Methodology for managing shipbuilding project by integrated optimality

By

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ABSTRACT

1.1 Small to medium shipyards in developing shipbuilding countries face a persistent challenge to contain project cost and deadline due mainly to the ongoing development in facility and assorted product types. A methodology has been proposed to optimize project activities at the global level of project planning based on strength of dependencies between activities and subsequent production units at the local level. To achieve an optimal performance for enhanced competitiveness, both the global and local level of shipbuilding processes must be addressed. This integrated optimization model first uses Dependency Structure Matrix (DSM) to derive an optimal sequence of project activities based on Triangularization algorithm. Once optimality of project activities in the global level is realized then further optimization is applied to the local levels, which are the corresponding production processes of already optimized project activities. A robust optimization tool, Response Surface Method (RSM), is applied to ascertain optimum setting of various factors and resources at the production activities. Data from a South Asian shipyard has been applied to validate the fitness of the proposed method. Project data and computer simulated data are combined to carry out experiments according to the suggested layout of Design of Experiments (DOE). With the application of this model, it is possible to study the bottleneck dynamics of the production process. An optimum output of the yard, thus, may be achieved by the integrated optimization of project activities and corresponding production processes with respect to

resource allocation. Therefore, this research may have a useful significance towards the improvement in shipbuilding project management.

This thesis is dedicated to the valiant heroes who had gifted away the victory of Bangladesh on 16 December, 1971 at the cost of their invaluable lives.

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Abbreviations

AKY	*Aker Finland Yard*
AMTAC	*Advanced Maritime Technology Application Center*
AoA	*Activity on Arrow*
AoN	*Activity on Node*
CAD	*Computer Aided Design*
CBS	*Curved Block Assembly Shop*
CC	*Concurrent Construction*
CC	*Critical Chain*
CCAM	*Critical Chain Analysis method*
CCM	*Critical Chain Method*
CCPM	*Critical Chain Project Management*
CE	*Concurrent Engineering*
CGT	*Compensated Gross Tonnage*
CLSP	*Capacitated Lot Sizing Problem*
COM	*Communication Matrix*
CP	*Critical Path*
CPM	*Critical Path Method*
DAS	*Daewoo Shipbuilding Scheduling*
DES	*Discrete Event Simulation*
DFSS	*Design for Six Sigma*
DIMM	*Design Interface Management Matrices*
DMADV	*Define, Measure, Analyze, Design, Verify*
DMAIC	*Define, Measure, Analyze, Improve, Control*
DOE	*Design of Experimentss*
DPPS	*Dynamic Production Planning System*

DSIC	*Dalian Shipbuilding Industry Co., Ltd.*
DSM	*Dependency Structure Matrix*
EDP	*Electronic Data Processing*
EOT	*Electrical Overhead Travelling*
FSG	*Flensburger Schiffbaugesellschaft*
ICP	*Information & Communication platforms*
IDEF	*Integration Definition*
JIT	*Just in Time*
JLM	*Jos. L. Meyer*
JSP	*Job Shop Problem*
LSS	*Lean Six Sigma*
MIP	*Mixed Integer Programming*
MPC	*Multipurpose Container Vessel*
MSP	*Microsoft Project Planning*
NGNN	*Northrop Grumman Newport News Shipyard*
NGSS	*Northrop Grumman Ship Systems*
NP	*Nodes Plan*
OGL	*Optimality at the global level*
OLL	*Optimality at the local level*
ONR	*Office of Naval Research*
PBS	*Panel led Block Assembly Shop*
PDS	*Physical Distribution Scheduling*
PERT	*Program Evaluation and Review Technique*
PM	*Project Manager*
PMIS	*Project Management Information System*
PSPC	*Performance Standard for Paint Coating*
QFD	*Quality Function Deployment*

RSM	*Response Surface Method*
SimCoMar	*Simulation Co-operation in the Maritime Industry*
SMS	*Small to Medium Shipyard*
SPC	*Statistical Process Control*
SPEXS	*Ship Production Execution System*
SSA	*Simplified Simulated Annealing*
STS	*Simulation Tool-kit for Shipbuilding*
TE	*Expected Time*
TOC	*Theory of Constraint*
TQM	*Total Quality Management*
TRPP	*Triennium Rolling Production Plan*
UNO	*University of New Orleans*
VLCC	*Very Large Crude Oil Carrier*
WBS	*Work Break Down Structure*
WIP	*Work-in-process*
WTM	*Work Transformation Matrix*

1 Chapter One. Introduction

1.2 Introduction

The present business model of shipyards around the world is evolving through competitions from emerging shipbuilding markets. As a result, requirements and expectations of ship owners are becoming increasingly greater in terms of quality, cost and delivery time. This evolution is felt even stronger by rapid development of new information & communication platforms (ICP), which facilitates a direct communication link between service providers and their clients, an innovation in applied techniques. In this type of context, company performance is built on two dimensions – a technological dimension, whose goal is to increase intrinsic performance of marketed products in order to satisfy requirements of quality and low cost of ownership for these products and an innovation in applied techniques. The ultimate goal is to have a product with superior quality, produced in forecasted time and within budget. Technological novelty plays an important role and can be a discerning element for market growth and share. From a shipyard's perspective, market penetration with innovative technology in product comes in tandem with the process of actual manufacturing and managing the construction project. Efforts for continuous improvement on cost and quality are seen to have created driving force in the task of shipbuilding management. A shipyard is categorized as an on-demand manufacturing system where rapid technological growth of product and the customization requirements for these products expected by the customers are modeled in a changed environment. Korea can sell a vessel for less than what American domestic shipyards pay for materials (ICAF, 2002). This requires Korean yards to have flexible production system, be able to adapt to market demands and requirements rather quickly and efficiently. There are other aspects like organizational preparedness for improvement on production performance, accomplishment of delivery dates, supply & inventory, and work in progress management (WIP) are among others, in which Koreans have excelled significantly. This competitive dimension plays an increasingly important role as shipping markets are becoming ever volatile and progressive with the introduction of newer environment friendly technology and regulations. In essence, shipping industry requires shorter response time from shipbuilders to act on the changes.

Therefore, companies must have powerful methods and tools at their disposal for production organization and control (BAI, 1998). This production organization must be considered also from its position in the supply chain where a company must be focused on the best possible conditions (WU and et al., 1995).

To achieve these goals set above in the most optimal way, a typical shipyard normally relies on the implementation of a number of functions including scheduling. Indeed, scheduling function is intended for the organization of human and technological resources used in workshops and workstations to directly satisfy client requirements or demands issued from a production plan prepared by the planning department. Planning, in a shipyard, is done on the basis of work structure. These works are in practice broken down and accomplished in several activities with interdependencies. In the backdrop of effective application of optimal resource utilization, planning function must systematize the simultaneous carrying out of several jobs using flexible but constrained resources available in hands, which becomes a composite problem to resolve. In addition, planning department eventually is accountable for product manufacturing. It’s competence and failures will therefore greatly condition the shipyard’s relationship with its ship owners in the framework of meeting delivery target. Within a shipbuilding organization, this function has apparently always been present, but in present day, it faces ever more complex problems because of the large number of jobs that must be executed simultaneously with shorter manufacturing times - striking a balance with minimal use of resources. This situation emanates from the result of the escalating competitive environment and thus calls for an investigation into the solution approach or improvement to the practice.

An efficient and potent solution to scheduling issues in the shipbuilding industry constitutes a significant economic challenge. Formulation of scheduling may appear like a day-to-day job, but it is worthy to note that there is no "cure-all” method which can accommodate all the variabilities to produce an effective single point scheduling solution, rather one solution may be claimed as more suitable than the others for a particular application. In essence, in the literature, there has been researches on generic scheduling issues distinguished by the nature of jobs to be executed or resources available to perform them. Shipbuilding project becomes very overwhelming to manage against the background of interaction of activities among stakeholders such as designer, classification society, owner's representatives, vendors and internal departments in the yard. A ship may take anything from six months to many months to build depending on the size and type of the vessel. Besides, available slots at the vendors' manufacturing plants for the critical machineries, as an external factor, play a critical role in meeting minimum ship delivery time. On the flip side, within the yard, planners will have to take into account of this information. Planning of production tasks is the manifestation of dependency correlation between interacting activities or jobs. However, a planning department, in most of the cases, plans its associated works or jobs at the shops and workstations keeping in view the delivery target or any other milestone as set by the management. A group of planned jobs or works may follow a defined work break down structure (WBS) according to zone or system orientation. This even may arbitrarily be defined by the planning department to any manageable structure and along the line of the convention of concerned shipyard. These plans are widely used to exercise on the tasks grouped in weekly, fortnightly or monthly target. Interactions and dependency between activities and works are not addressed by the conventional planning and mostly a heuristic method coupled with norms and practices are commonly followed. A lack of capture into the insights of interactions may lead to increased allocation of resources for sequential or successive completion of tasks. Extended production time may feature in the absence of optimal reflection of concurrent and simultaneous jobs in the planning. If we try to imagine the number of activities a ship under construction may come across over the building period, it may turn out to be hundreds of rows on the planning paper. A re-sequenced optimal plan may, thereby, be possible to create if we could sequence these activities in a manner where all the interactions between activities could be recorded, clearly identified and dependency loops between competing activities emphasized, where applicable. Each activity requires at least two major attributes among others to accomplish-- resource and time. Resource may be defined as workers, materials, machines, capital etc. Therefore, once these activities are sequenced in an order, it might be possible to manage ship construction project with more control, futuristic planning, less resources, and time. Thus, an optimality at the global level (OGL) of the project planning may be realized and building time may be reduced. However, much of the benefit from this optimal sequence of activities rests on the implementation of this planning at the shop level management of resources or, in other word, shop level scheduling. Shop scheduling has drawn in a large interest from academia and industry alike, and much of the researches have been conducted over the last half a century of the millennium. In contrast, shipbuilding is primarily categorized as a combination of assembly and manufacturing industry encompassing shops, works-stations in the form of panel line, sub-assembly, fabrication, and "work-in-situ" on board the ship at outfitting stage. Therefore, mere shop scheduling is not good enough to address this resource management across this broad spectrum of dissimilar stages. However, simulation of the activity-transformed-works and jobs may be able to shed light into the fundamental behavior of this discrete processing system in response to the various degrees of resources allocation. Output from a particular process of activity-transformed-works might be observed and analyzed in a computer environment and the most significant factors or resources may be sorted out through simulation together with consultative feedback from production managers. Design of Experiments (DOE), an advanced statistical analysis, can play a very vital role to analyze whether the amount or the level of resource allocation is the most optimal for a given output expected from the processing system under investigation. Evidential outcome from this analysis will yield the suggestion of optimal setting for resources in the procedure. Derivation of optimal production process with estimated resource arrangement will ensure optimality at the local level (OLL) of the shipbuilding project and thereby integration of optimality at the global level (OGL) of project sequence with further search of optimality at the local level (OLL) will be achieved. This integration might offer pragmatically functional method for managing assorted marine construction project.

OGL deals with optimal sequence of activities at the initial level of project planning, but allocation of resources has to be conducted in a manner to ensure the optimal expense of resources for a given activity process, extrapolated from the initial plan. In this research, we will aim at proposing an effective methodology which may be useful in capturing interactions and dependency between activities and thereby in achieving an optimized outline of project and subsequent production process. It is to provide a platform for small to medium shipyards operating in a habitual environment of evolution, change, and competition. This methodology forms a strategy for modeling and optimizing sequence of activities of shipbuilding project and resources utilized in accomplishing those activities so that a project can be managed and controlled in an effective manner. This helps to ensure that production cost can be minimized, product quality can be maximized and, perhaps most importantly, project completion time can be reduced by taking many uncertainties of project in consideration during the course of optimization procedure.

1.3 Motivation: Lessons from Real Life Experience

In every research, inspiration has far a reaching significance in the entire journey, starting from the initial planning to the very end. It works as the driving force during the modulations of the uncertainties. Since the beginning of author's career with shipbuilding industry more than a decade ago, it has naturally occurred to him to observe and question issues ranging simple to complex in a way, popularly known as "common sense". Cause and effect reasoning, which has always been a part of the search, can guide an inquisitive mind to discover far-fetched solution to challenging problems. An urge is felt to share personal experiences of the author in the proceeding text with the readers. The following narrative is one of many stories, the author had come across in the industry. Work experience in the yard has instilled in him a great deal of ideas and broadened the quest for better solution to relevant challenging problems. For one of the projects, the author had to join a co-ordination meeting with the project manager (PM) of a Tug Boat, which was supposed to be delivered to the client within following 15 (fifteen) days since then, while the apprehension was running high about falling behind the delivery deadline. The client was a government organization and supposedly a bit less flexible than private ship owners. PM explained how he envisaged to complete rest of the jobs within the stipulated time. He was asked whether he had with him any task schedule he could share with the author. He was promptly affirmative. He generally keeps his tasks in a note book and also his co-workers are well-briefed about what to do and when to do. However, the author had started to dip in the cloud of uncertainty toward completion deadline instinctively. A visit on board the vessel was thought necessary than having the meeting run for hours in the meeting room.

Thereafter, the author was ushered to the vessel to be shown around the jobs which are being attended and would need to be attended immediately. Having walked around, up and down the ladder, it was found that cluster of workers is attending jobs at different places. Some of them were painting edges, some were still pulling cables in the bridge, some were welding stanchions and bollards while a plenty of workers were just onlookers in others activities and wandering around wantonly while a few were blowing sparks by the hand grinder. It was felt instantly that much of those workers were probably not properly briefed about the job and the deadline in contrary to the initial assurance of the PM. This assumption had later been confirmed in a conversation with a random worker and there was an influence of either overflow or shortfall of workers or equipment. A while after the saunter, the author was standing next to the towing winch and watching around while a fork lift was carrying a small boat with outboard engine towards the quay. PM informed that it was intended for this Tug boat and will be placed on this aft deck. Upon further inquiry on the foundation of the boat and lifting device, it was found that the concerned foreman was not fully aware of the job. Foreman confirmed that foundation was ready at the shop and was scheduled to be brought in after three o'clock. About the lifting device, foreman could not confirm anything but informed that he thought that this would be an extendable deck crane supplied by a West European vendor and that was already stored in the warehouse. However, on further inquiry and after exchanging words with design department, PM informed that it was not a deck crane but a derrick to be built by the yard. The author was literally stunned at this new turn of events. PM then checked with fabrication shop for urgent production of the same and requested for arrangement of an immediate slot. Later in the afternoon, it was further discovered that yard inventory didn’t have class certified plate of the required thickness and these had to be ordered from overseas supplier. However, the legacy of disarray went on and the Tug Boat was finally delivered after around 60 (sixty) days of delay from the agreed delivery date. What probably can be summarized from the outcome of this sequence of events is that an array of missing links might have played roles as the root causes of the delay and mismatch, as follows:

a. Sequential task list

b. Cross checking with design department

c. Schedule of resources

d. Procurement

e. Co-ordination

f. Incompetence

In comparison with big shipyards, small to medium sized shipyards (SMS) are challenged with the management task of dissimilar projects. Big and established shipyards are usually equipped with the state-of-the-art facility having a major order for the construction of series and make-to-order ships / marine vessels, which are normally secured either through formal or informal competitive bidding process. Due to strategic competition, generic shipyards belonging to small to medium group offer or accept tight deadline for project completion including design deliveries to the satisfaction of the owner's stipulated deadline. Essential it becomes to overlap and integrate all focused disciplines of shipbuilding project, i.e., design, procurement and construction etc., from the day one of the project. Cross functional interaction among disciplines for information, resources and materials poses co-ordination challenge to the management team. Small to medium shipyards in a growing shipbuilding zone usually come across fierce competition in procuring contracts as these yards enjoy almost same level of competitive edges. Sequence execution in ship construction is mostly influenced by the method of construction, the spatial arrangement of the yard facilities and arbitrary imposition of externalities, while a great consideration is given to simultaneous and ongoing projects. Another challenge for this yard genre is to make investment decision in the facility and equipment due to the scarcity of available finance for many reasons. Ship construction projects undertaken by small to medium yards, like the one the author worked for, are required to be circumspect for future shipbuilding market and decide carefully on facility investment. Therefore, a satisfying facility and line of equipment is rather an outreaching goal the management always strives to achieve for. An explicit discussion is attempted in this regard in Chapter 5.

Prior to committing in the academic domain for research work, the author had felt an affirmative self-conviction to study into the theoretical aspect of solution approach to this ever-persistent management problem in the context of a small to medium shipbuilding yards in emerging markets. Therefore, motivation of the research prompts to find out a possible robust method to the management approach for this yard genre to make sure that the dissimilar projects carried out at these yards are managed in an optimal way against the backdrop of constant improvement to facility and diverse product ranges it produces. The author believes that optimality approach is best suited for an environment of unpredictability and heterogeneity, as this approach offers customization to situations over other conventional inflexible management methods as discussed in Chapter 3.

1.4 Background: Maritime Market Perspective

Shipping market is recognized as a global industry where the opportunity is endless but cyclical volatility features this industry and so is the shipbuilding. Ship construction is a very complex and expensive project. Each year billions of pounds are spent on the ship production and repair industry all around the world. European commission has recognized shipbuilding and repairing a knowledge-based-industry, in 2003, with future vision beyond cyclical turns. Shipbuilding follows the trend of shipping market influenced by the supply demand economics of various shipping services. The phenomena also includes military and commercial services, and various events of world-wide importance (Gorton *et al.*, 2000). Events of world importance are unpredictable and only last for seasons. Competition is increasing between shipyards. The more they meet the deadline and quality requirements, the higher the possibilities are there to be awarded with contracts and to consolidate its position in the market. Chinese shipyards are gaining a better position in the shipbuilding market due to the huge capacity that they are having from the shipbuilding boom experienced in the first decade of the current century, not to mention the cheap labor. There are other factors that influence the choice of shipyard such as costs, location, reputation and technological application among others. Korean yards are investing more in new products and technologies. New and emerging countries like India, Vietnam, Philippine and Bangladesh are focusing in the race for biting a portion of world shipbuilding market of non-specialized segment. The ability to develop new products and process rapidly and efficiently is a potent source of competitive advantage. When a firm seeks to add value to its product, processes and operation, its objective is to become better at designing or developing new products or strategies. In some cases, a complete reorganization is required to build and improve the company's procedure, processes, leadership skills, tools and methods, striving to do things faster (Wheelwright and Clark, 1992). Size, people, skills and functionality, among others, are unique characteristics of the shipbuilding industry and they are different even for the same job at different shipyards. But the core stages are relatively same but not necessarily same in terms of sequence of events or activities. Every shipbuilder depends on particular circumstances, strategies, market and also technology to give it a significant edge in the market place. Delay in the delivery of the ship penalizes the yard immensely and creates distrust between the parties and at the same time due to this non-performance of the production management, an indirect deleterious loss is accrued to the shipyard. Repercussion emanating from non-optimized production procedure extends further beyond the respective project. This problem needs careful attention and comparative research into management methods. It is also essential to eliminate untoward influence of the embedded management slacks contributing towards this non-performance. Therefore, this huge industry needs to be operated in an optimum level to live up to the demands of volatile shipping market with an expected ever increasing efficiency. A methodology may, therefore, be modeled to address this management problem with the target to minimize resource consumption while keeping the uniqueness and individuality of the shipbuilding yard in consideration.

1.5 Research Method

The research methodology has been designed in a way which would holistically encompass the literature, theory and practice in the field which offers the opportunity for searching a solution approach. This research method was guided in pseudo by the process adopted (Duffy and O'Donnell, 1998) by as shown in Figure 1.1.

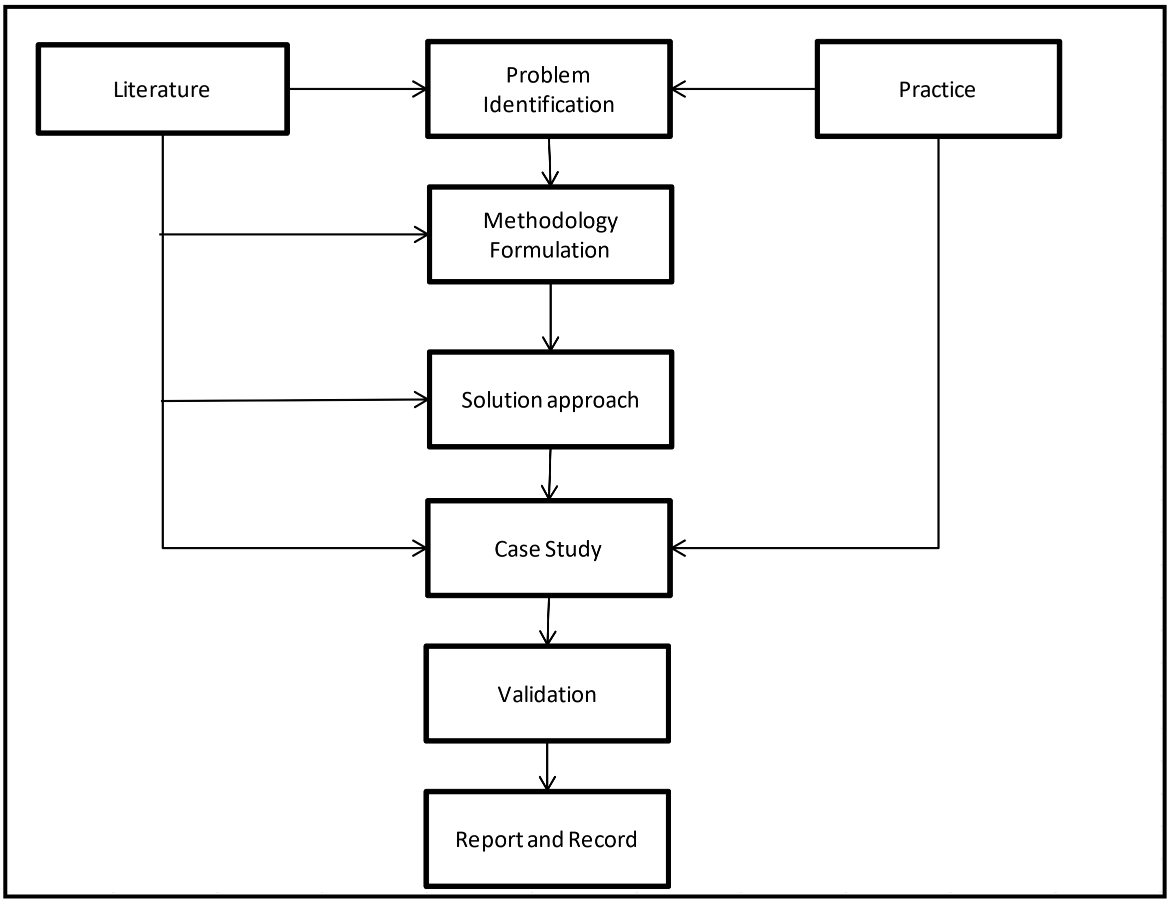


Figure 1.1 - Overall research methodology

With respect to the Figure 1.1 a problem in the management process of shipbuilding is identified from the real life practice in ship construction and the search for proposed solutions is carried out in relevant literature. On the basis of the recognized problem as evident from real life experience and from the survey of literature, it would be possible to theorize an improved and acceptable solution and thereby a research problem is formulated. From the very inception of the problem to solution approach to the problem, a thorough literature review is carried out. The solution scheme is then evaluated based on the case study cited from the industry. At the last leg, research is documented and the same is being presented in this thesis. (Duffy and O'Donnell, 1998) discussed validation and evaluation methods with respect to a proposed hypothesis. Validation focuses upon ascertaining a degree of truth for a particular hypothesis or solution. Evaluation measures the relation between a result, concept, method, toll, etc. against a datum of some kind such as requirements specification, known practice or performance targets. Both validation and evaluation use a variety of methods such as:

Case studies- particular shipbuilding management processes are studied and analyzed.

