with
interactor_1
    interactor1 : MPSPrinter
interactor_2
    interactor2 : PrintData
end

PilotChooseMissionandAircraft in
Interaction, Token with
interactor_1
    interactor1 : Pilot
interactor_2
    interactor2 :
ChooseMissionandAircraft
end

MissionPlanRetrievefromMissionPlan in
Interaction, Token with
interactor_1
    interactor1 : MissionPlan
interactor_2
    interactor2 : RetrievefromMissionPlan
end

MissionPlanChooseMissionandAircraft in
Interaction, Token with
interactor_1
    interactor1 : MissionPlan
interactor_2
    interactor2 :
ChooseMissionandAircraft
end
```

- **Includes Instances**

```
EraseCartridgeCheckforCartridge in
Includes, Token with
includes_base
    includesBase : EraseCartridge
includes_include
    includesInclude : CheckforCartridge
end

EraseCartridgeCheckCartridgeforData in
Includes, Token with
includes_base
    includesBase : EraseCartridge
includes_include
    includesInclude :
CheckCartridgeforData
end

EraseCartridgeEraseDatafromCartridge in
Includes, Token with
includes_base
    includesBase : EraseCartridge
includes_include
    includesInclude :
EraseDatafromCartridge
end

RetrievefromCartridgeCheckforCartridge in
Includes, Token with
includes_base
    includesBase : RetrievefromCartridge
includes_include
    includesInclude : CheckforCartridge
end

RetrievefromCartridgeCheckCartridgeforDat
a in Includes, Token with
includes_base
    includesBase : RetrievefromCartridge
includes_include
    includesInclude :
CheckCartridgeforData
end

RetrievefromCartridgeRetrieveDatafromCart
ridgein Includes, Token with
includes_base
    includesBase : RetrievefromCartridge
includes_include
    includesInclude :
RetrieveDatafromCartridge
end

RetrievefromCartridgeDisplayCartridgeData
in Includes, Token with
includes_base
    includesBase : RetrievefromCartridge
includes_include
    includesInclude :
DisplayCartridgeData
end

ChooseMissionandAircraftRetrievefromMissi
onPlan in Includes, Token with
includes_base
    includesBase :
ChooseMissionandAircraft
includes_include
    includesInclude :
RetrievefromMissionPlan
end
```

- **Extends Instances**

```
PrintDataDisplayCartridgeData in Extends,
Token with
extends_base
    extendsBase : PrintData
extends_extend
    extendsExtend : DisplayCartridgeData
end

SelectDatatoRetrieveRetrievefromCartrdige
in Extends, Token with
extends_base
    extendsBase : SelectDatatoRetrieve
extends_extend
    extendsExtend : RetrievefromCartrdige
end
```

Erase Cartridge Use Case Model

```
EraseCartridgeModel in UseCaseModel,
Token with model_name
    modelName : "Erase Cartridge Model"
ucm_comments
    ucmComments : EraseCartridgeComments
ucm_use_case
    ucmUseCase1 : EraseCartridge;
    ucmUseCase2 : CheckforCartridge;
    ucmUseCase3 : CheckCartridgeforData;
    ucmUseCase4 : EraseDatafromCartridge
```

```
ucm_actor
    ucmActor1 : Pilot;
    ucmActor2 : Cartridge
ucm_interaction
    ucmInteraction1 :
PilotEraseCartridge;
    ucmInteraction2 :
    CartridgeCheckforCartridge;
        ucmInteraction3 :
CartridgeCheckCartridgeforData;
    ucmInteraction4 :
CartridgeEraseDatafromCartridge
ucm_includes
    ucmIncludes1 :
        EraseCartridgeCheckforCartridge;
    ucmIncludes2 :
    EraseCartridgeCheckCartridgeforData;
    ucmIncludes3 :
    EraseCartridgeEraseDatafromCartridge
ucm_pre_condition
    ucmPreCondition1 : CCfDPre1NLS;
    ucmPreCondition2 : EDfCPre1NLS;
    ucmPreCondition3 : EDfCPre2NLS
ucm_post_condition
    ucmPostCondition1 : ECPost1NLS;
    ucmPostCondition2 : CfCPost1NLS;
    ucmPostCondition3 : CCfDPost1NLS;
    ucmPostCondition4 : EDfCPost1NLS
end

EraseCartridgeComments in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : ECCC1;
    mnlsComposite2 : ECCC2;
    mnlsComposite3 : ECCC3
mnls_plain_text
    mnlsPlainText1 : ECCPT1;
    mnlsPlainText2 : ECCPT2;
    mnlsPlainText3 : ECCPT3;
    mnlsPlainText4 : ECCPT4
mnls_module
    mnlsModule1 : CartridgeNode
mnls_transaction
    mnlsTransaction1 :
CheckforCartridgeNode;
    mnlsTransaction2 :
CheckCartridgeforDataNode
end

ECCC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : ECCPT1
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : ECCC2
end

ECCPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The purpose of this
diagram is to model the erasing of data
from a "
end

ECCC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : ECCPT2
subject_node
    subjectNode : CheckforCartridgeNode
following_fragment
    followingFragment : ECCC3
end

ECCPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : ". Checks are made to
ensure that a cartridge is physically
    present, using "
end

ECCC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : ECCPT3
subject_node
    subjectNode :
CheckCartridgeforDataNode
following_fragment
    followingFragment : ECCPT4
end

ECCPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " and also that there is
data on the cartridge, using "
end

ECCPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

Retrieve from Cartridge Use Case Model (Partial - Derived Elements not Shown)

```
RetrievefromCartridgeModel in
UseCaseModel, Token with model_name
    modelName : "Retrieve from Cartridge
Model"
ucm_comments
    ucmComments :
RetrievefromCartridgeComments
ucm_use_case
    ucmUseCase1 : RetrievefromCartridge;
    ucmUseCase2 : CheckforCartridge;
    ucmUseCase3 : CheckCartridgeforData;
    ucmUseCase4 :
RetrieveDatafromCartridge;
    ucmUseCase5 : SelectDatatoRetrieve;
    ucmUseCase6 : DisplayCartridgeData;
    ucmUseCase7 : PrintData
ucm_actor
    ucmActor1 : Pilot;
    ucmActor2 : MPSPrinter
ucm_interaction
    ucmInteraction1 :
PilotRetrievefromCartridge;
    ucmInteraction2 :

    CartridgeRetrieveDatafromCartridge;
    ucmInteraction3 :
        PilotSelectDatatoRetrieve;
    ucmInteraction4 :
        MPSPrinterPrintData
ucm_includes
    ucmIncludes1 :
  RetrievefromCartridgeCheckforCartridge;
    ucmIncludes2 :
  RetrievefromCartridgeCheckCartridgeforD
ata;
    ucmIncludes3 :
    RetrievefromCartridgeRetrieveDatafrom
Cartridge;
    ucmIncludes4 :
    RetrievefromCartridgeDisplayCartridge
Data
ucm_extends
    ucmExtends1 :
    PrintDataDisplayCartridgeData;
    ucmExtends2 :
    SelectDatatoRetrieveRetrievefromCartr
dige
ucm_pre_condition
    ucmPreCondition1 : RDfCPre1NLS;
    ucmPreCondition2 : PDPre1NLS;
    ucmPreCondition3 : DCDPre1NLS
ucmPostCondition
    ucmPostCondition1 : RfCPost1NLS;
    ucmPostCondition2 : RfCPost2NLS;
    ucmPostCondition3 : RDfCPost1NLS;
```

```
    ucmPostCondition4 : PDPost1NLS;
    ucmPostCondition5 : DCDPost1NLS;
    ucmPostCondition6 : SDtRPost1NLS
end

RetrievefromCartridgeComments in
MatraNaturalLanguageStructure, Token with
mnls_composite
    mnlsComposite1 : RfCC1;
    mnlsComposite2 : RfCC2
mnls_plain_text
    mnlsPlainText1 : RfCPT1;
    mnlsPlainText2 : RfCPT2;
    mnlsPlainText3 : RfCPT3
mnls_module
    mnlsModule1 : CartridgeNode;
    mnlsModule2 :
MissionPlanningSystemNode
end

RfCC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : RfCPT1
subject_node
    subjectNode : CartridgeNode
following_fragment
    followingFragment : RfCC2
end

RfCPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The purpose of this
diagram is to model retrieval of data
from the "
end

RfCC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : RfCPT2
subject_node
    subjectNode :
MissionPlanningSystemNode
following_fragment
    followingFragment : RfCPT3
end

RfCPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " and its storage on the "
end

RfCPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

Choose Mission and Aircraft Use Case Model (Partial - Derived Elements not Shown)

```
ChooseMissionandAircraftModel in
UseCaseModel, Token with model_name
    modelName : "Choose Mission and
Aircraft Model"
ucm_use_case
    ucmUseCase1 :
ChooseMissionandAircraft;
    ucmUseCase2 : RetrievefromMissionPlan
ucm_actor
    ucmActor1 : Pilot;
    ucmActor2 : MissionPlan
ucm_interaction
    ucmInteraction1 :
        PilotChooseMissionandAircraft;
    ucmInteraction2 :
        MissionPlanRetrievefromMissionPla
n;
    ucmInteraction3 :
    MissionPlanChooseMissionandAircraft
ucm_includes
    ucmIncludes1 :
    ChooseMissionandAircraftRetrievefromM
issionPlan
ucm_pre_condition
    ucmPreCondition1 : CMAPre1NLS;
    ucmPreCondition2 : RfMPPre1NLS
ucmPostCondition
    ucmPostCondition1 : CMAPost1NLS;
    ucmPostCondition2 : CMAPost2NLS;
    ucmPostCondition3 : RfMPPost1NLS
end
```

- **Service Instances**

```
MissionAdministration in Service, Token
with
service_name
    serviceName : "Mission
Administration"
service_use_case
    serviceUseCase1 :
RetrievefromCartridge;
    serviceUseCase2:
ChooseMissionandAircraft
end


CartridgeAdministration in Service, Token
with
service_name
    serviceName : "Cartridge
Administration"
service_use_case
    serviceUseCase1 : EraseCartridge
end
```

- **Hawk MPS Use Case View (Partial)**

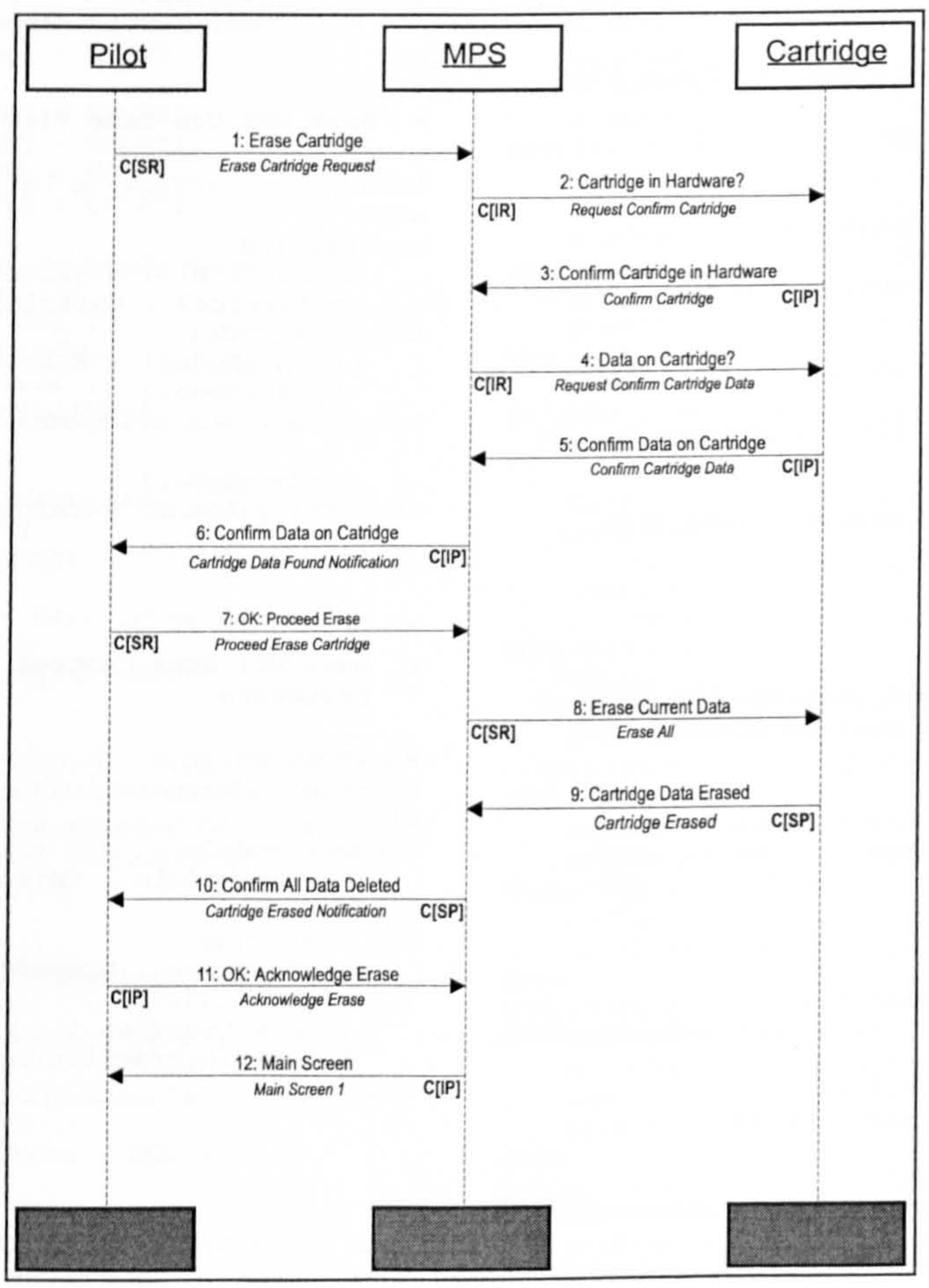
```
HawkMPSUseCaseView in UseCaseView, Token
with
ucv_service
    ucvService1 : MissionAdministration;
    ucvService2 : CartridgeAdministration
use_case_model
    useCaseModel1 : EraseCartridgeModel;
    useCaseModel2 :
RetrievefromCartridgeModel;

    useCaseModel3 :
ChooseMissionandAircraftModel

end
```

- **Hawk MPS User Centred Requirements Structure**

```
HawkMPSUCRS in
UserCentredRequirementsStructure, Token
with
subject_module
    subjectModule : "Mission Planning
System"
use_case_view
    useCaseView : HawkMPSUseCaseView
interaction_view
    interactionView :
    HawkMPSInteractionView
end
```

Scenario Name: Erase Cartridge - Normal Path

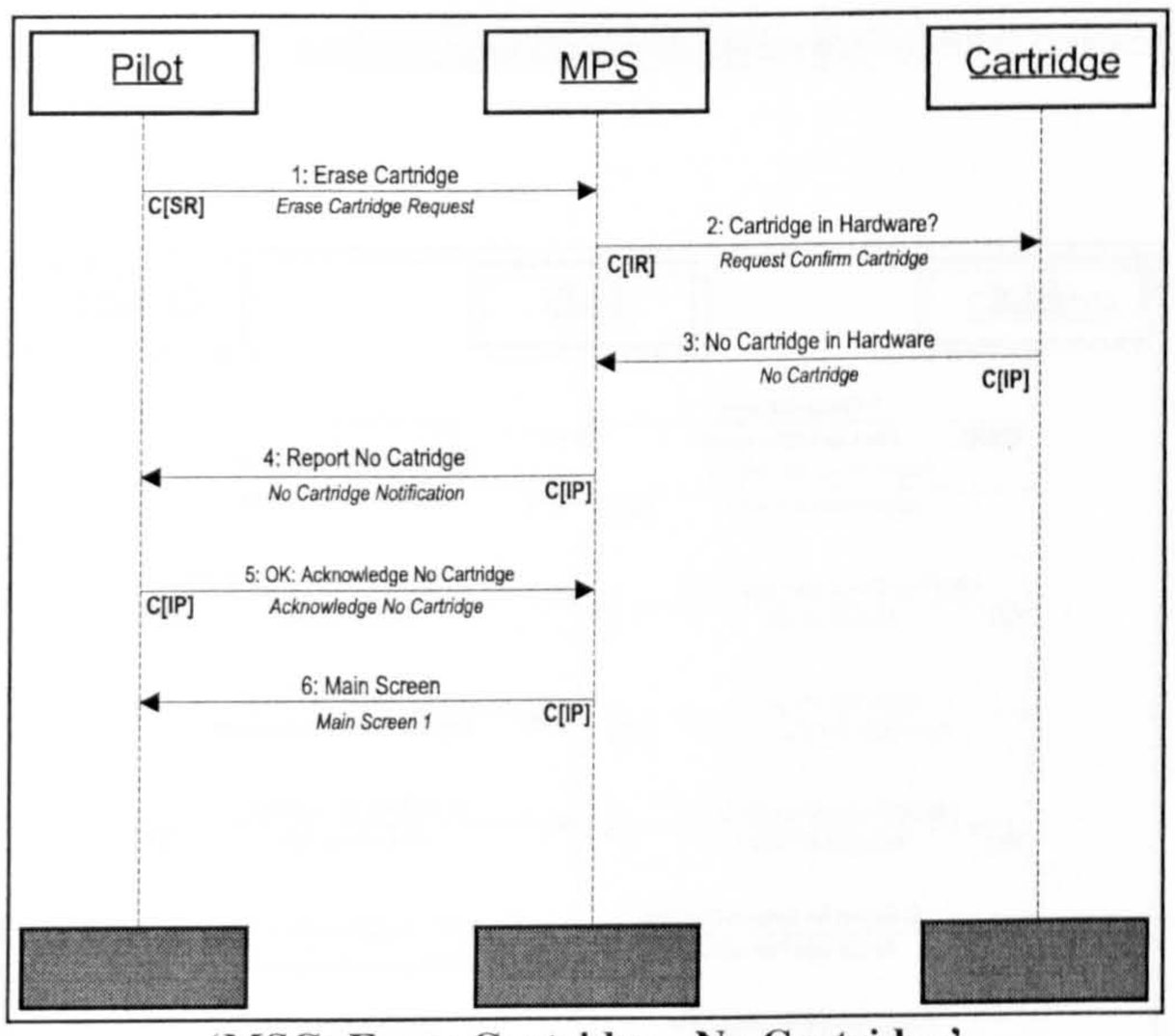
1. **C[SR]** The [sdr Pilot] selects the [msg Erase Cartridge option : Erase Cartridge Request] on the [rcr MPS] Main Screen.
2. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [msg is a cartridge present in the hardware? : Request Confirm Cartridge].
3. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is a cartridge present in the hardware : Confirm Cartridge].
4. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [is data on the cartridge? : Request Confirm Cartridge Data].
5. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is data on the cartridge : Confirm Cartridge Data].
6. **C[IP]** The [sdr MPS] informs the [rcr Pilot] that [msg there is data on the cartridge : Cartridge Data Found Notification] .
7. **C[SR]** The [sdr Pilot] indicates to the [rcr MPS] that it is [msg OK to proceed with Cartridge Erase : Proceed Erase Cartridge].
8. **C[SR]** The [sdr MPS] tells the [rcr Cartridge] to [msg erase the current data : Erase All].
9. **C[SP]** The [sdr Cartridge] indicates to the [rcr MPS] that [msg all current data has been deleted : Cartridge Erased].
10. **C[SP]** The [sdr MPS] indicates to the [rcr Pilot] that [msg all current data has been deleted : Cartridge Erased Notification].
11. **C[IP]** The [sdr Pilot] sends an [msg acknowledgment : Acknowledge Erase] to the [rcr MPS].
12. **C[IP]** The [sdr MPS] displays to the [rcr Pilot] the [msg Main Screen MainScreen_1].



'MSC: Erase Cartridge - Normal Path'

Scenario Name: Erase Cartridge - No Cartridge Present

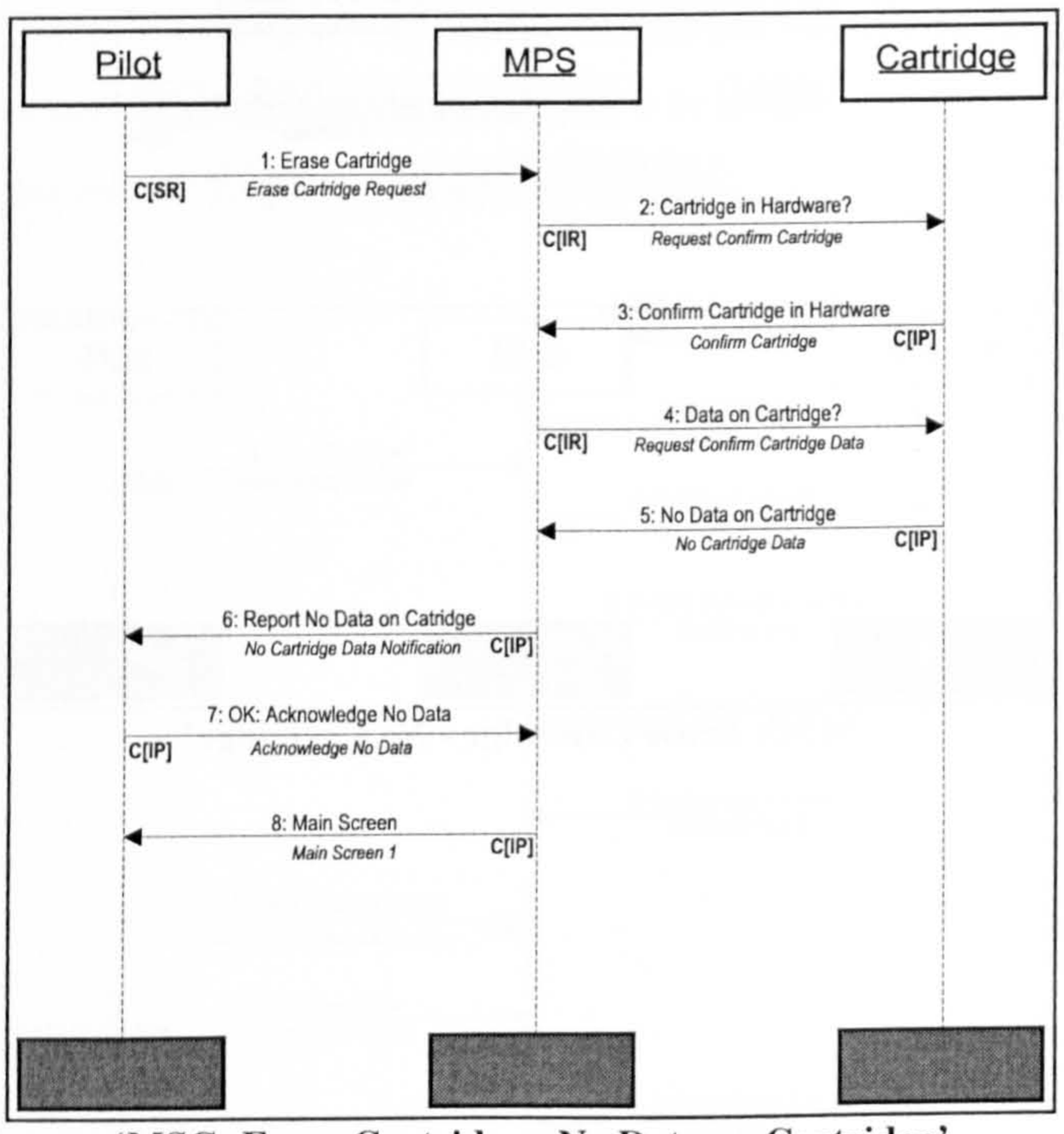
1. **C[SR]** The [sdr Pilot] selects the [msg Erase Cartridge option : Erase Cartridge Request] on the [rcr MPS] Main Screen.
2. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [msg is a cartridge present in the hardware? : Request Confirm Cartridge].
3. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is no cartridge present in the hardware : No Data].
4. **C[IP]** The [sdr MPS] informs the [rcr Pilot] that there is [msg no cartridge is present in the hardware : No Cartridge Notification].
5. **C[IP]** The [sdr Pilot] sends an [msg acknowledgment : Acknowledge No Cartridge] to the [rcr MPS].
6. **C[IP]** The [sdr MPS] displays to the [rcr Pilot] the [msg Main Screen MainScreen_1].



'MSC: Erase Cartridge - No Cartridge'

Scenario Name: Erase Cartridge - No Data on Cartridge

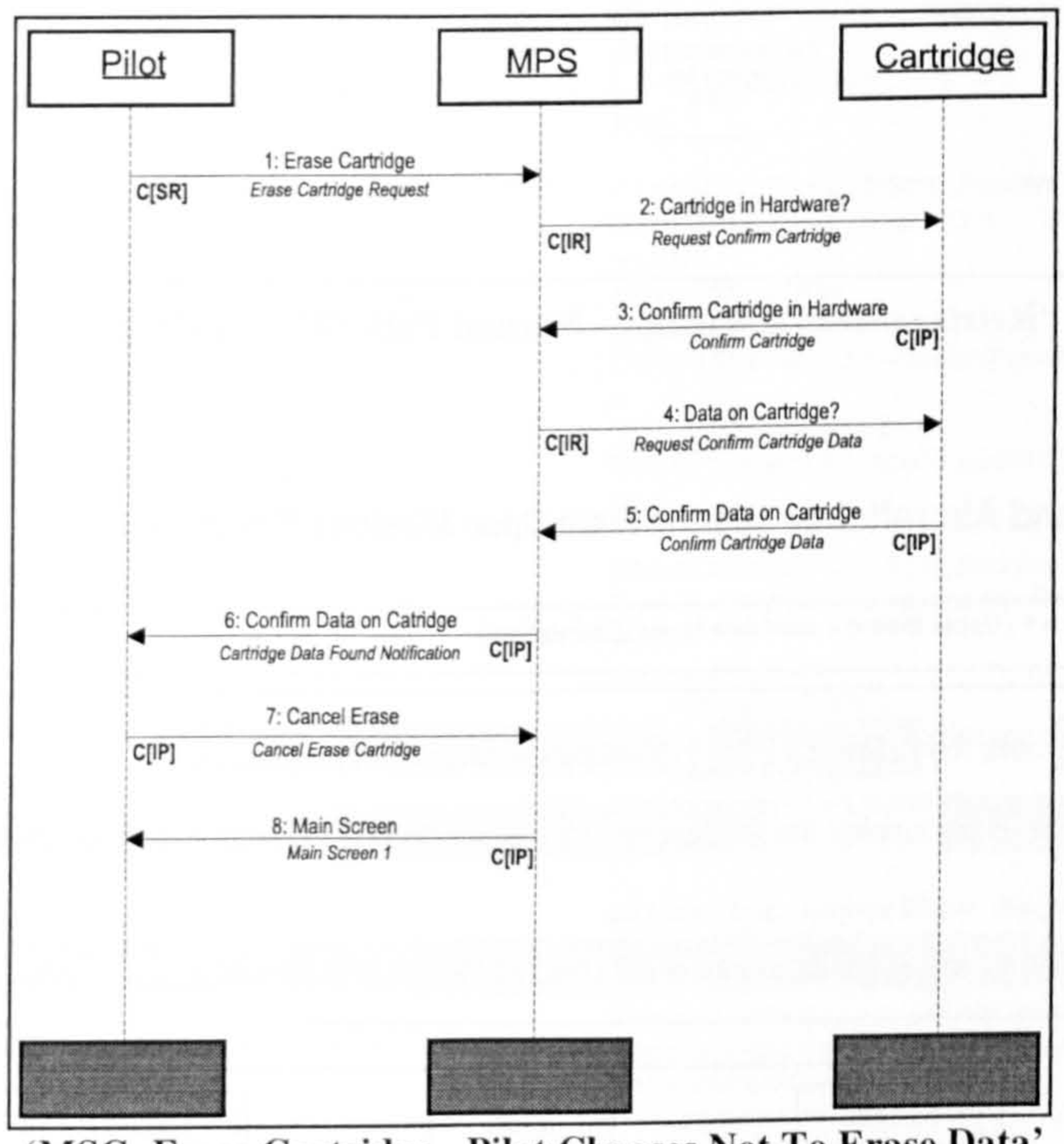
1. **C[SR]** The [sdr Pilot] selects the [msg Erase Cartridge option : Erase Cartridge Request] on the [rcr MPS] Main Screen.
2. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [msg is a cartridge present in the hardware? : Request Confirm Cartridge].
3. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is a cartridge present in the hardware : Confirm Cartridge].
4. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [is data on the cartridge? : Request Confirm Cartridge Data].
5. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is no data on the cartridge : No Cartridge Data].
6. **C[IP]** The [sdr MPS] informs the [rcr Pilot] that there is [msg no data on the cartridge: No Cartridge Data Notification].
7. **C[IP]** The [sdr Pilot] sends an [msg acknowledgment : Acknowledge No Data] to the [rcr MPS].
8. **C[IP]** The [sdr MPS] displays to the [rcr Pilot] the [msg Main Screen MainScreen_1].



'MSC: Erase Cartridge - No Data on Cartridge'

Scenario Name: Erase Cartridge - Pilot Chooses Not to Erase Data

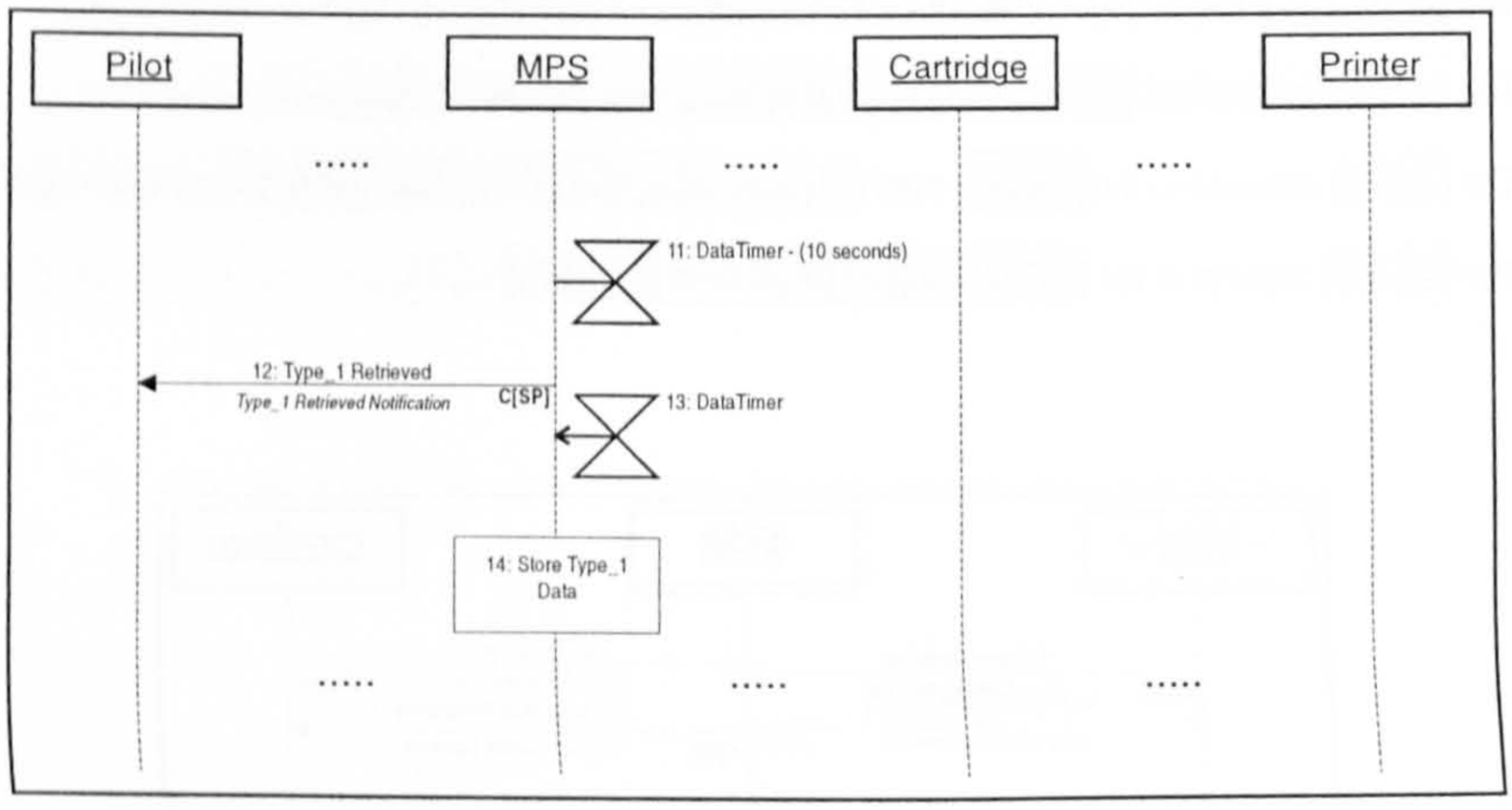
1. **C[SR]** The [sdr Pilot] selects the [msg Erase Cartridge option : Erase Cartridge Request] on the [rcr MPS] Main Screen.
2. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [msg is a cartridge present in the hardware? : Request Confirm Cartridge].
3. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is a cartridge present in the hardware : Confirm Cartridge].
4. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [is data on the cartridge? : Request Confirm Cartridge Data].
5. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is data on the cartridge : Confirm Cartridge Data].
6. **C[IP]** The [sdr MPS] informs the [rcr Pilot] that [msg there is data on the cartridge : Cartridge Data Found Notification] .
7. **C[IP]** The [sdr Pilot] indicates to the [rcr MPS] that he wishes to [msg cancel the Erase Cartridge request : Cancel Erase Cartridge].
8. **C[IP]** The [sdr MPS] displays to the [rcr Pilot] the [msg Main Screen MainScreen_1].



'MSC: Erase Cartridge - Pilot Chooses Not To Erase Data'

Retrieve From Cartridge - Normal Path (Fragement)

11. **T** The [timer-set MPS] sets the [timer DataTimer] to [duration 10 seconds].
12. **C[SP]** The [sdr MPS] informs the [rcr Pilot] that [msg type_1 data has been retrieved : Type_1 Retrieved Notification].
13. **T** The [host-on-timeout MPS] [timer DataTimer] times-out.
14. **A** The [sdr/rcr MPS] [act stores type_1 data : Store Type_1 Data].

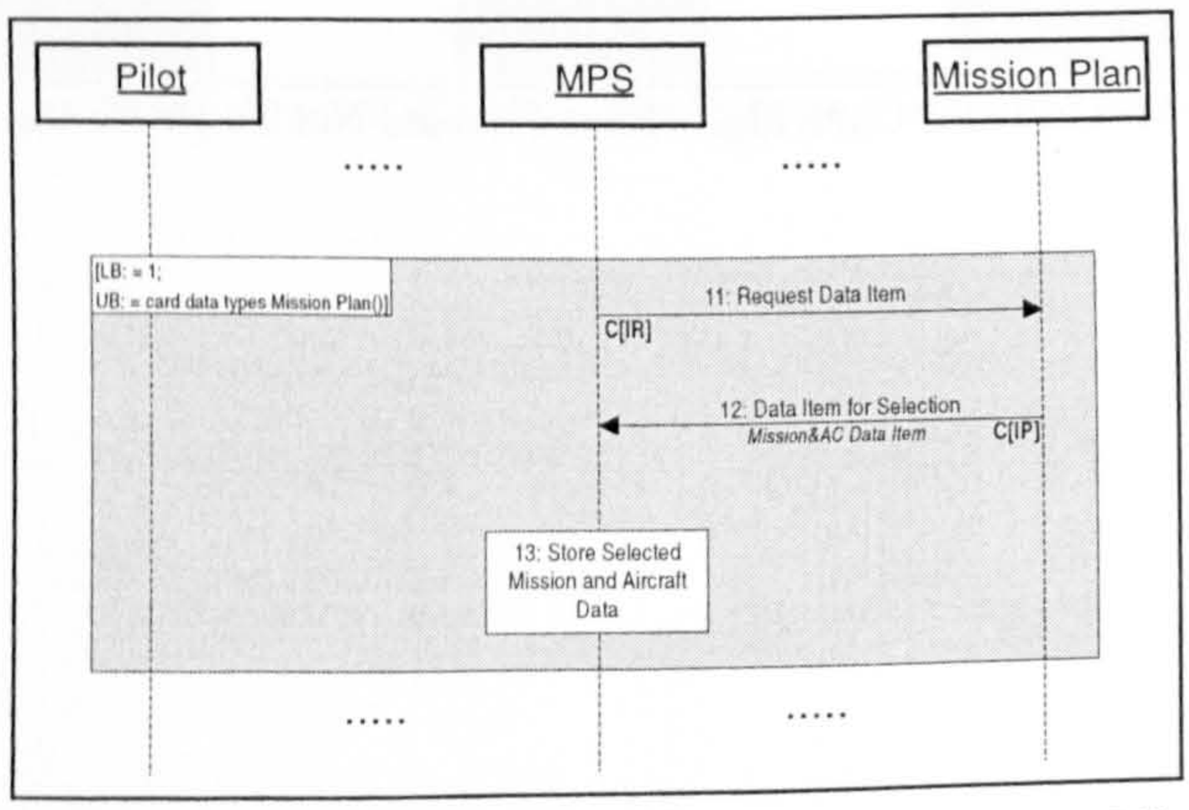


'Retrieve from Cartridge - Normal Path (Timing Fragment)'

Choose Mission and Aircraft: New Mission From Open Missions (Fragement)

ITERATION: Lower Bound = 1 : Upper Bound = *card* data types MissionPlan()

11. **C[IR]** The [sdr MPS] asks the [rcr Mission Plan] to [msg supply a data item : Request Data Item].
12. **C[IP]** The [sdr Mission Plan] supplies the [msg data item for the selected Mission and Aircraft : Mission&AC Data Item] to the [rcr MPS].
13. **A** The [sdr/rcr MPS] [act stores the data item for the selected Mission and Aircraft : Store Selected Mission&AC Data].



'Choose Mission and Aircraft - New Mission From Open Missions (Event Group Fragment)'

I. Instantiation of Interaction View for Erase Cartridge Scenarios

- **Instantiation of Interaction View**