Industrial studies- actual production practice is studied and analyzed through a variety of techniques, e.g., interviews, protocol analysis, methods and contract study, etc.

Worked example- similar to case studies, scenarios of particular production processes are simulated and analyzed.

1.6 Research Aim and Objectives

The aim of the research is to propose a methodology of managing sequence and process for ship manufacturing especially intended to minimize escalation of all forms of resource utilization through searching for optimal combination of resource engagement and sequence of project elements or activities in the context of small to medium shipyards (SMS) in emerging shipbuilding market. In short, to optimize a shipbuilding plan and formulate optimized production processes in view of resource usage, following are the summarized objectives, against the framework of diversified and dissimilar stages of ship production:

- To develop relevant literature within the field of shipbuilding production and the science of production management.
- To establish a number of prevalent concepts which provides a basis and justification for the optimized approach for the evaluation of production process for shipyard to reduce waste and expense.
- To review specific literature which addresses production for customized product with respect to uncertainty and identify key issues related to their improved performance.
- To recognize limitation of existing approach to ship production and management practice with respect to objectivity.

- To identify a set of knowledge requirement to the development of a resource layout integrated production sequence.
- To develop a novel, integrated and holistic approach to manage ship manufacturing combining project management and actual production processes.
- To evaluate the developed approach with respect to identified management issue using a case study from the industry.
- To identify strengths and limitation of the approach based on the evaluation.
- To identify areas of future work.

1.7 Organization of the Thesis

Chapter 1. Introduction

This chapter has described background, motivation and objectives of the thesis and the necessity for an integrated approach to shipbuilding project implementation. It has briefly narrated necessity for optimality in the management of shipbuilding activities with an attention to the current shipbuilding trend.

Chapter 2. Literature review

This chapter will discuss relevant literatures in the field of production management and scheduling with particular attention to shipbuilding industry, its processes and latest innovation and application of simulation technology.

Chapter 3: Potential Management Techniques & Tools required for Shipbuilding Project

This chapter will discuss various project management concepts with particular attention to various management techniques applied in a range of industries.

In chapter 4: Methodology of integrated management framework

This chapter will describe in detail the proposed method and its application supported by available literature of the proposed tools used in the method and will give an idea how this can be used in shipbuilding management. It will demonstrate the procedure and strength of Dependency Structure Matrix (DSM) over other conventional methods and will describe Response Surface Method (RSM) and its application across a diverse field of study to find optimality in the process and system.

Chapter 5: Application and case study

This chapter will describe the practical case study conducted using project data of an ongoing shipbuilding project at a shipyard located in an emerging shipbuilding market in South Asia, Bangladesh. A project of Oil Tanker will be analyzed and application of Dependency Structure Matrix will be shown to achieve optimality in the project sequence management.

Chapter 6. Conclusions

Achievement and contribution in the field of Shipbuilding management research will be discussed together with limitation and strength of the methodology will be reviewed. Recommendation for future direction of the research will be discussed.

1.8 Summary

This chapter starts with a general discussion in the field of manufacturing industry and the challenges it faces in regards to the production schedule, advent of new technology, changing shipping environment with particular attention to shipbuilding industry. The motivation and background study reveals the justification for undertaking this research in the field of shipbuilding management for small to medium shipyards in emerging shipbuilding market. The objective of the research is aimed at finding out an integrated management approach based on optimality which would consider both the global level of project planning and local level of manufacturing processes so that a consistent philosophy may possibly be adopted throughout the project. The objective is then broken down into a number of further outcomes which are perceived to be probable derivatives of the research.

2 Chapter Two. Literature Review

2.1 Introduction

This chapter introduces the field of engineering project planning, scheduling and management. Furthermore, it presents literature survey with respect to shipbuilding, production planning and engineering project management. Simulation techniques have seen wide applications to explore the underlying structure of studied area of research and have also been applied to solve many planning issues in the field production engineering. The main objective of this revisit in the literature is to establish a number of prevalent concepts related to optimization approach across the area of engineered systems and project management in the area of shipbuilding. Such prevalent concepts provide the basis for quantification of proposed methodology in subsequent chapters.

To stay competitive, the shipbuilding industry, like other industries, continuously goes through insightful changes for reducing costs and lead times. In many instances these changes are prompted by domestic as well as international competition. Shipbuilding industry has attempted many kinds of automation technologies and project management methods. Many intelligent systems and models were developed to deal with scheduling for shop-floor (Choi and Park, 1997) and spatial block scheduling (Park *et al.*, 1996), (K. J. Lee *et al.*, 1996), (Cho *et al.*, 1999), (Seo *et al.*, 2007) and (Cho *et al.*, 1996). Some researchers proposed simulation methods for subassembly production (Yim, 2004) and steel processing facilities (Williams *et al.*, 2001). Because of complexities and uncertainties of ship construction process and the varieties of shipbuilding projects, those endeavors focused on several particular areas which could solve some of the special problems, and they only partly increased the efficiency of design and production in the shipbuilding process. Additionally, some areas that do not seem to be easy also were researched and adopted in some countries and regions, especially in Japan, South Korea, Taiwan, and Denmark. Significant advantages were derived from those research results. T. Amemiya presented an example of systematization narrowed down to planning schedules and process control (Amemiya, 1994). Nakayamma proposed a process planning system for how the information for the product should be represented and how the knowledge for process planning should be described systematically (Nakayama, 1994). Di Filippo and Manzon stated a real application of integrated steel workshop for shipbuilding (Di Filippo *et al.*, 1998). Storch (Storch, 1999) and Koenig etc. (P. C. Koenig *et al.*, 2002) explored the potential application of the concepts of lean thinking and lean manufacturing. In recent decades, much attention has been paid to information models, automations and CIM (Computer Integrated Manufacture) systems for the shipbuilding process (Aoyama and Nomoto, 1997), (Shimizu and Koyama, 1991). Particularly, Lee developed a practical integrated scheduling system, including several technological breakthroughs, such as spatial scheduling, dynamic assembly line scheduling, and neural network based man-hours estimation (J. K. Lee *et al.*, 1997). McLean and Shao discussed an integration mechanism for shipbuilding simulation that can analyze the anticipated impact of new workloads, evaluate production scenarios, and identify resource problems (McLean and Goudong, 2001). Although the enhanced expert systems exist, some newly founded large shipbuilding enterprises have developed their own specific features that have not been studied yet.

2.2 Difference among various management concepts

Item	Project Management	Production Management	Process Management	Scheduling
Definition	✓ Project management focuses on results, with clear goals and detailed plans for managing finances and manpower. ✓ Project is a unique endeavor with a beginning and an end undertaken to achieve a goal. ✓ Organizational function of planning, organizing, securing and managing resources. ✓ Applies processes and knowledge over time ✓ Aligns cross-functional teams to complete projects (Answers; Edelenbos and Klijn, 2009; AIPMM, 2013)	✓ Planning and controlling of production process so that it moves smoothly at the required level of output while meeting cost and quality objectives ✓ Production management includes responsibility for product and process design, planning and control issues involving capacity and quality, and organization and supervision of the workforce (Britannica)	✓ Process management focuses guiding the process by reacting flexibility to changes and by bringing different actors together ✓ Process is a repetitive collection of interrelated tasks aimed at achieving a certain goal ✓ Process management involves the understanding, design, and improvement of processes. ✓ Process Management is planning, monitoring, and improving the permanent (or semi-permanent) repetitive actions/work that produces or supports the production of goods or services. ✓ Process is something that is not constricted with deadlines (Answers; Answers;	✓ Scheduling issue considers the internal resources (typically workstations) of a production system and aims to allocate appropriate sub-activities to those resources. ✓ To compute and fix the baseline schedule in advance to allocate finite resources to each individual activity, and to provide a basis for material procurement, commitment of shipping to external activities. (Bourrières and Lecompte-Alix, 2010; Suwa *et al.*, 2010)

			BBS; Robert and Larry, 2007; Edelenbos and Klijn, 2009)	
Important Task	✓ Maximize revenue ✓ Lead product development activities ✓ Reduce development cost ✓ Maximize profit ✓ Deliver high quality (AIPMM, 2013)	✓ Increased sales ✓ Supporting marketing, finances and personnel ✓ Satisfy customers ✓ Introduce new products ✓ Facing competition ✓ Improving quality & minimizing cost of production (Kalyan-city-life)	✓ More Sales ✓ Reduced Costs ✓ Less waste ✓ Increased productivity and higher margins (BBS)	✓ Holding down costs through better use of personnel and equipment ✓ Increased throughput ✓ Decreased turnaround time ✓ User deadline met ✓ Avoidance of overloading & underuse of resources ✓ Predictability of future equipment and personnel needs.(ISTTS)
Focus	Controlling the project phases according to five features: the quality of the content, cost, time, organization and information (Edelenbos and Klijn, 2009)	Focus is on managing men, machines, methods, materials, money (Britannica)	process management should be continual for getting maximum efficiency (BBS)	✓ Directing and controlling resources of workers, machines, and materials in a coordinated and timely fashion in order to deliver a project within the limited funding and time available. (M. Zhang *et al.*, 2009)
Framework	✓ Initiate ✓ Plan ✓ Execute ✓ Monitor/Control ✓ Close (AIPMM, 2013)	✓ Identification of constraints and critical activities ✓ Mapping interdependency	✓ Analyze ✓ Re-design and model ✓ Implement ✓ Monitor ✓ Manage ✓ Automate (AIIM)	✓ Making a work breakdown structure (an effort estimate for each task) ✓ Preparing a resource list

		relationship between constraints ✓ Mapping the impact of constraints on the production schedule ✓ Quantification of additional production duration of critical activities based on project conditions ✓ Prepare look-ahead schedule of production assignments ✓ Match production assignments and resources capacities ✓ Preparation of execution plan for each critical activity ✓ Production performance assessment ✓ Production failure analysis (Singh, 2007)		✓ In order for a project schedule to be healthy: a) The schedule must be constantly updated. b) The Estimation at Completion value must be equal to the baseline value. c) The remaining effort must be appropriately distributed among team members (Wikipedia)
Constraints	✓ Scope (Quality) ✓ Cost ✓ Schedule(Time) (Wikipedia)	✓ Planning: Capacity constraints & Cost constraints ✓ Scheduling: Task Precedence constraints, economical constraints, technical constraints	✓ Capacity utilization (Capacity management entails long-term planning (e.g., new facilities and equipment investment) and short-term control (e.g., over	✓ Logical (task precedence) ✓ Technical (transformation and transport resource capacities) and ✓ Economical (work and stock costs) constraints

		(transformation and transport resources constraints) (Bourrières and Lecompte-Alix, 2010)	workforce size, overtime budgets, etc.)) ✓ Variability (dynamic operating conditions and complex internal challenges that cause changes in inputs, operations and outputs ✓ Inventory (Inventory management involves the planning and control of process inputs and outputs to achieve competitive priorities while satisfying all demands.) (Robert and Larry, 2007)	(Bourrières and Lecompte-Alix, 2010)

2.3 Scheduling and planning in shipbuilding

Shipbuilding is a complex production system characterized by a complicated work and organization structure, prolonged production lead time, and heterogeneous resource requirements. Thus, effectively planning and scheduling present a challenging task and requires the timely coordination between the successive production stages in shipbuilding projects. Many research activities on shipbuilding scheduling and planning problem have been carried out by researchers for a long time. Many efforts in the past have been made to find more efficient methods for planning and scheduling in shipbuilding.

2.3.1 Shipbuilding Project Scheduling

(K. Hua and Baoding, 2010) attempted to solve project scheduling problem with fuzzy activity duration times, which tends to minimize the total cost with completion time limits. In order to solve the project scheduling problem, the authors developed three types of fuzzy models. A hybrid intelligent algorithm was designed which integrated fuzzy simulation and genetic algorithm (GA) to deal with the project scheduling problem with fuzzy constraints.

To maximize the number of building blocks produced in a given hall over a certain time horizon, (Maud *et al.*, 2008; Caprace *et al.*, 2013) worked on a space and time allocation problem. The authors have modeled the problem as a 3-dimensional bin packing problem (3D-BPP). The 3D-BPP was handled by a Guided Local Search heuristic which was initially developed for the 3D-BPP. The efficiency and usefulness of the Guided Local Search (GLS) approach in the context of industry have been established as well.

(Kajiwara *et al.*, 2009) put their effort on how to model a complex shipbuilding line consisting of assembly lines and stockyards. The authors modeled the scheduling problems of shipbuilding lines by a linear system representation based on Max-Plus algebra, the objective was to keep delivery dates strictly by adjusting arrival times of parts or materials based on model predictive control theory.

In order to plan and utilize work area space efficiently within large manufacturing facilities, (Daniel *et al.*, 2008) proposed an activity-based spatial scheduling tool (SST). The purpose of using activity-based spatial scheduling tool is to save significant amount of time in the overall floor space planning effort as well as using shipyard work space effectively, while maintaining critical production schedule.

(D. Zhao *et al.*, 2009) focused on discussing how to solve the multi-objective shipbuilding scheduling problem (MSP) subjected to special process constraint in which the sort of jobs processed on every machine is restricted. The authors proposed a new genetic algorithm (IGA) based on a vector group encoding method in order to effectively solve the scheduling problem. A Chinese shipyard has been chosen to verify the practical application effect of new genetic algorithm and the simulation results of IGA have been shown to be effective and preferential over genetic algorithm presented by other authors.

(Garcia and Rabadi, 2013) developed exact and approximate methods for parallel multiple-area spatial scheduling with release times. They considered a particularly complex class of spatial scheduling problems that involved scheduling each job into one of several possible processing areas in parallel to minimize the total amount of tardy time. The authors considered assigning not only the time slots to each job but also locations and orientations within the limited physical processing space as well. They considered a mixed integer programming formulation for the problem and developed an effective heuristic able to make high quality schedules.

For scheduling of the shipyard block erection system (SBES), (Zhong, 2012) developed a modified discrete particle swarm optimization (PSO) based on the reachability analysis of Petri nets. The main objective is to model multiprocessing paths and a concurrent assembly procedure for SBES. Graphical formulation of major constraints in scheduling problems and accurate presentation of complex assembly relationships have been shown using timed petri net (TPN). Numerical simulation results proved that the proposed TPN–PSO scheduler is better than the conventional scheduling method.

(Z. Zhang *et al.*, 2010) proposed a spatial scheduling approach based on an improved particle swarm optimization (PSO) algorithm to determine the optimal processing sequence and spatial location of blocks. Effective decrease of makespan and increase of spatial utilization have been made possible by using the proposed improved algorithm. The algorithm could decrease complexity of scheduling manually greatly and is very advantageous for future research.

(LI *et al.*, 2010) developed an intelligent scheduling system based on theory of constraints (TOC) for the piping production of shipbuilding. The system, which integrates product model, operation model, factory model and a comprehensive knowledge database for production and scheduling, has been proven its capability to solve the complex scheduling problem of piping factory. The generation of required operations, the determination of appropriate workflows and the allocation of suitable facilities can be executed automatically by using the system.

(Koh *et al.*, 2011) developed an efficient spatial schedule for the mega-block assembly yard to increase not only the shipbuilding productivity but arrange and assemble as many mega-blocks as possible within a time period. A length-time two-dimensional packing model was developed for the problem that deals with fixed shaped objects. The authors proposed a genetic algorithm based heuristic algorithm using computational geometry theory since the optimization model cannot be solved using an analytical method. Computational experiments have been carried out to show that the proposed algorithm can provide good quality solutions.

(Yoon *et al.*, 2012) focused on developing an efficient spatial schedule for the skid system that uses the semi tandem system to increase the space utilization. They presented a two-dimensional packing model and proposed a heuristic algorithm to use the skid scheduling system. To determine the launching schedule of ships and the spatial schedule for the skid, they developed a hybrid genetic algorithm based on the algorithm which was first developed by (Koh *et al.*, 2011) and developed a new model and new approach. According to the author skid scheduling algorithm maximizes the number of ships on the skid and minimizes delayed or early launching of each ship.

(Liu *et al.*, 2012) proposed a novel hybrid planning method to solve the space-constrained production planning problem considering the system uncertainties. They introduced a two-level framework with dynamic block dispatching at the high level and static block spatial placement at the low level. To maintain the space continuum during the evolution of the dynamic assembly layout, the authors formulated a discrete spatial optimization problem and solved using an enumeration-based algorithm. The proposed method has been validated through experiment in order to manifest its applicability in shipyard.

In order to obtain the optimum block sequence and spatial layout, (Zheng *et al.*, 2015) investigated typical block features and available resources. After the investigation they established a heuristic block spatial scheduling model based on that analysis and proposed some strategies in order to minimize makespan. The proposed algorithm has been proven to be better compared to genetic algorithm and grid algorithm in handling large-scale block scheduling.

(Roh and Cha, 2011) developed an efficient block transportation scheduling system for solving a block transportation scheduling problem. The authors developed a mathematical formulation for the block transportation scheduling problem for multiple transporters by considering a minimization of the travel distance without loading and the interferences between transporters. In order to solve the problem, they proposed a hybrid optimization algorithm comprising two steps. Firstly, Ant algorithm was used to ascertain the blocks to be moved by each transporter and secondly, the transportation sequence of the blocks for each transporter was determined. The developed system was applied to an actual block transportation scheduling problem of a shipyard.

2.3.2 *Shipbuilding production planning*

An aggregate production planning (APP) approach for shipbuilding within the manufacturing context has been proposed by (Liu *et al.*, 2011) to provide a sound frame work for effectively planning and managing ship production and construction. With a view to reduce the total variation of aggregate man-hour and minimize the logistic demands of the interim products, the authors developed a directed genetic algorithm based solver. The proposed method has demonstrated good results in handling various situations with different planning strategies.

(Qu *et al.*, 2013) proposed a methodology-integrated case-based reasoning (CBR) and constraints-based reasoning to improve the assembly sequence planning (ASP) for complicated products in shipbuilding. This methodology is able to generate the feasible assembly sequences automatically and cope with large-scale problems as well when considering products of realistic size and constraints. Genetic algorithm was designed to evaluate and select the optimal sequence automatically from the reference assembly sequence. The proposed methodology has been verified by conducting experiments using real data and it has been seen that this method can solve many complex assemblies.

(Mark *et al.*, 2004) worked on a product-centric approach to plan and design shipbuilding facility. The overall objective was to maximize the efficiency of a new structural fabrication facility in order to minimize excessive and non-value-added time spent in material movement, setting up of jobs and resources allocation. This has been done in two steps. First, a structured process modeling methodology was implemented on a product-by-product basis. This served both to document the existing structural fabrication process and identify resources and time required and served as a process improvement from prior to investing in the new facility. Second, the detailed requirements from the process models were used to define the resource requirements for the new facility. These requirements enabled the definition of a product-centric facility design.

(Marcello *et al.*, 2014) proposed an innovative and modular computer-based approach to the planning of activities in large-scale projects. The proposed approach, computer-aided activity planning (CAAP), has been used to analyze the outfitting planning problem in the yachting industry. Considering the shipyard resources, the CAAP system is able to define, sequence, and schedule the activities of the whole outfitting process automatically. The CAAP has been applied in a software called NautiCAAP in order to verify its applicability.

(Ryu *et al.*, 2008) put their effort to develop a spatial planning and scheduling system that can support the spatial planning and scheduling in block assembly shops, and the workload balance of workshops. The objective is to present a system which is able to interactively plan the allocation of blocks and description of the implementation of its functional operations. An object-oriented methodology has been used to design and implement the functional components of the system. According to the author, this system can be expanded to any workshop that requires spatial planning and scheduling.

(Z. Zhang *et al.*, 2013) established an optimization model intending to reduce the operation cost. This was a multi-level combinational optimization problem belonging to NP-difficulty problem. The authors focused on developing an encoding mechanism which can effectively provide the particular place and storage location of steel plates in the steel plate yard. The authors implemented greedy algorithm to solve the problem and application data obtained from a shipyard was used to validate the model.

(Fafandjel *et al.*, 2010) presented a computer-integrated cost structure optimization model for defining an optimal and profitable ship production cost structure. The proposed method can reduce the risk on profit margin and provides assistance in the decision-making processes with a view to keep the production costs under control. The mathematical model for achieving an optimal structure of the production costs was verified and tested against a real example of the construction of tankers.

(Zhou and Sun, 2010) worked on intelligent work preparation for hull construction with optimized assembly planning system to save delivery time. The authors developed Productivity Extension Module (PEM) as a secondary development of software based on AutoCAD. In order to provide an optimized assembly plan for the shipyards they focused on generating 3D topological ship construction module and creating parts and stiffeners automatically for nesting with interfaces to other software. A benchmark has also been provided based on a real project to demonstrate the effectiveness of PEM.

(Zou *et al.*, 2010) developed a model to optimize the shipbuilding supply chain network. The purpose of the authors was to meet the need of ship-owners and to improve the overall competitiveness of ship manufacturing. For this case, a Chinese shipbuilding supply chain network has been studied. To optimize the model, the authors used variational inequality theory. Qualitative and quantitative analysis of supply chain have been carried out to improve the management performance by optimizing the overall ship construction business model.

Optimization of a line-cutting procedure for ship hull construction has been proposed by (WENG and SUNG, 2008). The objective was to minimize the total trim loss and maintain the working efficiency of the cutting procedure in order to optimize the stock arrangement associated with rule based piece arrangement. The authors used an effective *tabu* search for the optimization. Numerical computations for two real cases have been performed and compared with other research.

(Moyst and Das, 2008) studied on optimization of ship design and construction phases. The authors intended to analyze the optimum overlap of the design and construction phases and the total hours required for a new shipbuilding program. A Linear Programming (LP) model has been developed for this purpose. It has been found that a reduction in construction direct labor hours s achieved by reducing the amount of overlap between the design and construction phases. N order to validate the approach actual case study results have been compared with the Linear Programming results.

A digital shipyard resource optimization module using API in CATIA has been designed by (Sun, 2011). The author's objective was to solve the ship enterprise resource optimization in the three dimensional visual environment. Resources allocation and simulation models and drawings have been established using the developed program module. Under the visual environment, several tasks have been performed including evaluation of system layout and analysis of production line load and bottleneck. Mathematical statistical model analysis system has been used to simulate the system fault and maintenance as well.

(Mads *et al.*, 2002) studied on the control of resource allocation on a production line at a shipyard. According to the authors, when tasks are executed in accordance with prescribed plan, the probability of getting optimal performance of manufacturing cells subject to disturbances becomes less. For this reason, the effect of disturbances in manufacturing cells could be minimized by control. The authors studied rule-based control and optimization-based control of resource allocation and compared them to see which one gives better result. They came to the conclusion that optimization-based controller is able to minimize the disturbance better compared to the rule-based controller.

2.3.3 Further simulation study in shipbuilding

(Okumoto, 2006) has used the concept of "simulation-based production" in shipbuilding and also digital manufacturing; the 3-D CAD had shown the application of computer optimized manufacturing in IHIMU (IHI Marine United Inc.), Japan. The authors argued that production simulation becomes possible for both hull structures and fittings using 3D product models, and further improvements in efficiency, safety, and quality are expected. Lots of applications for production simulation are obtained such as checking the feasibility of the construction procedure and efficiency of the work, assessing the interactions of humans and structures in the space and optimizing the construction process. Using the three dimensional product models, which is the core of Computer-Integrated Manufacturing (CIM), design and production planning of the simulation base can be carried out, and global optimization can be obtained. Some examples are introduced namely, erection planning, scaffolding planning and installation of rudder. Erection work is the most important process in shipbuilding, which stores blocks on a building dock and connects them to each other using cranes in sequence. Planning the erection work with all departments concerned is very vital considering work efficiency and safety since the efficiency of this process affects the total production period. Turnover and connection of blocks are often carried out using a series of cranes. Simulation of a hull block carried out before actual block installation, which enabled safe and efficient construction. With simulation, smooth installation is possible and problems concerning the block erection can be solved. Besides, simulation has been carried out in IHIMU for scaffolding planning. Scaffoldings are very important tools for achieving ship construction in higher places safely and efficiently. Aerial vehicles have been widely applied as a substitution for the temporary scaffolds. They are used in the building dock in the inside and outside of ship hulls. However, in order to avoid interference between the boom of aerial vehicles and hull structures beforehand, they analyzed the boom movements through three dimensional simulations. Furthermore, IHIMU used simulation for rudder setting. Pre-construction simulation of rudder installation has made them successful in constructing rudder with less skilled workers.