```
HawkMPSInteractionView in
InteractionView, Token with
interaction_model
    interactionModel1 :
CheckforCartridgeModel;
    interactionModel2 :
CheckCartridgeforDataModel;
    interactionModel3 :
EraseDatafromCartridgeModel;
    interactionModel4 :
EraseCartridgeModel
.....
end
```

- **Instantiation of Instance Definitions**

```
MPSInstance in Instance, Token with
instance_name
    instanceName : "MPS"
end

CartridgeInstance in Instance, Token
with
instance_name
    instanceName : "Cartridge"
end

PilotInstance in Instance, Token with
instance_name
    instanceName : "Pilot"
end

MissionPlanInstance in Instance, Token
with
instance_name
    instanceName : "Mission Plan"
end
```

- **Instantiation of Interaction View Elements**

Instantiation of Check For Cartridge Interaction Model

```
CheckforCartridgeModel in
InteractionModel, Token with
model_name
    modelName : "Check For Cartridge
Descriptions"
describes_use_case
    describesUseCase : "Check for
Cartridge"
inm_scenario
    inmScenario1 :
CheckforCartridge_NormalPath;
    inmScenario2 :
CheckforCartridge_NoCartridge
.....
-- other elements may be derived using
an implementation of the rules in in
App.A, Pt.2 (xi).
end
```

Instantiation of Check for Cartridge : Normal Path

```
CheckforCartridge_NormalPath in
Scenario, Token with
scenario_title
    scenarioTitle : "Check for
Cartridge - Normal Path"
is_exception
    isException : False
scenario_event
    scenarioEvent1 :
CheckforCartridgeRequest;
    scenarioEvent2 :
ConfirmCartridgePresent
scn_seq_no
    scnSeqNo1 :
CheckforCartridgeRequest_NormalPathSSN;
    scnSeqNo2 :
ConfirmCartridgePresentSSN
tsn_viewpoint
    tsnViewpoint :
CheckforCartridge_NormalPathTSV
msc_viewpoint
    mscViewpoint :
CheckforCartridge_NormalPathMSV
end

CheckforCartridgeRequest_NormalPathSSN
in SequenceNumber, Token with
sequence_no
    sequenceNo : 1
end

ConfirmCartridgePresentSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 2
end

CheckforCartridge_NormalPathTSV in
TsnScenarioViewpoint, Token
with
tsv_tsn_comm
    tsvTsnComm1 :
CheckforCartridgeRequestTextDescription
;
    tsvTsnComm2 :
ConfirmCartridgePresentTextDescription
end

CheckforCartridge_NormalPathMSV in
MscScenarioViewpoint, Token
with
msv_msc_comm
    msvMscComm1 :
CheckforCartridgeRequestMSCDescription;
    msvMscComm2 :
ConfirmCartridgePresentMSCDescription
end
```

Check for Cartridge Request Event Instantiation

```
CheckforCartridgeRequest in
CommunicationEvent, Token with
interaction_type
    interactionType : "IR"
sequence_no
    sequenceNo1 :
CheckforCartridgeRequest_NormalPathSSN;
    sequenceNo2 :
CheckforCartridgeRequest_NoCartridgeSSN
included_seq_no
    includedSeqNo1 :
CheckforCartridgeRequest_EC_NP_ISN;
    includedSeqNo2 :
CheckforCartridgeRequest_EC_NC_ISN;
    includedSeqNo3 :
CheckforCartridgeRequest_EC_ND_ISN;
    includedSeqNo4 :
CheckforCartridgeRequest_EC_PCNTED_ISN
tsn_communication_event
    tsnCommunicationEvent :
CheckforCartridgeRequestTextDescription
msc_communication_event
    mscCommunicationEvent :
CheckforCartridgeRequestMSCDescription
end
```

```
CheckforCartridgeRequestTextDescription
in TsnCommunication, Token with
communication_description
    communicationDescription :
CheckforCartridgeRequestEventText
end

CheckforCartridgeRequestEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : CfCREC1;
    mnlsComposite2 : CfCREC2;
    mnlsComposite3 : CfCREC3
mnls_plain_text
    mnlsPlainText1 : CfCREPT1;
    mnlsPlainText2 : CfCREPT2;
    mnlsPlainText3 : CfCREPT3;
    mnlsPlainText4 : CfCREPT4
tsn_sender_node
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : CartridgeInstance
tsn_message_node
    tsnMessageNode :
RequestConfirmCartridge
end

CfCREC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CfCREPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : CfCREC2
end

CfCREC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CfCREPT2
subject_node
    subjectNode : CartridgeInstance
following_fragment
    followingFragment : CfCREC3
end

CfCREC3 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CfCREPT3
subject_node
    subjectNode :
RequestConfirmCartridge
following_fragment
    followingFragment : CfCREPT4
end

CfCREPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

CfCREPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " asks the "
end

CfCREPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " whether there "
end

CfCREPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

RequestConfirmCartridge in Message,
Token with
message_name
    messageName : "Request Confirm
Cartridge"
tsn_msg_parameter
    tsnMsgParameter :
RequestConfirmCartridgeTsnParameter
msc_msg_parameter
    mscMsgParameter :
RequestConfirmCartridgeMscParameter
end

RequestConfirmCartridgeTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "is a cartridge
present in the hardware?"
end

RequestConfirmCartridgeMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "Cartridge in
Hardware?"
end

CheckforCartridgeRequestMSCDescription
in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance :
CartridgeInstance
msc_message
    mscMessage :
RequestConfirmCartridge
end
```

Confirm Cartridge Present Event Instantiation

```
ConfirmCartridgePresent in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
ConfirmCartridgePresentSSN
included_seq_no
    includedSeqNo1 :
ConfirmCartridgePresent_EC_NP_ISN;
    includedSeqNo2 :
ConfirmCartridgePresent_EC_ND_ISN;
    includedSeqNo3 :
ConfirmCartridgePresent_EC_PCNTED_ISN
follows_from
    followsFrom :
CheckforCartridgeRequest
tsn_communication_event
    tsnCommunicationEvent :
ConfirmCartridgePresentTextDescription
msc_communication_event
    mscCommunicationEvent :
ConfirmCartridgePresentMSCDescription
end

ConfirmCartridgePresentTextDescription
in TsnCommunication, Token with
communication_description
    communicationDescription :
ConfirmCartridgePresentEventText
end
```

```
ConfirmCartridgePresentEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : CCPEC1;
    mnlsComposite2 : CCPEC2;
    mnlsComposite3 : CCPEC3
mnls_plain_text
    mnlsPlainText1 : CCPEPT1;
    mnlsPlainText2 : CCPEPT2;
    mnlsPlainText3 : CCPEPT3;
    mnlsPlainText4 : CCPEPT4
tsn_sender_node
    tsnSenderNode : CartridgeInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode : ConfirmCartridge
end

CCPEC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : CCPEPT1
subject_node
    subjectNode : CartridgeInstance
following_fragment
    followingFragment : CCPEC2
end

CCPEC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : CCPEPT2
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : CCPEC3
end

CCPEC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : CCPEPT3
subject_node
    subjectNode : ConfirmCartridge
following_fragment
    followingFragment : CCPEPT4
end

CCPEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

CCPEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " responds to the "
end

CCPEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that "
end

CCPEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

ConfirmCartridge in Message, Token with
message_name
    messageName : "Confirm Cartridge"
tsn_msg_parameter
    tsnMsgParameter :
ConfirmCartridgeTsnParameter
msc_msg_parameter
    mscMsgParameter :
ConfirmCartridgeMscParameter
end

ConfirmCartridgeTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "there is a
cartridge present in the hardware"
end

ConfirmCartridgeMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "Confirm Cartridge
in Hardware"
end

ConfirmCartridgePresentMSCDescription
in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance :
CartridgeInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : ConfirmCartridge
end
```

Instantiation of Check for Cartridge : No Cartridge (Loaded in the Hardware)

```
CheckforCartridge_NoCartridge in
Scenario, Token with
scenario_title
    scenarioTitle : "Check for
Cartridge - No Cartridge Present"
is_exception
    isException : True
scenario_event
    scenarioEvent1 :
CheckforCartridgeRequest;
    scenarioEvent2 : NoCartridgePresent
scn_seq_no
    scnSeqNo1 :
CheckforCartridgeRequest_NoCartridgeSSN
;
    scnSeqNo2 : NoCartridgePresentSSN
tsn_viewpoint
    tsnViewpoint :
CheckforCartridge_NoCartridgeTSV
msc_viewpoint
    mscViewpoint :
CheckforCartridge_NoCartridgeMSV
end

CheckforCartridgeRequest_NoCartridgeSSN
in SequenceNumber, Token with
sequence_no
    sequenceNo : 1
end

NoCartridgePresentSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 2
end

CheckforCartridge_NoCartridgeTSV in
TsnScenarioViewpoint, Token
with
tsv_tsn_comm
    tsvTsnComm1 :
CheckforCartridgeRequestTextDescription
;
    tsvTsnComm2 :
NoCartridgePresentTextDescription
end
```

```
CheckforCartridge_NoCartridgeMSV in
MscScenarioViewpoint, Token
with
msv_msc_comm
    msvMscComm1 :
CheckforCartridgeRequestMSCDescription;
    msvMscComm2 :
NoCartridgePresentMSCDescription
end
```

No Cartridge Present Event Instantiation

```
NoCartridgePresent in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 : NoCartridgePresentSSN
included_seq_no
    includedSeqNo1 :
NoCartridgePresent_EC_NC_ISN
follows_from
    followsFrom :
CheckforCartridgeRequest
tsn_communication_event
    tsnCommunicationEvent :
NoCartridgePresentTextDescription
msc_communication_event
    mscCommunicationEvent :
NoCartridgePresentMSCDescription
end

NoCartridgePresentTextDescription in
TsnCommunication, Token with
communication_description
    communicationDescription :
NoCartridgePresentEventText
end

NoCartridgePresentEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : NCPEC1;
    mnlsComposite2 : NCPEC2;
    mnlsComposite3 : NCPEC3
mnls_plain_text
    mnlsPlainText1 : NCPEPT1;
    mnlsPlainText2 : NCPEPT2;
    mnlsPlainText3 : NCPEPT3;
    mnlsPlainText4 : NCPEPT4
tsn_sender_node
    tsnSenderNode : CartridgeInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode : NoCartridge
end

NCPEC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCPEPT1
subject_node
    subjectNode : CartridgeInstance
following_fragment
    followingFragment : NCPEC2
end

NCPEC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCPEPT2
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : NCPEC3
end

NCPEC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCPEPT3
subject_node
    subjectNode : NoCartridge
following_fragment
    followingFragment : NCPEPT4
end

NCPEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

NCPEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " responds to the "
end

NCPEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that "
end

NCPEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

NoCartridge in Message, Token with
message_name
    messageName : "No Cartridge"
tsn_msg_parameter
    tsnMsgParameter :
NoCartridgeTsnParameter
msc_msg_parameter
    mscMsgParameter :
NoCartridgeMscParameter
end

NoCartridgeTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "there is no
cartridge present in the hardware"
end

NoCartridgeMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "No Cartridge in
Hardware"
end

NoCartridgePresentMSCDescription in
MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance :
CartridgeInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : NoCartridge
end
```

Instantiation of Check Cartridge For Data Interaction Model

```
CheckCartridgeforDataModel in
InteractionModel, Token with
model_name
    modelName : "Check Cartridge for
Data Descriptions"
describes_use_case
    describesUseCase : "Check Cartridge
for Data"
```

```
inm_scenario
    inmScenario1 :
CheckCartridgeforData_NormalPath;
    inmScenario2 :
CheckCartridgeforData_NoData
---
-- other elements may be derived using
an implementation of the rules in in
App.A, Pt.2 (xi).
end
```

Instantiation of Check Cartridge for Data: Normal Path

```
CheckCartridgeforData_NormalPath in
Scenario, Token with
scenario_title
    scenarioTitle : "Check Cartridge
for Data - Normal Path"
is_exception
    isException : False
scenario_event
    scenarioEvent1 :
CheckCartridgeforDataRequest;
    scenarioEvent2 :
ConfirmCartridgeDataPresent
scn_seq_no
    scnSeqNo1 :
CheckCartridgeforDataRequest_NormalPath
SSN;
    scnSeqNo2 :
ConfirmCartridgeDataPresentSSN
tsn_viewpoint
    tsnViewpoint :
CheckCartridgeforData_NormalPathTSV
msc_viewpoint
    mscViewpoint :
CheckCartridgeforData_NormalPathMSV
end

CheckCartridgeforDataRequest_NormalPath
SSN in SequenceNumber, Token with
sequence_no
    sequenceNo : 1
end

ConfirmCartridgeDataPresentSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 2
end

CheckCartridgeforData_NormalPathTSV in
TsnScenarioViewpoint, Token
with
tsv_tsn_comm
    tsvTsnComm1 :
CheckCartridgeforDataRequestTextDescrip
tion;
    tsvTsnComm2 :
ConfirmCartridgeDataPresentTextDescript
ion
end

CheckCartridgeforData_NormalPathMSV in
MscScenarioViewpoint, Token
with
msv_msc_comm
    msvMscComm1 :
CheckCartridgeforDataRequestMSCDescript
ion;
    msvMscComm2 :
ConfirmCartridgeDataPresentMSCDescripti
on
end
```

Check Cartridge for Data Request Event Instantiation

```
CheckCartridgeforDataRequest in
CommunicationEvent, Token with
interaction_type
    interactionType : "IR"
sequence_no
    sequenceNo1 :
CheckCartridgeforDataRequest_NormalPath
SSN;
    sequenceNo2 :
CheckCartridgeforDataRequest_NoDataSSN
included_seq_no
    includedSeqNo1 :
CheckCartridgeforDataRequest_EC_NP_ISN;
    includedSeqNo2 :
CheckCartridgeforDataRequest_EC_ND_ISN;
    includedSeqNo3 :
CheckCartridgeforDataRequest_EC_PCNTED_
ISN
tsn_communication_event
    tsnCommunicationEvent :
CheckCartridgeforDataRequestTextDescrip
tion
msc_communication_event
    mscCommunicationEvent :
CheckCartridgeforDataRequestMSCDescript
ion
end

CheckCartridgeforDataRequestTextDescrip
tion in TsnCommunication, Token with
communication_description
    communicationDescription :
CheckCartridgeforDataRequestEventText
end

CheckCartridgeforDataRequestEventText
in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : CCfDREC1;
    mnlsComposite2 : CCfDREC2;
    mnlsComposite3 : CCfDREC3
mnls_plain_text
    mnlsPlainText1 : CCfDREPT1;
    mnlsPlainText2 : CCfDREPT2;
    mnlsPlainText3 : CCfDREPT3;
    mnlsPlainText4 : CCfDREPT4
tsn_sender_node
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : CartridgeInstance
tsn_message_node
    tsnMessageNode :
RequestConfirmCartridgeData
end

CCfDREC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CCfDREPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : CCfDREC2
end

CCfDREC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CCfDREPT2
subject_node
    subjectNode : CartridgeInstance
following_fragment
    followingFragment : CCfDREC3
end

CCfDREC3 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CCfDREPT3
subject_node
```

```
    subjectNode :
RequestConfirmCartridgeData
following_fragment
    followingFragment : CCfDREPT4
end

CCfDREPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

CCfDREPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " asks the "
end

CCfDREPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " whether there "
end

CCfDREPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

RequestConfirmCartridgeData in Message,
Token with
message_name
    messageName : "Request Confirm
Cartridge Data"
tsn_msg_parameter
    tsnMsgParameter :
RequestConfirmCartridgeDataTsnParameter
msc_msg_parameter
    mscMsgParameter :
RequestConfirmCartridgeDataMscParameter
end

RequestConfirmCartridgeDataTsnParameter
in MessageDescription, Token with
msg_parameter
    msgParameter : "is data on the
cartridge?"
end

RequestConfirmCartridgeDataMscParameter
in MessageDescription, Token with
msg_parameter
    msgParameter : "Data on Cartridge?"
end

CheckCartridgeforDataRequestMSCDescript
ion in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance :
CartridgeInstance
msc_message
    mscMessage :
RequestConfirmCartridgeData
end
```

Confirm Cartridge Data Present Event Instantiation

```
ConfirmCartridgeDataPresent in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
ConfirmCartridgeDataPresentSSN
included_seq_no
    includedSeqNo1 :
ConfirmCartridgeDataPresent_EC_NP_ISN;
    includedSeqNo2 :
ConfirmCartridgeDataPresent_EC_PCNTED_I
SN
follows_from
    followsFrom :
CheckCartridgeforDataRequest
tsn_communication_event
    tsnCommunicationEvent :
ConfirmCartridgeDataPresentTextDescript
ion
msc_communication_event
    mscCommunicationEvent :
ConfirmCartridgeDataPresentMSCDescripti
on
end

ConfirmCartridgeDataPresentTextDescript
ion in TsnCommunication, Token with
communication_description
    communicationDescription :
ConfirmCartridgeDataPresentEventText
end

ConfirmCartridgeDataPresentEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : CCDPEC1;
    mnlsComposite2 : CCDPEC2;
    mnlsComposite3 : CCDPEC3
mnls_plain_text
    mnlsPlainText1 : CCDPEPT1;
    mnlsPlainText2 : CCDPEPT2;
    mnlsPlainText3 : CCDPEPT3;
    mnlsPlainText4 : CCDPEPT4
tsn_sender_node
    tsnSenderNode : CartridgeInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode :
ConfirmCartridgeData
end

CCDPEC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CCDPEPT1
subject_node
    subjectNode : CartridgeInstance
following_fragment
    followingFragment : CCDPEC2
end

CCDPEC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CCDPEPT2
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : CCDPEC3
end

CCDPEC3 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CCDPEPT3
subject_node
    subjectNode : ConfirmCartridgeData
following_fragment
    followingFragment : CCDPEPT4
end

CCDPEPT1 in PlainTextNode, Token with
mnls_text
```

```
    mnlsText : "The "
end

CCDPEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " responds to the "
end

CCDPEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that "
end

CCDPEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

ConfirmCartridgeData in Message, Token
with
message_name
    messageName : "Confirm Cartridge
Data"
tsn_msg_parameter
    tsnMsgParameter :
ConfirmCartridgeDataTsnParameter
msc_msg_parameter
    mscMsgParameter :
ConfirmCartridgeDataMscParameter
end

ConfirmCartridgeDataTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "there is data on
the cartridge"
end

ConfirmCartridgeDataMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "Confirm Data on
Cartridge"
end

ConfirmCartridgeDataPresentMSCDescripti
on in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance :
CartridgeInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : ConfirmCartridgeData
end
```

Instantiation of Check Cartridge for Data : No Data Present (on Cartridge)

```
CheckCartridgeforData_NoData in
Scenario, Token with
scenario_title
    scenarioTitle : "Check Cartridge
for Data - No Data Present"
is_exception
    isException : True
scenario_event
    scenarioEvent1 :
CheckCartridgeforDataRequest;
    scenarioEvent2 :
NoCartridgeDataPresent
scn_seq_no
    scnSeqNo1 :
CheckCartridgeforDataRequest_NoCartridg
eDataSSN;
    scnSeqNo2 :
NoCartridgeDataPresentSSN
tsn_viewpoint
    tsnViewpoint :
CheckCartridgeforData_NoCartridgeDataTS
V
msc_viewpoint
    mscViewpoint :
CheckCartridgeforData_NoCartridgeDataMS
V
end

CheckCartridgeforDataRequest_NoCartridg
eDataSSN in SequenceNumber, Token with
sequence_no
    sequenceNo : 1
end

NoCartridgeDataPresentSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 2
end

CheckCartridgeforData_NoCartridgeDataTS
V in TsnScenarioViewpoint, Token
with
tsv_tsn_comm
    tsvTsnComm1 :
CheckCartridgeforDataRequestTextDescrip
tion;
    tsvTsnComm2 :
NoCartridgeDataPresentTextDescription
end

CheckCartridgeforData_NoCartridgeDataMS
V in MscScenarioViewpoint, Token
with
msv_msc_comm
    msvMscComm1 :
CheckCartridgeforDataRequestMSCDescript
ion;
    msvMscComm2 :
NoCartridgeDataPresentMSCDescription
end
```

No Cartridge Data Present Event Instantiation

```
NoCartridgeDataPresent in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
NoCartridgeDataPresentSSN
included_seq_no
    includedSeqNo1 :
NoCartridgeDataPresent_EC_ND_ISN
follows_from
    followsFrom :
CheckCartridgeforDataRequest
tsn_communication_event
    tsnCommunicationEvent :
NoCartridgeDataPresentTextDescription
msc_communication_event
    mscCommunicationEvent :
NoCartridgeDataPresentMSCDescription
end

NoCartridgeDataPresentTextDescription
in TsnCommunication, Token with
communication_description
    communicationDescription :
NoCartridgeDataPresentEventText
end
```

```
NoCartridgeDataPresentEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : NCDPEC1;
    mnlsComposite2 : NCDPEC2;
    mnlsComposite3 : NCDPEC3
mnls_plain_text
    mnlsPlainText1 : NCDPEPT1;
    mnlsPlainText2 : NCDPEPT2;
    mnlsPlainText3 : NCDPEPT3;
    mnlsPlainText4 : NCDPEPT4
tsn_sender_node
    tsnSenderNode : CartridgeInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode : NoCartridgeData
end

NCDPEC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : NCDPEPT1
subject_node
    subjectNode : CartridgeInstance
following_fragment
    followingFragment : NCDPEC2
end

NCDPEC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : NCDPEPT2
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : NCDPEC3
end

NCDPEC3 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : NCDPEPT3
subject_node
    subjectNode : NoCartridgeData
following_fragment
    followingFragment : NCDPEPT4
end

NCDPEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

NCDPEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " responds to the "
end

NCDPEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that "
end

NCDPEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

NoCartridgeData in Message, Token with
message_name
    messageName : "No Cartridge Data"
tsn_msg_parameter
    tsnMsgParameter :
NoCartridgeDataTsnParameter
msc_msg_parameter
    mscMsgParameter :
NoCartridgeDataMscParameter
end

NoCartridgeDataTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "there is no data on
the cartridge"
end

NoCartridgeDataMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "No Data on
Cartridge"
end

NoCartridgeDataPresentMSCDescription in
MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance :
CartridgeInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : NoCartridgeData
end
```

Instantiation of Erase Data from Cartridge Interaction Model

```
EraseDatafromCartridgeModel in
InteractionModel, Token with
model_name
    modelName : "Erase Data from
Cartridge Descriptions"
describes_use_case
    describesUseCase : "Erase Data from
Cartridge"
inm_scenario
    inmScenario1 :
EraseDatafromCartridge
.....
-- other elements may be derived using
an implementation of the rules in in
App.A, Pt.2 (xi).
end
```

Instantiation of Erase Data from Cartridge

```
EraseDatafromCartridge in Scenario,
Token with
scenario_title
    scenarioTitle : "Erase Data from
Cartridge"
is_exception
    isException : False
scenario_event
    scenarioEvent1 :
EraseCurrentDataRequest;
    scenarioEvent2 :
CurrentDataErasedNotification
scn_seq_no
    scnSeqNo1 :
EraseCurrentDataRequestSSN;
    scnSeqNo2 :
CurrentDataErasedNotificationSSN
tsn_viewpoint
    tsnViewpoint :
EraseDatafromCartridgeTSV
msc_viewpoint
    mscViewpoint :
EraseDatafromCartridgeMSV
end
```

```
EraseCurrentDataRequestSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 1
end

CurrentDataErasedNotificationSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 2
end

EraseDatafromCartridgeTSV in
TsnScenarioViewpoint, Token
with
tsv_tsn_comm
    tsvTsnComm1 :
EraseCurrentDataRequestTextDescription;
    tsvTsnComm2 :
CurrentDataErasedNotificationTextDescri
ption
end

EraseDatafromCartridgeMSV in
MscScenarioViewpoint, Token
with
msv_msc_comm
    msvMscComm1 :
EraseCurrentDataRequestMSCDescription;
    msvMscComm2 :
CurrentDataErasedNotificationMSCDescrip
tion
end
```

Erase Current Data Request Event Instantiation

```
EraseCurrentDataRequest in
CommunicationEvent, Token with
interaction_type
    interactionType : "SR"
sequence_no
    sequenceNo1 :
EraseCurrentDataRequestSSN
included_seq_no
    includedSeqNo1 :
EraseCurrentDataRequest_EC_NP_ISN
tsn_communication_event
    tsnCommunicationEvent :
EraseCurrentDataRequestTextDescription
msc_communication_event
    mscCommunicationEvent :
EraseCurrentDataRequestMSCDescription
end

EraseCurrentDataRequestTextDescription
in TsnCommunication, Token with
communication_description
    communicationDescription :
EraseCurrentDataRequestEventText
end

EraseCurrentDataRequestEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : ECDREC1;
    mnlsComposite2 : ECDREC2;
    mnlsComposite3 : ECDREC3
mnls_plain_text
    mnlsPlainText1 : ECDREPT1;
    mnlsPlainText2 : ECDREPT2;
    mnlsPlainText3 : ECDREPT3;
    mnlsPlainText4 : ECDREPT4
tsn_sender_node
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : CartridgeInstance
tsn_message_node
    tsnMessageNode : EraseAll
end

ECDREC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : ECDREPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : ECDREC2
end

ECDREC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : ECDREPT2
subject_node
    subjectNode : CartridgeInstance
following_fragment
    followingFragment : ECDREC3
end

ECDREC3 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : ECDREPT3
subject_node
    subjectNode : EraseAll
following_fragment
    followingFragment : ECDREPT4
end

ECDREPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

ECDREPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " tells the "
end

ECDREPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " to "
end

ECDREPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

EraseAll in Message, Token with
message_name
    messageName : "Erase All"
tsn_msg_parameter
    tsnMsgParameter :
EraseAllTsnParameter
msc_msg_parameter
    mscMsgParameter :
EraseAllMscParameter
end

EraseAllTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "erase the current
data"
end

EraseAllMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "Erase Current Data"
end

EraseCurrentDataRequestMSCDescription
in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
```

```
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance :
CartridgeInstance
msc_message
    mscMessage : EraseAll
end
```

Current Data Erased Notification Event Instantiation

```
CurrentDataErasedNotification in
CommunicationEvent, Token with
interaction_type
    interactionType : "SP"
sequence_no
    sequenceNo1 :
CurrentDataErasedNotificationSSN
included_seq_no
    includedSeqNo1 :
CurrentDataErasedNotification_EC_NP_ISN
follows_from
    followsFrom :
EraseCurrentDataRequest
tsn_communication_event
    tsnCommunicationEvent :
CurrentDataErasedNotificationTextDescri
ption
msc_communication_event
    mscCommunicationEvent :
CurrentDataErasedNotificationMSCDescrip
tion
end

CurrentDataErasedNotificationTextDescri
ption in TsnCommunication, Token with
communication_description
    communicationDescription :
CurrentDataErasedNotificationEventText
end

CurrentDataErasedNotificationEventText
in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : CDENEC1;
    mnlsComposite2 : CDENEC2;
    mnlsComposite3 : CDENEC3
mnls_plain_text
    mnlsPlainText1 : CDENEPT1;
    mnlsPlainText2 : CDENEPT2;
    mnlsPlainText3 : CDENEPT3;
    mnlsPlainText4 : CDENEPT4
tsn_sender_node
    tsnSenderNode : CartridgeInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode : CartridgeErased
end

CDENEC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CDENEC2
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : CDENEC3
end

CDENEC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CDENEPT1
subject_node
    subjectNode : CartridgeInstance
following_fragment
    followingFragment : CDENEPT2
end

CDENEC3 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CDENEPT3
subject_node
    subjectNode : CartridgeErased
following_fragment
    followingFragment : CDENEPT4
end

CDENEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

CDENEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " indicates to the "
end

CDENEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that "
end

CDENEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

CartridgeErased in Message, Token with
message_name
    messageName : "Cartridge Erased"
tsn_msg_parameter
    tsnMsgParameter :
CartridgeErasedTsnParameter
msc_msg_parameter
    mscMsgParameter :
CartridgeErasedMscParameter
end

CartridgeErasedTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "all current data
has been deleted"
end

CartridgeErasedMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "Cartridge Data
Erased"
end

CurrentDataErasedNotificationMSCDescrip
tion in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance :
CartridgeInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : CartridgeErased
end
```

Instantiation of Erase Cartridge Interaction Model

```
EraseCartridgeModel in
InteractionModel, Token with
model_name
    modelName : "Erase Cartridge
Descriptions"
describes_use_case
    describesUseCase : "Erase
Cartridge"
inm_scenario
    inmScenario1 :
EraseCartridge_NormalPath;
    inmScenario2 :
EraseCartridge_NoCartridge;
    inmScenario3 :
EraseCartridge_NoDataOnCartridge;
    inmScenario4 :
EraseCartridge_PilotChoosesNotToEraseDa
ta
....
-- other elements may be derived using
an implementation of the rules in in
App.A, Pt.2 (xi).
end
```

Instantiation of Erase Cartridge: Normal Path (Partial)

```
EraseCartridge_NormalPath in Scenario,
Token
with
scenario_title
    scenarioTitle : "Erase Cartridge -
Normal Path"
is_exception
    isException : False
scenario_event
    scenarioEvent1 :
EraseCartridgeRequest;
    scenarioEvent2 :
ConfirmDataPresentonCartridge;
    scenarioEvent3 :
ProceedCartridgeEraseRequest;
    scenarioEvent4 :
DataErasedNotification;
    scenarioEvent5 :
DataErasedAcknowledgement;
    scenarioEvent6 :
MainScreenDisplay_1
includes_scenario
    includesScenario1 :
CheckforCartridge_NormalPath;
    includesScenario2 :
CheckCartridgeforData_NormalPath;
    includesScenario3 :
EraseDatafromCartridge
included_event
    includedEvent1 :
CheckforCartridgeRequest;
    includedEvent2 :
ConfirmCartridgePresent;
    includedEvent3 :
CheckCartridgeforDataRequest;
    includedEvent4 :
ConfirmCartridgeDataPresent;
    includedEvent5 :
EraseCurrentDataRequest;
    includedEvent6 :
CurrentDataErasedNotification
-- 'included_event' may be instantiated
using a variation of the rule in App.A,
Pt.2 (vii.c);
scn_seq_no
    scnSeqNo1 :
EraseCartridgeRequest_NormalPathSSN;
    scnSeqNo2 :
ConfirmDataPresentonCartridge_NormalPat
hSSN;
    scnSeqNo3 :
ProceedCartridgeEraseRequestSSN;
    scnSeqNo4 :
DataErasedNotificationSSN;
    scnSeqNo5 :
DataErasedAcknowledgementSSN;
    scnSeqNo6 :
MainScreenDisplay_1_NormalPathSSN
scn_included_seq_no
    scnIncludedSeqNo1 :
CheckforCartridgeRequest_EC_NP_ISN;
    scnIncludedSeqNo2 :
ConfirmCartridgePresent_EC_NP_ISN;
    scnIncludedSeqNo3 :
CheckCartridgeforDataRequest_EC_NP_ISN;
    scnIncludedSeqNo4 :
ConfirmCartridgeDataPresent_EC_NP_ISN;
    scnIncludedSeqNo5 :
EraseCurrentDataRequest_EC_NP_ISN;
    scnIncludedSeqNo6 :
CurrentDataErasedNotification_EC_NP_ISN
tsn_viewpoint
    tsnViewpoint :
EraseCartridge_NormalPathTSV
msc_viewpoint
    mscViewpoint :
EraseCartridge_NormalPathMSV
end

EraseCartridgeRequest_NormalPathSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 1
end

ConfirmDataPresentonCartridge_NormalPat
hSSN in SequenceNumber, Token
with
sequence_no
    sequenceNo : 6
end

ProceedCartridgeEraseRequestSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 7
end

DataErasedNotificationSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 10
end

DataErasedAcknowledgementSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 11
end

MainScreenDisplay_1_NormalPathSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 12
end

CheckforCartridgeRequest_EC_NP_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 2
end

ConfirmCartridgePresent_EC_NP_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 3
end

CheckCartridgeforDataRequest_EC_NP_ISN
in SequenceNumber, Token with
sequence_no
```

```
    sequenceNo : 4
end

ConfirmCartridgeDataPresent_EC_NP_ISN
in SequenceNumber, Token with
sequence_no
    sequenceNo : 5
end

EraseCurrentDataRequest_EC_NP_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 8
end

CurrentDataErasedNotification_EC_NP_ISN
in SequenceNumber, Token with
sequence_no
    sequenceNo : 9
end

EraseCartridge_NormalPathTSV in
TsnScenarioViewpoint, Token
with
tsv_tsn_comm
    tsvTsnComm1 :
EraseCartridgeRequestTextDescription;
    tsvTsnComm2 :
ConfirmDataPresentonCartridgeTextDescri
ption;
    tsvTsnComm3 :
ProceedCartridgeEraseRequestTextDescrip
tion;
    tsvTsnComm4 :
DataErasedNotificationTextDescription;
    tsvTsnComm5 :
DataErasedAcknowledgementTextDescriptio
n;
    tsvTsnComm6 :
MainScreenDisplay_1TextDescription
end

EraseCartridge_NormalPathMSV in
MscScenarioViewpoint, Token
with
msv_msc_comm
    msvMscComm1 :
EraseCartridgeRequestMSCDescription;
    msvMscComm2 :
ConfirmDataPresentonCartridgeMSCDescrip
tion;
    msvMscComm3 :
ProceedCartridgeEraseRequestMSCDescript
ion;
    msvMscComm4 :
DataErasedNotificationMSCDescription;
    msvMscComm5 :
DataErasedAcknowledgementMSCDescription
;
    mscMscComm6 :
MainScreenDisplay_1MSCDescription
end
```

Erase Cartridge Request Event Instantiation

```
EraseCartridgeRequest in
CommunicationEvent, Token with
interaction_type
    interactionType : "SR"
sequence_no
    sequenceNo1 :
EraseCartridgeRequest_NormalPathSSN;
    sequenceNo2 :
EraseCartridgeRequest_NoCartridgeSSN;
    sequenceNo3 :
EraseCartridgeRequest_NoDataOnCartridge
SSN;
    sequenceNo4 :
EraseCartridgeRequest_PilotChoosesNotTo
EraseDataSSN
tsn_communication_event
    tsnCommunicationEvent :
EraseCartridgeRequestTextDescription
msc_communication_event
    mscCommunicationEvent :
EraseCartridgeRequestMSCDescription
end

EraseCartridgeRequestTextDescription in
TsnCommunication, Token with
communication_description
    communicationDescription :
EraseCartridgeRequestEventText
end

EraseCartridgeRequestEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : ECREC1;
    mnlsComposite2 : ECREC2;
    mnlsComposite3 : ECREC3
mnls_plain_text
    mnlsPlainText1 : ECREPT1;
    mnlsPlainText2 : ECREPT2;
    mnlsPlainText3 : ECREPT3;
    mnlsPlainText4 : ECREPT4
tsn_sender_node
    tsnSenderNode : PilotInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode :
EraseCartridgeRequest
end

ECREC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : ECREPT1
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : ECREC2
end

ECREC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : ECREPT2
subject_node
    subjectNode : EraseCartridgeRequest
following_fragment
    followingFragment : ECREC3
end

ECREC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : ECREPT3
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : ECREPT4
end

ECREPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

ECREPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " selects the "
end

ECREPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " on the "
end

ECREPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : " Main Screen."
```

```
end

EraseCartridgeRequest in Message, Token
with
message_name
    messageName : "Erase Cartridge
Request"
tsn_msg_parameter
    tsnMsgParameter :
EraseCartridgeRequestTsnParameter
msc_msg_parameter
    mscMsgParameter :
EraseCartridgeRequestMscParameter
end

EraseCartridgeRequestTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "Erase Cartridge
option"
end

EraseCartridgeRequestMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "Erase Cartridge"
end

EraseCartridgeRequestMSCDescription in
MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : PilotInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : EraseCartridgeRequest
end
```

Confirm Data Present on Cartridge Event Instantiation

```
ConfirmDataPresentonCartridge in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
ConfirmDataPresentonCartridge_NormalPat
hSSN;
    sequenceNo2 :
ConfirmDataPresentonCartridge_PilotChoo
sesNotToEraseDataSSN
follows_from
    followsFrom :
ConfirmCartridgeDataPresent
tsn_communication_event
    tsnCommunicationEvent :
ConfirmDataPresentonCartridgeTextDescri
ption
msc_communication_event
    mscCommunicationEvent :
ConfirmDataPresentonCartridgeMSCDescrip
tion
end

ConfirmDataPresentonCartridgeTextDescri
ption in TsnCommunication, Token with
communication_description
    communicationDescription :
ConfirmDataPresentonCartridgeEventText
end

ConfirmDataPresentonCartridgeEventText
in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : CDPoCEC1;
    mnlsComposite2 : CDPoCEC2;
    mnlsComposite3 : CDPoCEC3
mnls_plain_text
    mnlsPlainText1 : CDPoCEPT1;
    mnlsPlainText2 : CDPoCEPT2;
    mnlsPlainText3 : CDPoCEPT3;
    mnlsPlainText4 : CDPoCEPT4
tsn_sender_node
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : PilotInstance
tsn_message_node
    tsnMessageNode :
CartridgeDataFoundNotification
end

CDPoCEC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CDPoCEPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : CDPoCEC2
end

CDPoCEC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CDPoCEPT2
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : CDPoCEC3
end

CDPoCEC3 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : CDPoCEPT3
subject_node
    subjectNode :
CartridgeDataFoundNotification
following_fragment
    followingFragment : CDPoCEPT4
end

CDPoCEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

CDPoCEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " indicates to the "
end

CDPoCEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that "
end

CDPoCEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

CartridgeDataFoundNotification in
Message, Token with
message_name
    messageName : "Cartridge Data Found
Notification"
tsn_msg_parameter
    tsnMsgParameter :
CartridgeDataFoundNotificationTsnParame
ter
msc_msg_parameter
```

```
    mscMsgParameter :
CartridgeDataFoundNotificationMscParame
ter
end

CartridgeDataFoundNotificationTsnParame
ter in MessageDescription, Token with
msg_parameter
    msgParameter : "there is data on
the cartridge"
end

CartridgeDataFoundNotificationMscParame
ter in MessageDescription, Token with
msg_parameter
    msgParameter : "Confirm Data on
Cartridge"
end

ConfirmDataPresentonCartridgeMSCDescrip
tion in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance : PilotInstance
msc_message
    mscMessage :
CartridgeDataFoundNotification
end
```

Proceed Cartridge Erase Request Event Instantiation

```
ProceedCartridgeEraseRequest in
CommunicationEvent, Token with
interaction_type
    interactionType : "SR"
sequence_no
    sequenceNo1 :
ProceedCartridgeEraseRequestSSN
follows_from
    followsFrom :
ConfirmDataPresentonCartridge
tsn_communication_event
    tsnCommunicationEvent :
ProceedCartridgeEraseRequestTextDescrip
tion
msc_communication_event
    mscCommunicationEvent :
ProceedCartridgeEraseRequestMSCDescript
ion
end

ProceedCartridgeEraseRequestTextDescrip
tion in TsnCommunication, Token with
communication_description
    communicationDescription :
ProceedCartridgeEraseRequestEventText
end

ProceedCartridgeEraseRequestEventText
in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : PCEREC1;
    mnlsComposite2 : PCEREC2;
    mnlsComposite3 : PCEREC3
mnls_plain_text
    mnlsPlainText1 : PCEREPT1;
    mnlsPlainText2 : PCEREPT2;
    mnlsPlainText3 : PCEREPT3;
    mnlsPlainText4 : PCEREPT4
tsn_sender_node
    tsnSenderNode : PilotInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode :
ProceedEraseCartridge
end

PCEREC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : PCEREPT1
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : PCEREC2
end

PCEREC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : PCEREPT2
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : PCEREC3
end

PCEREC3 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : PCEREPT3
subject_node
    subjectNode : ProceedEraseCartridge
following_fragment
    followingFragment : PCEREPT4
end

PCEREPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

PCEREPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " indicates to the "
end

PCEREPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that it is "
end

PCEREPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

ProceedEraseCartridge in Message, Token
with
message_name
    messageName : "Proceed Erase
Cartridge"
tsn_msg_parameter
    tsnMsgParameter :
ProceedEraseCartridgeTsnParameter
msc_msg_parameter
    mscMsgParameter :
ProceedEraseCartridgeMscParameter
end

ProceedEraseCartridgeTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "OK to proceed with
Cartridge Erase"
end
```

```
ProceedEraseCartridgeMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "OK: Proceed Erase"
end

ProceedCartridgeEraseRequestMSCDescript
ion in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : PilotInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : ProceedEraseCartridge
end
```

Data Erased Notification Event Instantiation

```
DataErasedNotification in
CommunicationEvent, Token with
interaction_type
    interactionType : "SP"
sequence_no
    sequenceNo1 :
DataErasedNotificationSSN
follows_from
    followsFrom :
CurrentDataErasedNotification
tsn_communication_event
    tsnCommunicationEvent :
DataErasedNotificationTextDescription
msc_communication_event
    mscCommunicationEvent :
DataErasedNotificationMSCDescription
end

DataErasedNotificationTextDescription
in TsnCommunication, Token with
communication_description
    communicationDescription :
DataErasedNotificationEventText
end

DataErasedNotificationEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : DENEC1;
    mnlsComposite2 : DENEC2;
    mnlsComposite3 : DENEC3
mnls_plain_text
    mnlsPlainText1 : DENEPT1;
    mnlsPlainText2 : DENEPT2;
    mnlsPlainText3 : DENEPT3;
    mnlsPlainText4 : DENEPT4
tsn_sender_node
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : PilotInstance
tsn_message_node
    tsnMessageNode :
CartridgeErasedNotification
end

DENEC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DENEPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : DENEC2
end

DENEC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DENEPT2
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : DENEC3
end

DENEC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DENEPT3
subject_node
    subjectNode :
CartridgeErasedNotification
following_fragment
    followingFragment : DENEPT4
end

DENEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

DENEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " indicates to the "
end

DENEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that "
end

DENEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

CartridgeErasedNotification in Message,
Token with
message_name
    messageName : "Cartridge Erased
Notification"
tsn_msg_parameter
    tsnMsgParameter :
CartridgeErasedNotificationTsnParameter
msc_msg_parameter
    mscMsgParameter :
CartridgeErasedNotificationMscParameter
end

CartridgeErasedNotificationTsnParameter
in MessageDescription, Token with
msg_parameter
    msgParameter : "all current data
has been deleted"
end

CartridgeErasedNotificationMscParameter
in MessageDescription, Token with
msg_parameter
    msgParameter : "Confirm All Data
Deleted"
end

DataErasedNotificationMSCDescription in
MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance : PilotInstance
```

```
msc_message
    mscMessage :
CartridgeErasedNotification
end
```

Data Erased Acknowledgement Event Instantiation

```
DataErasedAcknowledgement in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
DataErasedAcknowledgementSSN
follows_from
    followsFrom :
DataErasedNotification
tsn_communication_event
    tsnCommunicationEvent :
DataErasedAcknowledgementTextDescriptio
n
msc_communication_event
    mscCommunicationEvent :
DataErasedAcknowledgementMSCDescription
end

DataErasedAcknowledgementTextDescriptio
n in TsnCommunication, Token with
communication_description
    communicationDescription :
DataErasedAcknowledgementEventText
end

DataErasedAcknowledgementEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : DEAEC1;
    mnlsComposite2 : DEAEC2;
    mnlsComposite3 : DEAEC3
mnls_plain_text
    mnlsPlainText1 : DEAEPT1;
    mnlsPlainText2 : DEAEPT2;
    mnlsPlainText3 : DEAEPT3;
    mnlsPlainText4 : DEAEPT4
tsn_sender_node
    tsnSenderNode : PilotInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode : AcknowledgeErase
end

DEAEC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DEAEPT1
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : DEAEC2
end

DEAEC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DEAEPT2
subject_node
    subjectNode : AcknowledgeErase
following_fragment
    followingFragment : DEAEC3
end

DEAEC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DEAEPT3
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : DEAEPT4
end

DEAEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

DEAEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " sends an "
end

DEAEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " to the "
end

DEAEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

AcknowledgeErase in Message, Token with
message_name
    messageName : "Acknowledge Erase"
tsn_msg_parameter
    tsnMsgParameter :
AcknowledgeEraseTsnParameter
msc_msg_parameter
    mscMsgParameter :
AcknowledgeEraseMscParameter
end

AcknowledgeEraseTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "acknowledgement"
end

AcknowledgeEraseMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "OK: Acknowledge
Erase"
end

DataErasedAcknowledgementMSCDescription
in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : PilotInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : AcknowledgeErase
end
```

Main Screen Display (from Erase Cartridge) Event Instantiation

```
MainScreenDisplay_1 in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
MainScreenDisplay_1_NormalPathSSN;
    sequenceNo2 :
MainScreenDisplay_1_NoCartridgeSSN;
    sequenceNo3 :
MainScreenDisplay_1_NoDataOnCartridgeSS
N;
    sequenceNo4 :
MainScreenDisplay_1_PilotChoosesNotToEr
aseDataSSN
follows_from
```

```
    followsFrom1 :
DataErasedAcknowledgement;
    followsFrom2 :
NoCartridgeAcknowledgement;
    followsFrom3 :
NoCartridgeDataPresentAcknowledgement;
    followsFrom4 : CancelEraseRequest
tsn_communication_event
    tsnCommunicationEvent :
MainScreenDisplay_1TextDescription
msc_communication_event
    mscCommunicationEvent :
MainScreenDisplay_1MSCDescription
end

MainScreenDisplay_1TextDescription in
TsnCommunication, Token with
communication_description
    communicationDescription :
MainScreenDisplay_1EventText
end

MainScreenDisplay_1EventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : MSD_1EC1;
    mnlsComposite2 : MSD_1EC2;
    mnlsComposite3 : MSD_1EC3
mnls_plain_text
    mnlsPlainText1 : MSD_1EPT1;
    mnlsPlainText2 : MSD_1EPT2;
    mnlsPlainText3 : MSD_1EPT3;
    mnlsPlainText4 : MSD_1EPT4
tsn_sender_node
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : PilotInstance
tsn_message_node
    tsnMessageNode : MainScreen_1
end

MSD_1EC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : MSD_1EPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : MSD_1EC2
end

MSD_1EC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : MSD_1EPT2
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : MSD_1EC3
end

MSD_1EC3 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : MSD_1EPT3
subject_node
    subjectNode : MainScreen_1
following_fragment
    followingFragment : MSD_1EPT4
end

MSD_1EPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

MSD_1EPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " displays to the "
end

MSD_1EPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " the "
end

MSD_1EPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

MainScreen_1 in Message, Token with
message_name
    messageName : "Main Screen"
end

MainScreenDisplay_1MSCDescription in
MscCommunication, Token
with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance : PilotInstance
msc_message
    mscMessage : MainScreen_1
end
```

Instantiation of Erase Cartridge: No Cartridge Present