(Kwangkook *et al.*, 2009) has applied discrete event simulation and simulated annealing, and proposed a model called Ship Production Execution System (SPEXS) in their research to carry out a materials flow analysis to maximize process productivity and to place simulation optimization technology in the hands of decision makers, such as production planners and supervisors. Simulation model was validated using a real production scenario and the comparison showed a very favorable agreement between the actual panel shop and the simulation model. The proposed system supports production planners by general dispatching rules and optimization to make better scheduling decisions on the shop floor.

(Y. Hua *et al.*, 2011) has sown a new method of virtual ship assembly modeling which integrates ship three-dimensional design and ship construction planning. A workflow model of simulation modeling based on the virtual ship assembly process was also proposed and a method of information transformation between the ship three-dimensional design and ship construction plan was formulated. Its underlying structure has drawn in information of ship three-dimensional design, construction planning, and virtual assembly and integrated into one system.

(P. Koenig, 2006) reported a joint collaborative research between University of Michigan, Ann Arbor, Michigan, USA and Seoul National University, Seoul, Korea of developing a improved modeling and/or decision analysis approaches for shipbuilding using advance simulation based o DELMIA package and tried to developed the definition of the shipbuilding industry and shipyard entities, and their attributes and behaviors.

Application of simulation in planning has been tried in many instances. However, simulation is just a tool to mimic real life as accurately as possible. But to optimize a particular process, there requires further research into this field.

2.3.4 Integration of multi-level production planning: a make-to-order product

There have been different approaches for production planning of multi-level production systems. According to the type of the production system regarded at each level it can be classified (Kolisch, 2000) as:

(i) integrated project scheduling and part ordering,

(ii) multi-level capacitated lot sizing, and

(iii) integrated lot sizing and scheduling.

2.3.4.1 Integrated project scheduling and part ordering

Project scheduling and part ordering depicts the case where on the first level multiple projects have to be scheduled subject to precedence and resource constraints. The jobs of the project require parts at the second level. Costs associated with the parts are ordering and holding cost.

(Aquilano and Smith, 1980) were the first who integrated project scheduling and material requirements planning. Without providing a formal decision model, they depict a single project which has to be scheduled subject to precedence constraints only. The jobs of the project require parts. In order to determine the time-phased

demand for these parts, a two-stage approach was proposed. First, latest start times for the jobs are calculated by traditional backward recursion (Elmaghraby, 1977) from the project's due date. The obtained start times determine the gross requirements for parts. The second phase performs calculation of the net requirement by balancing gross requirements, on the hand inventories, and scheduled receipts in a forward oriented fashion (Vollmann *et al.*, 1992). Finally, a lot-for-lot policy is used to calculate planned production quantities for the parts.
Hastings et al (Hastings *et al.*, 1982) extend this approach. They performed forward oriented scheduling of jobs by explicitly considering scarce capacities. The time-phased demand of parts is obtained from the earliest precedence and resource feasible start times of the jobs. Hastings et al. coin this approach "schedule-based materials requirements planning" instead of "lead time materials requirements planning" which derives the start times of jobs by un-capacitated backward recursion of jobs from the due date. Sum and Hill (Sum and Hill, 1993) consider multiple projects, scarce capacities on the scheduling level, and lot sizing decisions on the fabrication level. Without providing a decision model, they suggest a two-stage approach. First, backward loading of the jobs subject to capacity constraints is done. Second, three greedy heuristics are proposed in order to perform the order sizing for the time-phased part demand of the jobs. Smith-Daniels (Smith-Daniels and Smith-Daniels, 1987) extended the work of (Aquilano and Smith, 1980). They propose a MIP model for a single project, multi-part ordering problem where a single project has to be scheduled such that the sum of holding cost for parts and jobs, ordering cost for parts, and penalty cost for a project delay is minimized. An MIP model is proposed and it is shown that the optimal solution is obtained by realizing a late-start schedule and solving the remaining single-level un-capacitated dynamic lot sizing models to optimality. In an experimental investigation Smith-Daniels compared the optimal solutions to the ones which were obtained by a lot-for-lot strategy and showed that the latter resulted in significantly higher cost. The scope of the model is headed towards a cash oriented perspective. The objective function maximizes the net present value of the integrated project scheduling and part ordering model and a new constraint depicts the dynamic cash balance constraint for each period.

Dodin and Elimam (Dodin and Elimam, 2001) modified the model of Smith-Daniels (Smith-Daniels and Smith-Daniels, 1987) by allowing job crashing and considering rewards for project termination ahead of the due date. Dodin and Elimam show (i) that in the case of no reward payments an optimal solution is obtained by scheduling every job at its latest start time and (ii) that the optimal schedule either start at time zero or ends at the projects due date. Based on these observations, Dodin and Elimam device a simple heuristic which, based on the instance at hand, alternatively generates an earliest start or latest start schedule with jobs at normal or at crash duration. The remaining lot-size problems are solved with the part-period heuristic (DeMatteis, 1968). Ronen and Trietsch (Ronen and Trietsch, 1998) consider the case where the parts demanded by jobs can be sourced from different suppliers. Furthermore, the processing times of jobs and the lead time of parts is not deterministic but stochastic. Each part-supplier combination is defined by a price and a lead time distribution. Holding cost accrue if parts arrive ahead of the time needed by the job.

If late parts delay the project beyond its due date, lateness cost is debited. The decision problem is, to choose for each part a supplier and an ordering time such that the total expected cost is minimized. Assuming that the variability of the processing times is negligible, Ronen and Trietsch proposed the following solution procedure. First, latest start times of the jobs are computed by backward recursion from the project's due date (Elmaghraby, 1977). Then, order times for each part are computed, and finally, a supplier is chosen for each part. The method is embedded in a decision support system (Ronen and Trietsch, 1998).

2.3.4.2 Multi-level capacitated lot sizing

Multi-level capacitated lot sizing models depict a production system with multiple levels where on each level lot sizing rather than scheduling decision has to be undertaken. Given are the demands for multiple parts (which are usually referred to as items) where each part is depicted by a multi-level product structure. Each part within the product structure has to be fabricated on one level of the production system. Since there is no priority in lot size, any amount of a part can be produced as long as the capacity constraints are respected. Production of a part incurs setup cost and in some cases setup times; part inventories incur holding cost. The problem is to obtain a cost minimal production plan which respects the scarce capacities of the resources on all levels of the production system and delivers final demand parts without backlogging. Models and methods for these intricate problems can be distinguished w.r.t. the type of product structure allowed and w.r.t. the amount of aggregation. Regarding the product structure, general product structures and assembly product structures can be distinguished (Eppen and Martin, 1987). Regarding the amount of aggregation, so called big bucket and small bucket models can be distinguished. Big bucket models such as the capacitated lot sizing problem (CLSP) has a rather high aggregation level where one period amounts about a week. Here, scheduling decisions, which determine the sequence of production lots in one period are not taken into account. Contrary, in small bucket models, a period embraces a smaller time span and the planning problem is to simultaneously determine lot sizes and lot sequences in each period. Multi-level big bucket problems with general product structures have been addressed in (Stadtler, 1996) and (Templemeier and Helber, 1994). Helber gave a cash-flow oriented model where the net present value is maximized. Work on special big bucket problems where either serial or assembly product structures are taken into account or constrained resources are only considered on one production level can be found, amongst others, in (Harrison and Lewis, 1996) and (Kuik *et al.*, 1993). Work on multilevel, small bucket models with general product structures has been presented by (Kimms, 1997).

2.3.4.3 Integrated lot sizing and scheduling

Lasserre (Lasserre, 1992) introduces a model which integrates the lot sizing decision on an aggregated decision level and the scheduling decision on a detailed decision level. The lot sizing decision is modeled as a multi-part, single level CLSP and the scheduling decision is modeled as a job shop problem (JSP) (Pinedo, 1995). The production decisions for one period in the lot sizing model determine an entire JSP. (Dauzere-Peres and Lasserre, 1994) propose a solution method which alternates between solving the lot sizing problem for a fixed sequence of the jobs at the machines and solving the scheduling problem for given lot sizes. In the evolution of a ship through the various production stages, e.g., shops, panel shops, where similar jobs are repeated, it might encounter problems where decision of parts ordering and lot sizing are encountered frequently even if other planning tools are set to play. Above survey brings out a rational conclusion that integration of multilevel production planning may produce different solution to different engineering problem. However, the success of the application of any of the methods will depend on the heuristic analysis of the concerned project planner.

From the literature, it is observed that the effort for integration of the project has been on the basis of lead time of production activity but a clear understanding of how the project activities are interrelated for collaborative progression of the project has not been studied. Objective of the optimization in the second level was on the basis of lot sizing and part ordering cost but no consideration of resource arrangement has been attempted.

2.4 Necessity of project management in shipbuilding

The use of project management techniques and knowledge as a combination of tools for managing simple to relative complex projects experienced in our everyday life continues to grow with the advancement of civilization and technology. Since the start of industrial revolution, the world has seen a remarkable growth in the size and complexity of organization. The artisan's shops of primitive era have evolved into million-pound corporations of today. An integral part of this revolutionary change has been a tremendous increase in the division of labor and segmentation of management responsibilities in the organizations. The results have been spectacular. However, along with its blessings, this increasing specialization has created new problems, problems that are still occurring in many organizations. One problem is the competitions among the organizations for market access with effective products and services within relatively shortest possible time and budget. This has necessitated the augmentation of planning the project implementation sequences. Project management has earned its highest ever attention from the leaders in industry in past two decades. In 1950's and 1960's, the aerospace, defense, and large construction industries were the primary users of project management techniques and tools. Project management has come forward because the characteristics of our present-day society demand the development of new methods of management. Of the many forces involved, three are dominant:

1. the exponential expansion of human knowledge and mental capacity; 2. the growing demand for a broad range of complex, sophisticated, customized goods and services; and 3. the evolution of worldwide competitive markets for the production and consumption of goods and services. All three forces combined synergy mandates the use of teams to solve problems that used to be solved by individuals. It is felt no greater anywhere than in shipbuilding. These influences have increased the complexity of products or produced services and the processes used to produce them in multi-folds. In the past, we have experienced vast majority of the projects as external in nature to the organization--building a new skyscraper, designing and launching a space shuttle- but the use of projects lately had primarily been in the area of projects internal to organization: developing new product, opening a new venture, improving services, though the external projects still continue to grow. This chapter will further traverse through the practiced standard, steps and explanation in project management and planning methods, management philosophies and application. Core five steps project management structure, as depicted in subsequent sections, has been encouraged by the spirit of PMBOK®GUIDE of project management institute.

2.4.1 Project management importance

The basic purpose of initiating a shipbuilding project is to achieve delivery goals and accomplish jobs within scheduled time. The reason for organizing the tasks as project is to focus the responsibility and authority for the attainment of goals on an individual level or small group. In spite of the fact that the project manager (PM) often lacks the authority at the level consistent with his or her responsibility, the manager is expected to coordinate and integrate all activities needed to reach the project's goal.

Feedback on project management indicates that the majority of the organizations using it’s experience for better control and better customer relations, (Davis, 1974), and probably an increase in their project's return on investment (Ibbs and Kwak, 1997). A shorter development time, lower costs, higher quality and reliability, and higher profit margins, sharper orientation towards results, better interdepartmental coordination and higher worker morale are a few of the many derivatives from organized project management.

On the negative side, most organizations report that project management results in greater organizational complexity. Many also report that project organization increases the likelihood that organizational policy will be violated considering the degree of autonomy required for the PM. A few firms reported higher costs, more management difficulties, and low personnel utilization (Meredith and Samuel, 2010). The disadvantages of project management also emanate from the same sources- but the balance of project management weighs in favor of the advantages if the work to be done is appropriate for a project. However, in shipyards each shipbuilding project is regarded as enormous tasks required to be realized over months and, hence organized project management techniques are adopted as initiated by the organization.

There is also real limitation of the project management. The mere creation of a project may be an admission that the parent organization and its managers cannot accomplish the desired outcomes through the functional organization. In a shipyard, though there are functional departments but they are required to be coordinated for multiple projects. Hence, each project is required to be managed by PM. The stake or risks in using project management may be high, but no more so than in any other form of management.

2.4.2 Strategic planning in project

Projects are often utilized as a means of achieving an organization's strategic plan. Projects are typically authorized as a result of one or more of the following strategic considerations (PMI., 2008):

i) Market demand (e.g., a car company authorizing a project to build more fuel-efficient cars in response to gasoline shortages),
ii) Strategic opportunity/business need (e.g., a training company authorizing a project to create a new course to increase its revenues),
iii) Customer request (e.g., a shipyard is designing a new tanker in response to a customer's new trading route plan),
iv) Technological advance (e.g., an electronics firm authorizing a new project to develop a faster, cheaper, and smaller laptop after advances in computer memory and electronics technology), and

v) Legal requirements (e.g., a shipyard authorizes a project to establish guidelines for the compliance with new PSPC-performance standard for protective coatings-regulation in paint coating).

Strategic planning for project management is the development of a standard methodology of project management, which can be used over and over again, and which will produce a high likelihood of achieving the project's objectives (Kerzner, 2004). Although a group of projects within a program can have discrete benefits, they can also contribute to the benefits of the program, to the objectives of the portfolio, and to the strategic plan of the organization A hierarchy of objectives and strategies can be formed as a result of using strategy planning process; this can be a very effective means of structuring and managing strategy and communicating it to the organization (Ashley and Peter, 2004). It should be noted that a program is defined as a group of related projects managed in a coordinated way to obtain benefits and control not available from managing them individually. This can be replicated in the case of series of marine vessels being produced from the same design. Programs may include elements of related works outside the scope of the discrete projects in the program. Without the repetitive process of strategic planning, sub-units end to drift off in their own direction without regards to their role as a subsystem in a larger system of goals and objectives. Another advantage is that it provides a vehicle for the communication of overall goals to all level of management in the organization (Kerzner, 2004).

2.4.3 Operations management in project

In any organization, only two aspects of work exist—on-going operations and projects. Projects are defined as unique, temporary endeavors with a specific beginning and end. Operations constitute an organization's on-going, repetitive activities, such as accounting or production (Projectinsight., 2012). Though temporary in nature, projects can help achieve the organizational goals when they are aligned with the organization's strategy. Organizations sometimes change their operations, products, or systems by creating strategic business initiatives. Projects require project management while operations require business process management or operations management. Projects can intersect with operations at various points during the product life cycle, such as:

- At each closeout phase;
- When developing a new product, upgrading a product, or expanding outputs;
- Improvement of operations or the product development process; or
- Until the divestment of the operations at the end of the product life cycle.

At each point, deliverables and knowledge are transferred between the project and operations for implementation of the delivered work. Operations are permanent endeavors that produce repetitive outputs, with resources assigned to do basically the same set of tasks according to the standards institutionalized in a product life cycle. Unlike the ongoing nature of operations, projects are temporary endeavors. Organizations perform work to achieve a set of objectives. In many organizations the work performed can be categorized as either project or operations work. Projects and operations differ primarily in those operations are ongoing and produce repetitive products, services, or results. Projects, along with team members and often the opportunity, are temporary and end. Conversely, operations work is ongoing and sustains the organization over time. Operations work does not terminate when its current objectives are met but instead follow new directions to support the organization's strategic plans. Operations work supports the business environment where projects are executed. As a result, there is generally a significant amount of interaction between the operations departments and the project team as they work together to achieve project goals. An example of this is when a project is created to redesign a sailing boat in boat building company with design capability. The project manager may work with multiple operational managers to research sailing preferences over existing designs, draw up technical specifications, build a prototype, test it, and begin manufacturing. The team will interface with the operational departments to determine the manufacturing capacity of current equipment, or to determine the most appropriate time to transform production lines to produce the new product. The amount of resources supplied from operations will vary from project to project. Interaction is evitable when individuals from operations are assigned as dedicated project resources. Their operational expertise is used to carry out and assist in the completion of project deliverables by working with the rest of the project team to complete the project. Depending on the nature of the project, the deliverables may modify or contribute to the existing operations work. In this case, the operations department will integrate the deliverables into future business practices. Information system developing, enhancing of an operational department.

2.4.4 Project lifecycle and organization

Most projects go through similar stages on the path from origin to completion, i.e., slow start and slow finish in the scale of percentage completion and these two stages encompass project lifecycle in between (Jack and Samuel, 2003). Projects and project management take place in an environment that is broader than that of the project itself. Understanding this broader context helps ensure that work is carried out in alignment with the goals of the enterprise and managed in accordance with the established practice methodologies of the organization.
Different writers have stressed on different phases in the lifecycle. Weisss and Wysocki have proposed a five step such as define, plan, organize, execute and close in the lifecycle (Weiss and Wysocki, 1994). A life cycle can be documented with a methodology. The project life cycle can be determined or shaped by the unique aspects of the organization, industry or technology employed. While every project has a definite start and a definite end, the specific deliverables and activities that take place in between will vary widely with the project. The life cycle provides the basic framework for managing the project, regardless of the specific work involved.

Projects vary in size and complexity. No matter how large or small, simple or complex, all projects can be mapped to the following life cycle structure, see Figure 2.1:

- Starting the project,
- Organizing and preparing,
- Carrying out the project work, and
- Closing the project.

This generic life cycle structure is often referred to when communicating with upper management or other entities less familiar with the details of the project. This high-level view can provide a common frame of reference for comparing projects—even if they are dissimilar in nature.

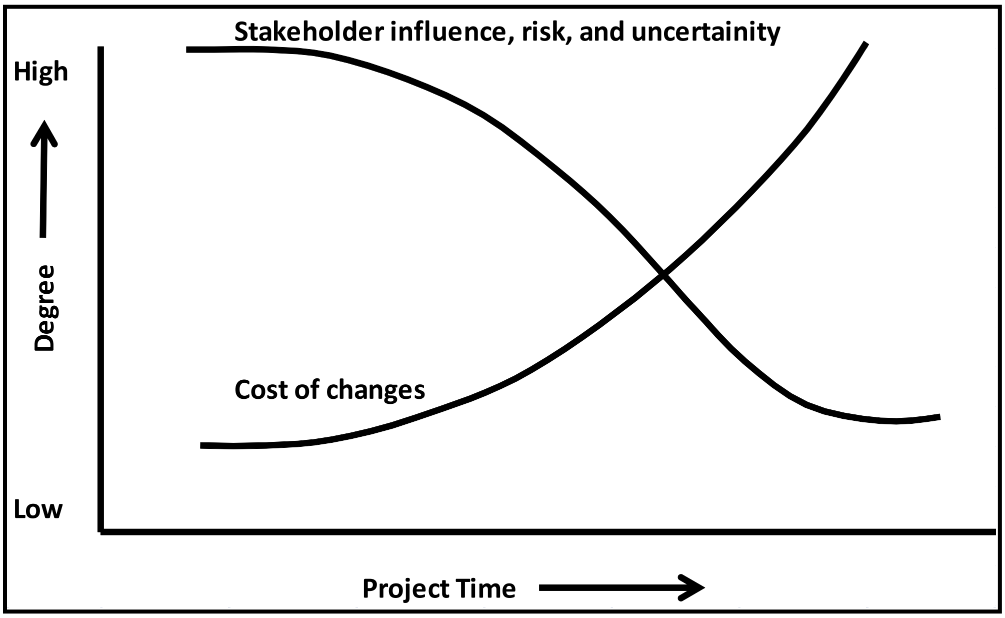


Figure 2.1 -Typical cost and staffing levels across the project life cycle: adapted from (PMI., 2008)

The generic life cycle structure generally displays the following characteristics:

- Cost and staffing levels are low at the start, peak as the work is carried out, and drop rapidly as the project draws to a close. The dashed line in Figure 2.1 illustrates this typical pattern.
- Stakeholder influences, risk, and uncertainty, are greatest at the start of the project. These factors decrease over the life of the project.
- Ability to influence the final characteristics of the project's product, without significantly impacting cost, is highest at the start of the project and decreases as the project progresses towards completion. Figure 2.2 illustrates the idea that the cost of changes and correcting errors typically increases substantially as the project approaches completion.

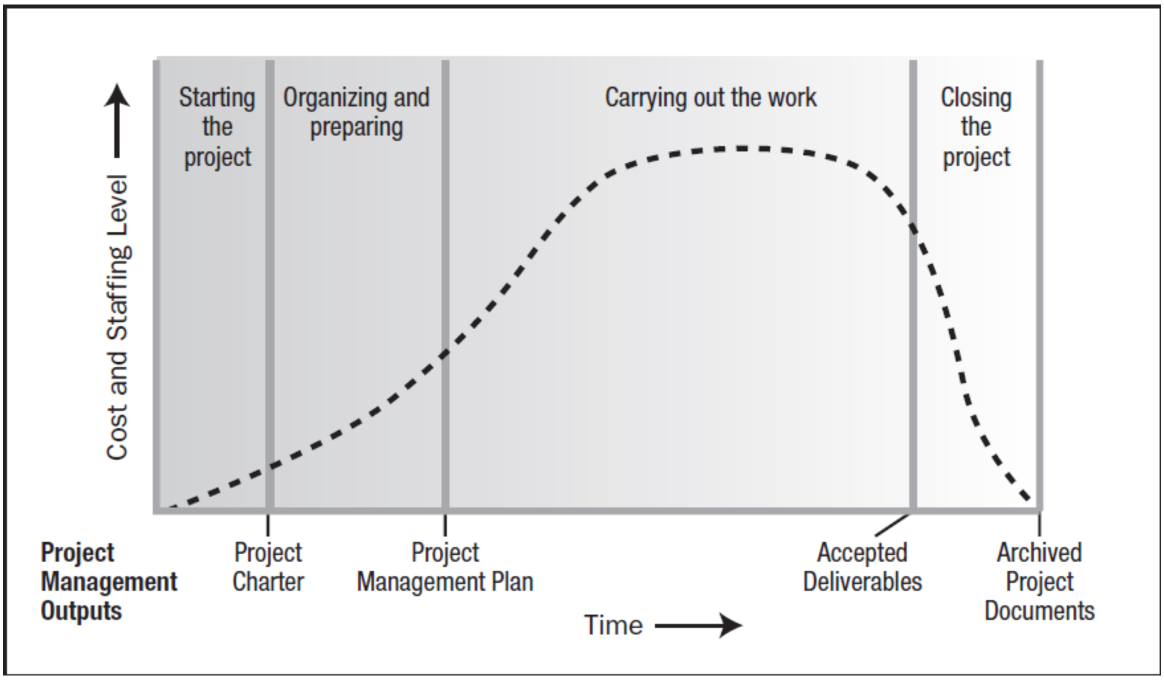


Figure 2.2 -Impact of variable based on project time (PMI., 2008)

The last product life cycle phase for a product is generally the product's retirement. Project life cycles occur in one or more phases of a product life cycle. All projects have a purpose or objective, but in those cases where the objective is a service or result, there may be a life cycle for the service or result, not a product life cycle.