```
EraseCartridge_NoCartridge in Scenario,
Token
with
scenario_title
    scenarioTitle : "Erase Cartridge -
No Cartridge Present"
is_exception
    isException : True
scenario_event
    scenarioEvent1 :
EraseCartridgeRequest;
    scenarioEvent2 :
NoCartridgePresentNotification;
    scenarioEvent3 :
NoCartridgeAcknowledgement;
    scenarioEvent4 :
MainScreenDisplay_1
includes_scenario
    includesScenario1 :
CheckforCartridge_NoCartridge
included_event
    includedEvent1 :
CheckforCartridgeRequest;
    includedEvent2 : NoCartridgePresent
-- again, 'included_event' may be
instantiated using a variation of the
rule in App.A, Pt.2 (vii.c)
scn_seq_no
    scnSeqNo1 :
EraseCartridgeRequest_NoCartridgeSSN;
    scnSeqNo2 :
NoCartridgePresentNotificationSSN;
    scnSeqNo3 :
NoCartridgeAcknowledgementSSN;
    scnSeqNo4 :
MainScreenDisplay_1_NoCartridgeSSN
scn_included_seq_no
    scnIncludedSeqNo1 :
CheckforCartridgeRequest_EC_NC_ISN;
    scnIncludedSeqNo2 :
NoCartridgePresent_EC_NC_ISN
tsn_viewpoint
```

```
    tsnViewpoint :
EraseCartridge_NoCartridgeTSV
msc_viewpoint
    mscViewpoint :
EraseCartridge_NoCartridgeMSV
end

EraseCartridgeRequest_NoCartridgeSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 1
end

NoCartridgePresentNotificationSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 4
end

NoCartridgeAcknowledgementSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 5
end

MainScreenDisplay_1_NoCartridgeSSN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 6
end

CheckforCartridgeRequest_EC_NC_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 2
end

NoCartridgePresent_EC_NC_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 3
end

EraseCartridge_NoCartridgeTSV in
TsnScenarioViewpoint, Token
with
tsv_tsn_comm
        tsvTsnComm1 :
EraseCartridgeRequestTextDescription;
        tsvTsnComm2 :
NoCartridgePresentNotificationTextDescr
iption;
        tsvTsnComm3 :
NoCartridgeAcknowledgementTextDescripti
on;
        tsvTsnComm4 :
MainScreenDisplay_1TextDescription
end

EraseCartridge_NoCartridgeMSV in
MscScenarioViewpoint, Token
with
msv_msc_comm
        msvMscComm1 :
EraseCartridgeRequestMSCDescription;
        msvMscComm2 :
NoCartridgePresentNotificationMSCDescri
ption;
        msvMscComm3 :
NoCartridgeAcknowledgementMSCDescriptio
n;
        msvMscComm4 :
MainScreenDisplay_1MSCDescription
end
```

No Cartridge Present Notification Event Instantiation

```
NoCartridgePresentNotification in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
NoCartridgePresentNotificationSSN
follows_from
    followsFrom : NoCartridgePresent
tsn_communication_event
    tsnCommunicationEvent :
NoCartridgePresentNotificationTextDescr
iption
msc_communication_event
    mscCommunicationEvent :
NoCartridgePresentNotificationMSCDescri
ption
end

NoCartridgePresentNotificationTextDescr
iption in TsnCommunication, Token with
communication_description
    communicationDescription :
NoCartridgePresentNotificationEventText
end

NoCartridgePresentNotificationEventText
in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : NCPNEC1;
    mnlsComposite2 : NCPNEC2;
    mnlsComposite3 : NCPNEC3
mnls_plain_text
    mnlsPlainText1 : NCPNEPT1;
    mnlsPlainText2 : NCPNEPT2;
    mnlsPlainText3 : NCPNEPT3;
    mnlsPlainText4 : NCPNEPT4
tsn_sender_node
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : PilotInstance
tsn_message_node
    tsnMessageNode :
NoCartridgeNotification
end

NCPNEC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : NCPNEPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : NCPNEC2
end

NCPNEC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : NCPNEPT2
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : NCPNEC3
end

NCPNEC3 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : NCPNEPT3
subject_node
    subjectNode :
NoCartridgeNotification
following_fragment
    followingFragment : NCPNEPT4
end

NCPNEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end
```

```
NCPNEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " informs the "
end

NCPNEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that there is "
end

NCPNEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

NoCartridgeNotification in Message,
Token with
message_name
    messageName : "No Cartridge
Notification"
tsn_msg_parameter
    tsnMsgParameter :
NoCartridgeNotificationTsnParameter
msc_msg_parameter
    mscMsgParameter :
NoCartridgeNotificationMscParameter
end

NoCartridgeNotificationTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "no cartridge
present in the hardware"
end

NoCartridgeNotificationMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "Report No
Cartridge"
end

NoCartridgePresentNotificationMSCDescri
ption in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance : PilotInstance
msc_message
    mscMessage :
NoCartridgeNotification
end
```

No Cartridge Acknowledgement Event Instantiation

```
NoCartridgeAcknowledgement in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
NoCartridgeAcknowledgementSSN
follows_from
    followsFrom :
NoCartridgePresentNotification
tsn_communication_event
    tsnCommunicationEvent :
NoCartridgeAcknowledgementTextDescripti
on
msc_communication_event
    mscCommunicationEvent :
NoCartridgeAcknowledgementMSCDescriptio
n
end

NoCartridgeAcknowledgementTextDescripti
on in TsnCommunication, Token with
communication_description
    communicationDescription :
NoCartridgeAcknowledgementEventText
end

NoCartridgeAcknowledgementEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : NCAEC1;
    mnlsComposite2 : NCAEC2;
    mnlsComposite3 : NCAEC3
mnls_plain_text
    mnlsPlainText1 : NCAEPT1;
    mnlsPlainText2 : NCAEPT2;
    mnlsPlainText3 : NCAEPT3;
    mnlsPlainText4 : NCAEPT4
tsn_sender_node
    tsnSenderNode : PilotInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode :
AcknowledgeNoCartridge
end

NCAEC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCAEPT1
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : NCAEC2
end

NCAEC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCAEPT2
subject_node
    subjectNode :
AcknowledgeNoCartridge
following_fragment
    followingFragment : NCAEC3
end

NCAEC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : NCAEPT3
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : NCAEPT4
end

NCAEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

NCAEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " sends an "
end

NCAEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " to the "
end

NCAEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end
```

```
AcknowledgeNoCartridge in Message,
Token
with
message_name
    messageName : "Acknowledge No
Cartridge"
tsn_msg_parameter
    tsnMsgParameter :
AcknowledgeNoCartridgeTsnParameter
msc_msg_parameter
    mscMsgParameter :
AcknowledgeNoCartridgeMscParameter

end

AcknowledgeNoCartridgeTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "acknowledgement"
end

AcknowledgeNoCartridgeMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "OK: Acknowlege No
Cartridge"
end

NoCartridgeAcknowledgementMSCDescriptio
n in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : PilotInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : AcknowledgeNoCartridge
end

Instantiation of Erase Cartridge: No
Data on Cartridge

EraseCartridge_NoDataOnCartridge in
Scenario, Token with
scenario_title
    scenarioTitle : "Erase Cartridge -
No Data on Cartridge"
is_exception
    isException : True
scenario_event
    scenarioEvent1 :
EraseCartridgeRequest;
    scenarioEvent2 :
NoCartridgeDataPresentNotification;
    scenarioEvent3 :
NoCartridgeDataPresentAcknowledgement;
    scenarioEvent4 :
MainScreenDisplay_1
includes_scenario
    includesScenario1 :
CheckforCartridge_NormalPath;
    includesScenario2 :
CheckCartridgeforData_NoData
included_event
    includedEvent1 :
CheckforCartridgeRequest;
    includedEvent2 :
ConfirmCartridgePresent;
    includedEvent3 :
CheckCartridgeforDataRequest;
    includedEvent4 :
NoCartridgeDataPresent

-- again 'included_event' may be
instantiated using a variation of the
rule in App.A, Pt.2 (vii.c)
scn_seq_no
    scnSeqNo1 :
EraseCartridgeRequest_NoDataOnCartridge
SSN;
    scnSeqNo2 :
NoCartridgeDataPresentNotificationSSN;
    scnSeqNo3 :
NoCartridgeDataPresentAcknowledgementSS
N;
    scnSeqNo4 :
MainScreenDisplay_1_NoDataOnCartridgeSS
N
scn_included_seq_no
    scnIncludedSeqNo1 :
CheckforCartridgeRequest_EC_ND_ISN;
    scnIncludedSeqNo2 :
ConfirmCartridgePresent_EC_ND_ISN;
    scnIncludedSeqNo3 :
CheckCartridgeforDataRequest_EC_ND_ISN;
    scnIncludedSeqNo4 :
NoCartridgeDataPresent_EC_ND_ISN
tsn_viewpoint
    tsnViewpoint :
EraseCartridge_NoDataOnCartridgeTSV
msc_viewpoint
    mscViewpoint :
EraseCartridge_NoDataOnCartridgeMSV
end

EraseCartridgeRequest_NoDataOnCartridge
SSN in SequenceNumber, Token
with
sequence_no
    sequenceNo : 1
end

NoCartridgeDataPresentNotificationSSN
in SequenceNumber, Token with
sequence_no
    sequenceNo : 6
end

NoCartridgeDataPresentAcknowledgementSS
N in SequenceNumber, Token with
sequence_no
    sequenceNo : 7
end

MainScreenDisplay_1_NoDataOnCartridgeSS
N in SequenceNumber, Token with
sequence_no
    sequenceNo : 8
end

CheckforCartridgeRequest_EC_ND_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 2
end

ConfirmCartridgePresent_EC_ND_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 3
end

CheckCartridgeforDataRequest_EC_ND_ISN
in SequenceNumber, Token with
sequence_no
    sequenceNo : 4
end

NoCartridgeDataPresent_EC_ND_ISN in
SequenceNumber, Token with
sequence_no
    sequenceNo : 5
end
```

```
EraseCartridge_NoDataOnCartridgeTSV in
TsnScenarioViewpoint, Token
with
tsv_tsn_comm
        tsvTsnComm1 :
EraseCartridgeRequestTextDescription;
        tsvTsnComm2 :
NoCartridgeDataPresentNotificationTextD
escription;
        tsvTsnComm3 :
NoCartridgeDataPresentAcknowledgementTe
xtDescription;
        tsvTsnComm4 :
MainScreenDisplay_1TextDescription
end

EraseCartridge_NoDataOnCartridgeMSV in
MscScenarioViewpoint, Token
with
msv_msc_comm
        msvMscComm1 :
EraseCartridgeRequestMSCDescription;
        msvMscComm2 :
NoCartridgeDataPresentNotificationMSCDe
scription;
        msvMscComm3 :
NoCartridgeDataPresentAcknowledgementMS
CDescription;
        msvMscComm4 :
MainScreenDisplay_1MSCDescription
end
```

No Cartridge Data Present Notification Event Instantiation

```
NoCartridgeDataPresentNotification in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
NoCartridgeDataPresentNotificationSSN
follows_from
    followsFrom :
NoCartridgeDataPresent
tsn_communication_event
    tsnCommunicationEvent :
NoCartridgeDataPresentNotificationTextD
escription
msc_communication_event
    mscCommunicationEvent :
NoCartridgeDataPresentNotificationMSCDe
scription
end

NoCartridgeDataPresentNotificationTextD
escription in TsnCommunication, Token
with
communication_description
    communicationDescription :
NoCartridgeDataPresentNotificationEvent
Text
end

NoCartridgeDataPresentNotificationEvent
Text in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : NCDPNEC1;
    mnlsComposite2 : NCDPNEC2;
    mnlsComposite3 : NCDPNEC3
mnls_plain_text
    mnlsPlainText1 : NCDPNEPT1;
    mnlsPlainText2 : NCDPNEPT2;
    mnlsPlainText3 : NCDPNEPT3;
    mnlsPlainText4 : NCDPNEPT4
tsn_sender_node
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : PilotInstance
tsn_message_node
    tsnMessageNode :
NoCartridgeDataNotification
end

NCDPNEC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : NCDPNEPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : NCDPNEC2
end

NCDPNEC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : NCDPNEPT2
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : NCDPNEC3
end

NCDPNEC3 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : NCDPNEPT3
subject_node
    subjectNode :
NoCartridgeDataNotification
following_fragment
    followingFragment : NCDPNEPT4
end

NCDPNEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

NCDPNEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " informs the "
end

NCDPNEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that there is "
end

NCDPNEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

NoCartridgeDataNotification in Message,
Token with
message_name
    messageName : "No Cartridge Data
Notification"
tsn_msg_parameter
    tsnMsgParameter :
NoCartridgeDataNotificationTsnParameter
msc_msg_parameter
    mscMsgParameter :
NoCartridgeDataNotificationMscParameter
end

NoCartridgeDataNotificationTsnParameter
in MessageDescription, Token with
msg_parameter
    msgParameter : "no data on the
cartridge"
end

NoCartridgeDataNotificationMscParameter
in MessageDescription, Token with
msg_parameter
    msgParameter : "Report No Data on
Cartridge"
```

```
end

NoCartridgeDataPresentNotificationMSCDe
scription in MscCommunication, Token
with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance : PilotInstance
msc_message
    mscMessage :
NoCartridgeDataNotification
end
```

No Cartridge Data Acknowledgment Event Instantiation

```
NoCartridgeDataPresentAcknowledgement
in CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 :
NoCartridgeDataPresentAcknowledgementSS
N
follows_from
    followsFrom :
NoCartridgeDataPresentNotification
tsn_communication_event
    tsnCommunicationEvent :
NoCartridgeDataPresentAcknowledgementTe
xtDescription
msc_communication_event
    mscCommunicationEvent :
NoCartridgeDataPresentAcknowledgementMS
CDescription
end

NoCartridgeDataPresentAcknowledgementTe
xtDescription in TsnCommunication,
Token with
communication_description
    communicationDescription :
NoCartridgeDataPresentAcknowledgementEv
entText
end

NoCartridgeDataPresentAcknowledgementEv
entText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : NCDPAEC1;
    mnlsComposite2 : NCDPAEC2;
    mnlsComposite3 : NCDPAEC3
mnls_plain_text
    mnlsPlainText1 : NCDPAEPT1;
    mnlsPlainText2 : NCDPAEPT2;
    mnlsPlainText3 : NCDPAEPT3;
    mnlsPlainText4 : NCDPAEPT4
tsn_sender_node
    tsnSenderNode : PilotInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode : AcknowledgeNoData
end

NCDPAEC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : NCDPAEPT1
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : NCDPAEC2
end

NCDPAEC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : NCDPAEPT2
subject_node
    subjectNode : AcknowledgeNoData
following_fragment
    followingFragment : NCDPAEC3
end

NCDPAEC3 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : NCDPAEPT3
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : NCDPAEPT4
end

NCDPAEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

NCDPAEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " sends an "
end

NCDPAEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " to the "
end

NCDPAEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

AcknowledgeNoData in Message, Token
with
message_name
    messageName : "Acknowledge No Data"
tsn_msg_parameter
    tsnMsgParameter :
AcknowledgeNoDataTsnParameter
msc_msg_parameter
    mscMsgParameter :
AcknowledgeNoDataMscParameter
end

AcknowledgeNoDataTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "acknowledgement"
end

AcknowledgeNoDataMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "OK: Acknowledge No
Data"
end

NoCartridgeDataPresentAcknowledgementMS
CDescription in MscCommunication, Token
with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
```

```
msc_sender_instance
    mscSenderInstance : PilotInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : AcknowledgeNoData
end
```

Instantiation of Erase Cartridge: Pilot Chooses Not to Erase Data

```
EraseCartridge_PilotChoosesNotToEraseDa
ta in Scenario, Token
with
scenario_title
    scenarioTitle : "Erase Cartridge -
Pilot Chooses Not to Erase Data"
is_exception
    isException : True
scenario_event
    scenarioEvent1 :
EraseCartridgeRequest;
    scenarioEvent2 :
ConfirmDataPresentonCartridge;
    scenarioEvent3 :
CancelEraseRequest;
    scenarioEvent4 :
MainScreenDisplay_1
includes_scenario
    includesScenario1 :
CheckforCartridge_NormalPath;
    includesScenario2 :
CheckCartridgeforData_NormalPath
included_event
    includedEvent1 :
CheckforCartridgeRequest;
    includedEvent2 :
ConfirmCartridgePresent;
    includedEvent3 :
CheckCartridgeforDataRequest;
    includedEvent4 :
ConfirmCartridgeDataPresent
-- again 'included_event' may be
instantiated using a variation of the
rule in App.A, Pt.2 (vii.c)
scn_seq_no
    scnSeqNo1 :
EraseCartridgeRequest_PilotChoosesNotTo
EraseDataSSN;
    scnSeqNo2 :
ConfirmDataPresentonCartridge_PilotChoo
sesNotToEraseDataSSN;
    scnSeqNo3 : CancelEraseRequestSSN;
    scnSeqNo4 :
MainScreenDisplay_1_PilotChoosesNotToEr
aseDataSSN
scn_included_seq_no
    scnIncludedSeqNo1 :
CheckforCartridgeRequest_EC_PCNTED_ISN;
    scnIncludedSeqNo2 :
ConfirmCartridgePresent_EC_PCNTED_ISN;
    scnIncludedSeqNo3 :
CheckCartridgeforDataRequest_EC_PCNTED_
ISN;
    scnIncludedSeqNo4 :
ConfirmCartridgeDataPresent_EC_PCNTED_I
SN
tsn_viewpoint
    tsnViewpoint :
EraseCartridge_PilotChoosesNotToEraseDa
taTSV
msc_viewpoint
    mscViewpoint :
EraseCartridge_PilotChoosesNotToEraseDa
taMSV
end

EraseCartridgeRequest_PilotChoosesNotTo
EraseDataSSN in SequenceNumber, Token
with
sequence_no
    sequenceNo : 1
end

ConfirmDataPresentonCartridge_PilotChoo
sesNotToEraseDataSSN in SequenceNumber,
Token with
sequence_no
    sequenceNo : 6
end

CancelEraseRequestSSN in
SequenceNumber, Token
with
sequence_no
    sequenceNo : 7
end

MainScreenDisplay_1_PilotChoosesNotToEr
aseDataSSN in SequenceNumber, Token
with
sequence_no
    sequenceNo : 8
end

CheckforCartridgeRequest_EC_PCNTED_ISN
in SequenceNumber, Token with
sequence_no
    sequenceNo : 2
end

ConfirmCartridgePresent_EC_PCNTED_ISN
in SequenceNumber, Token with
sequence_no
    sequenceNo : 3
end

CheckCartridgeforDataRequest_EC_PCNTED_
ISN in SequenceNumber, Token with
sequence_no
    sequenceNo : 4
end

ConfirmCartridgeDataPresent_EC_PCNTED_I
SN in SequenceNumber, Token with
sequence_no
    sequenceNo : 5
end

EraseCartridge_PilotChoosesNotToEraseDa
taTSV in TsnScenarioViewpoint, Token
with
tsv_tsn_comm
        tsvTsnComm1 :
EraseCartridgeRequestTextDescription;
        tsvTsnComm2 :
ConfirmDataPresentonCartridgeTextDescri
ption;
        tsvTsnComm3 :
CancelEraseRequestTextDescription;
        tsvTsnComm4 :
MainScreenDisplay_1TextDescription
end

EraseCartridge_PilotChoosesNotToEraseDa
taMSV in MscScenarioViewpoint, Token
with
msv_msc_comm
        msvMscComm1 :
EraseCartridgeRequestMSCDescription;
        msvMscComm2 :
ConfirmDataPresentonCartridgeMSCDescrip
tion;
        msvMscComm3 :
CancelEraseRequestMSCDescription;
        msvMscComm4 :
MainScreenDisplay_1MSCDescription
end
```

Cancel Erase Request Event Instantiation

```
CancelEraseRequest in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
sequence_no
    sequenceNo1 : CancelEraseRequestSSN
follows_from
    followsFrom :
ConfirmDataPresentonCartridge
tsn_communication_event
    tsnCommunicationEvent :
CancelEraseRequestTextDescription
msc_communication_event
    mscCommunicationEvent :
CancelEraseRequestMSCDescription
end

CancelEraseRequestTextDescription in
TsnCommunication, Token with
communication_description
    communicationDescription :
CancelEraseRequestEventText
end

CancelEraseRequestEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : CEREC1;
    mnlsComposite2 : CEREC2;
    mnlsComposite3 : CEREC3
mnls_plain_text
    mnlsPlainText1 : CEREPT1;
    mnlsPlainText2 : CEREPT2;
    mnlsPlainText3 : CEREPT3;
    mnlsPlainText4 : CEREPT4
tsn_sender_node
    tsnSenderNode : PilotInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode :
CancelEraseCartridge
end

CEREC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : CEREPT1
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : CEREC2
end

CEREC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : CEREPT2
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : CEREC3
end

CEREC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : CEREPT3
subject_node
    subjectNode : CancelEraseCartridge
following_fragment
    followingFragment : CEREPT4
end

CEREPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

CEREPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " indicates to the "
end

CEREPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that he wishes to "
end

CEREPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

CancelEraseCartridge in Message, Token
with
message_name
    messageName : "Cancel Erase
Cartridge"
tsn_msg_parameter
    tsnMsgParameter :
CancelEraseCartridgeTsnParameter
msc_msg_parameter
    mscMsgParameter :
CancelEraseCartridgeMscParameter
end

CancelEraseCartridgeTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "cancel the Erase
Cartridge request"
end

CancelEraseCartridgeMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "Cancel Erase"
end


CancelEraseRequestMSCDescription in
MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : PilotInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : CancelEraseCartridge
end
```

ii. Instantiation of Retrieve From Cartridge (Timing Fragment)

Set Data Timer (Event # 11) Instantiation

```
SetDataTimer1 in TimingEvent, Token
with
    .....
tsn_timing_event
    tsnTimingEvent :
SetDataTimer1TextDescription
msc_timing_event
    mscTimingEvent :
SetDataTimer1MSCDescription
end

SetDataTimer1TextDescription in
TsnTiming, Token with
timing_description
    timingDescription :
SetDataTimer1EventText
end

SetDataTimer1EventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : SDT1EC1;
    mnlsComposite2 : SDT1EC2;
    mnlsComposite3 : SDT1EC3
mnls_plain_text
    mnlsPlainText1 : SDT1EPT1;
    mnlsPlainText2 : SDT1EPT2;
    mnlsPlainText3 : SDT1EPT3;
    mnlsPlainText4 : SDT1EPT4
tsn_timer_set_node
    tsnTimerSetNode : MPSInstance
tsn_timer_instance_node
    tsnTimerInstanceNode : DataTimer
tsn_timer_duration
    tsnTimerDuration :
SetDataTimer1Duration
end

SDT1EC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : SDT1EPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : SDT1EC2
end

SDT1EC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : SDT1EPT2
subject_node
    subjectNode : DataTimer
following_fragment
    followingFragment : SDT1EC3
end

SDT1EC3 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : SDT1EPT3
subject_node
    subjectNode : SetDataTimer1Duration
following_fragment
    followingFragment : SDT1EPT4
end

SDT1EPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

SDT1EPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " sets the "
end

SDT1EPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " to "
end

SDT1EPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

DataTimer in Timer, Token with
timer_name
    timerName : "DataTimer"
timer_duration
    timerDuration1 :
SetDataTimer1Duration
end

SetDataTimer1Duration in TimerDuration,
Token with
duration
    _Duration : "10 Seconds"
end

SetDataTimer1MSCDescription in
MscTiming, Token with
msc_timer_set_instance
    mscTimerSetInstance : MPSInstance
msc_timer_instance
    mscTimerInstance : DataTimer
msc_timer_duration
    mscTimerDuration :
SetDataTimer1Duration
end
```

Type_1 (Data) Retrieved Notification (Event # 12) Instantiation

```
RetrievedType1Notification in
CommunicationEvent, Token with
interaction_type
    interactionType : "SP"
    .....
tsn_communication_event
    tsnCommunicationEvent :
RetrievedType1NotificationTextDescripti
on
msc_communication_event
    mscCommunicationEvent :
RetrievedType1NotificationMSCDescriptio
n
end

RetrievedType1NotificationTextDescripti
on in TsnCommunication, Token with
communication_description
    communicationDescription :
RetrievedType1NotificationEventText
end

RetrievedType1NotificationEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : RT1NEC1;
    mnlsComposite2 : RT1NEC2;
    mnlsComposite3 : RT1NEC3
mnls_plain_text
    mnlsPlainText1 : RT1NEPT1;
    mnlsPlainText2 : RT1NEPT2;
    mnlsPlainText3 : RT1NEPT3;
    mnlsPlainText4 : RT1NEPT4
tsn_sender_node
```

```
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : PilotInstance
tsn_message_node
    tsnMessageNode :
Type_1RetrievedNotification
end

RT1NEC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : RT1NEPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : RT1NEC2
end

RT1NEC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : RT1NEPT2
subject_node
    subjectNode : PilotInstance
following_fragment
    followingFragment : RT1NEC3
end

RT1NEC3 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : RT1NEPT3
subject_node
    subjectNode :
Type_1RetrievedNotification
following_fragment
    followingFragment : RT1NEPT4
end

RT1NEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

RT1NEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " informs the "
end

RT1NEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " that "
end

RT1NEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

Type_1RetrievedNotification in Message,
Token with
message_name
    messageName : "Type_1 Retrieved
Notification"
tsn_msg_parameter
    tsnMsgParameter :
RetrievedType1NotificationTsnParameter
msc_msg_parameter
    mscMsgParameter :
RetrievedType1NotificationMscParameter
end

RetrievedType1NotificationTsnParameter
in MessageDescription, Token with
msg_parameter
    msgParameter : "type_1 data has
been retrieved"
end

RetrievedType1NotificationMscParameter
in MessageDescription, Token with
msg_parameter
    msgParameter : "Type_1 Retrieved"
end

RetrievedType1NotificationMSCDescriptio
n in MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance : PilotInstance
msc_message
    mscMessage :
Type_1RetrievedNotification
end
```

Time-out Data Timer (Event # 13) Instantiation

```
TimeoutDataTimer1 in TimingEvent, Token
with
    .......
tsn_timing_event
    tsnTimingEvent :
TimeoutDataTimer1TextDescription
msc_timing_event
    mscTimingEvent :
TimeoutDataTimer1MSCDescription
end

TimeoutDataTimer1TextDescription in
TsnTiming, Token with
timing_description
    timingDescription :
TimeoutDataTimer1EventText
end

TimeoutDataTimer1EventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : TODT1EC1;
    mnlsComposite2 : TODT1EC2
mnls_plain_text
    mnlsPlainText1 : TODT1EPT1;
    mnlsPlainText2 : TODT1EPT2
mnls_null
    mnlsNull : TODT1ENull1
tsn_host_on_timeout_node
    tsnHostOnTimeoutNode : MPSInstance
tsn_timer_instance_node
    tsnTimerInstanceNode : DataTimer
end

TODT1EC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : TODT1EPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : TODT1EC2
end

TODT1EC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : TODT1ENull1
subject_node
    subjectNode : DataTimer
following_fragment
    followingFragment : TODT1EPT2
end
```

```
TODT1EPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

TODT1EPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " times-out."
end

TimeoutDataTimer1MSCDescription in
MscTiming, Token with
msc_host_on_timeout_instance
    mscHostOnTimeoutInstance :
MPSInstance
msc_timer_instance
    mscTimerInstance : DataTimer
end
```

Storage Type_1 Data (Event # 14) Instantiation

```
StorageType1 in InternalActionEvent,
Token with
    .......
tsn_action_event
    tsnActionEvent :
StorageType1TextDescription
msc_action_event
    mscActionEvent :
StorageType1MSCDescription
end

StorageType1TextDescription in TsnAction,
Token with
action_description
    actionDescription :
StorageType1EventText
end

StorageType1EventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : ST1EC1;
    mnlsComposite2 : ST1EC2
mnls_plain_text
    mnlsPlainText1 : ST1EPT1;
    mnlsPlainText2 : ST1EPT2
mnls_null
    mnlsNull : ST1ENull1
tsn_sdr_rcr_node
    tsnSdrRcrNode : MPSInstance
tsn_action_node
    tsnActionNode : StoreType_1Data
end

ST1EC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : ST1EPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : ST1EC2
end

ST1EC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : ST1ENull1
subject_node
    subjectNode : StoreType_1Data
following_fragment
    followingFragment : ST1EPT2
end

ST1EPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

ST1EPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

StoreType_1Data in Action, Token with
action_name
    actionName : "Store Type_1 Data"
tsn_act_parameter
    tsnActParameter :
StoreType1TsnParameter
end

StoreType1TsnParameter in
MessageDescription, Token with
action_parameter
    actionParameter : "stores type_1
data"
end

StorageType1MSCDescription in MscAction,
Token with
msc_sdr_rcr_instance
    mscSdrRcrInstance : MPSInstance
msc_system_action
    mscSystemAction : StoreType_1Data
end
```

III. Instantiation of Choose Mission and Aircraft (Event Group Fragment)

Data Item Request (Event # 11) Instantiation

```
DataItemRequest in CommunicationEvent,
Token with
interaction_type
    interactionType : "IR"
    .....
tsn_communication_event
    tsnCommunicationEvent :
DataItemRequestTextDescription
msc_communication_event
    mscCommunicationEvent :
DataItemRequestMSCDescription
end

DataItemRequestTextDescription in
TsnCommunication, Token with
communication_description
    communicationDescription :
DataItemRequestEventText
end

DataItemRequestEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : DIREC1;
    mnlsComposite2 : DIREC2;
    mnlsComposite3 : DIREC3
mnls_plain_text
    mnlsPlainText1 : DIREPT1;
    mnlsPlainText2 : DIREPT2;
    mnlsPlainText3 : DIREPT3;
    mnlsPlainText4 : DIREPT4
tsn_sender_node
    tsnSenderNode : MPSInstance
tsn_receiver_node
    tsnReceiverNode : MissionPlanInstance
tsn_message_node
    tsnMessageNode : RequestDataItem
end

DIREC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DIREPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : DIREC2
end

DIREC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DIREPT2
subject_node
    subjectNode : MissionPlanInstance
following_fragment
    followingFragment : DIREC3
end

DIREC3 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : DIREPT3
subject_node
    subjectNode : RequestDataItem
following_fragment
    followingFragment : DIREPT4
end

DIREPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

DIREPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " asks the "
end

DIREPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " to "
end

DIREPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

RequestDataItem in Message, Token with
message_name
    messageName : "Request Data Item"
tsn_msg_parameter
    tsnMsgParameter :
RequestDataItemTsnParameter
end

RequestDataItemTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "supply a data item"
end

DataItemRequestMSCDescription in
MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance : MPSInstance
msc_receiver_instance
    mscReceiverInstance :
MissionPlanInstance
msc_message
    mscMessage : RequestDataItem
end
```

Mission And Aircraft Data Item Provision (Event #12) Instantiation

```
MACDataItemProvision in
CommunicationEvent, Token with
interaction_type
    interactionType : "IP"
    .....
tsn_communication_event
    tsnCommunicationEvent :
MACDataItemProvisionTextDescription
msc_communication_event
    mscCommunicationEvent :
MACDataItemProvisionMSCDescription
end

MACDataItemProvisionTextDescription in
TsnCommunication, Token with
communication_description
    communicationDescription :
MACDataItemProvisionEventText
end

MACDataItemProvisionEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : MACDIPEC1;
    mnlsComposite2 : MACDIPEC2;
    mnlsComposite3 : MACDIPEC3
mnls_plain_text
    mnlsPlainText1 : MACDIPEPT1;
    mnlsPlainText2 : MACDIPEPT2;
```

```
    mnlsPlainText3 : MACDIPEPT3;
    mnlsPlainText4 : MACDIPEPT4
tsn_sender_node
    tsnSenderNode : MissionPlanInstance
tsn_receiver_node
    tsnReceiverNode : MPSInstance
tsn_message_node
    tsnMessageNode : Mission&ACDataItem
end

MACDIPEC1 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : MACDIPEPT1
subject_node
    subjectNode : MissionPlanInstance
following_fragment
    followingFragment : MACDIPEC2
end

MACDIPEC2 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : MACDIPEPT2
subject_node
    subjectNode : Mission&ACDataItem
following_fragment
    followingFragment : MACDIPEC3
end

MACDIPEC3 in MatraNLSComposite, Token
with
preceding_fragment
    precedingFragment : MACDIPEPT3
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : MACDIPEPT4
end

MACDIPEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

MACDIPEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : " supplies the "
end

MACDIPEPT3 in PlainTextNode, Token with
mnls_text
    mnlsText : " to the "
end

MACDIPEPT4 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

Mission&ACDataItem in Message, Token with
message_name
    messageName : "Mission&AC Data Item"
tsn_msg_parameter
    tsnMsgParameter :
Mission&ACDataItemTsnParameter
msc_msg_parameter
    mscMsgParameter :
Mission&ACDataItemMscParameter
end

Mission&ACDataItemTsnParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "data item for the
selected Mission and Aircraft"
end

Mission&ACDataItemMscParameter in
MessageDescription, Token with
msg_parameter
    msgParameter : "Data Item for
Selection"
end

MACDataItemProvisionMSCDescription in
MscCommunication, Token with
link_name
    linkName : "unspecified"
synchronisation
    _Synchronisation : = "sim"
frequency
    _Frequency : "aperiodic"
delayed
    _Delayed : False
msc_sender_instance
    mscSenderInstance :
MissionPlanInstance
msc_receiver_instance
    mscReceiverInstance : MPSInstance
msc_message
    mscMessage : Mission&ACDataItem
end
```

Storage Mission and Aircraft Data (Event #13) Instantiation

```
StorageMAC in InternalActionEvent, Token
with

    .....
tsn_action_event
    tsnActionEvent :
StorageMACTextDescription
msc_action_event
    mscActionEvent :
StorageMACMSCDescription
end

StorageMACTextDescription in TsnAction,
Token with
action_description
    actionDescription :
StorageMACEventText
end

StorageMACEventText in
ScenarioEventNaturalLanguageStructure,
Token with
mnls_composite
    mnlsComposite1 : SMACEC1;
    mnlsComposite2 : SMACEC2
mnls_plain_text
    mnlsPlainText1 : SMACEPT1;
    mnlsPlainText2 : SMACEPT2
mnls_null
    mnlsNull : SMACENull1
tsn_sdr_rcr_node
    tsnSdrRcrNode : MPSInstance
tsn_action_node
    tsnActionNode :
StoreSelectedMission&ACData
end

SMACEC1 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : SMACEPT1
subject_node
    subjectNode : MPSInstance
following_fragment
    followingFragment : SMACEC2
end

SMACEC2 in MatraNLSComposite, Token with
preceding_fragment
    precedingFragment : SMACENull1
subject_node
    subjectNode :
StoreSelectedMission&ACData
following_fragment
    followingFragment : SMACEPT2
end
```

```
SMACEPT1 in PlainTextNode, Token with
mnls_text
    mnlsText : "The "
end

SMACEPT2 in PlainTextNode, Token with
mnls_text
    mnlsText : "."
end

StoreSelectedMission&ACData in Action,
Token with
action_name
    actionName : "Store Selected
Mission&AC Data"
tsn_act_parameter
    tsnActParameter :
StoreSelectedMission&ACDataTsnParameter
msc_act_parameter
    mscActParameter :
StoreSelectedMission&ACDataMscParameter
end

StoreSelectedMission&ACDataTsnParameter
in MessageDescription, Token with
action_parameter
    actionParameter : "stores the data
item for the selected Mission and
Aircraft"
end

StoreSelectedMission&ACDataMscParameter
in MessageDescription, Token with
action_parameter
    actionParameter : "Store Selected
Mission and Aircraft Data"
end

StorageMACMSCDescription in MscAction,
Token with
msc_sdr_rcr_instance
    mscSdrRcrInstance : MPSInstance
msc_system_action
    mscSystemAction :
StoreSelectedMission&ACData
end
```

Grouping for Events 11-13

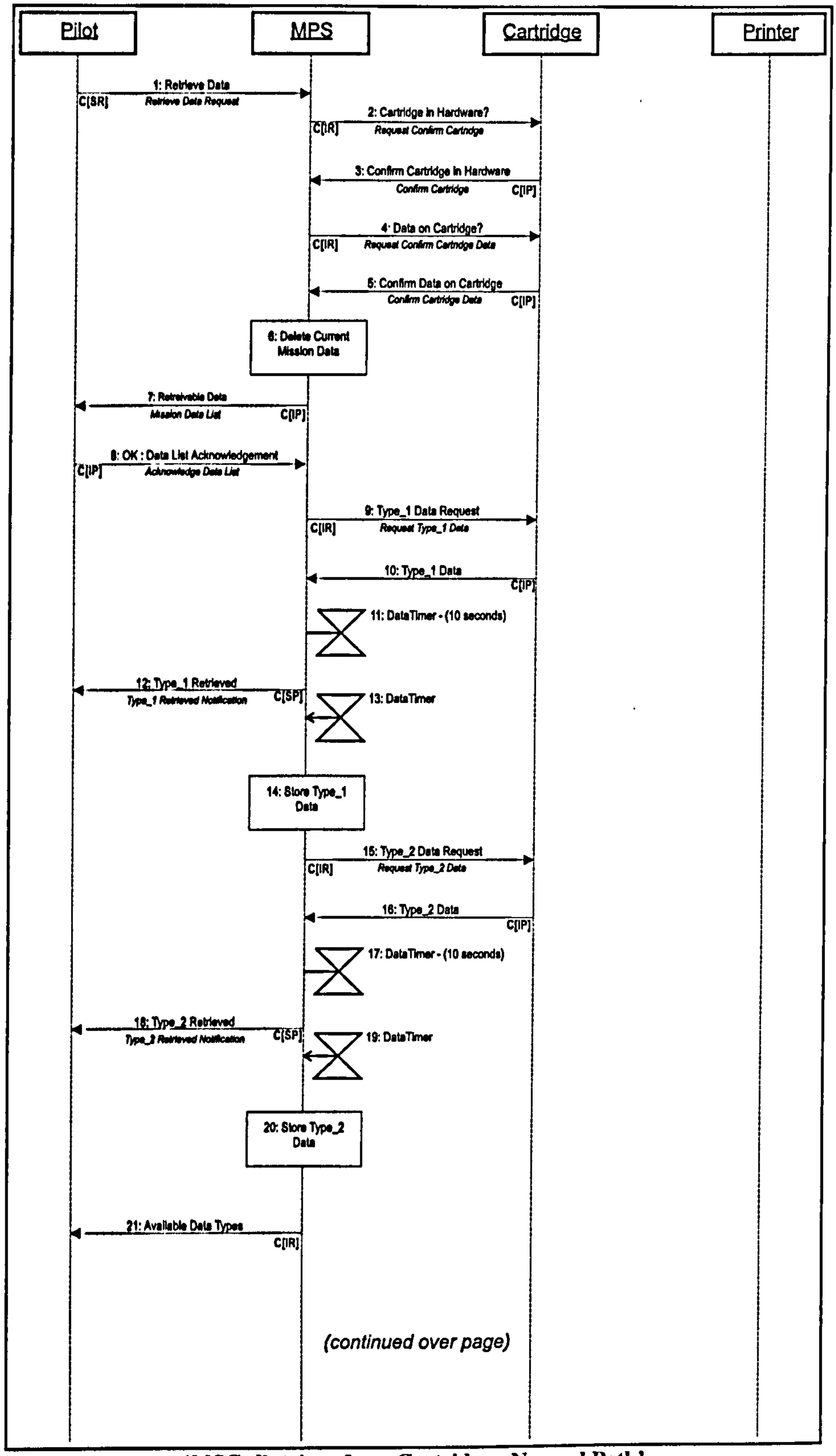
```
Events11To13Group in EventGroup, Token
with
group_event
    groupEvent1 : DataItemRequest;
    groupEvent2 : MACDataItemProvision;
    groupEvent3 : StorageMAC
grp_lb
    grpLb : Events11To13GroupLB
grp_ub
    grpUb : Events11To13GroupUB
end

Events11To13GroupLB in LowerBound, Token
with
lower_bound
    lowerBound : "1"
end