When the output of the project is related to a product, there are many possible relationships. For instance, the development of a new product could be a project on its own. Alternatively, an existing product might benefit from a project to add new functions or features, or a project might be created to develop a new model. Many facets of the product life cycle lend themselves to being run as projects, for example, performing a feasibility study, conducting market research, running an advertising campaign, installing a product, holding focus groups, conducting a product trial in a test market, etc. In each of these examples, the project life cycle would differ from the product life cycle. Shipbuilding project lifecycle is temporary and many of the standard project management practices for researching into the product type and acceptance are waived by the fact that prior to embarking on the actual building, the yard and owner come an agreement for equipment quality.

2.5 Summary

In this chapter, an extensive survey is conducted on the application of different scheduling techniques integrated in the planning of the project and production of the project subset activities. Some literatures on the importance of project management in shipbuilding areas are studied. Various management concepts like project management, production management, process management and scheduling are also demonstrated to differentiate from each other. It will be convenient for the reader to note that sometimes the words 'project' and 'production' might be used inter alia to describe a manufacturing phenomenon. Application of different techniques to make efficient scheduling, production planning has been seen in the research. However, the presence of optimal approach to integrated project planning and production of the project elements or activities has not been identified in the literature to address the problem identified in Chapter one. Upon reviewing production planning literature and established methods for managing scheduling in the engineering field, it is recognized that cost has been the major optimization goal in those schemes. Shipbuilding projects have seen the application of simulation technology in managing production, spatial layout, spatial arrangement of blocks, erection sequences, assembly sequences and in some instances CAD has also been used as a medium of simulation for advance study of construction. Few of the published literatures have been excerpted, reviewed and discussed in greater length for the convenience of in-depth understanding of the readers.

It has been identified that two major issues have no explicit mention in those studied literature:

a. Sequence study of shipbuilding projects optimized manufacturing where sequence can be clearly modularized in concurrency and granular production management can be adopted for optimum output.

b. Arrangement of optimal resources considering the interaction of resources or factors with each other and their influence on the dynamics of output measures.

Therefore, this research is focused and directed to bridge these identified gaps in literature and to propose a method, which will be applied in an ongoing shipbuilding project in a selected shipyard for validation.

3 Chapter Three. Techniques and Tools in Shipbuilding

3.1 Introduction

A shipbuilding project needs different types of techniques and tools in each stage of its production process. The high complexity of ship production, due to the interaction of many different disciplines, requires intensive and detailed techniques and tools for production scheduling, planning and management. It is necessary to increase the number of simultaneous tasks in order to obtain the best quality, the lowest price, and the shortest manufacturing lead time during the ship production process and these could only be achieved if a shipyard intends to use designated tools for the desired production. In the following section techniques and tools for a detailed production scheduling, planning and project management will be described.

3.2 Techniques and tools for shipbuilding project scheduling

Many of the literatures to date deal with scheduling problems in the field of operation research. Shipbuilding specific scheduling researches were conducted in a supportive environment mainly to cater to the interest of shipbuilding companies. Korea, USA and Germany have spearheaded research in the domain of shipbuilding scheduling. In following sections, a brief of the works so far carried out by joint effort of industry, academia and government will be discussed so that background research in the developed tools and techniques leading up to the present time can be grasped in a successive manner.

3.2.1 Scheduling system developed by Daewoo

Daewoo Shipbuilding Company, known as one of the largest shipbuilders in the world, had been facing with difficulties in planning and scheduling its production process. To address the issue Korea Advanced Institute of Science and Technology and Daewoo have teamed up to jointly perform a project called DAS (Daewoo Shipbuilding Scheduling) project between 1991 to 1993. This project is seen to be one of the earliest project in the field of shipbuilding scheduling and production planning in modern time. Shipbuilding is largely a make-to-order industry and production may time spans over years. Since the manufacturing process from the time of orders to final delivery is very complicated, the scheduling and control of human, material resources, and facilities a very complex task and reportedly a nightmare for the schedulers. Daewoo had attempted various project management software such as PRO-JACS, VISION and X-PERT, as well as in-house development with conventional programs with no success as this software primarily failed to grasp the complex interrelated scheduling activities and dynamic spatial layout of resources. DAS project adopted various operational research and artificial intelligence techniques to cope with the scheduling task. DAS project is divided into four key sub-system (J. K. Lee *et al.*, 1995):

DAS-ERECT: Erection scheduler at Docks

DAS-CURVE: Curved Block Assembly Shop Scheduler

DAS-PANEL: Paneled block assembly shop Scheduler

DAS-MH: Neural Network Based Man-Hour Estimator

Key approaches that have contributed to the success of DAS project can be categorized as follows:

1. Hierarchical Architecture for shipbuilding scheduling
2. Constraint Direct Graph Search
3. Spatial Scheduling
4. Dynamic Assembly Line Scheduling
5. Neural Network Based Man-hours Estimation
6. Three phased development strategy

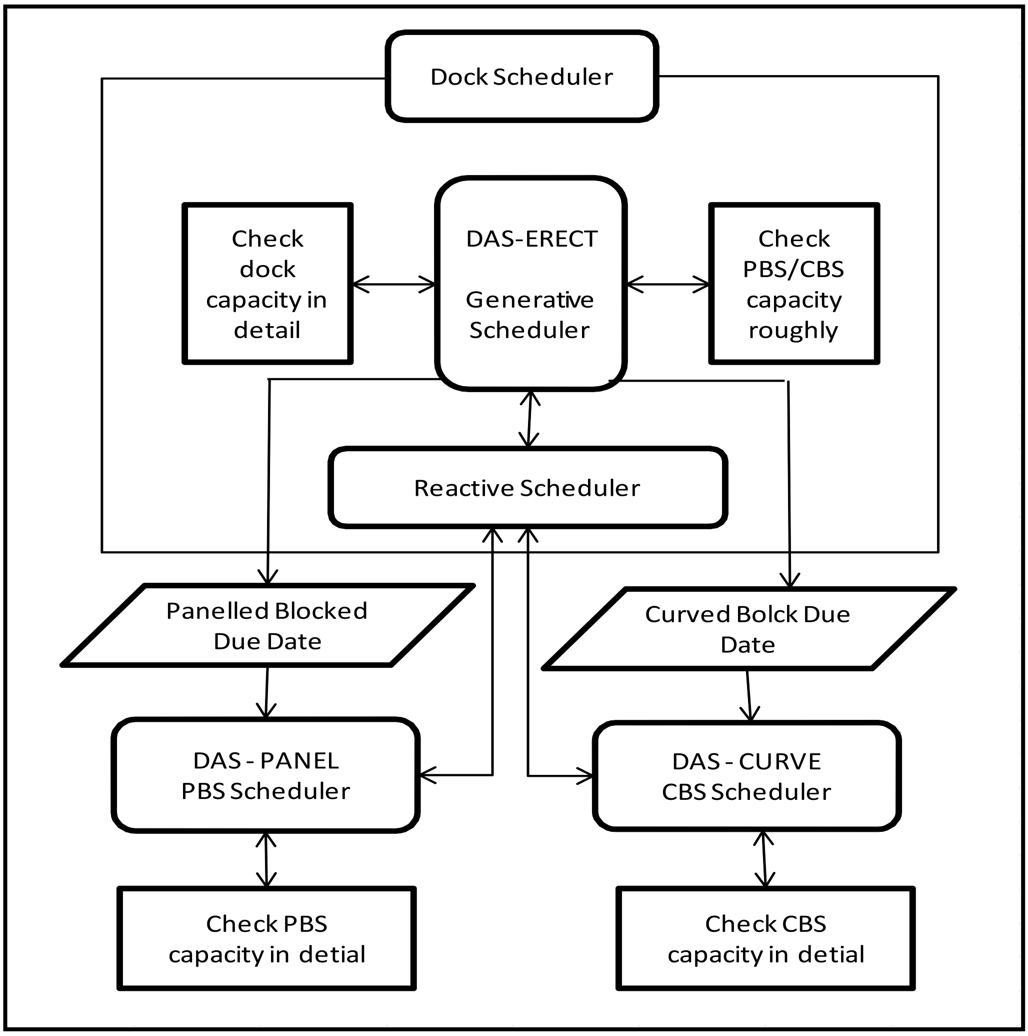


Figure 3.1 -Hierarchical architecture of shipbuilding scheduling: adapted from (J. K. Lee et al., 1995)

3.2.2 Hierarchical architecture for shipbuilding scheduling

This section deals with the scheduling of blocks at the dock and for this purpose, DAS-ERECT employs the hierarchical scheduling architecture along with the constraint directed graph search technique, during the generative scheduling stage, DAS-ERECT considers only the aggregate capacities of lower-level assembly shops like PBS (Panel led Block Assembly Shop) and CBS (Curved Block Assembly Shop). DAS-ERECT requests the relevant lower-level schedulers to deliverer blocks by the due date as shown in Figure 3.1. The scheduler at PBS and CBS- DAS-PANEL and DAS-CURVE, respectively schedules its own work area according to the requested due dates as well the detailed spatial and manpower constraints. In case of inconsistency, the lower-level shop scheduler reports problems to the higher level for adjustment of overtime level or due date.

3.2.3 Constraint direct graph Search

This search technique employs bottleneck review of the process as PERT (Program Evaluation and Review Technique) tool cannot handle capacity constraint. The important characteristics of erection scheduling can be summarized as follows:

a. Sequential erection at each dock

b. Large Search space

c. Technical Knowledge for Erection Sequencing

d. Utilization of resources, with objectives of

- Balanced loads among different stages of assembly operations

-Minimization of makespan and constraints of

-Human resource capacity in terms of man-hour

-Crane capacity

-Area capacity of workplaces.

-General technical constraint

-Constraints on partial sequence

-Constraints on precedence relationship

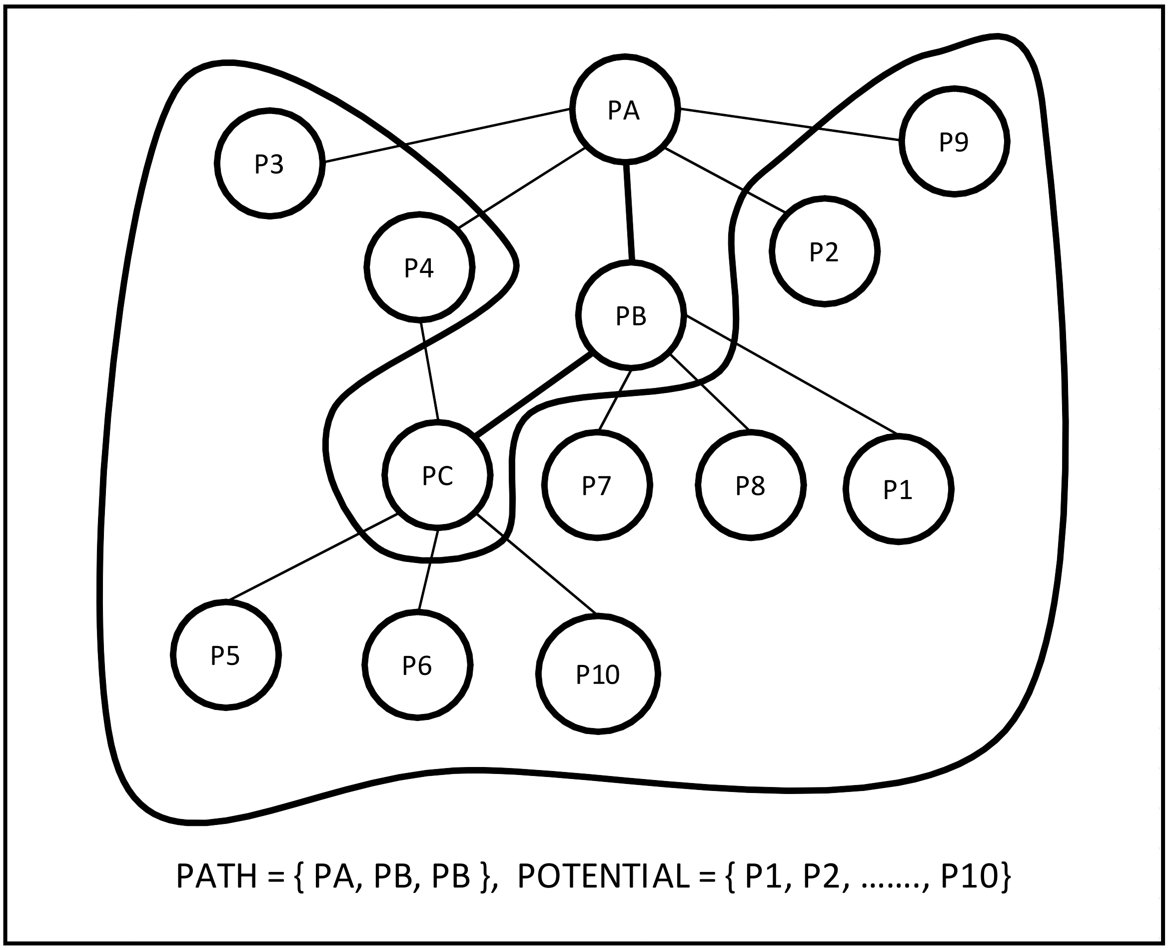


Figure 3.2 -Partially expanded graph search: adapted from (J. K. Lee et al., 1995)

In constraint directed search technique each node in the graph represents a block of the ship as shown in Figure 3.2. The graph search expands nodes and selects proper nodes possibly using an evaluation function. Application of pure graph search is limited as the measurement of multiple evaluation will be difficult to evaluate. Hence constraint directed graph search algorithm proves to be effective to handle this problem (J. K. Lee *et al.*, 1995).

3.2.4 Spatial scheduling in shipbuilding

It is necessary to employ expensive material handling equipment like cranes and work plates to handle heavy bulky blocks in shipyard. Since the space equipped with such facility is limited and bottlenecked, the scheduling needs to consider the spatial resources as well as traditional ones like manpower and machines. This is known as spatial scheduling. As the term implies, the spatial scheduling deals with the optimal dynamic spatial layout schedules. Figure 3.3 displays a spatial position of erectable blocks. In a shipyard, spatial scheduling problems occurs in various working areas like erection docks, pre-erection shops and block -assembly shops. So far, the spatial scheduling has been carried out manually without any automated aids, even though human experts have much experience in spatial scheduling, it takes a long time and heavy effort to produce a satisfactory schedule because of its huge search space required to consider blocks geometric shapes. Since spatial scheduling for six months is beyond the scope of human mental capacity, it has been impossible to build such a large spatial schedule in advance, Therefore, automation of spatial scheduling process has been a critical issue for the improvement of productivity in the shipbuilding plants and the total integration of scheduling system. In Daewoo, there has been some prior attempts to solve the spatial scheduling. One approach was a simple spatial scheduling system approximating the shape of the blocks to rectangle, but the field schedulers rejected using it because the approximation sacrifices the spatial utilization too much. In their research, the system called DAS-CURVE approximates the blocks shape to polygons as the users agreed.

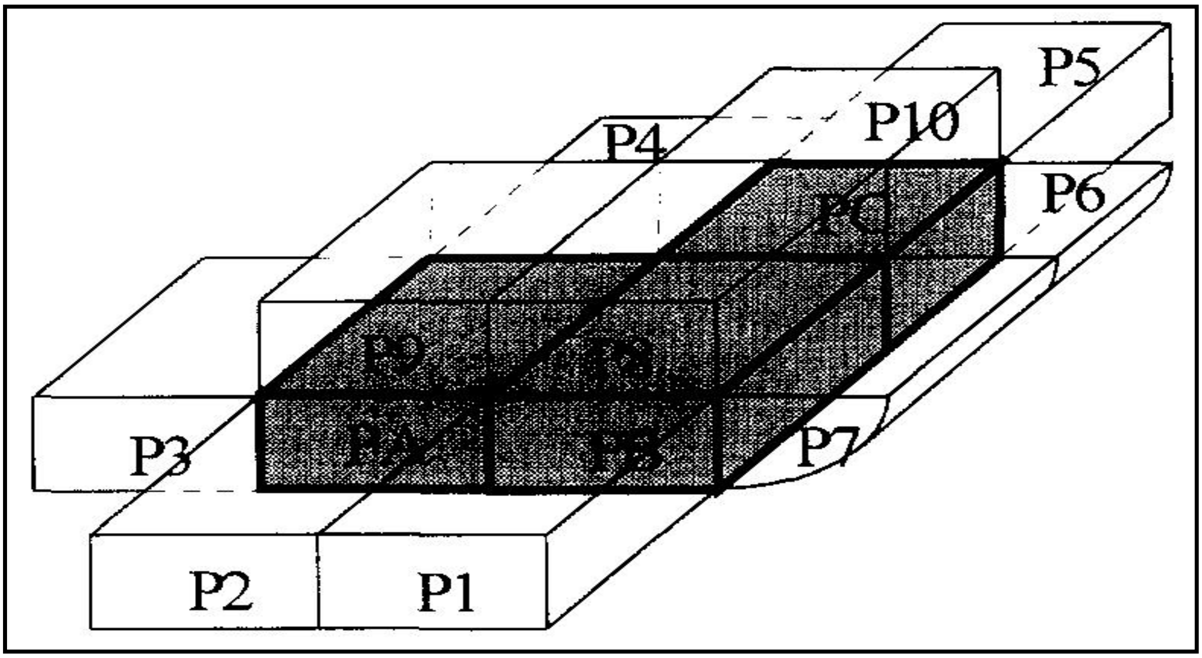


Figure 3.3-Spatial position of potentially erectable blocks (J. K. Lee et al., 1995)

The objectives of spatial scheduling may vary somewhat, depending on the manner of a given plant. In general, however, spatial scheduling system pursue due date satisfaction, maximal utilization of spatial and non-spatial resources, and minimization of waiting time for work-in process and final product inventories, Typical constraints include crane capacity, man-hour availability, assembly due date, precedence between associated assemblies, physical adjacency for coupled objects for operational efficiency, minimum required distance between blocks, and maximum acceptable waiting time for completed and work-in-process blocks, Typical necessary input data include jobs with due-dates and their constituent activities, required processing time for each activity, spatial shapes of work plates. In shipbuilding domain, the shapes of most objects tend to be convex polygons like triangles, rectangles, or trapezoids, some blocks may have some local concavity, However, in most cases, the local concave space is not usable by other objects. Therefore, they can be approximated as convex polygons.

3.2.4.1 Search space in spatial scheduling

Algorithm for spatial scheduling has been written considering the following sequence and constraints. To find a feasible position of an object a_i within a work plate 'W' that do not overlap a scheduled object b_i , the notion of *configuration space* was adopted which is the reference point of an object (a robot for example) with fixed orientation can possibly pass without colliding with present obstacle. Thus, this algorithm tackles two kind *configuration spaces*

-*Obstacle avoiding space*

-*Inner locatable space*

and arrive at *feasible locatable space*

3.2.5 Paneled block assembly shop scheduler

DAS-Panel covers the area of blocks and their sub-assemblies are welded on the assembly lines and adjacent off-lines respectively, Since the block size and compositions of sub-assemblies as well as the main assembly line should not be fixed in advance as shown in Figure 3.4. To improve the productivity of the

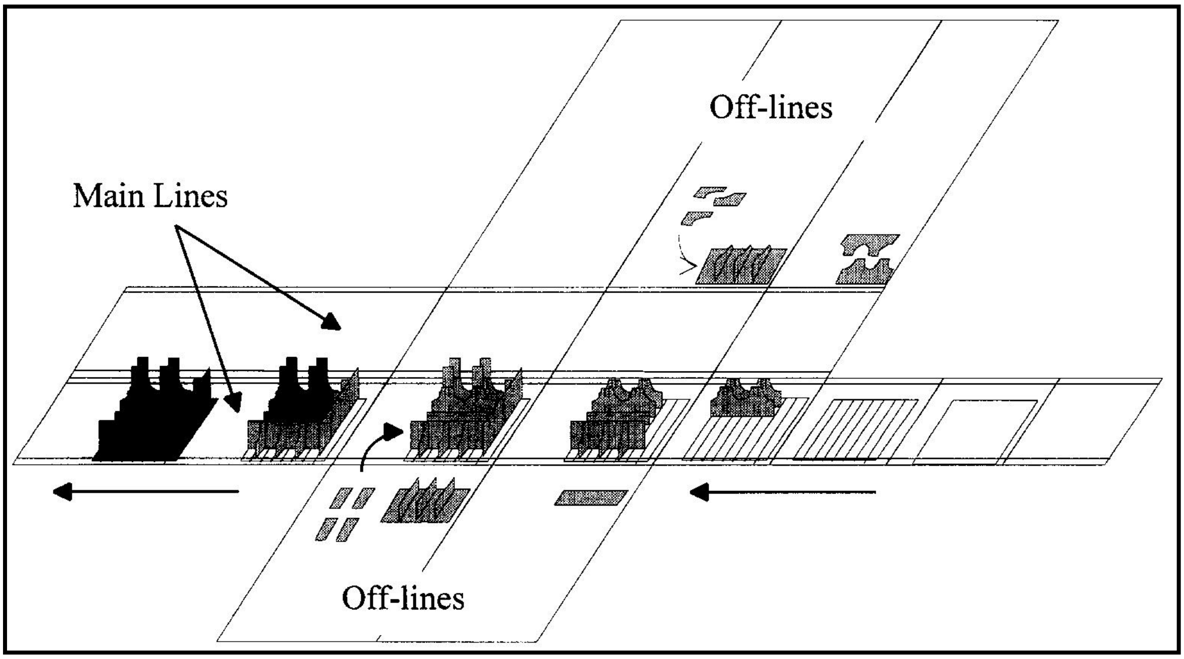


Figure 3.4-Typical assembly line (J. K. Lee et al., 1995)

assembly line, it was necessary to generate a schedule which can dynamically change the cycle time according to the characteristics of the blocks as shown in Figure 3.5. Its objective is not only to minimize the assembling time on the mainline, but also the waiting time of the sub-assemblies and blocks. DAS-PANEL was built using typical forward changing dynamic rule-based tool UNIK-FWD.

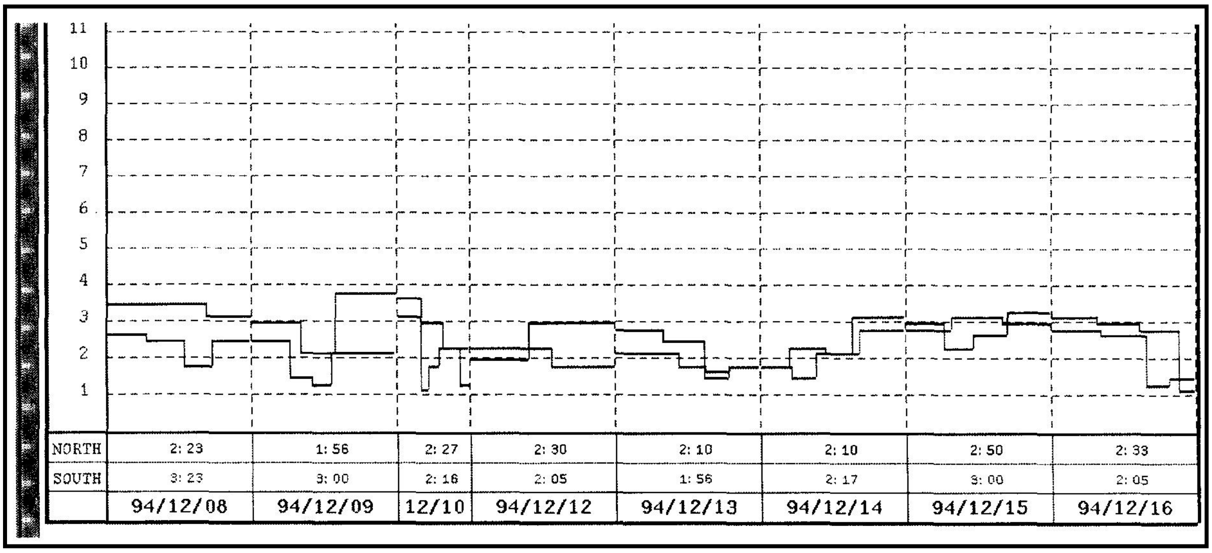


Figure 3.5- Output screen showing dynamically changing cycle time in DAS-PANEL (J. K. Lee et al., 1995)

3.2.6 Neural network-based man-hour estimator

To establish reliable scheduling system, the estimation of accurate man-hour requirement for each assembly is the pre-requisite. To supply the required welding man-hours inputs of each one-of-a-kind block for DAS scheduling systems, they adopted the artificial neural network as an estimator. They followed the following research procedure to build a reliable and efficient neural network:

-Select candidate variable: Four categories of variables were selected such as ship type, block type, block's physical characteristics, shop type

-Eliminate unnecessary variables: Highly correlated redundant cardinal variables were filtered out.

-Train and test the neural network with or without the preprocessing

- Compare and estimation performance by the neural network with the one by the regression analysis.

This neural network based estimator were reportedly outperformed the traditional unit estimator based on simple linear regression. However, this method has not considered the dynamic shift of man-hour in the non-linear environment. Man-hour and the four categories selected may not necessarily produce a linear relationship. One might argue that DAS method has only considered steel fabrication and block erection schedule in relation to spatial arrangement while shipbuilding has many other key stages which might need to be looked upon holistically at for an integrated scheduling. While DAS method may have facilitated multiple schedule scenario simulation for the field schedulers, it is constrained to CAD input of block geometries at the earliest stage of scheduling which limits its use only to the schedule of post design plant usage and a very important aspect of plant scheduling has not been addressed-a contingent scheduling system for change in the layout and facilities. This method may be very effective for the very shipyard it was developed for, however, this has not dealt with the initial project planning except for shop scheduling.

3.3 Techniques and tools for production planning

3.3.1 Dalian dynamic production planning

Dalian Shipbuilding Industry Co., Ltd. (DSIC) is the largest shipbuilding endeavor in China, and also one the largest in the world. DSIC has successively developed, designed and built many typical products that represent the advanced shipbuilding technology in China. It has formed a large-scale, serial and mass production for a 300,000 dwt VLCC (Very Large Crude Oil Carrier) and an 110,000 dwt Product Oil Tanker. This new kind of shipbuilding approach is helpful in reducing costs and shortening shipbuilding time. Therefore, DSIC adopted this corresponding management method and planning system.

Dynamic Production Planning System (DPPS) is proposed (Xiaobing *et al.*, 2008) according to the requirements and characteristics in large shipbuilding enterprises such as DSIC with main conditions of mass production and uncertainties. To perform capacity planning, workload is measured by material quantity, using physical distribution scheduling which traditionally was considered only to distribute materials. Since this research is oriented to a real life problem, they proposed a simplified simulated annealing (SSA) algorithm to get a meta-optimal plan at any required time.

The concept, as they call Triennium Rolling Production Plan (TRPP), is described in segmented presentation;

1.the hierarchical architecture for the DPPS and the contents and functions of each layer are introduced.
2. the critical object-oriented models are given to show how these important factors are integrated to the planning system.
3. physical distribution algorithm given using an assumption that the production process follows a normal distribution.

3.3.2 System architecture and model

(Xiaobing *et al.*, 2008) contended that there have been developed both normal project and the multi-project management methods and tools by scholars over past years. Many of them have been used successfully in shipbuilding enterprises. Valuable as these tools are, they have serious limitations in practice for project management in modern shipbuilding enterprises. Today, most of the shipbuilding orders tend to call for several ships with similar designs, not many different ship designs as in the past. As many as 14 ships in the same series have been ordered from DSIC to be delivered within 5 years. They share many similar characteristics as defined by PERT. Considering them at the same time is more efficient than planning for them individually. The standard takt time can be developed for each type of project. Based on this idea, the TRPP can be accomplished easily and effectively.

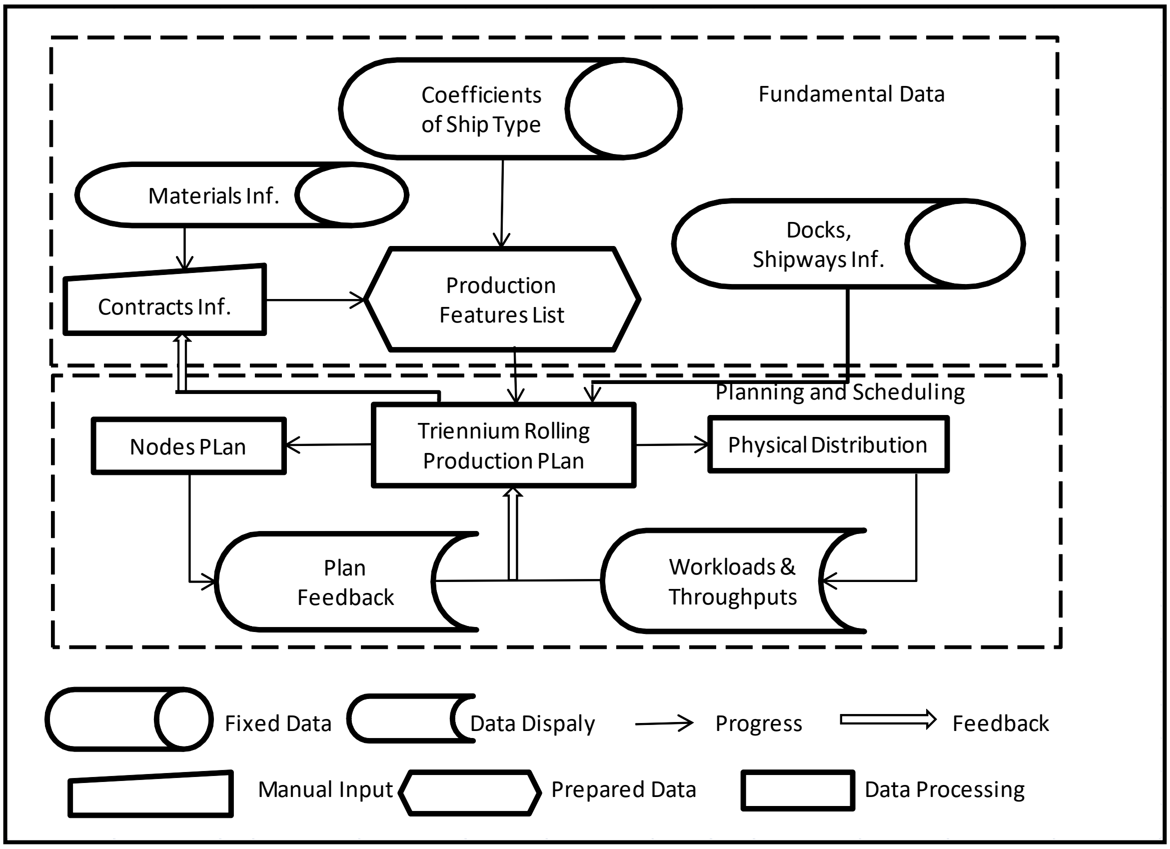


Figure 3.6 -Dynamic production planning (DPPS) system architecture: adapted from (Xiaobing et al., 2008)

3.3.2.1 Dynamic production plan system architecture

The DPPS employs a hierarchical architecture as shown in Figure 3.6. It also shows the information flows and the feedback. The first layer consists of fundamental data. All of the data can be considered as the system constraints. The information about materials, coefficients of all ship types, docks and slipways include some fixed data. Contracts are mainly manually input according to materials information and feedback from the simulated TRPP which is partly based on one or more virtual contracts. Almost all fundamental data are used to form a production features list which is prepared data for the TRPP. The production capabilities of docks and shipways are the most critical constraints for the TRPP. The second layer is the planning and scheduling layer that focuses on the TRPP. The TRPP is formed based on the fundamental data as well as the feedback from the actual work. The Nodes Plan (NP) and the Physical Distribution Scheduling (PDS) can be produced by the TRPP. The system provides interfaces for users to input data from workshops and display the progress comparing it to project plan. The TRPP should be regenerated when users are considering new contracts or they determine it is necessary according to the feedback. The DPPS was designed to be reactive to control all projects effectively. When the NP or the PDS is delayed or accomplished ahead of schedule, the system will give feedback to TRPP and arouse regeneration. The changes of fundamental data also can arouse regeneration of TRPP if they are serious enough.

Briefly, they proposed a dynamic production planning system oriented to the shipbuilding process. The system optimizes a long term production plan, which is called the triennium rolling production plan, as well as the node plan and the physical distribution plan. The hierarchical system architecture is introduced in the plan. The object-oriented models are used to incorporate all critical information such as production capacities. The physical distribution algorithm is developed assuming the material quantities consumed in the production process follow a normal distribution. The simplified simulated annealing algorithm is presented to increase the planning optimization speed, using the expected objectives as the temperatures and a mimetic approach to get a meta-optimal plan. The dynamic production planning system was tested as feasible and effective in a case study conducted at the Dalian Shipbuilding Industry Co., Ltd. in Dalian, China. The system can also be a simulation system to help to negotiate on new orders, because it can give a proposed lead time assuming the projected delivery date. This system is based on the notion that the shipyard will carry out the same type of vessel or series of vessels in multiple units over a long period, which might be a very practicing realism for Chinese shipyards with huge annual throughput. Therefore, DPPS planning tool has a very serious setback to be considered for application in smaller shipyards with heterogeneous projects. Capacity planning for each item and workshop is not considered in this planning, which might be a delimiting factor for optimal usage of resource. Optimal project plan may not necessarily ensure optimal resource usage in the production process.

3.3.3 AVEVA MARS planning

MARS is a shipbuilding specific ERP solution for managing integrated shipbuilding project. It is marketed" by AVEVA as a " shipbuilding process management system that optimizes project control, logistics, materials management, resource and production planning designed specifically for the shipbuilding industry to significantly reduce cost and time to build, increasing profitability of shipyards." AVEVA MARS consists of three core applications:

MARS Material (Material Management)

MARS Planning (Resource Planning and Control)

MARS Production (Production Management)

AVEVA MARS offers a large number of well-proven best practices, and this helps to streamline the entire shipyard work processes.

AVEVA MARS Planning helps to improve the transparency of order processing and to act and decide on the basis of up-to-date plans. All involved parties can act on the basis of the actual situation of all projects because AVEVA MARS Planning closes the loop between planning, control and feedback. Furthermore, it supports to maintain feasibility of plans by providing integrated resource management considering a multi project situation. At the onset of planning, the information pertaining to a project is not always complete. As the project progresses and as information becomes available, single processes are described in more detail with the help of secondary processes, but do not replace them. These “partial nets” can be handled independently but are always part of the overall plan (AVEVA, 2012).
Planning on the rough level requires the definition of resource loads for activities that sometimes last for weeks. To plan resources accordingly, the distribution of loads over the duration of the process becomes decisively important. AVEVA MARS Planning takes this into account and helps with product and resource specific stress curves. Complex projects are characterized by a high number of activities and logical links. To maintain an overview, a convenient tool for visualization is required and AVEVA MARS Planning provides this, including features for the graphic interactive definition of activities and their links.
AVEVA MARS Planning supports the assignment of resource requirement, costs, checkpoints, material, product structure, long lead items, floor space required, documents, drawings and instructions. The integrated detailed planning provided by AVEVA MARS Planning helps increase flexibility and planning reliability by the interactive assignment of tasks and manpower on shop floor level.

The necessity of taking engineering tasks into consideration during planning and control of "One-of-a- Kind" production is an essential requirement. Planning of engineering is to be seen as detailed planning of design and work preparation. AVEVA MARS Planning claims to support the drawing management and man power planning with features like assignment of drawings and personnel to engineering tasks.

3.4 Techniques and tools for simulation based planning

Traditional static tools are not sufficient for controlling the complex and intertwined elements of the shipbuilding process. The great number of variant parts and their dynamic effects can be shown and evaluated only by means of simulation. Capabilities of available simulation tools, already established in series production branches, have been researched to extend according to the requirements of one-of-a-kind productions. The focus has been set on the description of the product, resource and process structure, and the continuous product data flow to simulation. Against the backdrop of using these basic requirements, the application of simulation can be extended from layout and material flow planning to production planning on any level. The objective is to construct the ship in the virtual shipyard long enough before the start of the real production to allow plans to be improved alongside the production. Application fields for simulation comprise layout planning for the shipyard development, production planning ranging from strategic to tactical and operative planning tasks, and special analyses on logistics and supply. There have been considerable number of research on the application of simulation technology in the shipbuilding industry ranging from layout planning, sub-assembly planning, block erection planning, panel line operation but a very limited attempts have been made to apply simulation in outfitting process. In the following section, it will be seen how simulation has been successfully implemented in the planning of one of the modern European Shipyards called Flensburger Schiffbau-Gesellschaft (FSG) in Germany and a general review of other research in this applied field of simulation.

3.4.1 Application of simulation in German shipyards

Beginning in 1997 Flensburger Schiffbau-Gesellschaft (FSG) implemented simulation technology very successfully as a tool to plan the future development of production. Simulation technology in production and logistics was developed according to the requirements of the automotive industry. For this industry, several simulation tool sets, consisting of predefined modules built in an object-oriented modeling environment, are available in the market, so a production process can easily be modeled by a combination of simulation modules. Some years ago, no simulation modules, neither for the shipbuilding industry nor for related branches, were available. Therefore, FSG and Jos. L. Meyer (JLM) developed their own module-based simulation tool kits for the shipbuilding industry needs. The simulation tool kit for the shipbuilding (STS), as it is called, from FSG now covers tools for the whole steel fabrication, including internal logistics, and it has been developed and used in cooperation with shipyards and universities.

The rather compact layout of many other European shipyards called for simulation-based solutions in order to cope with the lack of space. Jos. L. Meyer (JLM) and Aker Ostsee have developed such tools, which is said to be helpful to optimize the utilization of their docks and halls (Maximilian *et al.*, 2004).

Even these yards are different in many ways of management and production strategy, their approaches in terms of developing object based simulation tool sets, integration of solutions into the yard’s electronic data processing (EDP) environment and planning processes, and many other related systems are quite closely alike. Therefore, these shipyards have joined their forces together to bundle efforts and share results in developing and using simulation. This has saved collective work and has encouraged other shipyards to join and benefit from the experience of shipyards more advanced in this work. A cooperative platform named SimCoMar (Simulation Co-operation in the Maritime Industry) has been established between the shipyards FSG and Nordseewerke Emden, supported by the Technical Universities of Hamburg-Harburg and Delft. The model is called Simulation Tool-kit for Shipbuilding (STS).

The layout planning at Flensburger Schiffbaugesellschaft (FSG) is modified subject to fulfilling conditions of production development project for achieving progress of productivity, keeping the actual crew. This has led to the emergence of a concept for the future shipyard which was realized by some investment projects. These investment projects are assured by simulations; that is, before the decision for the investment is made, all of its functionality and influence on the rest of the production has been verified. The application of the simulation in production planning at FSG is divided into the phases of strategic and tactical planning and operative control. In strategic planning, a new order is planned in the early design phase. Building methods and sequences have to be defined. The tactical planning focuses on the optimization of the plan for the next weeks in certain production stations considering sequences and manning level as parameter. In operational planning, foremen on the shop floor adjust to reactive changes, for example, breakdowns.

3.4.1.1 Superiority of simulation based on modules

FSG simulation models have been developed in modules in several different projects. Developed model, consisting of modules, can be adapted to the special needs of different projects by changing their parameters as shown in Figure 3.7. New functionalities can easily be added to the tool kit and then are made available in all existing models, which makes simulation models more manageable and a lot of mistakes can be avoided. It is also beneficial that new simulation modules can be tested easily in different environments before they are released for final use. Simulation modules can be created parallel, so different users can work on a problem simultaneously.

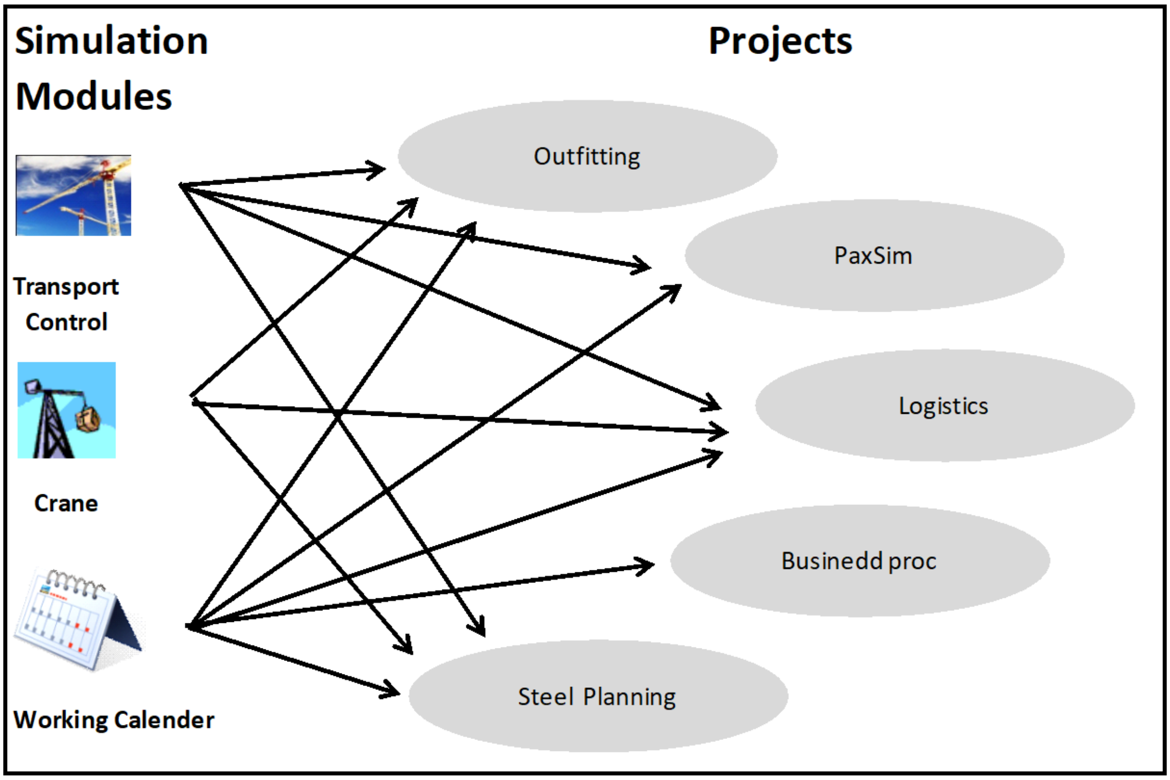


Figure 3.7 -Synergy effects by programming simulation modules: adapted from (Maximilian et al., 2004)

3.4.1.2 Model design for simulation

While modeling the production of Flensburger, the product with its parameters is strictly separated from the simulation model of the production, which means that different kinds of ships can be produced in the virtual shipyard. This is why the simulation model has to be universal. The product data are all geometrical and methodical information about the ship, and the simulation model includes all parameters describing the production facilities, resources, and processes as shown in Figure 3.8. One basic model can be used for the different applications of simulation.

This universal model is updated continuously for the strategic planning and can easily be configured for the different applications. Within various projects, a simulation model of the whole production at FSG has been completed. Final assembly has also been modeled in order to support the planning for the upcoming change of product type. In a parallel project, the model for the block assembly is being developed and integrated into the overall model as shown in Figure 3.9.

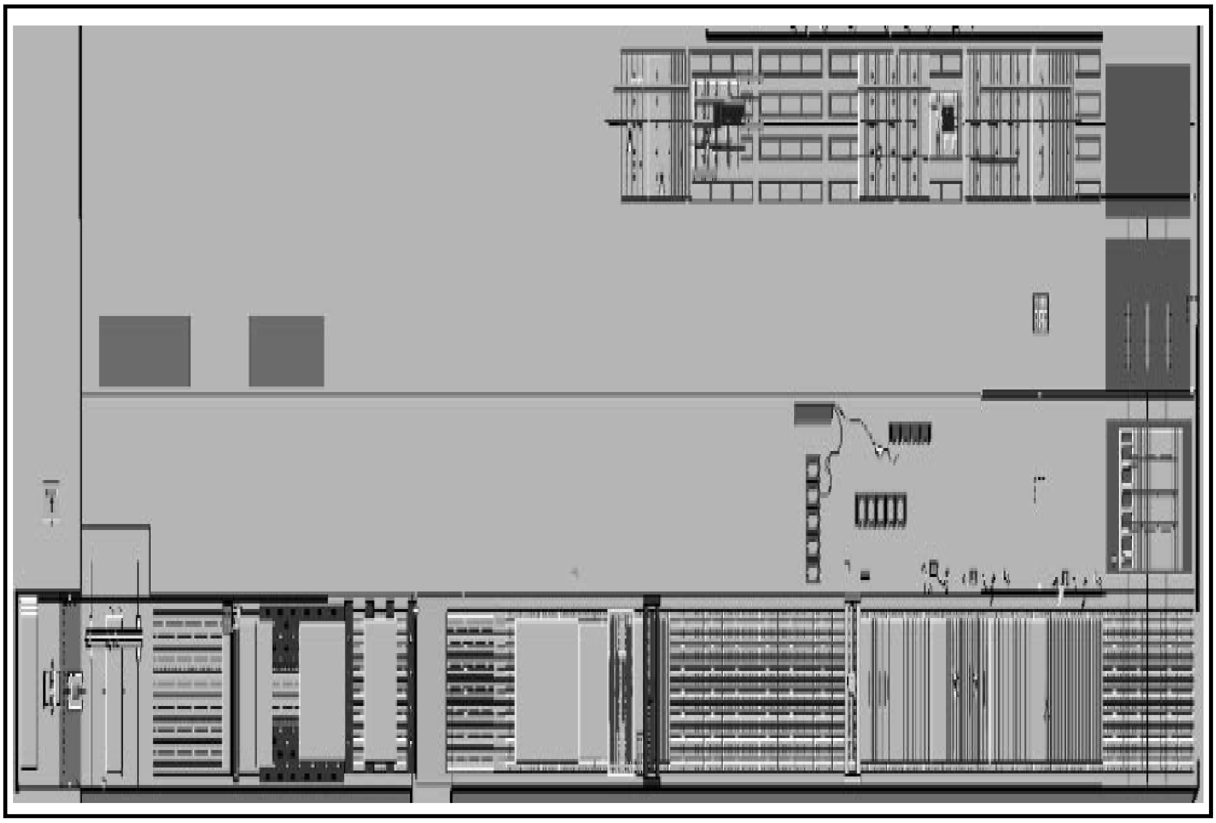


Figure 3.8 -Simulation model of the preproduction from panel line to section welding (Maximilian et al., 2004)

3.4.1.3 Data management

Product data for simulation are all the product's attributes and its single components that influence the turnaround time. The attributes are the geometrical information, such as dimensions, and information about the building method, such as sequences and assembly descriptions. To achieve an appropriate result from the simulation, each

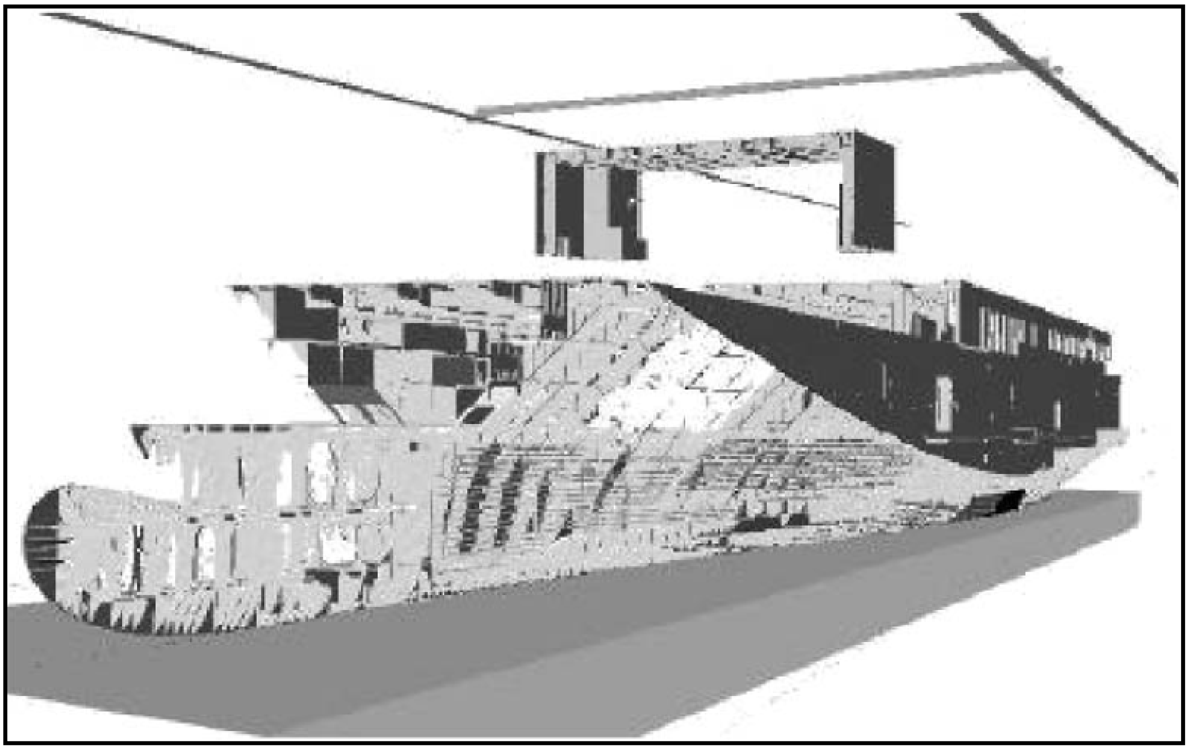


Figure 3.9 -Simulation model of the final assembly on the slipway (Maximilian et al., 2004)

single part of a ship, including all the pre-outfitting material, is described in the product data. The exact identification, the code for material control, all relevant geometrical dimensions, the weight, and the material quality are available. In the course of the simulation, these data are attached to every part as attributes. An automatic generation of product data is felt necessary and simulation for production planning to make interfaces to get access both to CAD and planning data. Afterward, these data are prepared for the simulation model in the simulation database. The FSG data flow to simulation is shown in Figure 3.10.