Events11To13GroupUB in UpperBound, Token
with
upper_bound
    upperBound : "card data types Mission
Plan()"
end
```

Appendix C (Part 2) - Additional Scenarios For Hawk Mission Planning System

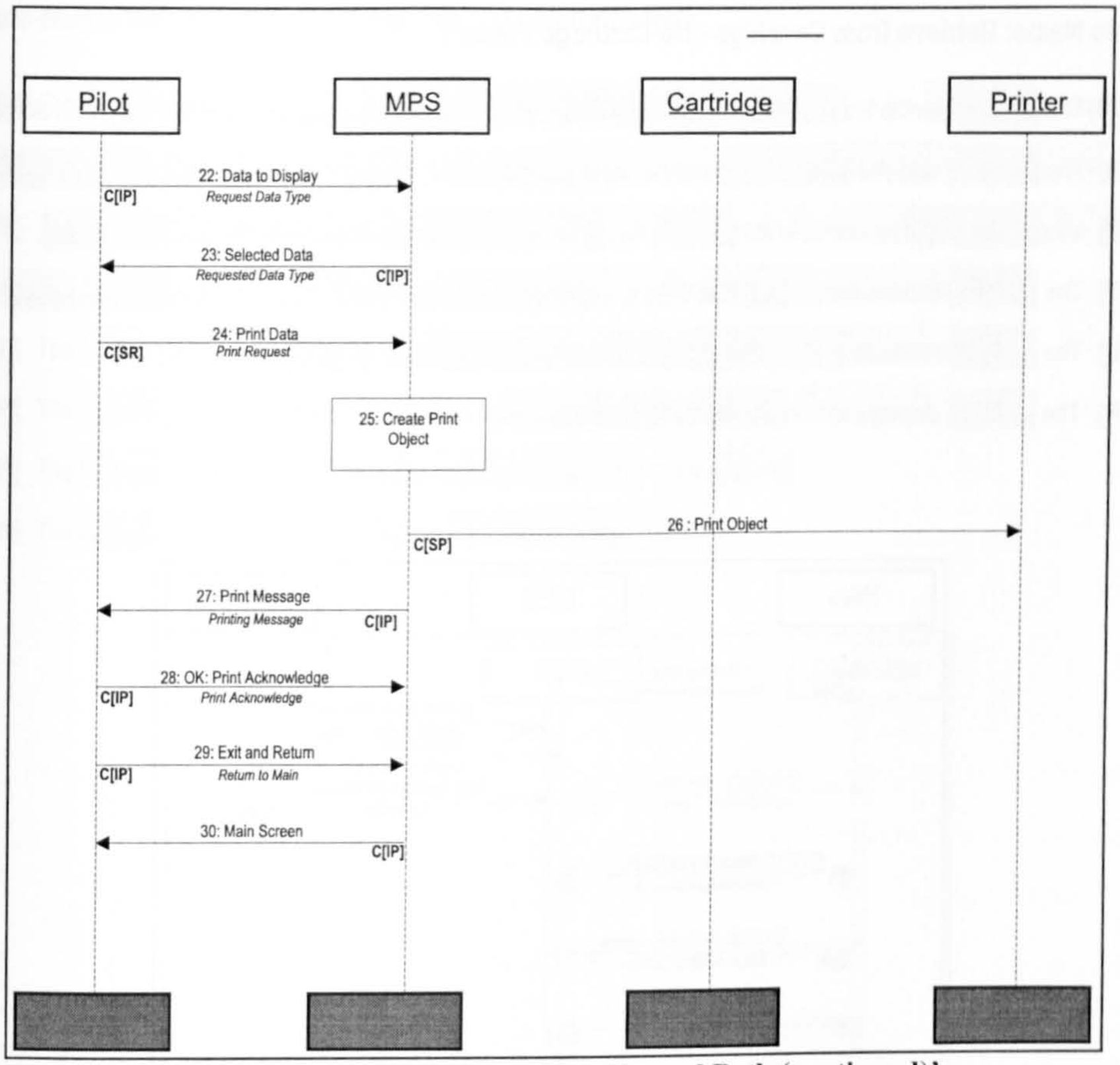
Use Case : Retrieve from Cartridge

Scenario Name: Retrieve from Cartridge - Normal Path

1. **C[SR]** The [sdr Pilot] selects the [msg Retrieve Data from Cartridge option : Retrieve Data Request] on the [rcr MPS] Main Screen.
2. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [msg is a cartridge present in the hardware? : Request Confirm Cartridge].
3. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is a cartridge present in the hardware : Confirm Cartridge].
4. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [is data on the cartridge? : Request Confirm Cartridge Data].
5. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is data on the Cartridge : Confirm Cartridge Data].
6. **A** The [sdr/rcr MPS] [act deletes any previously retrieved data : Delete Current MissionData].
7. **C[IP]** The [sdr MPS] displays a [msg list of retrievable data : Mission Data List] available to the [rcr Pilot].
8. **C[IP]** The [sdr Pilot] sends and [msg acknowledgment : Acknowledge Data List] to the [rcr MPS].
9. **C[IR]** The [sdr MPS] requests that the [rcr Cartridge] [msg supply type_1 data : Request Type_1 Data].
10. **C[IP]** The [sdr Cartridge] supplies [msg type_1 data] to the [rcr MPS].
11. **T** The [timer-set MPS] sets the [timer DataTimer] to [duration 10 seconds].
12. **C[SP]** The [sdr MPS] informs the [rcr Pilot] that [msg type_1 data has been retrieved : Type_1 Retrieved Notification].
13. **T** The [host-on-timeout MPS] [timer DataTimer] times-out.
14. **A** The [sdr/rcr MPS] [act stores type_1 data : Store Type_1 Data].
15. **C[IR]** The [sdr MPS] requests that the [rcr Cartridge] [msg supply type_2 data] : Request Type_2 Data].
16. **C[IP]** The [sdr Cartridge] supplies [msg type_2 data] to the [rcr MPS].
17. **T** The [timer-set MPS] sets the [timer DataTimer] to [duration 10 seconds].
18. **C[SP]** The [sdr MPS] informs the [rcr Pilot] that [msg type_2 data has been retrieved : Type_2 Retrieved Notification].
19. **T** The [host-on-timeout MPS] [timer DataTimer] times-out.
20. **A** The [sdr/rcr MPS] [act stores type_2 data : Store Type_2 Data].
21. **C[IR]** The [sdr MPS] displays the [list of available data types : Available Data Types] for the [rcr Pilot] to select from.
22. **C[IP]** The [sdr Pilot] selects a [msg data type to display : Request Data Type] from the [rcr MPS] screen.
23. **C[IP]** The [sdr MPS] displays the [msg selected data type : Requested Data Type] to the [rcr Pilot].
24. **C[SR]** The [sdr Pilot] selects the [msg Print Data : Print Request] on [rcr MPS] screen.
25. **A** The [sdr/rcr MPS] [act creates a print object : Create Print Object] from the displayed data.
26. **C[SP]** The [sdr MPS] sends the [msg print object] to the [rcr Printer].
27. **C[IP]** The [sdr MPS] informs the [rcr Pilot] indicating [msg the data is being printed : Printing Message].
28. **C[IP]** The [sdr Pilot] sends an [msg acknowledgment : Print Acknowledge] to the [rcr MPS].
29. **C[IP]** The [sdr Pilot] informs the [rcr MPS] that he wishes to [exit this function and return to the Main Screen : Return to Main].
30. **C[IP]** The [sdr MPS] displays to the [rcr Pilot] the [msg Main Screen].



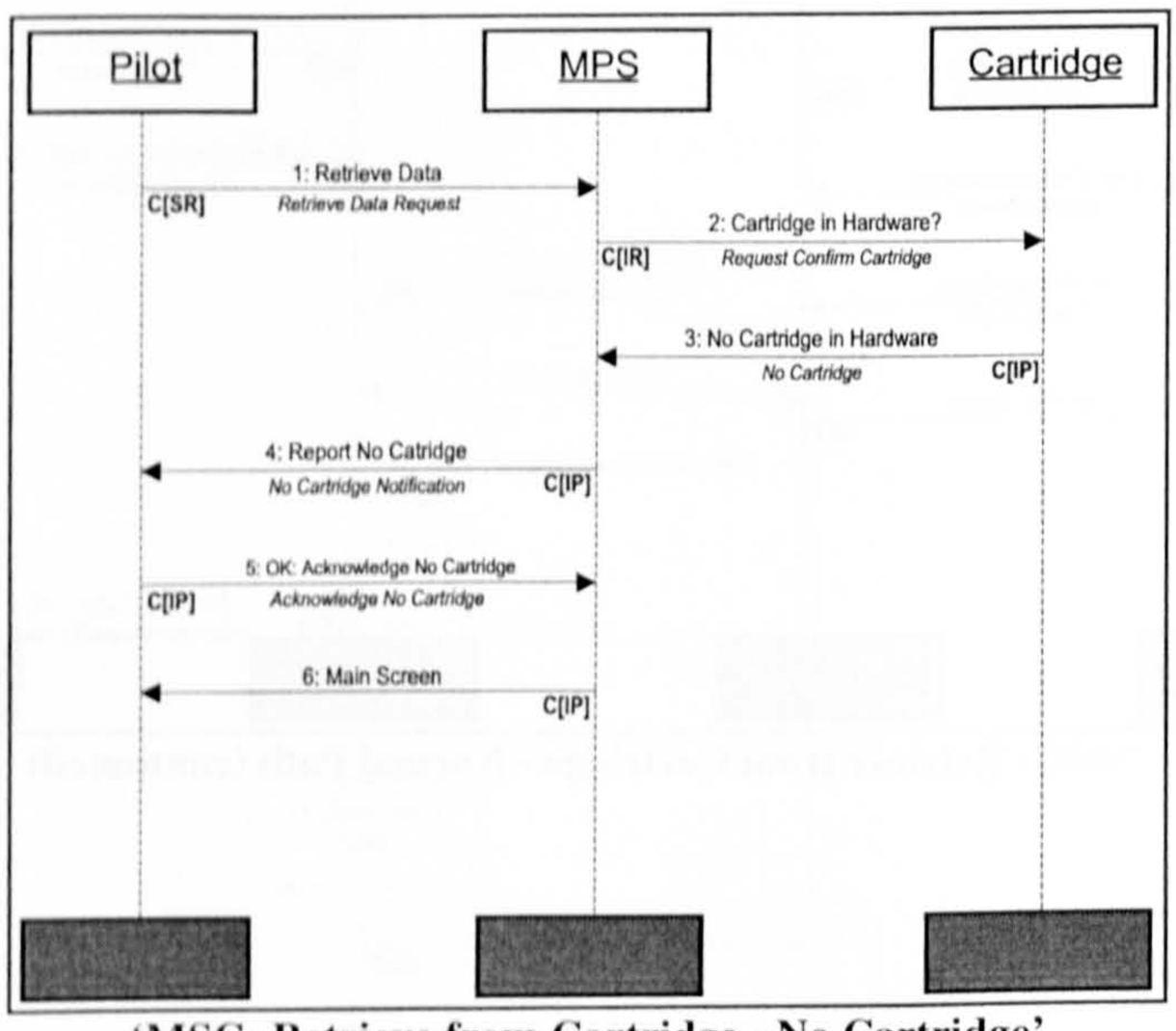
'MSC: Retrieve from Cartridge - Normal Path'



'MSC: Retrieve from Cartridge - Normal Path (continued)'

Scenario Name: Retrieve from Cartridge - No Cartridge Present

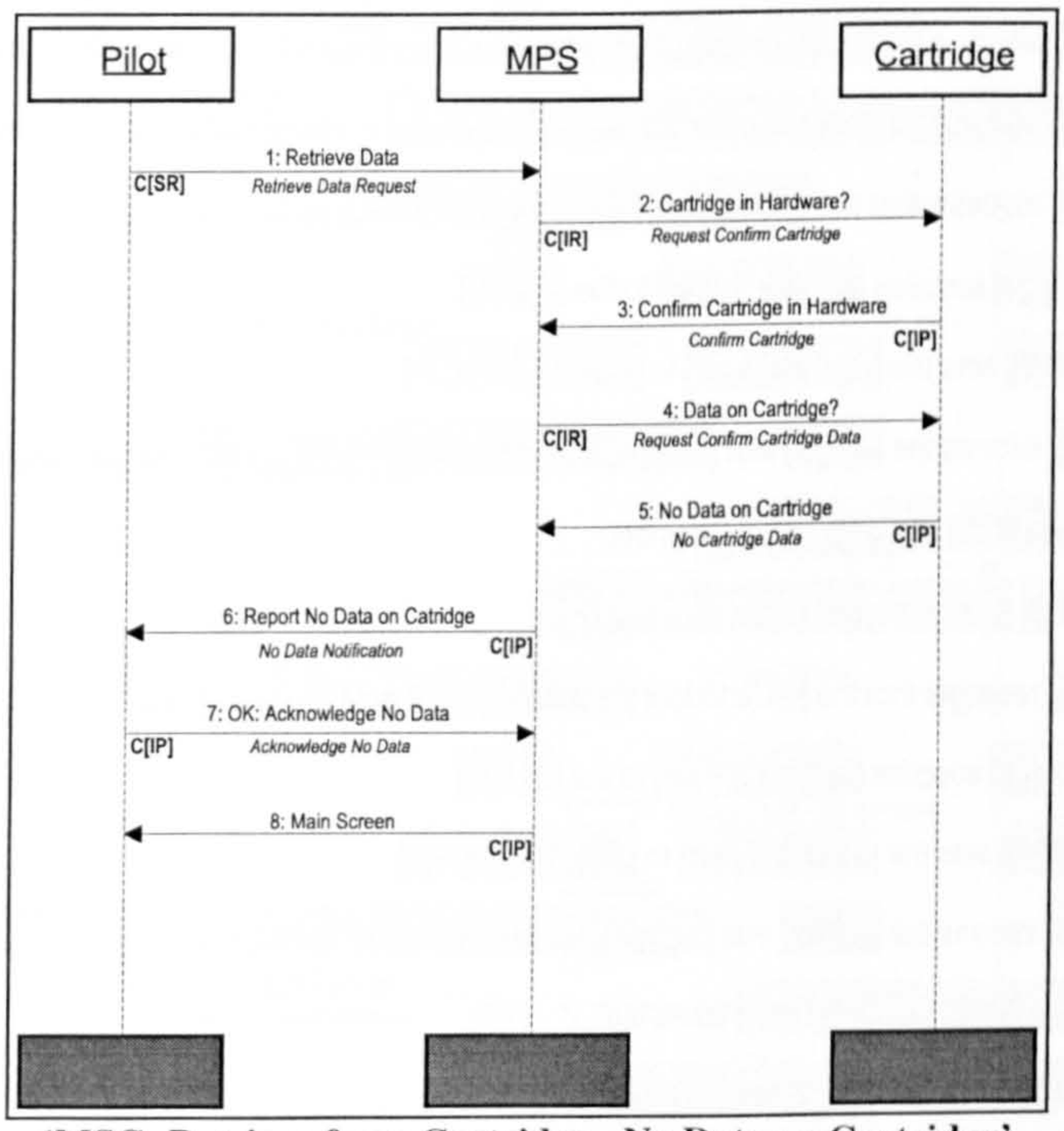
1. **C[SR]** The [sdr Pilot] selects the [msg Retrieve Data from Cartridge option : Retrieve Data Request] on the [rcr MPS] Main Screen.
2. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [msg is a cartridge present in the hardware? : Request Confirm Cartridge].
3. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is no cartridge present in the hardware : No Data].
4. **C[IP]** The [sdr MPS] informs the [rcr Pilot] that there is [msg no cartridge is present in the hardware : No Cartridge Notification].
5. **C[IP]** The [sdr Pilot] sends an [msg acknowledgment : Acknowledge No Cartridge] to the [rcr MPS].
6. **C[IP]** The [sdr MPS] displays to the [rcr Pilot] the [msg Main Screen].



'MSC: Retrieve from Cartridge - No Cartridge'

Scenario Name: Retrieve from Cartridge - No Data on Cartridge

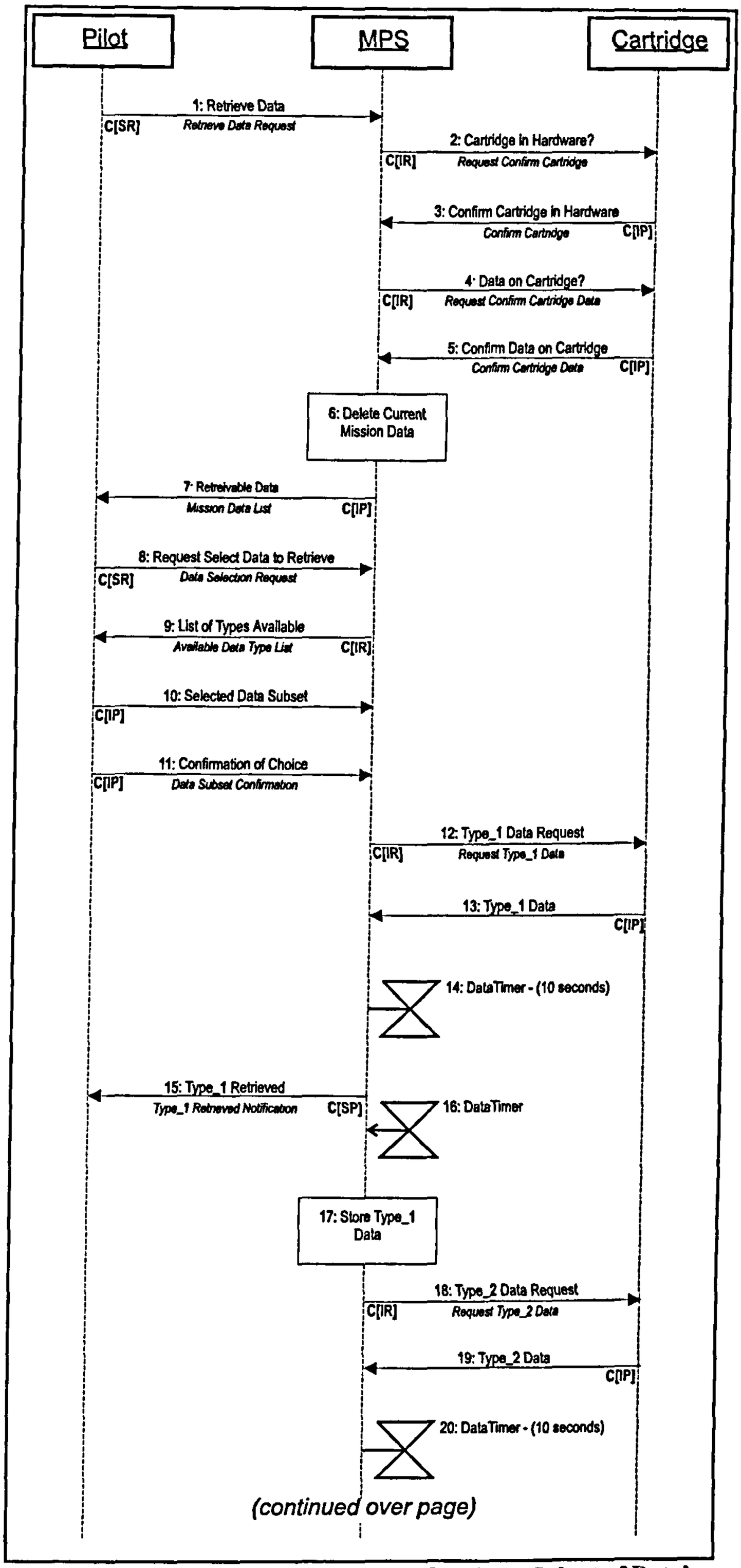
1. **C[SR]** The [sdr Pilot] selects the [msg Retrieve Data from Cartridge option : Retrieve Data Request] on the [rcr MPS] Main Screen.
2. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [msg is a cartridge present in the hardware? : Request Confirm Cartridge].
3. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is a cartridge present in the hardware : Confirm Cartridge].
4. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [is data on the cartridge? : Request Confirm Cartridge Data].
5. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is no data on the Cartridge : No Cartridge Data].
6. **C[IP]** The [sdr MPS] informs the [rcr Pilot] that there is [msg no data on the Cartridge: No Data Notification].
7. **C[IP]** The [sdr Pilot] sends an [msg acknowledgment : Acknowledge No Data] to the [rcr MPS].
8. **C[IP]** The [sdr MPS] displays to the [rcr Pilot] the [msg Main Screen].



'MSC: Retrieve from Cartridge - No Data on Cartridge'

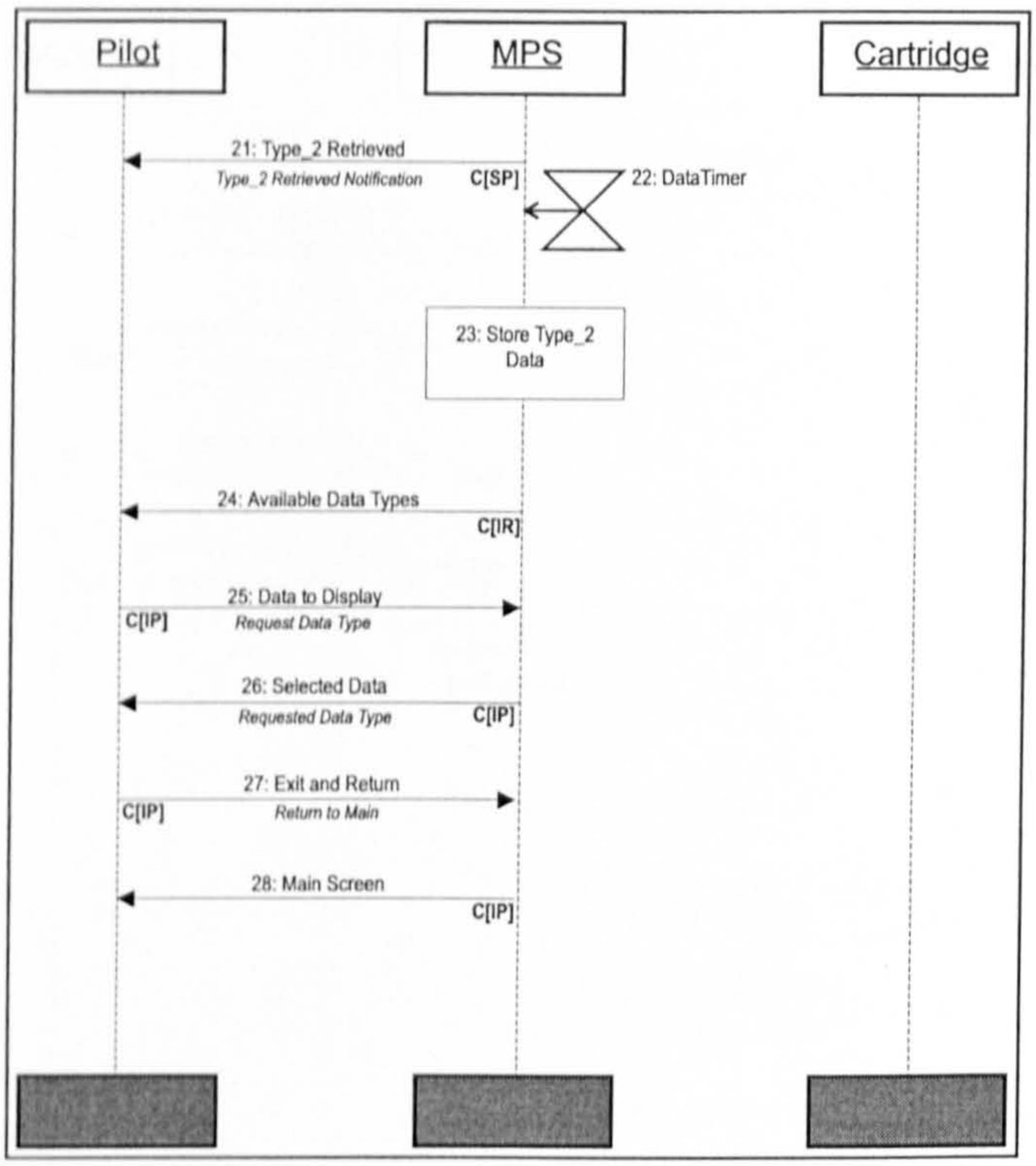
Scenario Name: Retrieve from Cartridge - Pilot Retrieves Subset of Data

1. **C[SR]** The [sdr Pilot] selects the [msg Retrieve Data from Cartridge option : Retrieve Data Request] on the [rcr MPS] Main Screen.
2. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [msg is a cartridge present in the hardware? : Request Confirm Cartridge].
3. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is a cartridge present in the hardware : Confirm Cartridge].
4. **C[IR]** The [sdr MPS] asks the [rcr Cartridge] whether there [is data on the cartridge? : Request Confirm Cartridge Data].
5. **C[IP]** The [sdr Cartridge] responds to the [rcr MPS] that [msg there is data on the Cartridge : Confirm Cartridge Data].
6. **A** The [sdr/rcr MPS] [act deletes any previously retrieved data : Delete Current MissionData].
7. **C[IP]** The [sdr MPS] displays a [msg list of retrievable data : Mission Data List] available to the [rcr Pilot].
8. **C[SR]** The [sdr Pilot] chooses the [msg Select Data to Retrieve option : Data Selection Request] from the [rcr MPS] screen.
9. **C[IR]** The [sdr MPS] displays a [msg list of available data types : Available Data List] for the [rcr Pilot] to select from.
10. **C[IP]** The [sdr Pilot] selects a [msg subset of the available types : Selected Data Subset] from the [rcr MPS] screen.
11. **C[IP]** The [sdr Pilot] [msg confirms this choice of data : Data Subset Confirmation] via the [rcr MPS] display screen.
12. **C[IR]** The [sdr MPS] requests that the [rcr Cartridge] [msg supply type_1 data] : Request Type_1 Data].
13. **C[IP]** The [sdr Cartridge] supplies [msg type_1 data] to the [rcr MPS].
14. **T** The [timer-set MPS] sets the [timer DataTimer] to [duration 10 seconds].
15. **C[SP]** The [sdr MPS] informs the [rcr Pilot] that [msg type_1 data has been retrieved : Type_1 Retrieved Notification].
16. **T** The [host-on-timeout MPS] [timer DataTimer] times-out.
17. **A** The [sdr/rcr MPS] [act stores type_1 data : Store Type_1 Data].
18. **C[IR]** The [sdr MPS] requests that the [rcr Cartridge] [msg supply type_2 data] : Request Type_2 Data].
19. **C[IP]** The [sdr Cartridge] supplies [msg type_2 data] to the [rcr MPS].
20. **T** The [timer-set MPS] sets the [timer DataTimer] to [duration 10 seconds].
21. **C[SP]** The [sdr MPS] informs the [rcr Pilot] that [msg type_2 data has been retrieved : Type_2 Retrieved Notification].
22. **T** The [host-on-timeout MPS] [timer DataTimer] times-out.
23. **A** The [sdr/rcr MPS] [act stores type_2 data : Store Type_2 Data].
24. **C[IR]** The [sdr MPS] displays the [list of available data types : Available Data Types] for the [rcr Pilot] to select from.
25. **C[IP]** The [sdr Pilot] selects a [msg data type to display : Request Data Type] from the [rcr MPS] screen.
26. **C[IP]** The [sdr MPS] displays the [msg selected data type : Requested Data Type] to the [rcr Pilot].
27. **C[IP]** The [sdr Pilot] informs the [rcr MPS] that he wishes to [exit this function and return to the Main Screen : Return to Main].
28. **C[IP]** The [sdr MPS] displays to the [rcr Pilot] the [msg Main Screen].



(continued over page)

'MSC: Retrieve from Cartridge - Pilot Retrieves Subset of Data'



'MSC: Retrieve from Cartridge - Pilot Retrieves Subset of Data (continued)'

Use Case : Choose Mission and Aircraft

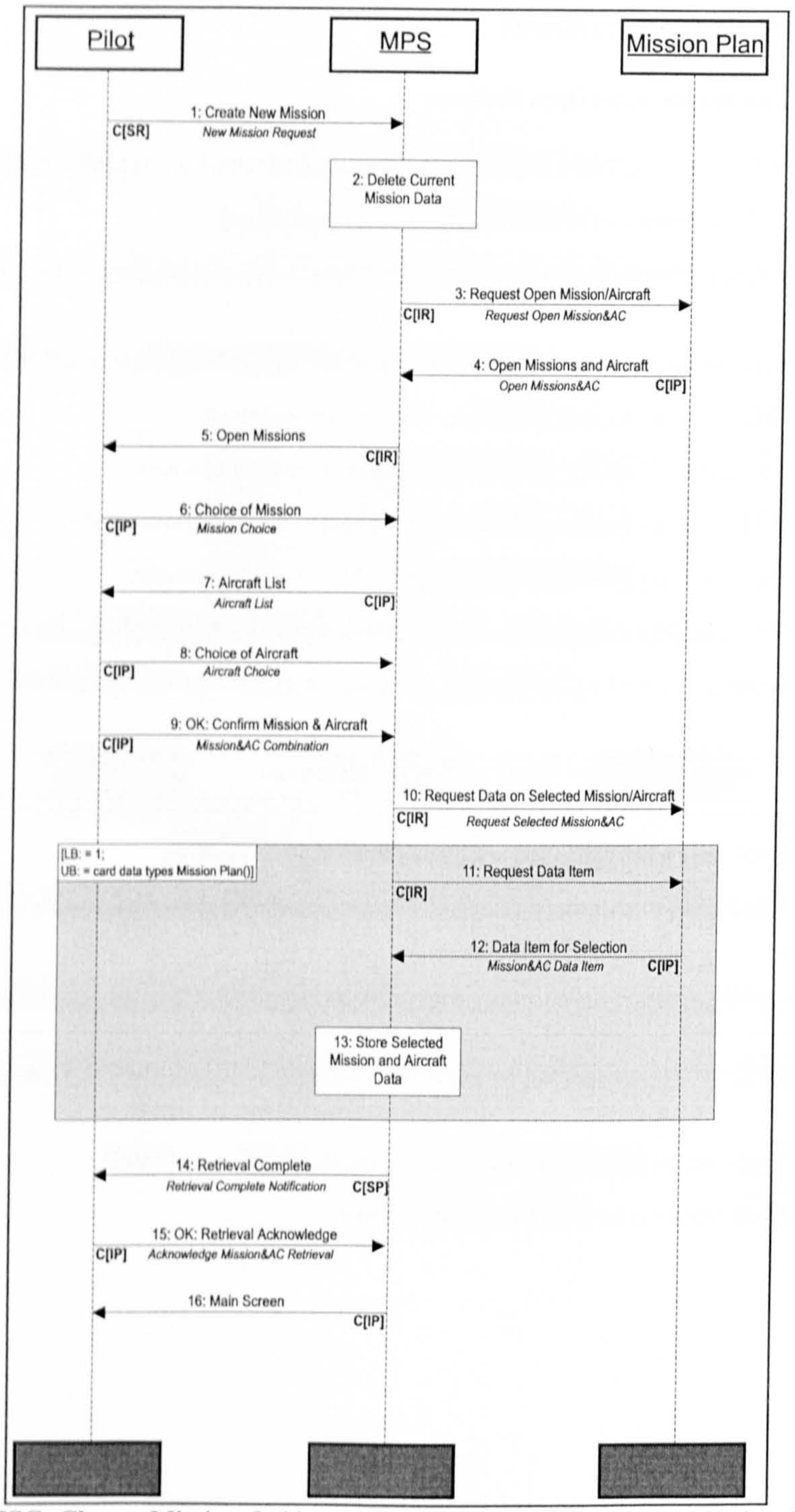
Scenario Name: New Mission From Open Missions

1. **C[SR]** The [sdr Pilot] selects the [msg Create A New Mission : New Mission Request] option from the [rcr MPS] Main Screen.
2. **A** The [sdr/rcr MPS] [act deletes data for existing Missions : Delete Current Mission Data].
3. **C[IR]** The [sdr MPS] [msg requests open Missions and associated Aircraft : Request Open Mission&AC] from the [rcr Mission Plan].
4. **C[IP]** The [sdr Mission Plan] supplies the [msg open Mission and Aircraft data: Open Mission&AC] to the [rcr MPS].
5. **C[IR]** The [sdr MPS] displays the [msg open Missions] for the [rcr Pilot] to select from.
6. **C[IP]** The [sdr Pilot] selects a [msg Mission of interest : Mission Choice] from the [rcr MPS] screen.
7. **C[IP]** The [sdr MPS] displays the [list of associated Aircraft : Aircraft List] for the [rcr Pilot] to select from.
8. **C[IP]** The [sdr Pilot] selects an [msg Aircraft of interest : Aircraft Choice] from the [rcr MPS] screen.
9. **C[IP]** The [sdr Pilot] [msg confirms the selected combination of Mission and Aircraft : Mission&AC Combination] to the [rcr MPS].
10. **C[IR]** The [sdr MPS] requests that the [rcr Mission Plan] supply [msg data for the selected Mission and Aircraft : Request Selected Mission&AC].

ITERATION: **Lower Bound = 1 : Upper Bound = *card* data types MissionPlan()**

11. **C[IR]** The [sdr MPS] asks the [rcr Mission Plan] to [msg supply a data item : Request Data Item].
12. **C[IP]** The [sdr Mission Plan] supplies the [msg data item for the selected Mission and Aircraft : Mission&AC Data Item] to the [rcr MPS].
13. **A** The [sdr/rcr MPS] [act stores the data item for the selected Mission and Aircraft : Store Selected Mission&AC Data].

14. **C[SP]** The [sdr MPS] indicates to the [rcr Pilot] that [msg all data has been retrieved from the Mission Plan : Mission&AC Retrieval Complete].
15. **C[IP]** The [sdr Pilot] sends an [msg acknowledgment : Acknowledge Mission&AC Retrieval] to the [rcr MPS].
16. **C[IP]** The [sdr MPS] displays to the [rcr Pilot] the [msg Main Screen].



'MSC: Choose Mission & Aircraft - New Mission From Open Missions'

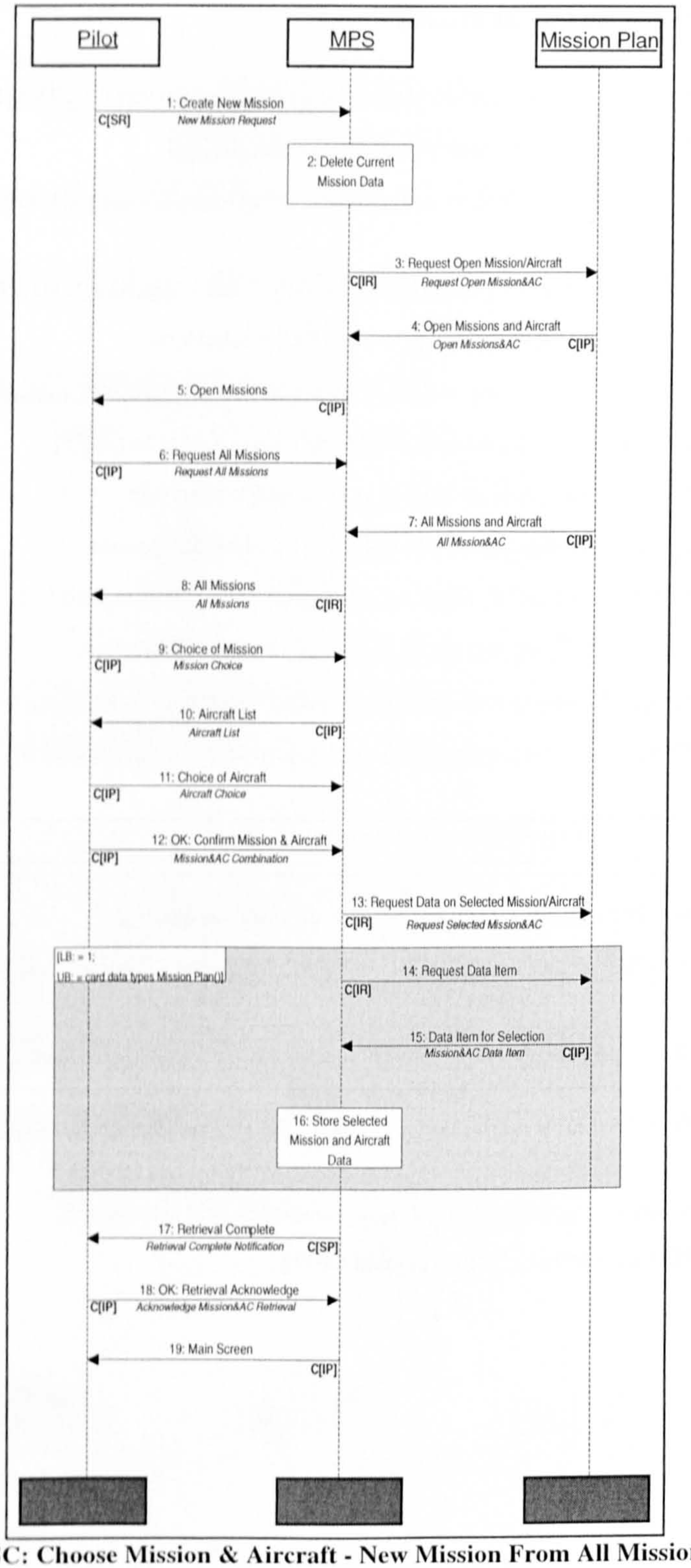
Scenario Name: New Mission From All Missions

1. **C[SR]** The [sdr Pilot] selects the [msg Create A New Mission : New Mission Request] option from the [rcr MPS] Main Screen.
2. **A** The [sdr/rcr MPS] [act deletes data for existing Missions : Delete Current Mission Data].
3. **C[IR]** The [sdr MPS] [msg requests open Missions and associated Aircraft : Request Open Mission&AC] from the [rcr Mission Plan].
4. **C[IP]** The [sdr Mission Plan] supplies the [msg open Mission and Aircraft data: Open Mission&AC] to the [rcr MPS].
5. **C[IP]** The [sdr MPS] displays the [msg open Missions] for the [rcr Pilot] to select from.
6. **C[IP]** The [sdr Pilot] asks the [rcr MPS] to display [msg all Missions stored in the Mission Plan : Request All Missions].
7. **C[IP]** The [sdr Mission Plan] supplies [msg all Missions and Aircraft : All Mission&AC] to the [rcr MPS].
8. **C[IR]** The [sdr MPS] displays [msg all Missions : All Missions] for the [rcr Pilot] to select from.
9. **C[IP]** The [sdr Pilot] selects a [msg Mission of interest : Mission Choice] from the [rcr MPS] screen.
10. **C[IP]** The [sdr MPS] displays the [list of associated Aircraft : Aircraft List] for the [rcr Pilot] to select from.
11. **C[IP]** The [sdr Pilot] selects an [msg Aircraft of interest : Aircraft Choice] from the [rcr MPS] screen .
12. **C[IP]** The [sdr Pilot] [msg confirms the selected combination of Mission and Aircraft : Mission&AC Combination] to the [rcr MPS].
13. **C[IR]** The [sdr MPS] requests that the [rcr Mission Plan] supply [msg data for the selected Mission and Aircraft : Request Selected Mission&AC].

ITERATION: **Lower Bound = 1 : Upper Bound = *card* data types MissionPlan()**

14. **C[IR]** The [sdr MPS] asks the [rcr Mission Plan] to [msg supply a data item : Request Data Item].
15. **C[IP]** The [sdr Mission Plan] supplies the [msg data item for the selected Mission and Aircraft : Mission&AC Data Item] to the [rcr MPS].
16. **A** The [sdr/rcr MPS] [act stores the data item for the selected Mission and Aircraft : Store Selected Mission&AC Data].

17. **C[SP]** The [sdr MPS] indicates to the [rcr Pilot] that [msg all data has been retrieved from the Mission Plan : Mission&AC Retrieval Complete].
18. **C[IP]** The [sdr Pilot] sends an [msg acknowledgment : Acknowledge Mission&AC Retrieval] to the [rcr MPS].
19. **C[IP]** The [sdr MPS] displays to the [rcr Pilot] the [msg Main Screen].



'MSC: Choose Mission & Aircraft - New Mission From All Missions'

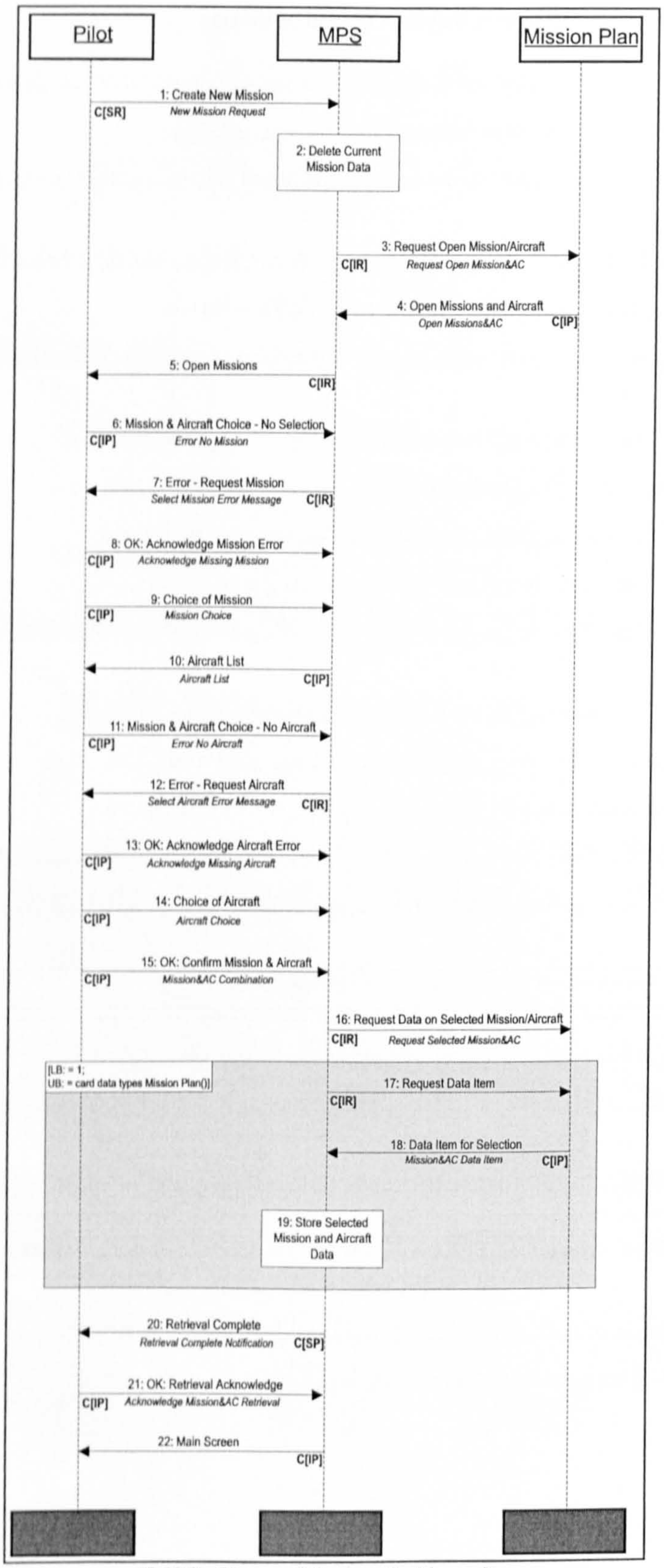
Scenario Name: Pilot Does Not Initially Select an Aircraft or Mission

1. **C[SR]** The [sdr Pilot] selects the [msg Create A New Mission : New Mission Request] option from the [rcr MPS] Main Screen.
2. **A** The [sdr/rcr MPS] [act deletes data for existing Missions : Delete Current Mission Data].
3. **C[IR]** The [sdr MPS] [msg requests open Missions and associated Aircraft : Request Open Mission&AC] from the [rcr Mission Plan].
4. **C[IP]** The [sdr Mission Plan] supplies the [msg open Mission and Aircraft data: Open Mission&AC] to the [rcr MPS].
5. **C[IR]** The [sdr MPS] displays the [msg open Missions] for the [rcr Pilot] to select from.
6. **C[IP]** The [sdr Pilot] [msg confirms the selected combination of Mission and Aircraft - without selecting Mission or aircraft : Error No Mission] to the [rcr MPS].
7. **C[IR]** The [rcr MPS] informs the [rcr Pilot] that [msg a Mission must be selected : Select Mission Error Message].
8. **C[IP]** The [sdr Pilot] sends an [msg acknowledgement : Acknowledge Missing Mission] to the [rcr MPS].
9. **C[IP]** The [sdr Pilot] selects a [msg Mission of interest : Mission Choice] from the [rcr MPS] screen.
10. **C[IP]** The [sdr MPS] displays the [list of associated Aircraft : Aircraft List] to the [rcr Pilot].
11. **C[IP]** The [sdr Pilot] [msg confirms the selected combination of Mission and Aircraft - without selecting aircraft : Error No Aircraft] to the [rcr MPS].
12. **C[IR]** The [rcr MPS] informs the [rcr Pilot] that [msg an Aircraft must be selected : Select Aircraft Error Message].
13. **C[IP]** The [sdr Pilot] sends an [msg acknowledgement : Acknowledge Missing Aircraft] to the [rcr MPS].
14. **C[IP]** The [sdr Pilot] selects an [msg Aircraft of interest : Aircraft Choice] from the [rcr MPS] screen.
15. **C[IP]** The [sdr Pilot] [msg confirms the selected combination of Mission and Aircraft : Mission&AC Combination] to the [rcr MPS].
16. **C[IR]** The [sdr MPS] requests that the [rcr Mission Plan] supply [msg data for the selected Mission and Aircraft : Request Selected Mission&AC].

ITERATION: **Lower Bound = 1 : Upper Bound = *card* data types MissionPlan()**

17. **C[IR]** The [sdr MPS] asks the [rcr Mission Plan] to [msg supply a data item : Request Data Item].
18. **C[IP]** The [sdr Mission Plan] supplies the [msg data item for the selected Mission and Aircraft : Mission&AC Data Item] to the [rcr MPS].
19. **A** The [sdr/rcr MPS] [act stores the data item for the selected Mission and Aircraft : Store Selected Mission&AC Data].

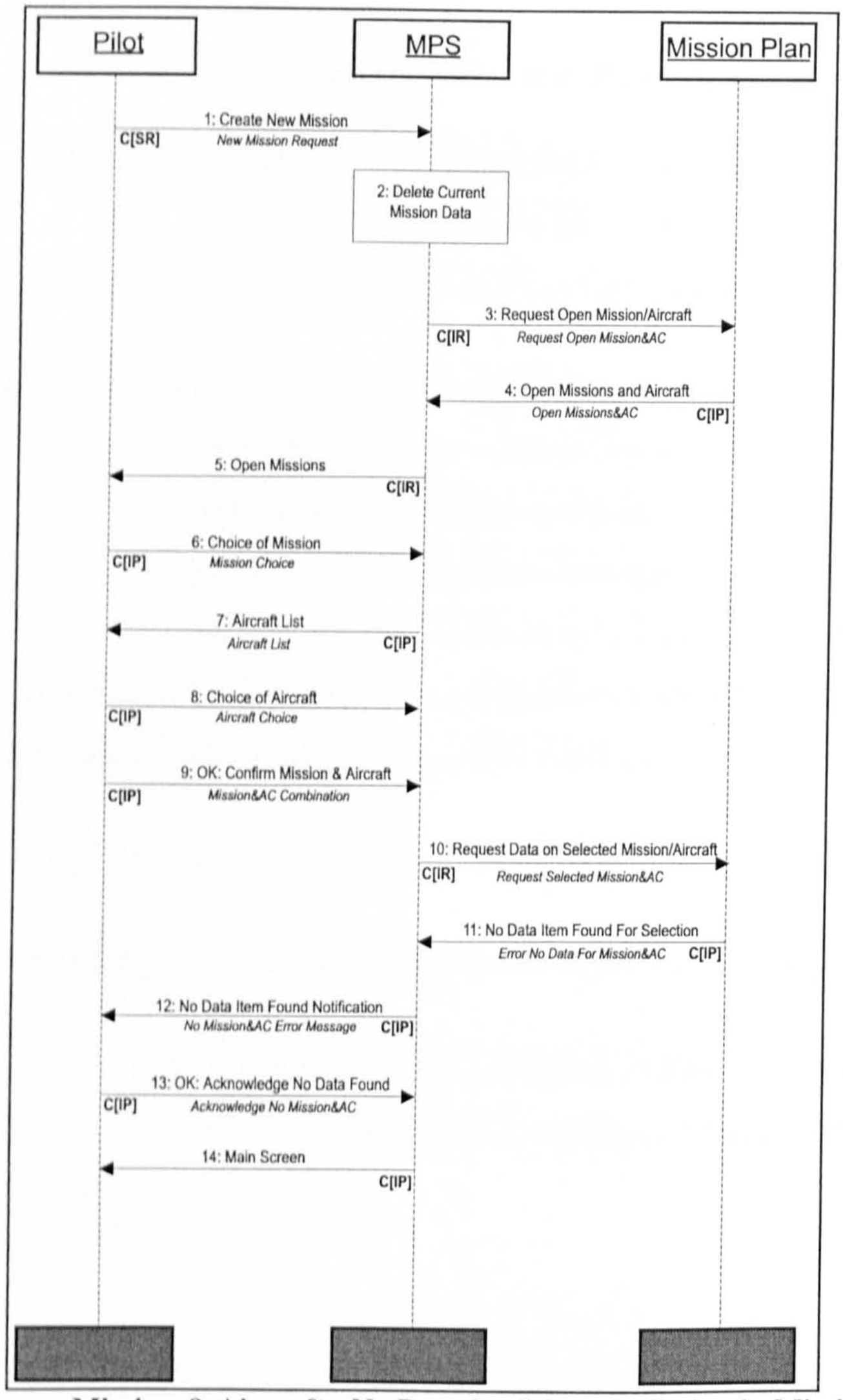
20. **C[SP]** The [sdr MPS] indicates to the [rcr Pilot] that [msg all data has been retrieved from the Mission Plan : Mission&AC Retrieval Complete].
21. **C[IP]** The [sdr Pilot] sends an [msg acknowledgment : Acknowledge Mission&AC Retrieval] to the [rcr MPS].
22. **C[IP]** The [sdr MPS] displays to the [rcr Pilot] the [msg Main Screen].



'MSC: Choose Mission & Aircraft -
Pilot Does Not Initially Select Aircraft or Mission'

Scenario Name: No Data for Selected Mission in Mission Plan

1. **C[SR]** The [sdr Pilot] selects the [msg Create A New Mission : New Mission Request] option from the [rcr MPS] Main Screen.
2. **A** The [sdr/rcr MPS] [act deletes data for existing Missions : Delete Current Mission Data].
3. **C[IR]** The [sdr MPS] [msg requests open Missions and associated Aircraft : Request Open Mission&AC] from the [rcr Mission Plan].
4. **C[IP]** The [sdr Mission Plan] supplies the [msg open Mission and Aircraft data: Open Mission&AC] to the [rcr MPS].
5. **C[IR]** The [sdr MPS] displays the [msg open Missions] for the [rcr Pilot] to select from.
6. **C[IP]** The [sdr Pilot] selects a [msg Mission of interest : Mission Choice] from the [rcr MPS] screen.
7. **C[IP]** The [sdr MPS] displays the [list of associated Aircraft : Aircraft List] to the [rcr Pilot].
8. **C[IP]** The [sdr Pilot] requests an [msg Aircraft of interest : Aircraft Choice] from the [rcr MPS] screen.
9. **C[IP]** The [sdr Pilot] [msg confirms the selected combination of Mission and Aircraft : Mission&AC Combination] to the [rcr MPS].
10. **C[IR]** The [sdr MPS] requests that the [rcr Mission Plan] supply [msg data for the selected Mission and Aircraft : Request Selected Mission&AC].
11. **C[IP]** The [sdr Mission Plan] indicates to the [rcr MPS] that it has [msg no data for the selected Mission and Aircraft : Error No Data For Misson&AC].
12. **C[IP]** The [sdr MPS] indicates to the [rcr Pilot] that it has [msg no data for the selected Mission and Aircraft : No Mission&AC Error Message].
13. **C[IP]** The [sdr Pilot] sends an [msg acknowledgment : Acknowledge No Mission&AC] to the [rcr MPS].
14. **C[IP]** The [sdr MPS] displays to the [rcr Pilot] the [msg Main Screen].

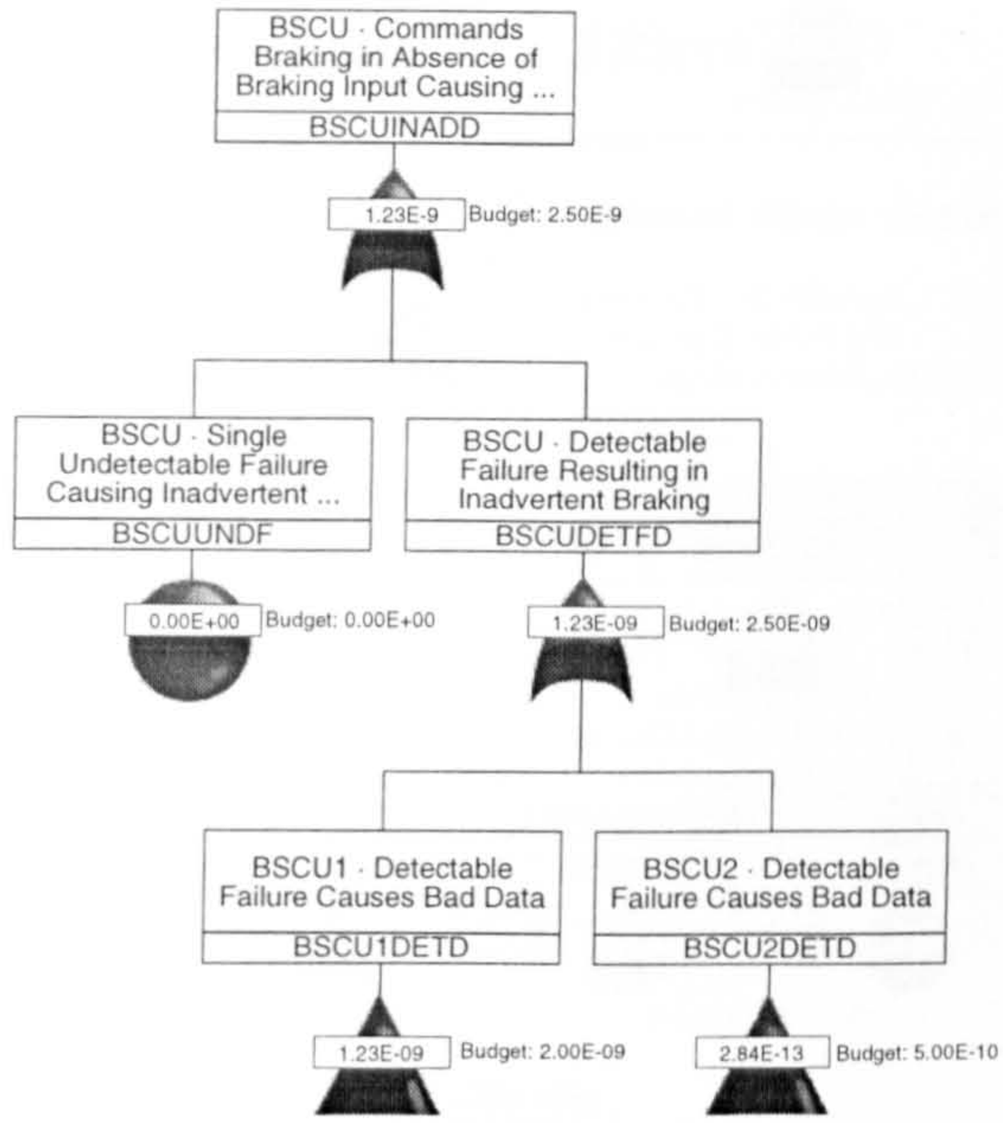


'MSC: Choose Mission & Aircraft - No Data for Selected Mission in Mission Plan'

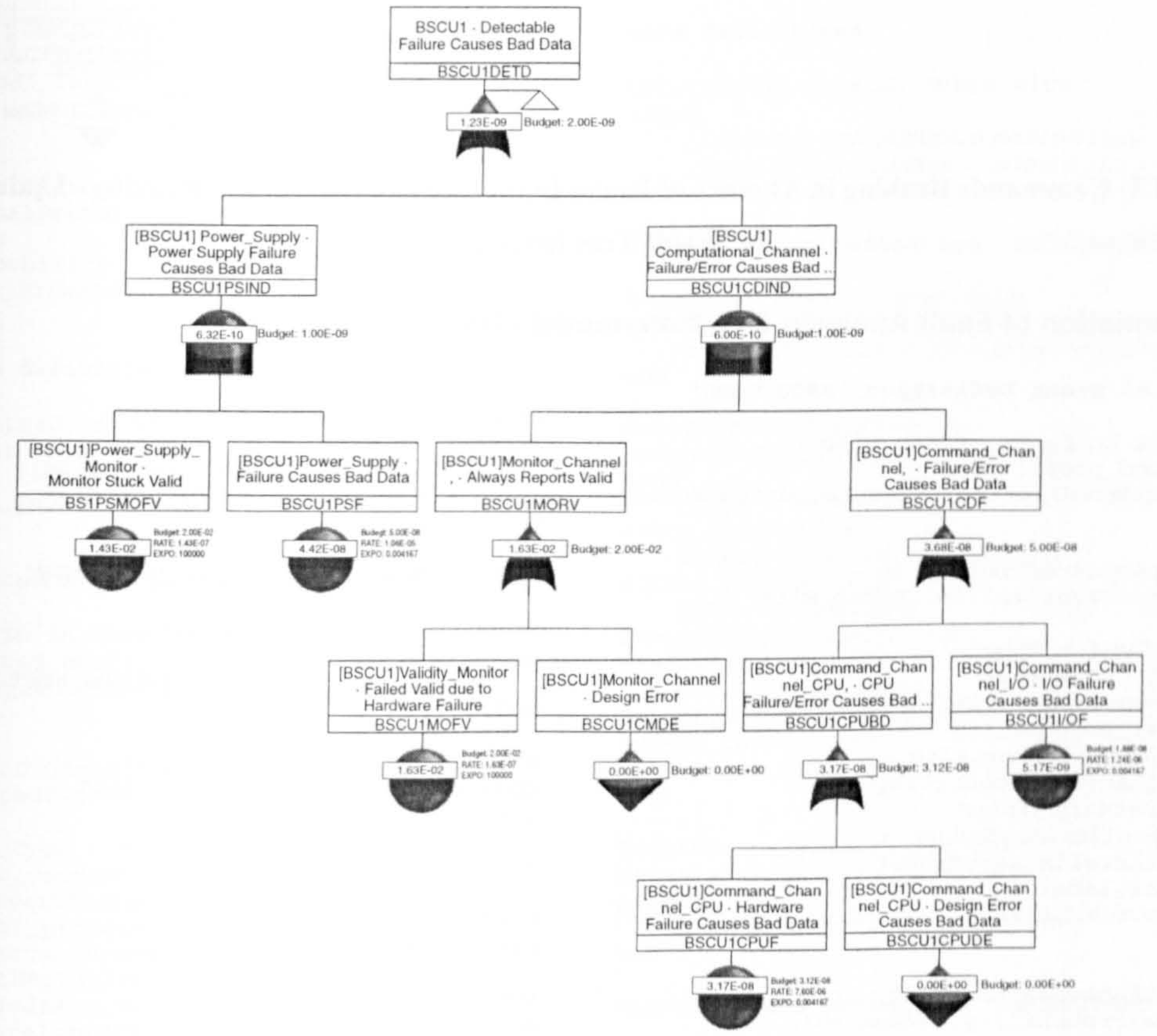
Appendix - D

This page deliberately left blank

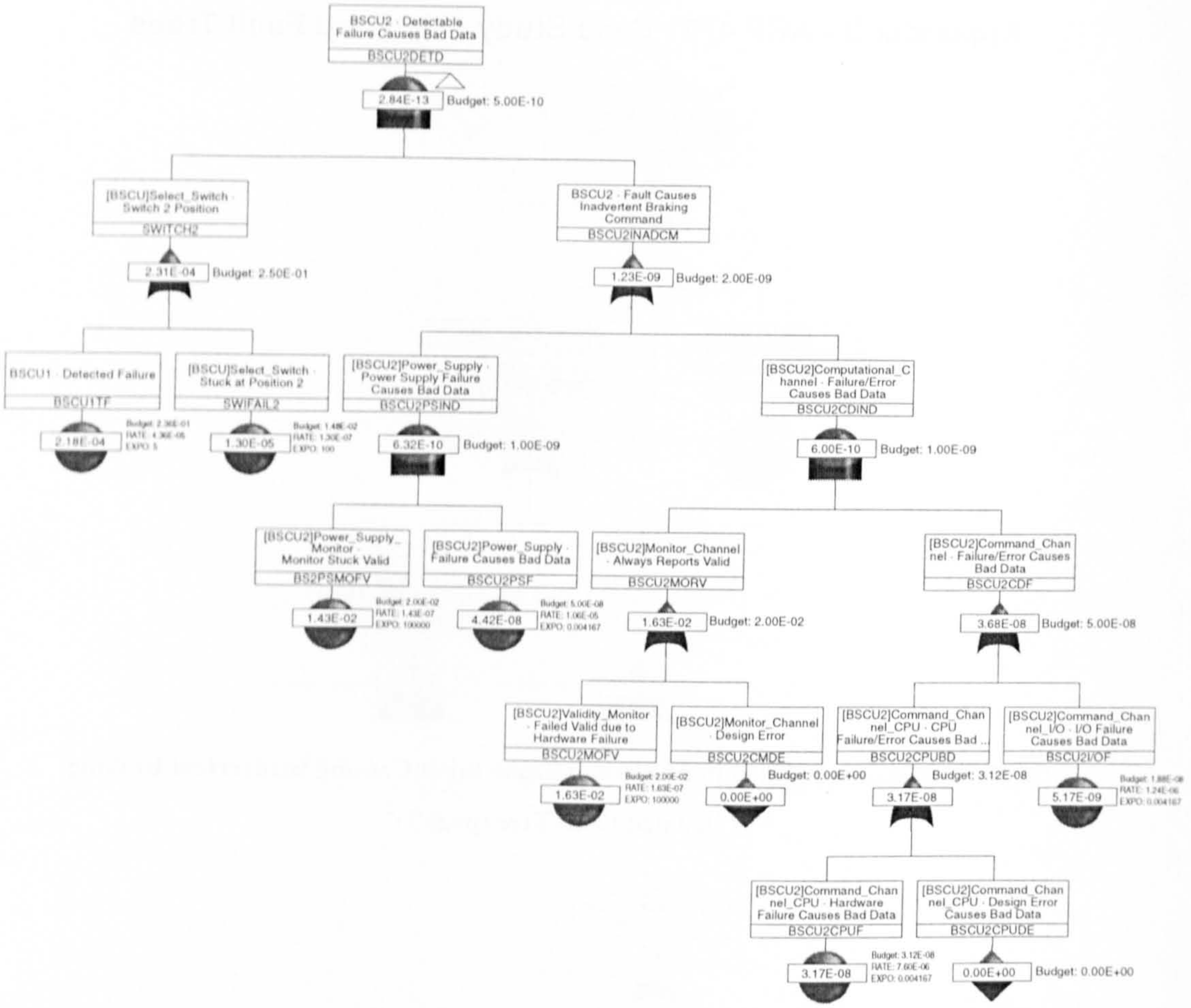
Appendix D - ARP 4761 Case Study : Updated Fault Trees



'BSCU Commands Braking in Absence of Brake Input Causing Inadvertent Braking - Updated Fault Tree (page 1)'



'BSCU Commands Braking in Absence of Brake Input Causing Inadvertent Braking - Updated Fault Tree (page 2)'



'BSCU Commands Braking in Absence of Brake Input Causing Inadvertent Braking - Updated Fault Tree (page 3)'

Instantiation of Fault Analysis Tree Meta-model - Updated Fault Tree

Updated Event Definition 'BSCUINADD'