3.4.1.4 Planning of simulation layout

Simulation has been used at FSG for the layout planning for over a decade now. Therefore, a model of the whole steel production was created and adjusted for new layout alternatives. One typical ship of FSG's product mix was selected as a reference ship and made available for the simulation model with all its detailed data. The changes in layout can be evaluated by means of the different turnaround performance.

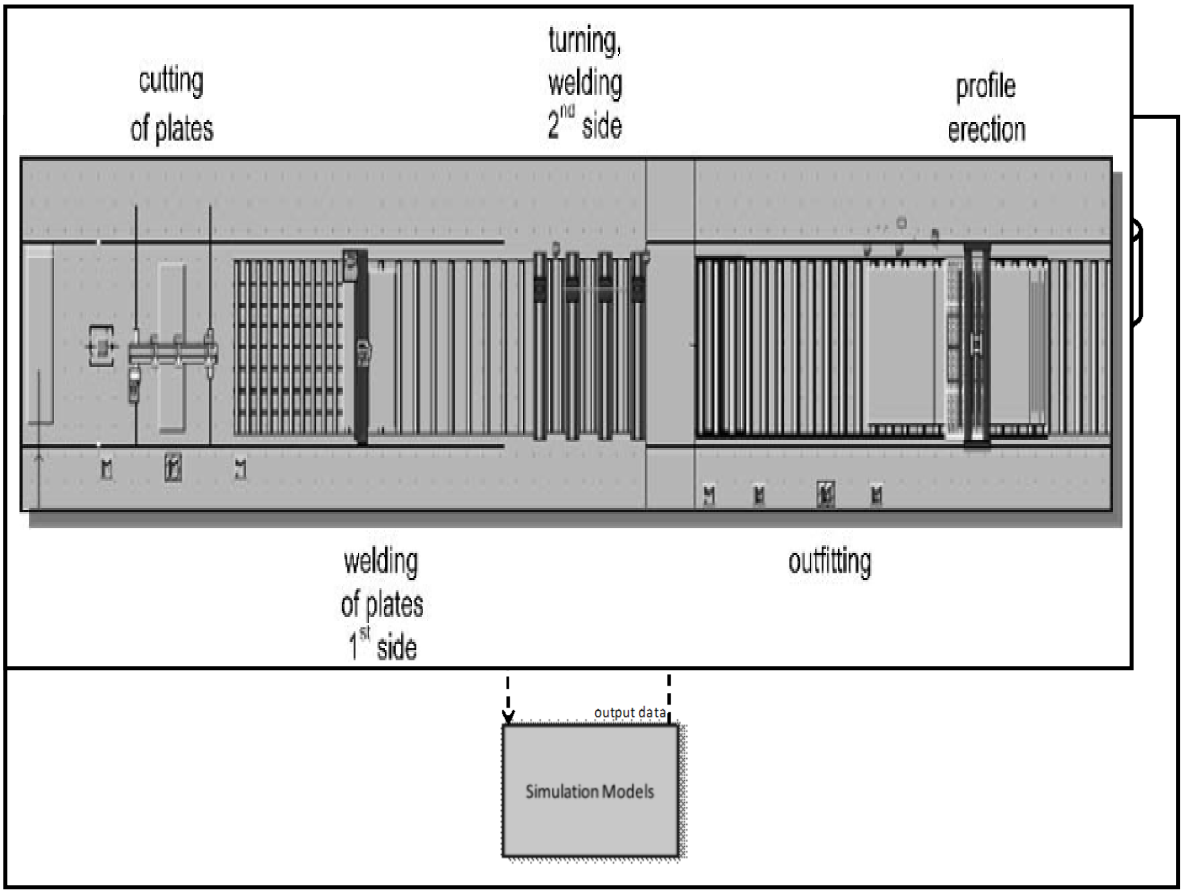


Figure 3.10 -Data flow to simulation at FSG: adapted from (Maximilian et al., 2004)

3.4.1.5 Panel line as one example of use

Within the shipyard development project, a concept for a new panel line has been created. This concept contained a completely new combination of plants in restricted space and was assured by the simulation. The new panel line was implemented in the summer of 2001 and fully reached the required performance. Figure 3.11 shows the simulation model of the new panel line.

Figure 3.11 -Simulation model of the panel line (Maximilian et al., 2004)

On this production line plates are welded together and afterward stiffened by profiles. Additionally, outfitting materials, such as lashing foundations, are assembled and welded here. A comparison for the usage of different stations for the C-box container vessel, the actual type of ship being built at FSG, with an upcoming RO/RO ship has also been produced on the virtual panel line for comparison with the containership. The different utilization while producing the different ships is shown in Figure 3.12. Explicit differences can be seen in that output data. The plasma cutting machine is the bottleneck in the production of the containership, but with RO/RO ship production, the profile welding station becomes a bottleneck and the number of blocked times at the plasma cutting station increases

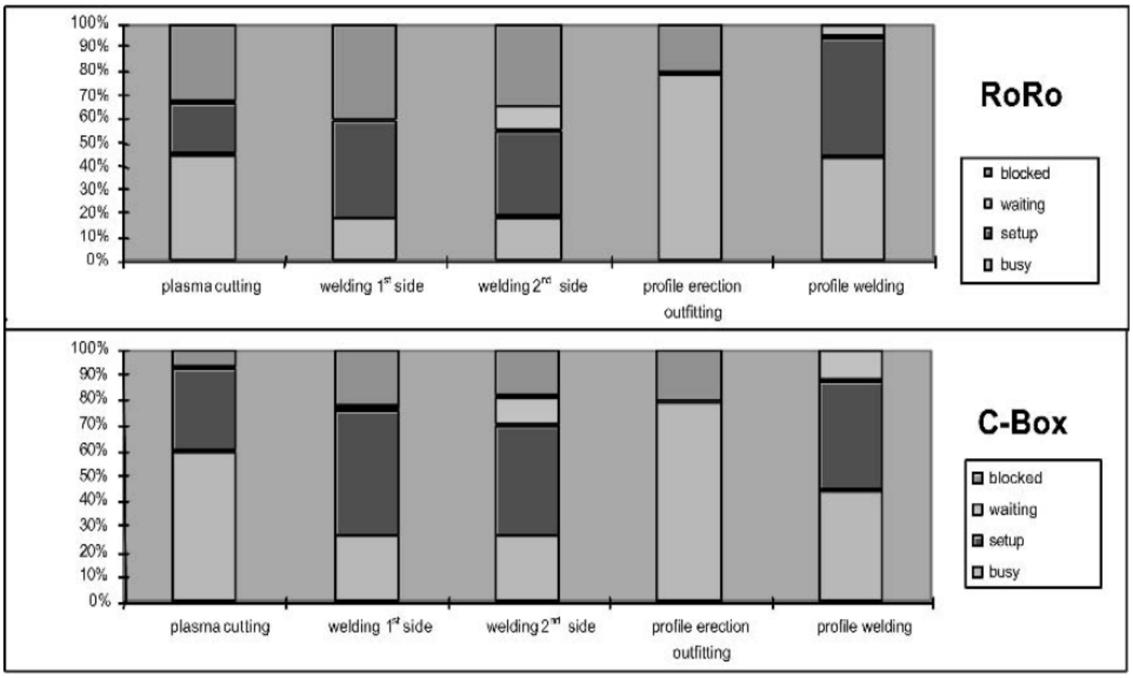


Figure 3. 12 -Utilization of panel line for different types of ship (Maximilian et al., 2004)

3.4.1.6 Simulation for production planning

The simulation model developed for layout planning is also used for the planning of the future production program at FSG. Latest data about the orders to be produced in the next weeks are continuously generated, allowing the production program of the next 2 (two) months to be simulated with realistic data to support the tactical planning. Through the simulation, the planner verifies his plan and improves it if necessary. He has a special user interface at his disposal where he finds the parameters he has influence on, such as sequences and personnel capacity.

3.4.1.7 Panel line and section assembly planning tool

After the end of the investment project for the new panel line, the simulation model was available for the tactical production planning. The model was extended to meet the requirements of this application and implemented into the planning within a project. The plan is regularly tested for its feasibility by the planner or the foreman. The results are then used to define the required manning level for the panel line and the section assembly. The following steps are necessary to verify the plan:

1. Adjustment of parameters
2. Run of the simulation
3. Interpretation of the results.

If the results do not meet the target requirements, another cycle of the three steps must follow. Before the actual simulation run, the simulation parameters have to be adjusted. The foreman or the planner enters the planned or the available manning level on the simulation database. He has a special dialog where he can assign the workers by qualification and shifts.

3.4.1.8 Interpretation of results of simulation run

The settings of the simulation database, the actual product and planning data, and the actual production dates are read into the simulation model. The simulation run is carried out, and after reaching the end date, the simulation results are saved.
For the evaluation of the simulation run, several methods of analysis are available. First of all, one can check to see if the simulation has met the schedule. The influence of one production station on another can be shown by a graph. The simulation can also show if there is not enough buffer to feed the next station properly. If the simulation does not meet the schedule, bottlenecks can be detected. There are utilization diagrams of the different plants for each week and

the station with the biggest part of the working time can be called the bottleneck. Furthermore, utilization of personnel can be evaluated per week. Low utilization of workers of a special qualification may indicate the possibility of reducing the manning level.

3.5 Management concepts in project: practice paradigm

Management of the project inevitably entails brining into the picture those persons and groups that have both contractual interest and vested interests in the management of the project as well as its outcome (David, 1998). The specific project will influence the constraints on which the project manager needs to focus. The relationship among these factors is such that if any one factor changes, at least one other factor is likely to be affected. For example, if the schedule is shortened, often the budget needs to be increased to add additional resources to complete a ship construction in less time. If a budget increase is not possible, the scope or quality may be reduced to deliver a product in less time for the same budget. However, this may always not be the case due to the involvement of different stake holders in a shipbuilding project. Project stakeholders may have differing ideas as to which factors are the most important, creating an even greater challenge. Changing the project requirements may create additional risks. The project team must be able to assess the situation and balance the demands in order to deliver a successful project. Because of the potential for change, the project management plan is iterative and goes through progressive elaboration throughout the project's life cycle. management team to manage to a greater level of detail as the project evolves.

3.5.1 Project management nutshell

Project management is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements. Project management is accomplished through the appropriate application and integration of the 42 (forty two) logically grouped project management processes comprising the 5 (five) process groups (www.pmi.org). These five process groups are:

a) Initiating,

b) Planning,

c) Executing,

d) Monitoring and controlling, and
e) Closing.

PMBOK®Guide has reported an identification and description of the five project management process groups required for any project. These five process groups have clear dependencies and are typically performed in the same sequence on each project. They are independent of application areas or industry focus. Individual process groups and individual constituent processes are often iterated prior to completing the project. The constituent processes can have interactions within a process group and among process groups. The nature of these interactions varies from project to project and may or may not be performed in a particular order. The process flow diagram, Figure 3.13, provides an overall summary of the basic flow and interactions among process groups and specific stakeholders. A process group includes the constituent project management processes that are linked by the respective inputs and outputs where the result or outcome of one process becomes the input to another.

3.5.1.1 Initiating process

The Initiating Process consists of those processes performed to define a new project or a new phase of an existing project by obtaining authorization to start the project or phase. Within the initiating processes, the initial scope is defined and initial financial resources are committed. Statement of requirement after consultation with the customer is prepared which may include contract, preliminary schedule, resource requirement. Project file is also initiated for documentation of project progress with as many standard format as possible (Young, 2007). If not already assigned, the project manager will be selected. This information is captured in the project charter and stakeholder register. When the project charter is approved, the project becomes officially authorized. Although the project management team may help write the project charter, approval and funding are handled external to the project boundaries, see Figure 3.14. As part of the Initiating process group, many large or complex projects may be divided into separate phases. In such projects, the initiating processes are carried out during subsequent phases to validate the decisions made during the original development of project charter.

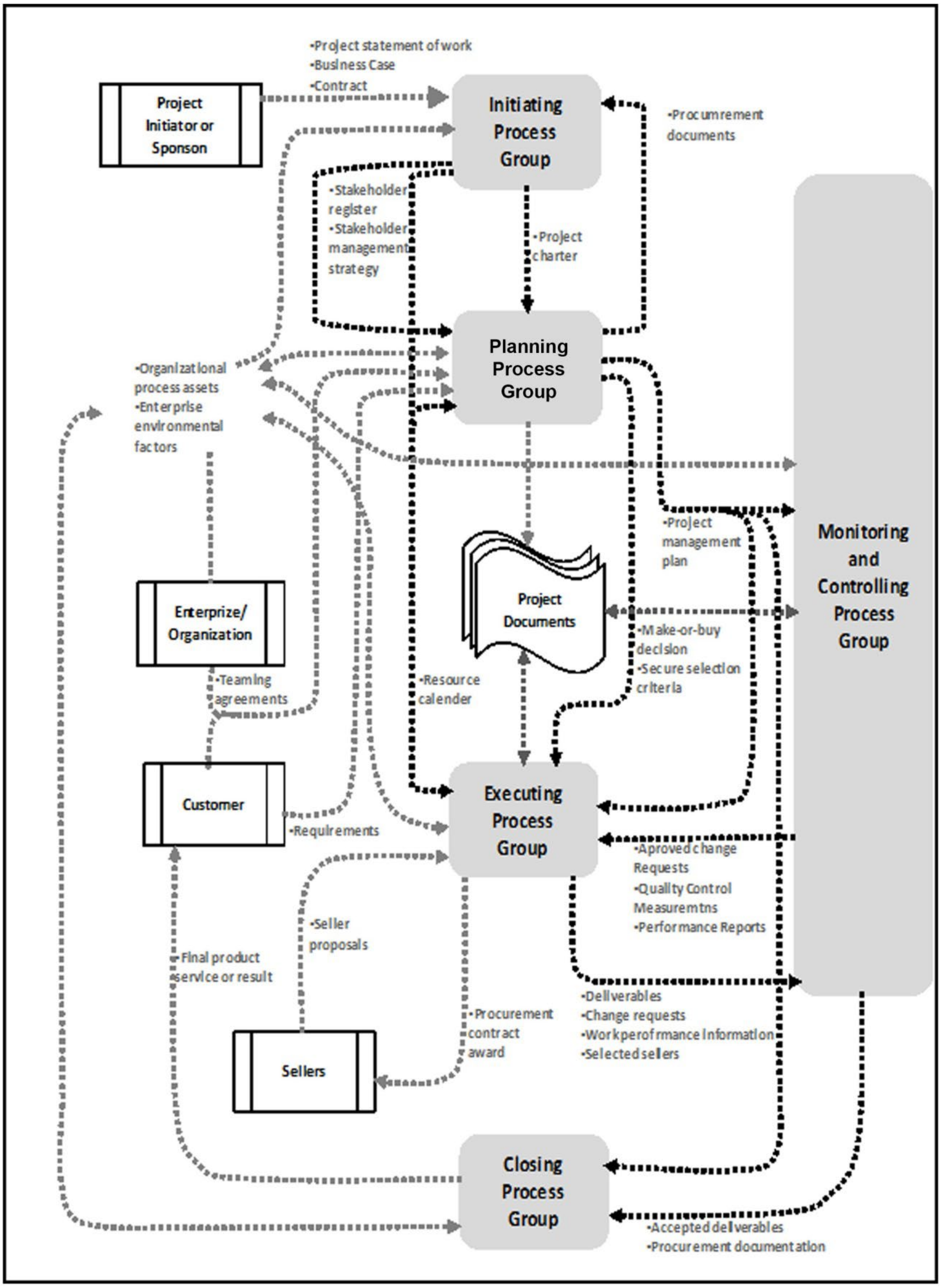


Figure 3.13 -Process flow diagram: adapted from (PMI., 2008)

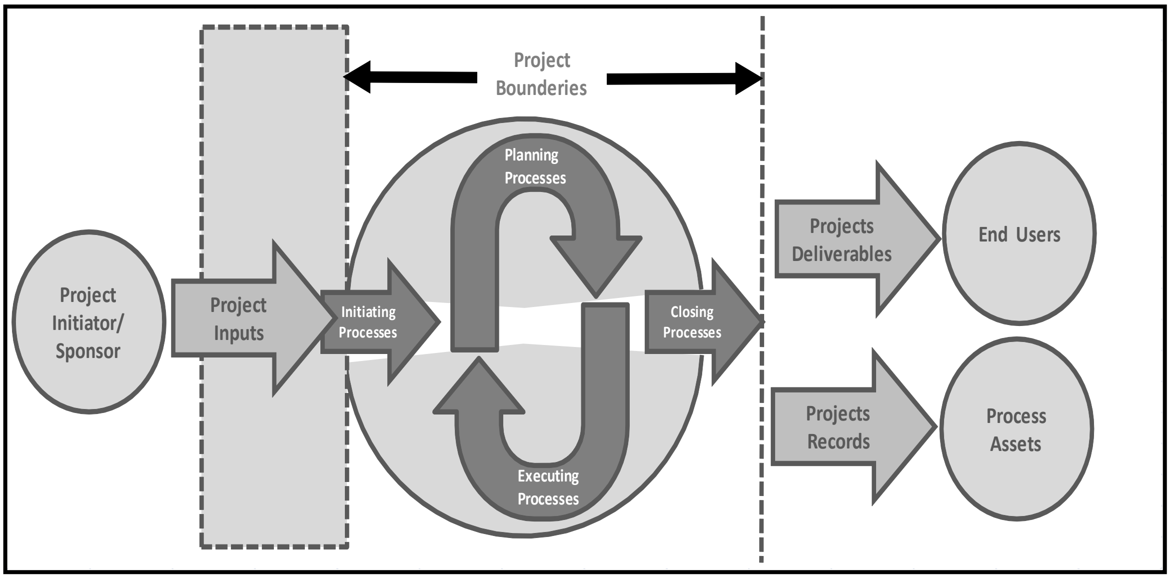


Figure 3.14 -Project boundary flow chart: adapted from (PMI., 2008)

Initiating processes may be performed by organizational, program, or portfolio processes external to the project's scope of control. For example, prior to commencing a project, the need for high-level requirements may be documented as part of a larger organizational initiative. In a shipbuilding project, while the initialing process may involve the contractual agreement, primary specification, makers list and so on, but it may not require justification of project alternatives as in an intangible project. The documentation for this decision may also contain the initial project scope statement, deliverables, project duration, and a forecast of the resources for the organization's investment analysis. As part of the initiating process, the project manager is given the authority to apply organizational resources to the subsequent project activities.

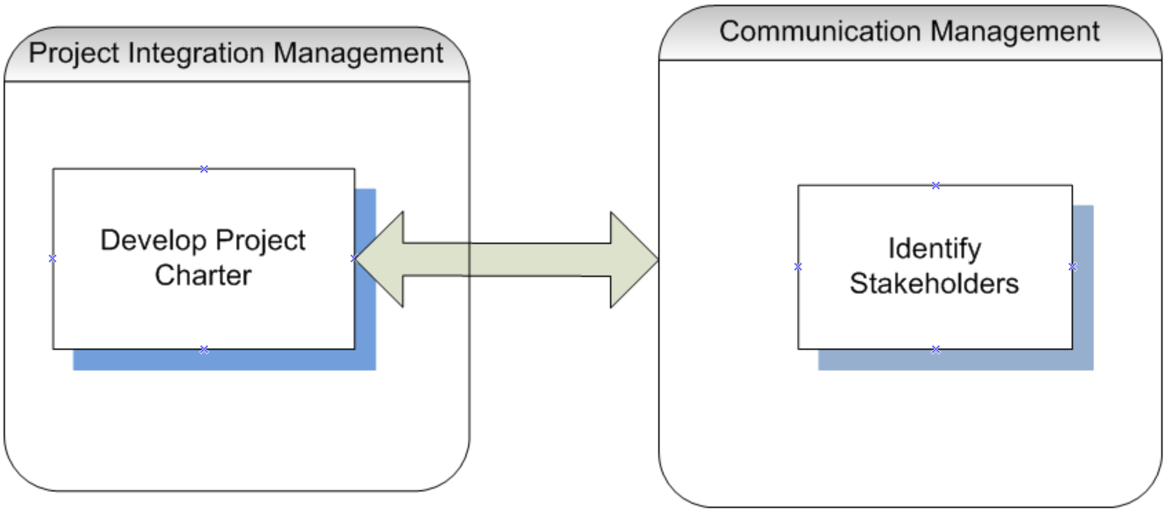


Figure 3.15 - Initiating process group: adapted from (PMI., 2008)

3.5.1.2 Planning process

The Planning process consists of those processes accomplished to ascertain the total span of the effort, identify and improve the objectives, and create the course of action requisite to achieve those objectives.

The planning processes build up the project management plan and the project documents that will be made basis to carry out the project. The multi-faceted nature of project planning opens up repeated feedback loops for additional analysis. As more project information and distinctiveness are grouped together and understood, additional planning may be required (PMI., 2008).

The essential process in planning is to use the collective experience and knowledge of project team and others invited to the planning session and will identify key stages and analyze estimates of time, cost resources, and quality, communication, risk, and procurements (Young, 2007). Updates arising from approved changes during the project may significantly impact parts of the project management plan and the project documents. Updates to these documents provide greater precision with respect to schedule, costs, and resource requirements to meet the defined project scope.

Project is a complicated process to manage and plans act as the map of this process. The map must have sufficient detail to determine what must be done next but be simple enough that workers are not lost in welter of minute (Meredith and Samuel, 2010). The project team should encourage involvement from all appropriate stakeholders when planning the project, developing the project management plan, and project documents. Since the feedback and refinement process cannot continue indefinitely, procedures set by the organization dictate when the initial planning effort ends.

Other interactions among the processes within the planning process group are dependent upon the nature of the project. For example, for some projects there will be little or no identifiable risk until after significant planning has been done. At that time, the team might recognize that the cost and schedule targets are overly aggressive, thus involving considerably more risk than previously understood. The results of the iterations are documented as updates to the project management plan or project documents. A shipbuilding project goes through almost all the processes as shown in Figure 3.16 before a working plan is created, though all the steps may not necessarily be recorded but discussed among project personnel.

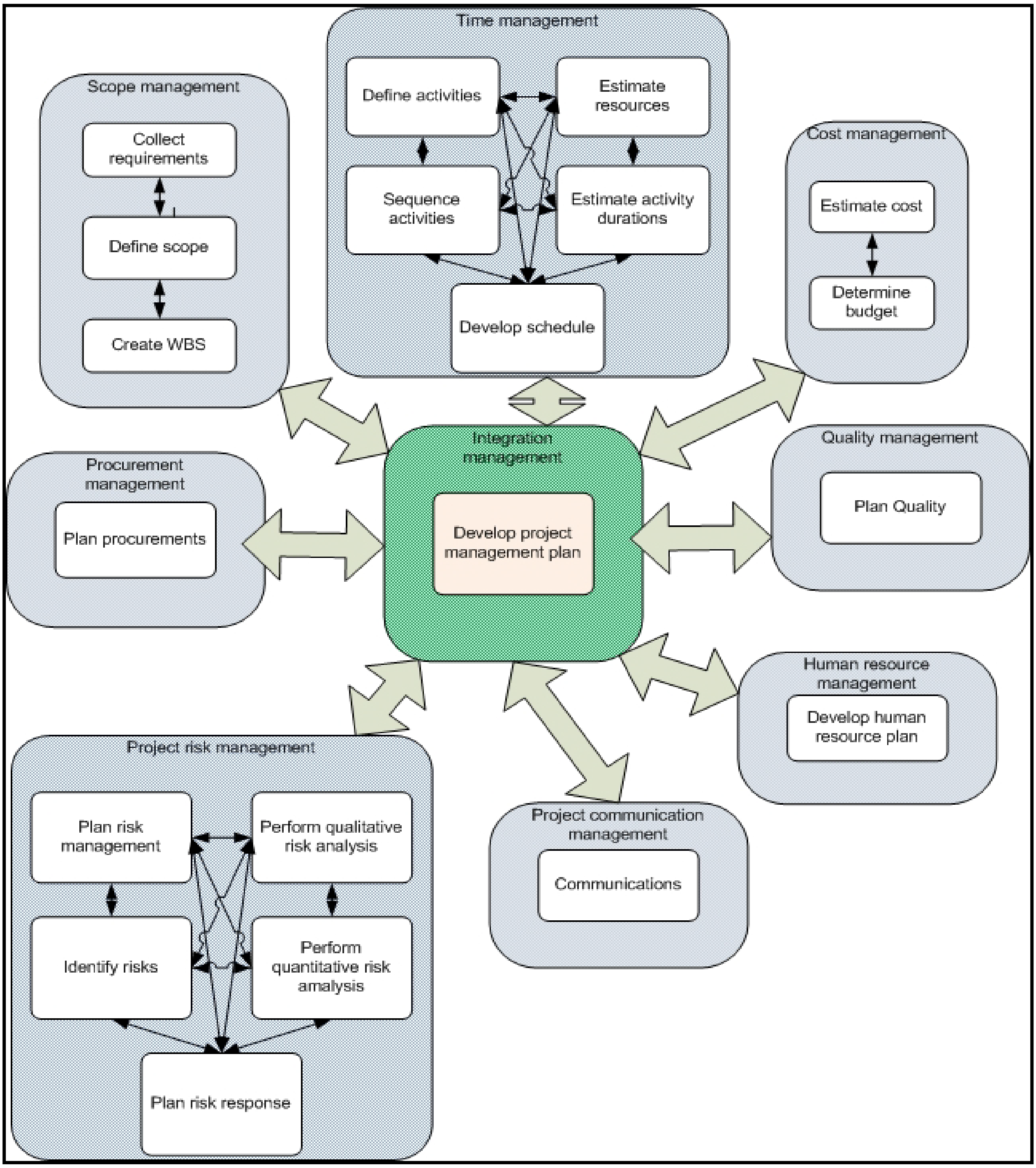


Figure 3.16 -Planning process: adapted from (PMI., 2008)

3.5.1.2.1 Planning techniques and tools

Management is continually seeking new and better control techniques to cope with the complexities, masses of data, and tight deadlines that are characteristic of many industries and their highly competitive environments today, as well as seeking better methods for presenting technical and cost data to customers.

There are several methods which are widely used in processing schedules of project. The early stages of the project must be spent carefully establishing a baseline plan that provides a clear definition of how the project scope will be accomplished on time, to budget and using available resources. Following is a list of methods existed in the literature:

a) Gantt or bar charts

b) Milestone charts

c) Line of balance

d) Program Evaluation and Review Technique (PERT) or Activity on Arrow (AoA)

e) Arrow Diagram Method (ADM) or Critical Path Method (CPM)

f) Precedence Diagram Method (PDM)

g) Graphical Evaluation and Review Technique (GERT)

h) Critical Chain Method Analysis (CCMA) or Theory of Constraints

Among all these methods PERT/CPA and GANTT chart have been used in the industry widely in way of being the central architecture of major project management software available commercially.

3.5.1.2.1.1Critical path method

Project management is not a new concept for organizations or managers. The concepts and ideas behind effective project management are however constantly been undergoing modification and improvement. A Dupont engineer, Morgan R. Walker and a Remington-Rand computer expert, James E. Kelly Jr, initially conceived the Critical Path Method (CPM). They created a unique way of representing the operations in the system. Their methods involved using unique arrow filled diagrams or network methods in 1957 (Archibald and Villoria, 1966; Korman, 2004). Critical Path Method (CPM) is the technique for analyzing projects by determining the longest sequence of tasks (or the sequence of task with the least slack) through a project network (Newbold, 1998). The main objective of the

CPM implementation was to determine how best to reduce the time required to perform routine and repetitive tasks that are needed to support an organization. Initially this methodology was identified to conduct routine tasks such as plant overhaul, maintenance and construction (Moder and Phillips, 1964). Critical path analysis is an extension of the bar chart. The CPM uses a work breakdown structure where all projects are divided into individual tasks or activities. For any project there is a sequence of events that have to be undertaken. Some tasks might be dependent on the completion of the previous tasks while other might be independent of the tasks ahead and can be undertaken at any given time (Lowe, 1966). Job durations and completion times also differ significantly. CP (Critical Path) analysis helps decision makers and project execution members to identify the best estimates (based on accurate information) of the time that is needed to complete the project. The CP analysis is also a helpful way of identifying if there are alternate paths or plans that can be undertaken to reduce the interruption and hurdles that can arise during the execution of any task. Critical path analysis consists of three phases—Planning, Analysis, and Scheduling and Controlling. All three activities are interdependent. But they require individual attention at all different stages of the project. It is important when using CPM that the project team has some historical information of the processes and the task and are able to reference this information during the planning and decision making process. There are two methods by which the Critical Path can be identified:

1. *The forward pass.* Here, CPM calculates the earliest time within which a project can be completed. "The date each activity is scheduled to begin is known as the "early start," and the date that each activity is scheduled to end is called "early finish" (Winter, 2003). In this method of critical path determination, the earliest possible date for starting of the project is identified and then the activities are lined up to identify the completion date.

2. *The backward pass.* Here, selecting the date when the organization wishes to complete the project or the last activity identifies CP. Time requirements are based on working backward from the final date desired for the last activity to the initial first activity. The dates identified in this method of CPM are called late start dates (for

the starting of the first activity) and the late finish dates (for the last activity in the project)

Important for the CPM using either the forward pass or the backward pass is that the total time needed for completion of the project does not change but the dates when the project can be started might differ based on the approach used in the two methods. The selection of either the forward or the backward pass depends on the final desired results and the available documents and accurate data needed to determine the time for every activity on the network diagram (Baram, 1994). Slack or float is defined as the time between the earliest starting time (using the forward pass method) and the latest starting time (using the backward pass method) used for identifying the critical path. Total float (float) is the amount of time an activity can be delayed without delaying the overall project completion time (Winter, 2003). Typically, the critical path has little or no slack or float built into the activities. Therefore, it can be stated that the activities on the critical path if subjected to extensive delays will make the project take longer to complete. If the earliest time that any activity can be started is the same as the latest time that the activity can be started, then the timing of starting that activity is very important for the project. In addition, ensuring that the activity has all the necessary resources as and when required is paramount. CPM also connects the different functional factors of planning and scheduling with that of cost accounting and finance.

CPM identifies the two important variables of any project, the time and the cost of the project. When CPM was initially introduced the techniques were best suited for well-defined projects with relatively small uncertainties in the execution of the project. During this time of CPM initial introduction markets were also very regional and localized and there were few dominant players in any given market. CPM was also well suited for activity-type network. There are external variables that can affect the CPM logic during the planning, scheduling and management process. Priority changes, “across the board” budget cuts, negotiations with other agencies, evolving regulations, etc., can jointly or severally impact the CPM schedule, necessitating frequent and potentially complex modifications (Knoke and Garza, 2003). Resource planning and tracking project schedules is very important for any project to be successful. If there is no leveling and no constraints of resources for the project then the manpower peaks early in the project (Just and Murphy, 1994). Floats and critical paths breakdowns are generally as a result of the resource constraints and different methods of crashing the project can yield different results for the project.

3.5.1.2.1.2 Construction of network activity for CPM and PERT

It should be important to see how the network for CPM is constructed. Activity construction for PERT is similar with CPM except the estimation of time. PERT will be discussed in subsequent section, but because of the likeliness, construction of both are illustrated together for the convenience.

The Key Concept used by CPM/PERT is that a small set of activities, which make up the longest path through the activity network control the entire project. If these "critical" activities could be identified and assigned to responsible persons, management resources could be optimally used by concentrating on the few activities which determine the fate of the entire project. Non-critical activities can be re-planned, rescheduled and resources for them can be reallocated flexibly, without affecting the whole project.

The first step in CPM/PERT is to construct a project network. In the project network each activity is represented by an arc connected by two nodes. The first node represents the start of the activity and the second node represents the end of it.

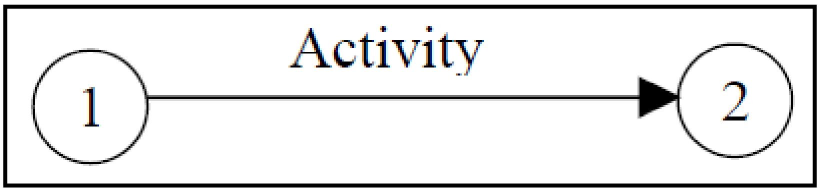


Figure 3.17-Simple activity on arrow network (Lockyer and Gordon, 2005)

The network should reflect activities precedence relations. Given a list of activities and predecessors, the following rules should be followed to construct a project network:

i. Node 1 represents the start of the project. An arc should lead from it to represent activities with no predecessors.

ii. A unique finish node representing the completion of the project should be included in the network.

iii. Nodes are numbered in such a way that the node representing completion of an activity always has a larger number than the node representing beginning of the activity.

iv. An activity should not be represented by more than one arc.

v. Two nodes could be connected by at most one arc.

vi. Each node should have at least one entering arc and at least one leaving arc.

To avoid violation of rules (iv)-(vi) a dummy activity with zero duration (represented by a doted arc) may be introduced.

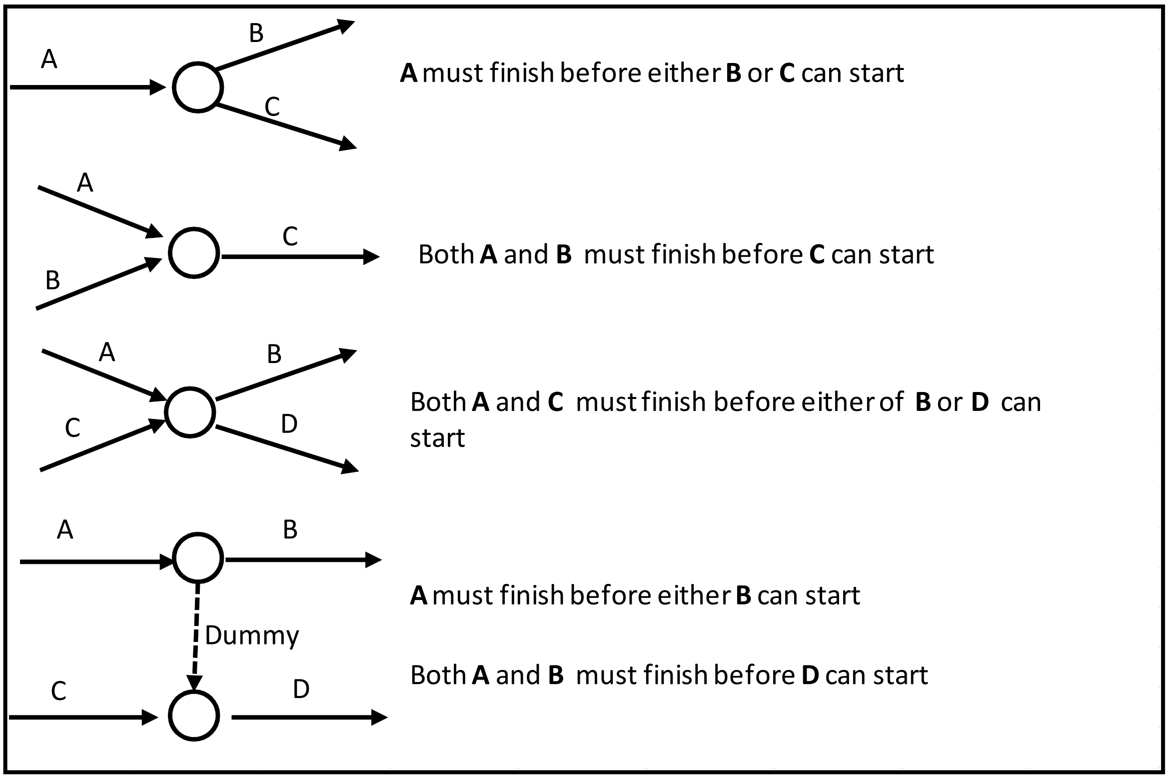


Figure 3.18 -Illustration of Network construction (Maddah, 2009)

A project to manufacture a product is composed of the following activities as in Figure 3.19.

Activity	Predecessors	Duration (days)
A = train workers	--	6
B = purchase row material	--	9
C = manufacture product 1	A, B	8
D = manufacture product 2	A, B	7
E = test product 2	D	10
F = Assemble products 1 and 2	C, E	12

Figure 3.19 -Example activity data (Maddah, 2009)

With the help of the above data, following activity network as in Figure 3.20: can be constructed.

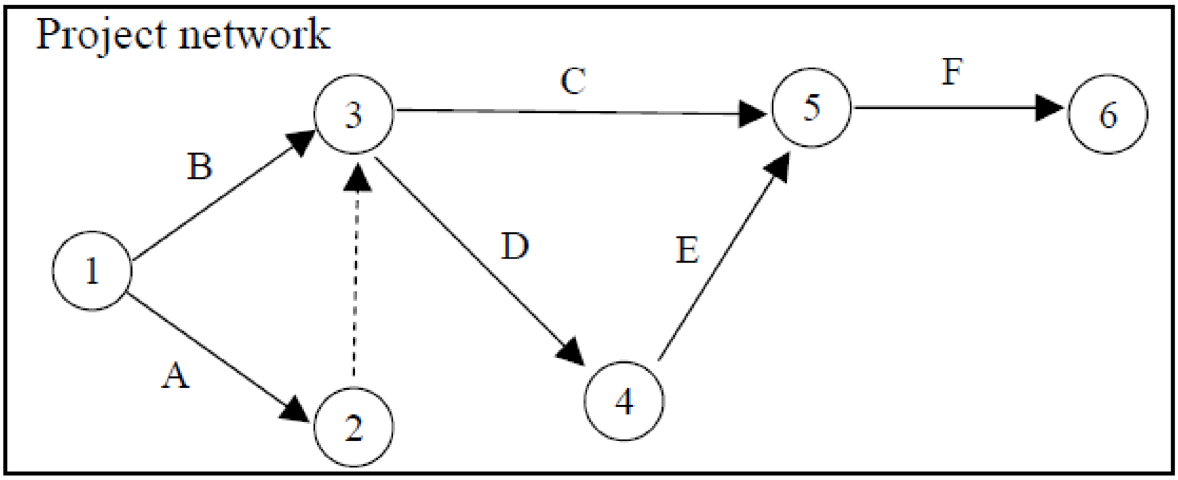


Figure 3.20 -Constructed activity network: reproduced from (Maddah, 2009)

The original versions of PERT and CPM used AOA (Activity-on-Arrow) project networks, so this was the conventional type for some years. However, AON (Activity-on-Node) project networks have some important advantages over AOA project networks for conveying the same information.

1. AON project networks are considerably easier to construct than AOA project networks.

2. AON project networks are easier to understand than AOA project networks for inexperienced users, including many managers.

3. AON project networks are easier to revise than AOA project networks when there are changes in the project.

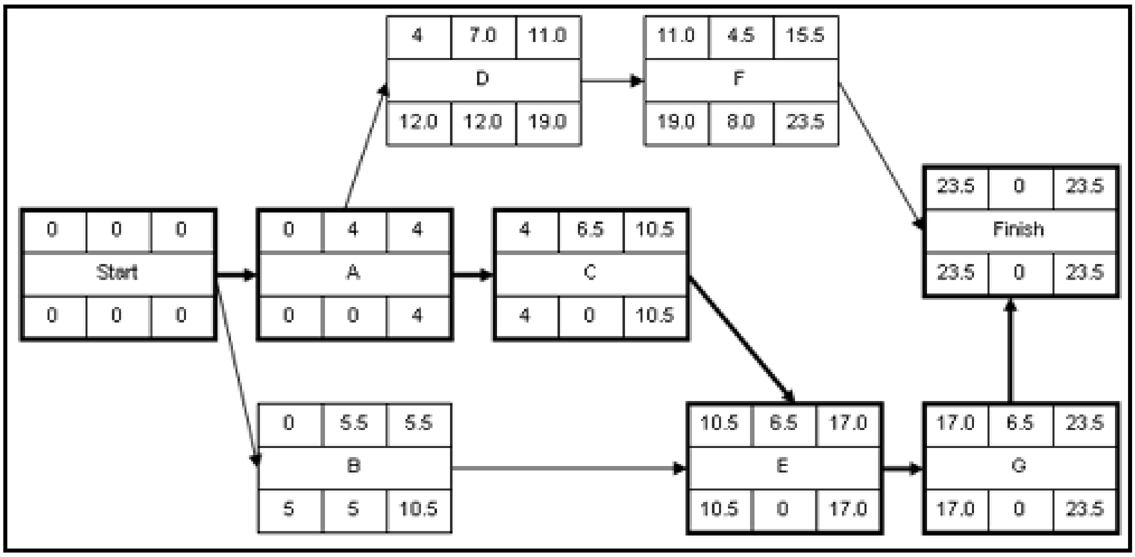


Figure 3.21 -Construction of Activity on Node network (Lockyer and Gordon, 2005)

Illustration in Figure 3.21 has ABCDEFG activities and each of them is represented by the corresponding node. Each node has got seven cells which contains following information as in Figure 3.22

1. Earliest Start (ES)	2. Duration (TE)	3. Earliest Finish (EF)
4. Task Description		
5. Latest Start (LS)	6. Slack (S)	7. Latest Finish (LF)

Figure 3.22 -Node cell construction (Lockyer and Gordon, 2005)

Clearly we can calculate total three path from start to finish in Figure 3.21 such as

A-D-F 4+7+4.5 =15.5 units

A-C-E-G 4+6.5+6.5+6.5 =23.5 units

B-E-G 5.5+6.5+6.5 =18.5 units

Critical path in this example is 23.5 units of time as it has the longest path among all the paths calculated from the start to the finish of the project. Critical path has no slack time in it. Any delay in any of the activity in critical path will cause overall delay in the project.

This example has seven tasks, labeled A through G. Some tasks are independent while others cannot be done until their predecessor task is completed. The optimistic time, the normal time estimate and the pessimistic time are estimated. To calculate TE (expected time) in PERT following formula is used

TE= (O + 4M + P) ÷ 6.

Where,

O= Optimistic time

M= Most likely time or normal time

P= Pessimistic time

In Table 3.1, a calculation for PERT duration is shown based on the above formula.

Activity	Predecessor	Optimistic Time	Normal / Most likely Time	Pessimistic Time	Expected time
A		2	4	6	4
B		3	5	10	5.5
C	A	3	7	8	6.5
D	A	4	7	10	7
E	B, C	3	7	8	6.5
F	D	3	4	8	4.5
G	E	3	7	8	6.5

Table 3.1 -PERT chart

3.5.1.2.1.3 Advantage of CPM

In the age where tools available to management are constantly changing and improving, the ability of CPM to still command respect among the project teams and managers is testimony to the fact that this tool has proved very valuable and beneficial. Listed below are some of the major reasons why CPM is still used in organizations today

1. CPM encourages managers and project members to graphically draw and identify various activities that need to be accomplished for project completion. This step encourages all members in the project team to evaluate and identify the requirements of the project in a critical and logical fashion.
2. The network diagram also offers a prediction of the completion time of the project and can help in the planning and scheduling of the activities needed for the completion of the project.
3. Identifying the critical path for the project is the next stage of the analysis of the network diagram. In doing this, the management of the project has a reasonable estimate of the potential problems that might occur and the activities at which these problems might occur. In many cases the critical path also determines the allocation of resources.
4. CPM also encourages a disciplined and logical approach to planning, scheduling and managing a project over a long period of time. Often, the root cause of many project overruns is the failure to identify the factors that have the potential to seriously impact the project. By forcing individuals in the project team to identify activities, attention to details can be achieved.
5. Optimization of the time-cost relationship in project management is also possible using the CPM as managers can visually identify the activities that can pose a problem if not managed and monitored effectively over a period of time.
6. Based on the time-cost variables, the project can be tweaked to best satisfy the goals and aims of the organization. For example, if a project team is able to identify that they need more time if the project has to be within a certain budget or vice versa, this fact is clear right from the start of the project.
7. Tracking the CPM is also helpful. Managers can identify areas where attention needs to be focused. Critical paths do not remain static for the life of the project; rather there is a very high chance that the CP might changes due to internal and external factors affecting the organization.

8. Scheduling of activities is possible. The CPM identifies the entire chain of activities. Often, during the initials stages of the project the number of activities and the cost requirements might be high; but as the project progresses the activities might sort themselves out into routine or critical. Project managers, instead of tacking the entire issue, can focus their attention to groups of activities that are immediate and have the ability to impact the next downstream activity.