```
EventA in Event, Token with
updated_profile
    updatedProfile : EventAUpdatedProfile
end

EventAUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "top"
event_connective
    eventConnective : OrGate1U
actual_probability
    actualProbability :
EventAActualProbability
preliminary_budget
    preliminaryBudget :
EventAPreliminaryBudget
actual_label
    actualLabel : EventAPreliminaryLabel
end

EventAActualProbability in
ActualProbability, Token with
probability
    _Probability : 1.23E-09
end
```

Gate definitions

```
OrGate1U in OrGate, Token with
input
    _Input1 : EventBUpdatedProfile;
    _Input2 : EventCUpdatedProfile
end
```

Updated Event Definition 'BSCUUNDF'

```
EventB in Event, Token with
updated_profile
    updatedProfile : EventBUpdatedProfile
end

EventBUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "bas"
actual_probability
    actualProbability :
EventBActualProbability
preliminary_budget
    preliminaryBudget :
EventBPreliminaryBudget
actual_label
    actualLabel : EventBActualLabel
end

EventBActualProbability in
ActualProbability, Token with
```

```
probability
    _Probability : 0.00E+00
end

EventBActualLabel in SimpleLabel, Token
with
simple_description
    simpleDescription :
EventBActualSimpleEventDescription
end

EventBActualSimpleEventDescription in
SimpleEventDescription, Token
with
entity
    _Entity : "BSCU"
condition
    _Condition : "Single Undetectable
Failure Causing Inadvertent Braking"
end
```

Updated Event Definition 'BSCUDETFD'

```
EventC in Event, Token with
updated_profile
    updatedProfile : EventCUpdatedProfile
end

EventCUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    eventConnective : OrGate2U
actual_probability
    actualProbability :
EventCActualProbability
preliminary_budget
    preliminaryBudget :
EventCPreliminaryBudget
actual_label
    actualLabel : EventCPreliminaryLabel
end

EventCActualProbability in
ActualProbability, Token
with
probability
    _Probability : 1.23E-09
end
```

Gate definitions

```
OrGate2U in OrGate, Token with
input
    _Input1 : EventDUpdatedProfile;
    _Input2 : EventEUpdatedProfile
end
```

Updated Event Definition 'BSCU1DETD'

```
EventD in Event, Token with
updated_profile
    updatedProfile : EventDUpdatedProfile
end

EventDUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : OrGate3U
actual_probability
    actualProbability :
EventDActualProbability
preliminary_budget
    preliminaryBudget :
EventDPreliminaryBudget
actual_label
    actualLabel : EventDPreliminaryLabel
end

EventDActualProbability in
ActualProbability, Token
with
probability
    _Probability : 1.23E-09
end
```

Updated Event Definition 'BSCU2DETD'

```
EventE in Event, Token with
updated_profile
    updatedProfile : EventEUpdatedProfile
end

EventEUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : AndGate3U
actual_probability
    actualProbability :
EventEActualProbability
preliminary_budget
    preliminaryBudget :
EventEPreliminaryBudget
actual_label
    actualLabel : EventEPreliminaryLabel
end

EventEActualProbability in
ActualProbability, Token
with
probability
    _Probability : 2.84E-13
end
```

Gate definitions

```
OrGate3U in OrGate, Token with
input
    _Input1 : EventFUpdatedProfile;
    _Input2 : EventGUpdatedProfile
end
```

Updated Event Definition 'BSCU1PSIND'

```
EventF in Event, Token with
updated_profile
    updatedProfile : EventFUpdatedProfile
end

EventFUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : AndGate1U
actual_probability
    actualProbability :
EventFActualProbability
preliminary_budget
    preliminaryBudget :
EventFPreliminaryBudget
actual_label
    actualLabel : EventFPreliminaryLabel
end

EventFActualProbability in
ActualProbability, Token with
probability
    _Probability : 6.32E-10
end
```

Updated Event Definition 'BSCU1CDIND'

```
EventG in Event, Token with
updated_profile
    updatedProfile : EventGUpdatedProfile
end
```

```
EventCUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : AndGate2U
actual_probability
    actualProbability :
EventGActualProbability
preliminary_budget
    preliminaryBudget :
EventGPreliminaryBudget
actual_label
    actualLabel : EventGPreliminaryLabel
end

EventGActualProbability in
ActualProbability, Token with
probability
    _Probability : 6.00E-10
end

Gate definitions

AndGate1U in AndGate, Token with
input
    _Input : HIEventSetU
end

AndGate2U in AndGate, Token with
input
    _Input : JKEventSetU
end

HIEventSetU in EventSet, Token with
event_profile
    eventProfile1 : EventHUpdatedProfile;
    eventProfile2 : EventIUpdatedProfile
end

JKEventSetU in EventSet, Token with
event_profile
    eventProfile1 : EventJUpdatedProfile;
    eventProfile2 : EventKUpdatedProfile
end

Updated Event Definition 'BS1PSMOFV'

EventH in Event, Token with
updated_profile
    updatedProfile : EventHUpdatedProfile
end

EventHUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "bas"
actual_probability
    actualProbability :
EventHActualProbability
preliminary_budget
    preliminaryBudget :
EventHPreliminaryBudget
actual_rate
    actualRate : EventHActualRate
actual_exposure
    actualExposure :
EventHPreliminaryExposure
actual_label
    actualLabel : EventHPreliminaryLabel
end

EventHActualProbability in
ActualProbability, Token with
probability
    _Probability : 1.43E-02
end

EventHActualRate in Rate, Token with
failure_rate
    failureRate : 1.43E-07
end

Updated Event Definition 'BSCU1PSF'

EventI in Event, Token with
updated_profile
    updatedProfile : EventIUpdatedProfile
end

EventIUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "bas"
actual_probability
    actualProbability :
EventIActualProbability
preliminary_budget
    preliminaryBudget :
EventIPreliminaryBudget
actual_rate
    actualRate : EventIActualRate
actual_exposure
    actualExposure :
EventIPreliminaryExposure
actual_label
    actualLabel : EventIPreliminaryLabel
end

EventIActualProbability in
ActualProbability, Token with
probability
    _Probability : 4.42E-08
end

EventIActualRate in Rate, Token with
failure_rate
    failureRate : 1.06E-05
end

Updated Event Definition 'BSCU1MORV'

EventJ in Event, Token with
updated_profile
    updatedProfile : EventJUpdatedProfile
end

EventJUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    eventConnective : OrGate4U
actual_probability
    actualProbability :
EventJActualProbability
preliminary_budget
    preliminaryBudget :
EventJPreliminaryBudget
actual_label
    actualLabel : EventJPreliminaryLabel
end

EventJActualProbability in
ActualProbability, Token with
probability
    _Probability : 1.63E-02
end

Updated Event Definition 'BSCU1CDF'

EventK in Event, Token with
updated_profile
    updatedProfile : EventKUpdatedProfile
end

EventKUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    eventConnective : OrGate5U
```

```
actual_probability
    actualProbability :
EventKActualProbability
preliminary_budget
    preliminaryBudget :
EventKPreliminaryBudget
actual_label
    actualLabel : EventKPreliminaryLabel
end

EventKActualProbability in
ActualProbability, Token with
probability
    _Probability : 3.68E-08
end
```

Gate definitions

```
OrGate4U in OrGate, Token with
input
    _Input1 : EventLUpdatedProfile;
    _Input2 : EventMUpdatedProfile
end

OrGate5U in OrGate, Token with
input
    _Input1 : EventNUpdatedProfile;
    _Input2 : EventOUpdatedProfile
end
```

Updated Event Definition 'BSCU1MOFV'

```
EventL in Event, Token with
updated_profile
    updatedProfile : EventLUpdatedProfile
end

EventLUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "bas"
actual_probability
    actualProbability :
EventLActualProbability
preliminary_budget
    preliminaryBudget :
EventLPreliminaryBudget
actual_rate
    actualRate : EventLActualRate
actual_exposure
    actualExposure :
EventLPreliminaryExposure
actual_label
    actualLabel : EventLPreliminaryLabel
end

EventLActualProbability in
ActualProbability, Token with
probability
    _Probability : 1.63E-02
end

EventLActualRate in Rate, Token with
failure_rate
    failureRate : 1.63E-07
end
```

Updated Event Definition 'BSCU1CMDE'

```
EventM in Event, Token with
updated_profile
    updatedProfile : EventMUpdatedProfile
end

EventMUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "und"
actual_probability
    actualProbability :
EventMActualProbability
preliminary_budget
    preliminaryBudget :
EventMPreliminaryBudget
actual_label
    actualLabel : EventMPreliminaryLabel
end

EventMActualProbability in
ActualProbability, Token with
probability
    _Probability : 0.00E+00
end
```

Updated Event Definition 'BSCU1CPUBD'

```
EventN in Event, Token with
updated_profile
    updatedProfile : EventNUpdatedProfile
end

EventNUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    eventConnective : OrGate6U
actual_probability
    actualProbability :
EventNActualProbability
preliminary_budget
    preliminaryBudget :
EventNPreliminaryBudget
actual_label
    actualLabel : EventNPreliminaryLabel
end

EventNActualProbability in
ActualProbability, Token with
probability
    _Probability : 3.17E-08
end
```

Updated Event Definition 'BSCU1I/OF'

```
EventO in Event, Token with
updated_profile
    updatedProfile : EventOUpdatedProfile
end

EventOUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "bas"
actual_probability
    actualProbability :
EventOActualProbability
preliminary_budget
    preliminaryBudget :
EventOPreliminaryBudget
actual_rate
    actualRate : EventOActualRate
actual_exposure
    actualExposure :
EventOPreliminaryExposure
actual_label
    actualLabel : EventOPreliminaryLabel
end

EventOActualProbability in
ActualProbability, Token with
probability
    _Probability : 5.17E-09
end

EventOActualRate in Rate, Token with
failure_rate
    failureRate : 1.24E-06
end
```

Gate definitions

```
OrGate6U in OrGate, Token with
input
    _Input1 : EventPUpdatedProfile;
    _Input2 : EventQUpdatedProfile
end

Updated Event Definition 'BSCU1CPUF'

EventP in Event, Token with
updated_profile
    updatedProfile : EventPUpdatedProfile
end

EventPUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "bas"
actual_probability
    actualProbability :
EventPActualProbability
preliminary_budget
    preliminaryBudget :
EventPPreliminaryBudget
actual_rate
    actualRate : EventPActualRate
actual_exposure
    actualExposure :
EventPPreliminaryExposure
actual_label
    actualLabel : EventPPreliminaryLabel
end

EventPActualProbability in
ActualProbability, Token with
probability
    _Probability : 3.17E-08
end

EventPActualRate in Rate, Token with
failure_rate
    failureRate : 7.60E-06
end

Updated Event Definition 'BSCU1CPUDE'

EventQ in Event, Token with
updated_profile
    updatedProfile : EventQUpdatedProfile
end

EventQUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "und"
actual_probability
    actualProbability :
EventQActualProbability
preliminary_budget
    preliminaryBudget :
EventQPreliminaryBudget
actual_label
    actualLabel : EventQPreliminaryLabel
end

EventQActualProbability in
ActualProbability, Token with
probability
    _Probability : 0.00E+00
end

Gate definitions

AndGate3U in AndGate, Token with
input
    _Input : RSEventSetU
end

RSEventSetU in EventSet, Token with
event_profile
    eventProfile1 : EventRUpdatedProfile;
    eventProfile2 : EventSUpdatedProfile
end

Updated Event Definition 'SWITCH2'

EventR in Event, Token with
updated_profile
    updatedProfile : EventRUpdatedProfile
end

EventRUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : OrGate7U
actual_probability
    actualProbability :
EventRActualProbability
preliminary_budget
    preliminaryBudget :
EventRPreliminaryBudget
actual_label
    actualLabel : EventRPreliminaryLabel
end

EventRActualProbability in
ActualProbability, Token with
probability
    _Probability : 2.31E-4
end

Updated Event Definition 'BSCU2INADCM'

EventS in Event, Token with
updated_profile
    updatedProfile : EventSUpdatedProfile
end

EventSUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : OrGate8U
actual_probability
    actualProbability :
EventSActualProbability
preliminary_budget
    preliminaryBudget :
EventSPreliminaryBudget
actual_label
    actualLabel : EventSPreliminaryLabel
end

EventSActualProbability in
ActualProbability, Token with
probability
    _Probability : 1.23E-9
end

Gate definitions

OrGate7U in OrGate, Token with
input
    _Input1 : EventTUpdatedProfile;
    _Input2 : EventUUpdatedProfile
end

OrGate8U in OrGate, Token with
input
    _Input1 : EventVUpdatedProfile;
    _Input2 : EventWUpdatedProfile
end

Updated Event Definition 'BSCU1TF'

EventT in Event, Token with
updated_profile
    updatedProfile : EventTUpdatedProfile
end
```

```
EventTUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "bas"
actual_probability
    actualProbability :
EventTActualProbability
preliminary_budget
    preliminaryBudget :
EventTPreliminaryBudget
actual_rate
    actualRate : EventTActualRate
actual_exposure
    actualExposure :
EventTPreliminaryExposure
actual_label
    actualLabel : EventTPreliminaryLabel
end

EventTActualProbability in
ActualProbability, Token with
probability
    _Probability : 2.18E-04
end

EventTActualRate in Rate, Token with
failure_rate
    failureRate : 4.36E-05
end
```

Updated Event Definition 'SWIFAIL2'

```
EventU in Event, Token with
updated_profile
    updatedProfile : EventUUpdatedProfile
end

EventUUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "bas"
actual_probability
    actualProbability :
EventUActualProbability
preliminary_budget
    preliminaryBudget :
EventUPreliminaryBudget
actual_rate
    actualRate : EventUActualRate
actual_exposure
    actualExposure : EventUActualExposure
actual_label
    actualLabel : EventUPreliminaryLabel
end

EventUActualProbability in
ActualProbability, Token with
probability
    _Probability : 1.30E-05
end

EventUActualRate in Rate, Token with
failure_rate
    failureRate : 1.30E-07
end

EventUActualExposure in Exposure, Token
with
period
    _Period : 100.00
end
```

Updated Event Definition 'BSCU2PSIND'

```
EventV in Event, Token with
updated_profile
    updatedProfile : EventVUpdatedProfile
end

EventVUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : AndGate4U
actual_probability
    actualProbability :
EventVActualProbability
preliminary_budget
    preliminaryBudget :
EventVPreliminaryBudget
actual_label
    actualLabel : EventVPreliminaryLabel
end

EventVActualProbability in
ActualProbability, Token with
probability
    _Probability : 6.32E-10
end
```

Updated Event Definition 'BSCU2CDIND'

```
EventW in Event, Token with
updated_profile
    updatedProfile : EventWUpdatedProfile
end

EventWUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : AndGate5U
actual_probability
    actualProbability :
EventWActualProbability
preliminary_budget
    preliminaryBudget :
EventWPreliminaryBudget
actual_label
    actualLabel : EventWPreliminaryLabel
end

EventWActualProbability in
ActualProbability, Token with
probability
    _Probability : 6.00E-10
end
```

Gate definitions

```
AndGate4U in AndGate, Token with
input
    _Input : XYEventSetU
end

XYEventSetU in EventSet, Token with
event_profile
    eventProfile1 : EventXUpdatedProfile;
    eventProfile2 : EventYUpdatedProfile
end

AndGate5U in AndGate, Token with
input
    _Input : ZAAEventSetU
end

ZAAEventSetU in EventSet, Token with
event_profile
    eventProfile1 : EventZUpdatedProfile;
    eventProfile2 : EventAAUpdatedProfile
end
```

Updated Event Definition 'BS2PSMOFV'

```
EventX in Event, Token with
updated_profile
    updatedProfile : EventXUpdatedProfile
end

EventXUpdatedProfile in
```

```
UpdatedEventProfile, Token with
type
    _Type : "bas"
actual_probability
    actualProbability :
EventXActualProbability
preliminary_budget
    preliminaryBudget :
EventXPreliminaryBudget
actual_rate
    actualRate : EventXActualRate
actual_exposure
    actualExposure :
EventXPreliminaryExposure
actual_label
    actualLabel : EventXPreliminaryLabel
end

EventXActualProbability in
ActualProbability, Token with
probability
    _Probability : 1.43E-02
end

EventXActualRate in Rate, Token with
failure_rate
    failureRate : 1.43E-07
end
```

Updated Event Definition 'BSCU2PSF'

```
EventY in Event, Token with
updated_profile
    updatedProfile : EventYUpdatedProfile
end

EventYUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "bas"
actual_probability
    actualProbability :
EventYActualProbability
preliminary_budget
    preliminaryBudget :
EventYPreliminaryBudget
actual_rate
    actualRate : EventYActualRate
actual_exposure
    actualExposure :
EventYPreliminaryExposure
actual_label
    actualLabel : EventYPreliminaryLabel
end

EventYActualProbability in
ActualProbability, Token with
probability
    _Probability : 4.42E-08
end

EventYActualRate in Rate, Token with
failure_rate
    failureRate : 1.06E-05
end
```

Updated Event Definition 'BSCU2MORV'

```
EventZ in Event, Token with
updated_profile
    updatedProfile : EventZUpdatedProfile
end

EventZUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : OrGate9U
actual_probability
    actualProbability :
EventZActualProbability
preliminary_budget
    preliminaryBudget :
EventZPreliminaryBudget
actual_label
    actualLabel : EventZPreliminaryLabel
end

EventZActualProbability in
ActualProbability, Token with
probability
    _Probability : 1.63E-02
end
```

Updated Event Definition 'BSCU2CDF'

```
EventAA in Event, Token with
updated_profile
    updatedProfile :
EventAAUpdatedProfile
end

EventAAUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : OrGate10U
actual_probability
    actualProbability :
EventAAActualProbability
preliminary_budget
    preliminaryBudget :
EventAAPreliminaryBudget
actual_label
    actualLabel : EventAAPreliminaryLabel
end

EventAAActualProbability in
ActualProbability, Token with
probability
    _Probability : 3.68E-08
end
```

Gate definitions

```
OrGate9U in OrGate, Token with
input
    _Input1 : EventBBUpdatedProfile;
    _Input2 : EventCCUpdatedProfile
end

OrGate10U in OrGate, Token with
input
    _Input1 : EventDDUpdatedProfile;
    _Input2 : EventEEUpdatedProfile
end
```

Updated Event Definition 'BSCU2MOFV'

```
EventBB in Event, Token with
updated_profile
    updatedProfile :
EventBBUpdatedProfile
end

EventBBUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "bas"
actual_probability
    actualProbability :
EventBBActualProbability
preliminary_budget
    preliminaryBudget :
EventBBPreliminaryBudget
actual_rate
    actualRate : EventBBActualRate
actual_exposure
    actualExposure :
EventBBPreliminaryExposure
```

```
actual_label
    actualLabel : EventBBPreliminaryLabel
end

EventBBActualProbability in
ActualProbability, Token with
probability
    _Probability : 1.63E-02
end

EventBBActualRate in Rate, Token with
failure_rate
    failureRate : 1.63E-07
end
```

Updated Event Definition 'BSCU2CMDE'

```
EventCC in Event, Token with
updated_profile
    updatedProfile :
EventCCUpdatedProfile
end

EventCCUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "und"
actual_probability
    actualProbability :
EventCCActualProbability
preliminary_budget
    preliminaryBudget :
EventCCPreliminaryBudget
actual_label
    actualLabel : EventCCPreliminaryLabel
end

EventCCActualProbability in
ActualProbability, Token with
probability
    _Probability : 0.00E+00
end
```

Updated Event Definition 'BSCU2CPUBD'

```
EventDD in Event, Token with
updated_profile
    updatedProfile :
EventDDUpdatedProfile
end

EventDDUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "int"
event_connective
    EventConnective : OrGate11U
actual_probability
    actualProbability :
EventDDActualProbability
preliminary_budget
    preliminaryBudget :
EventDDPreliminaryBudget
actual_label
    actualLabel : EventDDPreliminaryLabel
end

EventDDActualProbability in
ActualProbability, Token with
probability
    _Probability : 3.17E-08
end
```

Updated Event Definition 'BSCU2I/OF'

```
EventEE in Event, Token with
updated_profile
    updatedProfile :
EventEEUpdatedProfile
end

EventEEUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "bas"
actual_probability
    actualProbability :
EventEEActualProbability
preliminary_budget
    preliminaryBudget :
EventEEPreliminaryBudget
actual_rate
    actualRate : EventEEActualRate
actual_exposure
    actualExposure :
EventEEPreliminaryExposure
actual_label
    actualLabel : EventEEPreliminaryLabel
end

EventEEActualProbability in
ActualProbability, Token with
probability
    _Probability : 5.17E-09
end

EventEEActualRate in Rate, Token with
failure_rate
    failureRate : 1.24E-06
end
```

Gate definitions

```
OrGate11U in OrGate, Token with
input
    _Input1 : EventFFUpdatedProfile;
    _Input2 : EventGGUpdatedProfile
end
```

Updated Event Definition 'BSCU2CPUF'

```
EventFF in Event, Token with
updated_profile
    updatedProfile :
EventFFUpdatedProfile
end

EventFFUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "bas"
actual_probability
    actualProbability :
EventFFActualProbability
preliminary_budget
    preliminaryBudget :
EventFFPreliminaryBudget
actual_rate
    actualRate : EventFFActualRate
actual_exposure
    actualExposure :
EventFFPreliminaryExposure
actual_label
    actualLabel : EventFFPreliminaryLabel
end

EventFFActualProbability in
ActualProbability, Token with
probability
    _Probability : 3.17E-08
end

EventFFActualRate in Rate, Token with
failure_rate
    failureRate : 7.60E-06
end
```

Updated Event Definition 'BSCU2CPUDE'

```
EventGG in Event, Token with
updated_profile
    updatedProfile :
```

```
EventGGUpdatedProfile
end

EventGGUpdatedProfile in
UpdatedEventProfile, Token with
type
    _Type : "und"
actual_probability
    actualProbability :
EventGGActualProbability
preliminary_budget
    preliminaryBudget :
EventGGPreliminaryBudget
actual_label
    actualLabel : EventGGPreliminaryLabel
end

EventGGActualProbability in
ActualProbability, Token with
probability
    _Probability : 0.00E+00
end

Instantiation of Updated Fault Tree

BscuSsaUpdatedFT in UpdatedFaultTree,
Token with
    ftAndGate1 : AndGate1U;
    ftAndGate2 : AndGate2U;
    ftAndGate3 : AndGate3U;
    ftAndGate4 : AndGate4U;
    ftAndGate5 : AndGate5U
ft_or_gate
    ftOrGate1 : OrGate1U;
    ftOrGate2 : OrGate2U;
    ftOrGate3 : OrGate3U;
    ftOrGate4 : OrGate4U;
    ftOrGate5 : OrGate5U;
    ftOrGate6 : OrGate6U;
    ftOrGate7 : OrGate7U;
    ftOrGate8 : OrGate8U;
    ftOrGate9 : OrGate9U;
    ftOrGate10 : OrGate10U;
    ftOrGate11 : OrGate11U
ft_event_set
    ftEventSet1 : HIEventSetU;
    ftEventSet2 : JKEventSetU;
    ftEventSet3 : RSEventSetU;
    ftEventSet4 : XYEventSetU;
    ftEventSet5 : ZAAEventSetU
ft_event_profile
    ftEventProfile1 :
EventAUpdatedProfile;
    ftEventProfile2 :
EventBUpdatedProfile;
    ftEventProfile3 :
EventCUpdatedProfile;
    ftEventProfile4 :
EventDUpdatedProfile;
    ftEventProfile5 :
EventEUpdatedProfile;
    ftEventProfile6 :
EventFUpdatedProfile;
    ftEventProfile7 :
EventGUpdatedProfile;
    ftEventProfile8 :
EventHUpdatedProfile;
    ftEventProfile9 :
EventIUpdatedProfile;
    ftEventProfile10 :
EventJUpdatedProfile;
    ftEventProfile11 :
EventKUpdatedProfile;
    ftEventProfile12 :
EventLUpdatedProfile;
    ftEventProfile13 :
EventMUpdatedProfile;
    ftEventProfile14 :
EventNUpdatedProfile;
    ftEventProfile15 :
EventOUpdatedProfile;
    ftEventProfile16 :
EventPUpdatedProfile;
    ftEventProfile17 :
EventQUpdatedProfile;
    ftEventProfile18 :
EventRUpdatedProfile;
    ftEventProfile19 :
EventSUpdatedProfile;
    ftEventProfile20 :
EventTUpdatedProfile;
    ftEventProfile21 :
EventUUpdatedProfile;
    ftEventProfile22 :
EventVUpdatedProfile;
    ftEventProfile23 :
EventWUpdatedProfile;
    ftEventProfile24 :
EventXUpdatedProfile;
    ftEventProfile25 :
EventYUpdatedProfile;
    ftEventProfile26 :
EventZUpdatedProfile;
    ftEventProfile27 :
EventAAUpdatedProfile;
    ftEventProfile28 :
EventBBUpdatedProfile;
    ftEventProfile29 :
EventCCUpdatedProfile;
    ftEventProfile30 :
EventDDUpdatedProfile;
    ftEventProfile31 :
EventEEUpdatedProfile;
    ftEventProfile32 :
EventFFUpdatedProfile;
    ftEventProfile33 :
EventGGUpdatedProfile
ft_budget
    ftBudget1 : EventAPreliminaryBudget;
    ftBudget2 : EventBPreliminaryBudget;
    ftBudget3 : EventCPreliminaryBudget;
    ftBudget4 : EventDPreliminaryBudget;
    ftBudget5 : EventEPreliminaryBudget;
    ftBudget6 : EventFPreliminaryBudget;
    ftBudget7 : EventGPreliminaryBudget;
    ftBudget8 : EventHPreliminaryBudget;
    ftBudget9 : EventIPreliminaryBudget;
    ftBudget10 : EventJPreliminaryBudget;
    ftBudget11 : EventKPreliminaryBudget;
    ftBudget12 : EventLPreliminaryBudget;
    ftBudget13 : EventMPreliminaryBudget;
    ftBudget14 : EventNPreliminaryBudget;
    ftBudget15 : EventOPreliminaryBudget;
    ftBudget16 : EventPPreliminaryBudget;
    ftBudget17 : EventQPreliminaryBudget;
    ftBudget18 : EventRPreliminaryBudget;
    ftBudget19 : EventSPreliminaryBudget;
    ftBudget20 : EventTPreliminaryBudget;
    ftBudget21 : EventUPreliminaryBudget;
    ftBudget22 : EventVPreliminaryBudget;
    ftBudget23 : EventWPreliminaryBudget;
    ftBudget24 : EventXPreliminaryBudget;
    ftBudget25 : EventYPreliminaryBudget;
    ftBudget26 : EventZPreliminaryBudget;
    ftBudget27 : EventAAPreliminaryBudget;
    ftBudget28 : EventBBPreliminaryBudget;
    ftBudget29 : EventCCPreliminaryBudget;
    ftBudget30 : EventDDPreliminaryBudget;
    ftBudget31 : EventEEPreliminaryBudget;
    ftBudget32 : EventFFPreliminaryBudget;
    ftBudget33 : EventGGPreliminaryBudget
ft_actual
    ftActual1 : EventAActualProbability;
    ftActual2 : EventBActualProbability;
    ftActual3 : EventCActualProbability;
    ftActual4 : EventDActualProbability;
    ftActual5 : EventEActualProbability;
    ftActual6 : EventFActualProbability;
    ftActual7 : EventGActualProbability;
    ftActual8 : EventHActualProbability;
    ftActual9 : EventIActualProbability;
    ftActual10 : EventJActualProbability;
```

```
    ftActual11 : EventKActualProbability;
    ftActual12 : EventLActualProbability;
    ftActual13 : EventMActualProbability;
    ftActual14 : EventNActualProbability;
    ftActual15 : EventOActualProbability;
    ftActual16 : EventPActualProbability;
    ftActual17 : EventQActualProbability;
    ftActual18 : EventRActualProbability;
    ftActual19 : EventSActualProbability;
    ftActual20 : EventTActualProbability;
    ftActual21 : EventUActualProbability;
    ftActual22 : EventVActualProbability;
    ftActual23 : EventWActualProbability;
    ftActual24 : EventXActualProbability;
    ftActual25 : EventYActualProbability;
    ftActual26 : EventZActualProbability;
    ftActual27 : EventAAActualProbability;
    ftActual28 : EventBBActualProbability;
    ftActual29 : EventCCActualProbability;
    ftActual30 : EventDDActualProbability;
    ftActual31 : EventEEActualProbability;
    ftActual32 : EventFFActualProbability;
    ftActual33 : EventGGActualProbability
ft_rate
    ftRate1 : EventHActualRate;
    ftRate2 : EventIActualRate;
    ftRate3 : EventLActualRate;
    ftRate4 : EventOActualRate;
    ftRate5 : EventPActualRate;
    ftRate6 : EventTActualRate;
    ftRate7 : EventUActualRate;
    ftRate8 : EventXActualRate;
    ftRate9 : EventYActualRate;
    ftRate10 : EventBBActualRate;
    ftRate11 : EventEEActualRate;
    ftRate12 : EventFFActualRate
ft_exposure
    ftExposure1 :
EventHPreliminaryExposure
    ftExposure2 :
EventIPreliminaryExposure;
    ftExposure3 :
EventLPreliminaryExposure;
    ftExposure4 :
EventOPreliminaryExposure;
    ftExposure5 :
EventPPreliminaryExposure;
    ftExposure6 :
EventTPreliminaryExposure;
    ftExposure7 : EventUActualExposure;
    ftExposure8 :
EventXPreliminaryExposure;
    ftExposure9 :
EventYPreliminaryExposure;
    ftExposure10 :
EventBBPreliminaryExposure;
    ftExposure11 :
EventEEPreliminaryExposure;
    ftExposure12 :
EventFFPreliminaryExposure
ft_simple
    ftSimple1 : EventAPreliminaryLabel;
    ftSimple2 : EventBActualLabel;
    ftSimple3 : EventCPreliminaryLabel;
    ftSimple4 : EventDPreliminaryLabel;
    ftSimple5 : EventEPreliminaryLabel;
    ftSimple6 : EventFPreliminaryLabel;
    ftSimple7 : EventGPreliminaryLabel;
    ftSimple8 : EventHPreliminaryLabel;
    ftSimple9 : EventIPreliminaryLabel;
    ftSimple10 : EventJPreliminaryLabel;
    ftSimple11 : EventKPreliminaryLabel;
    ftSimple12 : EventLPreliminaryLabel;
    ftSimple13 : EventMPreliminaryLabel;
    ftSimple14 : EventNPreliminaryLabel;
    ftSimple15 : EventOPreliminaryLabel;
    ftSimple16 : EventPPreliminaryLabel;
    ftSimple17 : EventQPreliminaryLabel;
    ftSimple18 : EventRPreliminaryLabel;
    ftSimple19 : EventSPreliminaryLabel;
    ftSimple20 : EventTPreliminaryLabel;
    ftSimple21 : EventUPreliminaryLabel;
    ftSimple22 : EventVPreliminaryLabel;
    ftSimple23 : EventWPreliminaryLabel;
    ftSimple24 : EventXPreliminaryLabel;
    ftSimple25 : EventYPreliminaryLabel;
    ftSimple26 : EventZPreliminaryLabel;
    ftSimple27 : EventAAPreliminaryLabel;
    ftSimple28 : EventBBPreliminaryLabel;
    ftSimple29 : EventCCPreliminaryLabel;
    ftSimple30 : EventDDPreliminaryLabel;
    ftSimple31 : EventEEPreliminaryLabel;
    ftSimple32 : EventFFPreliminaryLabel;
    ftSimple33 : EventGGPreliminaryLabel
ft_simple_desc
    ftSimpleDesc1 :
EventASimpleEventDescription;
    ftSimpleDesc2 :
EventBActualSimpleEventDescription;
    ftSimpleDesc3 :
EventCSimpleEventDescription;
    ftSimpleDesc4 :
EventDSimpleEventDescription;
    ftSimpleDesc5 :
EventESimpleEventDescription;
    ftSimpleDesc6 :
EventFSimpleEventDescription;
    ftSimpleDesc7 :
EventGSimpleEventDescription;
    ftSimpleDesc8 :
EventHSimpleEventDescription;
    ftSimpleDesc9 :
EventISimpleEventDescription;
    ftSimpleDesc10 :
EventJSimpleEventDescription;
    ftSimpleDesc11 :
EventKSimpleEventDescription;
    ftSimpleDesc12 :
EventLSimpleEventDescription;
    ftSimpleDesc13 :
EventMSimpleEventDescription;
    ftSimpleDesc14 :
EventNSimpleEventDescription;
    ftSimpleDesc15 :
EventOSimpleEventDescription;
    ftSimpleDesc16 :
EventPSimpleEventDescription;
    ftSimpleDesc17 :
EventQSimpleEventDescription;
    ftSimpleDesc18 :
EventRSimpleEventDescription;
    ftSimpleDesc19 :
EventSSimpleEventDescription;
    ftSimpleDesc20 :
EventTSimpleEventDescription;
    ftSimpleDesc21 :
EventUSimpleEventDescription;
    ftSimpleDesc22 :
EventVSimpleEventDescription;
    ftSimpleDesc23 :
EventWSimpleEventDescription;
    ftSimpleDesc24 :
EventXSimpleEventDescription;
    ftSimpleDesc25 :
EventYSimpleEventDescription;
    ftSimpleDesc26 :
EventZSimpleEventDescription;
    ftSimpleDesc27 :
EventAASimpleEventDescription;
    ftSimpleDesc28 :
EventBBSimpleEventDescription;
    ftSimpleDesc29 :
EventCCSimpleEventDescription;
    ftSimpleDesc30 :
EventDDSimpleEventDescription;
    ftSimpleDesc31 :
EventEESimpleEventDescription;
    ftSimpleDesc32 :
EventFFSimpleEventDescription;
    ftSimpleDesc33 :
EventGGSimpleEventDescription
end
```

(Partial) Instantiation of Fault Tree Analysis

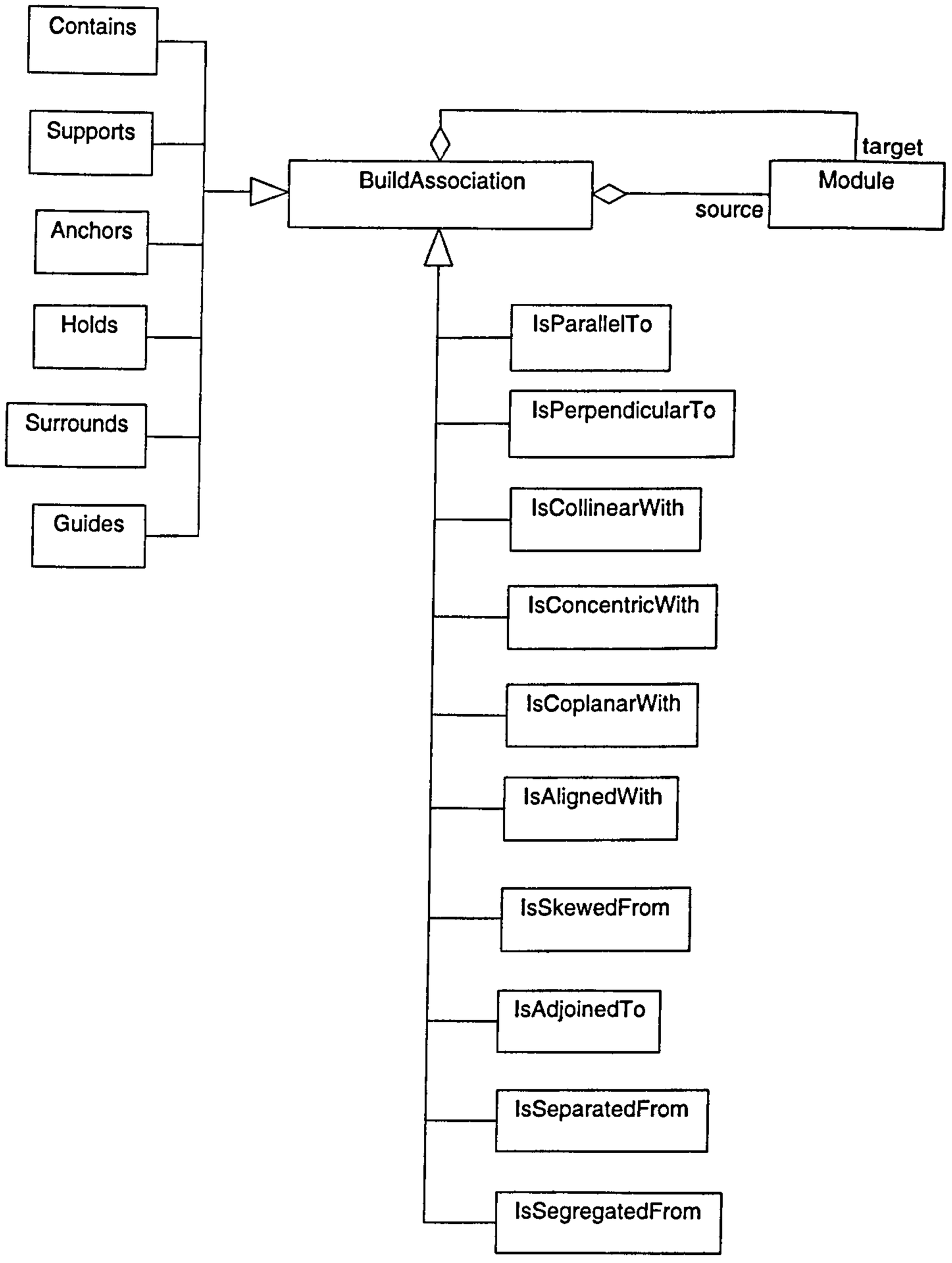
BscuFTA in FaultTreeAnalysis, Token with

```
fta_updated_tree
    ftaUpdatedTree : BscuSsaUpdatedFT
end
```

Appendix - E

This page deliberately left blank

Appendix E - Spatial Build Associations



'Catalogue of Spatial Relations'