8. The CPM also identifies slack and float time in the project. Thus, project managers can identify when resources can be reallocated to different activities and the shifting and moving of activities to best optimize the utilization of the resources.

9. Critical paths are also updated periodically for any project and offer the project manager and members a visual representation of the completion of various stages of the project and easily identify problem areas where further attention might be required.

10. In many large projects, there can be more than one critical path in the network diagram mapped out. When such a situation arises, CPM can help managers identify suitable plan of actions to handle these multiple critical paths.

11. CPM has been widely used by a variety of organizations in almost all industries with great success. CPM can also help estimate the project duration and this information can be used to minimized the sum of direct and indirect costs involved in the project planning and scheduling

12. CPM offers organizations a form of documentation that they can reuse for similar projects that they might undertake in the future. Documenting various activities and the root causes of the problems can help future-project manager avoid similar pitfalls. In addition, documentation can provide valuable data for estimation of time requirements and cost factors, as opposed to managers using estimations and guesses of the cost.

13. Critical Path Analysis formally identifies tasks which must be completed on time for the whole project to be completed on time, and also identifies which tasks can be delayed for a while if resource needs to be reallocated to catch up on missed tasks (Mindtools., 2012). The CPM can identify the paths that can be taken to accelerate a project to be completed prior to its due date or identify the shortest possible time or the least possible cost that is needed to complete a task.

14. CPM methods are based on deterministic models and the estimation of time activities are based on historical data maintained within the organization or data obtained from external sources

3.5.1.2.1.4 Disadvantage of CPM

CPM has a number of advantages and it has been able to provide companies using it a yardstick and a reasonable estimate of the time needed for the completion of the project. The main disadvantages of the critical path method are listed below. Many disadvantages are as a result of the technical and conceptual factors involved in the Critical path analysis (CPA) process

1. The CPA process can become complicated as the scope and extent of the project increases. Too many interconnecting activities can result in the network diagram becoming very complicated. The risk of making a mistake in calculation of the critical chain becomes very high as the number of activities increase.

2. The CPA depends on the fundamental concept that the managers and personnel involved in the project team are well versed with the various activities. Unfortunately, practical experience has shown that the principal assumption underlying CPM techniques, i.e., the project team's ability to reasonably predict the scope, schedule, and cost of each project, is frequently far beyond control (Knoke and Garza, 2003). The task of understanding the needs of the critical path get more complicated when there is more than one critical path in the project. In many situations, these paths might be parallel and feed into a common node in the network diagram. It becomes difficult in these situations to identify the best utilization of technology and resources for the critical paths.

4. In many cases, as the project progresses, the critical paths might change and evolve and past critical paths may no longer be valid and new CP have to be identified for the project at regular intervals.

5. The use of total float as a measure for assigning activities to their representative paths can become problematic when analyzing as built schedules. CPM is unable to calculate total float on an as built schedule in which estimated dates have been replaced by actual dates (Peters, 2003).

6. As critical paths and floats change the scheduling of personnel also changes. Reallocation of personnel is often very tricky as the individual might be working on

more than one project at a time and if the services of the individual are required on more than one critical path, the identification and distribution of the labor time can cause overloading of the personnel.

7. Very often, critical paths are not easy to identify especially if the project is unique and has never been undertaken by the organization in the past. The ability to provide estimates of time and cost for every activity in a tradition CPM process depends on historical data maintained by the company. In the absence of this data, decision makers are forced to speculate and assume time and cost requirements for the projects.

8. Traditionally, any good CPA requires that the process is understood and evaluated using the forward and the backward pass to determine slack or float times. In reality, however, the time constraints often result in decision makers using only one method to find the time and cost requirements.

9. CPA and network diagrams are highly dependent of information technology and computer software. The cost of set up of software systems in the organization can have high initial cost. Maintaining the software also requires expertise and monitoring that can quickly become very expensive if the organization does not have in house capabilities for this task.

10. Although the CPM method is very valuable in the extent of details that it provides, modifying the system constantly can be cumbersome especially if it involves reallocation of resources and time.

11. In spite of the widespread use of CPM in organization the manner in which it is used can differ significantly. Organizations that have a strong culture of timely completion might be utilizing the methodology in a more appropriate manner when compared to companies that use CPM only partially for planning and scheduling.

12. Knowledge management of data is important. Defining knowledge is never easy. Knowledge and information are different although they are often assumed to be the same. There are important distinctions between data, information and knowledge. Data are the raw facts collected by observation or monitoring. When data are filtered out to identify trends and organized it converts to information and when this information is used in the operation, planning and strategy it is converted to knowledge (Yahya and Goh, 2002). Information and knowledge get transmitted through an organization through communication networks. CPM depends on the

efficiency of these networks. However, CPM cannot handle the flow of information between the activities and therefore estimation of Critical Path may have variances with the actual completion time.

13. In many recent cases, fear of litigation and delay claims based on the CPA used by companies is also being observed. Lawyers are using experts to investigate the CPA that were undertaken by contractors for projects and identifying the reasons for project delays (Schumacher, 1997). When penalties and fines are imposed for late completion the CPM used by contractors can be subjected to scrutiny and might be responsible for organizations losing a case.

14. Many projects are generally long duration in nature. It is often observed that the personnel involved in the project also changes as the project evolves. Many of the initial members might have left the company or transferred to other departments or even retired and the new member might not be as well versed with the initial concepts and brainstorming that went into the creation of the network diagram. Changes and modification made over the period of time on the network diagram can also be difficult to track if a good method of documentation of the change is not made. Often, poor documentation is the cause of the same mistakes being repeated over a second time.

15. CPA also does not take into account the learning curve for new members on the project or for activities that are new and unique to the project (Badiru, 1995). Using past information of learning curves can help project managers estimate time variations in case a new employee is put on the task or a new process is required for any activity to be completed. CPM does not traditionally consider this as an important variable for allocation of time or resources.

3.5.1.2.1.5 PERT (program evaluation and review technique)

PERT was originally developed in 1958 and 1959 to meet the needs of the "age of massive engineering" where the techniques of Taylor and Gantt were inapplicable. The Special Projects Office of the U.S. Navy, concerned with performance trends on large military development programs, introduced PERT on its Polaris Weapon System in 1958, after the technique had been developed with the aid of the management consulting firm of Booz, Allen, and Hamilton. Since that time, PERT has spread rapidly throughout almost all industries. It is however, important to note, that PERT "deals only with the time constraints and does not include the quantity, quality and cost information desired in many projects; PERT should, therefore, be integrated with other methods of planning and control." (Evarts, 1964).

PERT scheduling is a six-step process. Steps one and two begin with the project manager laying out a list of activities to be performed and then placing these activities in order of precedence, thus identifying the interrelationships. These charts drawn by the project manager are called either logic charts, arrow diagrams, work flow, or simply networks. The arrow diagrams will look like Figure 3.21 with two exceptions: The activity time is not identified, and neither is the critical path. Step three is reviewing the arrow diagrams with the line managers, i.e., the true experts, in order to obtain their assurance that neither too many nor too few activities are identified, and that the interrelationships are correct. In step four, the functional manager converts the arrow diagram to a PERT chart by identifying the time duration for each activity. It should be noted here method that the time estimates that the line managers provide are based on the *assumption of unlimited resources* because the calendar dates have not yet been defined. Step five is the first iteration on the critical path. It is here that the project manager looks at the critical calendar dates in the definition of the project's requirements. If the critical path does not satisfy the calendar requirements, then the project manager must try to shorten the critical path by asking the line managers to take the "fat" out of their estimates. Step six is often the most overlooked step. Here the project manager places calendar dates on each event in the PERT chart, thus converting from planning under unlimited resources to planning with *limited resources.* Even though the line manager has given a time estimate, there is no guarantee that the correct resources will be available when needed. That is why this step is crucial. If the line manager cannot commit to the calendar dates, then re-planning will be necessary. PERT is well suited for projects that have high degrees of uncertainty in the time and cost variables and are suited for projects that are dependent on activities that have to be conducted at various locations around the world. The usage of PERT and CPM is not very much prevalent in shipbuilding because of the humongous data entry requirement and estimation. However, these attributes could be easily estimated from industry standard planning software is anybody is interested to do so.

3.5.1.2.1.6 The critical chain and understanding the theory of constraints

Goldratt introduced the concepts of critical chain for project management. He defined the critical chain as the longest chain of dependent steps. The dependencies between steps can be a result of a path or a result of a common resource (Goldratt, 1997). The critical chain thus refers to a combination of the critical path and the scarce resources that together constitute the constraints that need to be managed (Elton and Roe, 1998). The critical chain methodology incorporates the benefits of the CPM and PERT methodologies with the human and behavioral impact on project management in an organization. The Human element was not a major concern in the CPM and PERT and human tendencies were not considered critical in the completion of the tasks. The book *Critical Chain* applied the TOC to the task of project management (Schuyler, 2000). Where in the past TOC concentrated only on manufacturing and production, Goldratt with this book was able to use the main concepts of TOC to improve the productivity of the project management process. The critical chain yields the expected project completion date (Raz *et al.*, 2003) .There are five key factors incorporated in the critical chain method that has the potential to significantly improve the project performance:

1. Use of a synchronization mechanism to stagger work.

2. Creation of project networks that are true structures of dependency.

3. Creation of schedules that place safety strategically to protect against variability along the longest path of task and resource dependencies.

4. More effective work and management behaviors

5. Project management and resource assignment based on relative depletion of project safety (Chain, 2012) .

The critical chain refines and improves upon the critical path method used in project management. Very often, problems common to almost all projects are budget overruns, time overruns and the compromises in the quality and the performance of the product. In many project situations, decision managers and project manager are far removed from the actual task function and as a consequence have to either rely on dependable information or assume a lot of the information. Top management also forces options (decreasing the time to complete the project, cutting cost of the project or reducing the resources available for the project) on the project teams that are unrealistic.

Statistical fluctuations do exist in any operation and the ability to smooth out the variance can be achieved only within a certain range of the fluctuations (DeVor *et al.*, 1992). The TOC model postulated by Goldratt duplicates the requirements of Statistical Process Control (SPC) (Goldratt and Cox, 1993). TOC forced companies to look within their process at the constraints and bottlenecks that were hindrances in the generation of maximum profit. The theory of constraints looked for the critical path in any process. The machine with the slowest output, would determine the constraint. Labor and employee requirement is an important intrinsic factor that affects the internal environment in an organization in the TQM (Total Quality Management) model. The TOC model enhances the TQM model in this arena.

Goldratt stated *that a production facility is only as fast as the slowest process in the critical chain of the manufacturing*. Detailed understanding of the logistics involved in getting the product from suppliers to the customers, both internal and external is important (Ayers, 2001).

Analysis of the setup times in relation to the cost of manufacturing in a batch was also considered important by conventional standards for all resources bottleneck and non-bottlenecks before the launch of Goldratt's TOC model. This setup time however, is only considered really significant on bottleneck operations in the Goldratt model. An hour saved at a bottleneck is of very significant importance and will determine the bottom-line profits for an organization. Bottlenecks govern both throughput and inventories in a manufacturing system. An hour lost in a bottleneck is an hour lost in the total system. Consequently, an hour saved at a bottleneck operation is an hour saved in the entire process. The cost incurred due to the loss of an hour at the bottleneck is in fact the cost of an hour in the entire system (Goldratt, 1990).

An important relevance of the TOC for projects is the Critical Chain Scheduling. In this, the focus is shifted from assuring the achievement of task estimates and intermediate milestones to assuring the only date that matters--the final promised due date of a project. As a matter of fact, the scheduling mechanisms provided by Critical Chain Scheduling require the elimination of task due dates from project plans (Francis, 2001).

CCAM (Critical Chain analysis method) is even more complicated than CPM. This method requires that the managers and decision makers understand all the intricacies involved in the completion of the project. Trust in the management not to overburden or overstress the resources is an important consideration in the CCM (Critical Chain Method). As no dates are set, the workers might negatively impact the project if they perceive that the management is misusing their powers. Managers and experts of the activities are soon made aware that the estimates of time provided by them will be reduced by approximately 33%. To compensate for this factor there might be a tendency to over inflate the initial time requirements for the project. The level of over estimation by functional managers might also not be the same (Raz *et al.*, 2003).

Critical chain requires that all resources constantly provide current estimate of the time to complete their current task (Francis, 2001). This requires tremendous coordination of real time information from all resources to a centralized database that can be accessed at all times by key personnel. The CCPM (Critical Chain Project Management) is applicable to projects that are more manufacturing based and this management method might not always be applicable to projects that start with a few central activities and these activities spilt up at various stages and then are recombined at different periods of time in the project. The predecessors and successors from several chains can create very complex networks that cannot be scrutinized by used the simplistic buffer methodology. The critical chain and the associated buffers depend on a number of complex algorithms (resource leveling) to determine the time. CCPM however, does not specify any new or unique methodology for solving the algorithm (Raz *et al.*, 2003). While Goldratt postulates that the critical chain is static and does not change, in reality the critical chain can shift and change in a manner similar to the critical path making the system very dependent on smart technology to constantly track the new critical paths for the project. Buffer concept in CCPM also states that the resources should be offered to activities on the critical chain that have the least buffers. This factor however, does not take into account the penalties or fines that might be imposed due to non-completion of other activities that might not be on the critical chain.

While many of the software used for the project scheduling is very sophisticated and has many built-in checks and balances, the expertise of the individual evaluating the schedule and determining the critical chain is very important. This becomes very significant if there are multiple critical chains and the software picks one over the other. The feeding buffer for non-critical items might create a mock situation of critical chains that are not realistic or accurate. False alarms in scheduling might be set up if the buffering is not managed accurately.

3.5.1.2.1.7 GANTT chart

A Gantt chart is a horizontal bar chart developed as a production control tool in 1917 by Henry L. Gantt, an American engineer and social scientist. It is widely used in project management. Gantt chart provides a graphical illustration of a schedule that helps to plan, coordinate, and track specific tasks in a project. Gantt charts may be simple versions created on graph paper or more complex automated versions created using project management applications such as Microsoft Project or Excel (Margaret, 2007). A Gantt chart is constructed with a horizontal axis representing the total time span of the project, broken down into increments (for example, days, weeks, or months) and a vertical axis representing the tasks that make up the project. Horizontal bars of varying lengths represent the sequences, timing, and time span for each task. As the project progresses, secondary bars, arrowheads, or darkened bars may be added to indicate completed tasks, or the portions of tasks that have been completed. A vertical line is used to represent the report date. Gantt charts give a clear illustration of project status, but one problem with them is that they don't indicate task dependencies - it cannot be assessed as to how one task falling behind schedule affects other tasks. All the major project management software adopt Gantt chart as means to display the output of the produced schedule. A common error made by those who equate Gantt chart design with project design is that they attempt to define the project work breakdown structure at the same time that they define schedule activities. This practice makes it very difficult to follow the 100% Rule of WBS (Work Break Down Structure). Instead, the WBS should be fully defined to follow the 100% Rule, then the project schedule can be designed (PMI., 2003). Larger Gantt charts may not be suitable for most computer displays. A related criticism is that Gantt charts communicate relatively little information per unit area of display. Moreover, Gantt charts do not represent the size of a project or the relative size of work elements, therefore the magnitude of a behind-schedule condition is easily miss-communicated. If two projects are the same number of days behind schedule, the larger project has a larger impact on resource utilization, yet the Gantt does not represent this difference. Although project management software can show schedule dependencies as lines between activities, displaying a large number of dependencies may result in a cluttered or unreadable chart. In shipbuilding, Gantt chart is sometimes preferable method of representation in early stage of the project. A typical Gantt chart is shown in Figure 3.23.

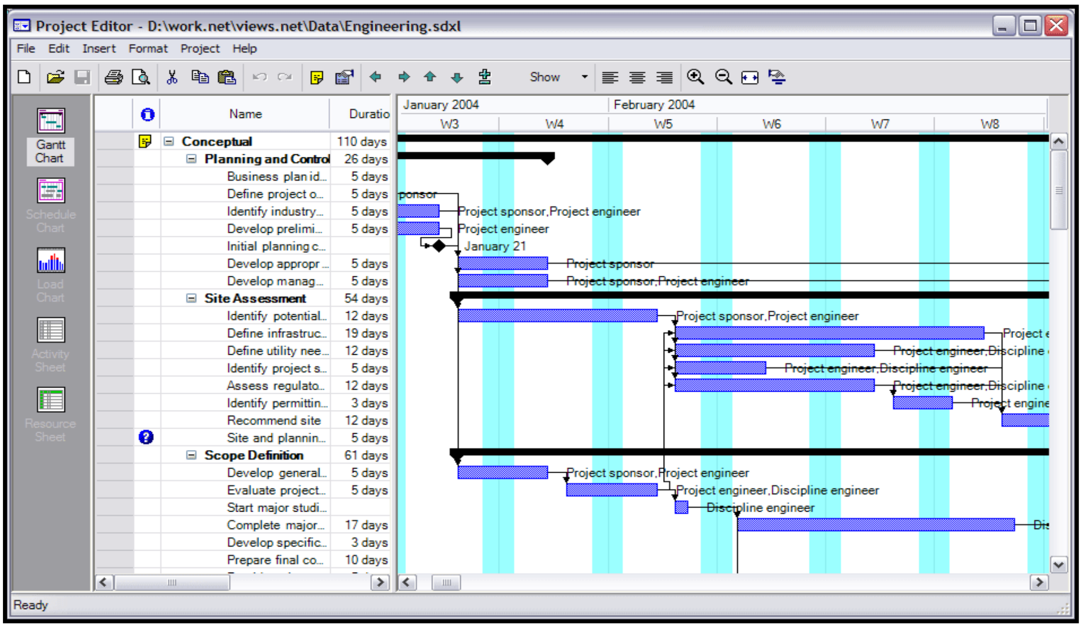


Figure 3.23 -Example Gantt chart (Gantt-Chart., 2012)

3.5.1.3 Executing process

The Executing Process Group consist of those processes executed to perform the tasks defined in the shipbuilding project management plan to conform the project specifications. This process group involves coordination of resources, as well as integrating and executing the activities of the project in conformity with the project management as shown in Figure 3.24.

During ship construction, execution of works may require planning updates and adjustment as the project progresses. This can include changes to expected activity durations, changes in resource productivity and availability, and uncertain risks. Such variances may affect the plan or project documents and may necessitate detailed analysis of appropriate project management responses. The results of the analysis can trigger change requests that, if approved, may modify the project management plan or other project documents and possibly require establishing new baselines. A large portion of the shipbuilding project's budget will be expended in performing the Executing Process Group processes including placing orders for equipment at vendors.

3.5.1.4 Monitor and control process

The monitoring and controlling process group consists of those processes essential to track, evaluate, and regulate the progress and performance of the project; identify any areas in which changes to the plan are required; and initiate the corresponding changes as shown in Figure 3.25. The key benefit of this process group is that project performance is observed and measured regularly and consistently to identify variances from the project management plan (PMI., 2008). The monitoring and controlling process group also includes controlling changes and recommending preventive action in anticipation of possible problems, monitoring the ongoing project activities against the project management plan. In shipbuilding, project monitoring is done by PM office, managers of relevant production units against a set of agreed upon guidelines and by the quality department.

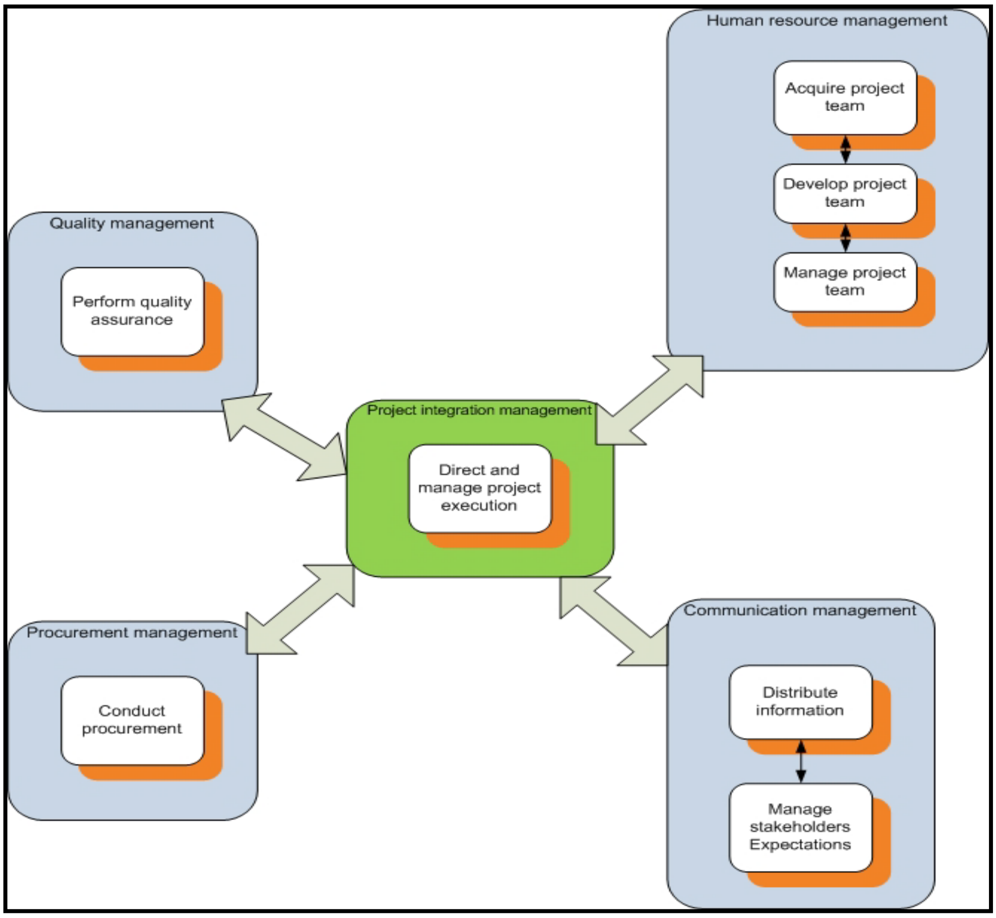


Figure 3.24 -Execution process: adapted from (PMI., 2008)

and the project performance baseline, and influencing the factors that could circumvent integrated change control so only approved changes are implemented. This continuous monitoring provides the project team insight into the health of the project and identifies any areas requiring additional attention. Monitoring verifies the progress of the work by analyzing status, volume completion, quality, cost and expenditure, behavior an cohesiveness of performance of team (Young, 2007). In multi-phase projects, the monitoring and controlling process group coordinates project phases in order to implement corrective or preventive actions to bring the project into compliance with the project management plan. This review can result in recommended and approved updates to the project management plan. For example, a missed activity finish date may require adjustments to the current staffing plan, reliance on overtime, or trade-offs between budget and schedule objectives.

3.5.1.5 Closing process

The closing process group consists of those processes performed to finalize all activities across all project management process groups to formally complete the project, phase, or contractual obligations as shown in Figure 3.26. This process group, when completed, verifies that the defined processes are completed within all the process groups to close the project or a project phase, as appropriate, and formally establishes that the project or project phase is complete (PMI., 2008). A clean closedown of the project gives a sense of a job well done and satisfaction for everyone who has been involved. Project closure process goes through the mostly common stages of obtaining acceptance by the customer or sponsor, conducting post-project or phase-end review, recording impacts of tailoring to any process, document lessons learned, releasing equipment and materials, completing and auditing project accounts, preparing a plan for staged transfer of responsibility to marketing department, application of appropriate updates to organizational process assets, archiving all relevant project documents in the Project Management Information System (PMIS) to be used as historical data, and close out procurements (Young, 2007). In shipbuilding there is an added significant component in closing phase which is the documentation of all the statutory certificates from Class authority, approved drawings, vendors' certificates and compilation of the same in order for the customer's record and future usage.

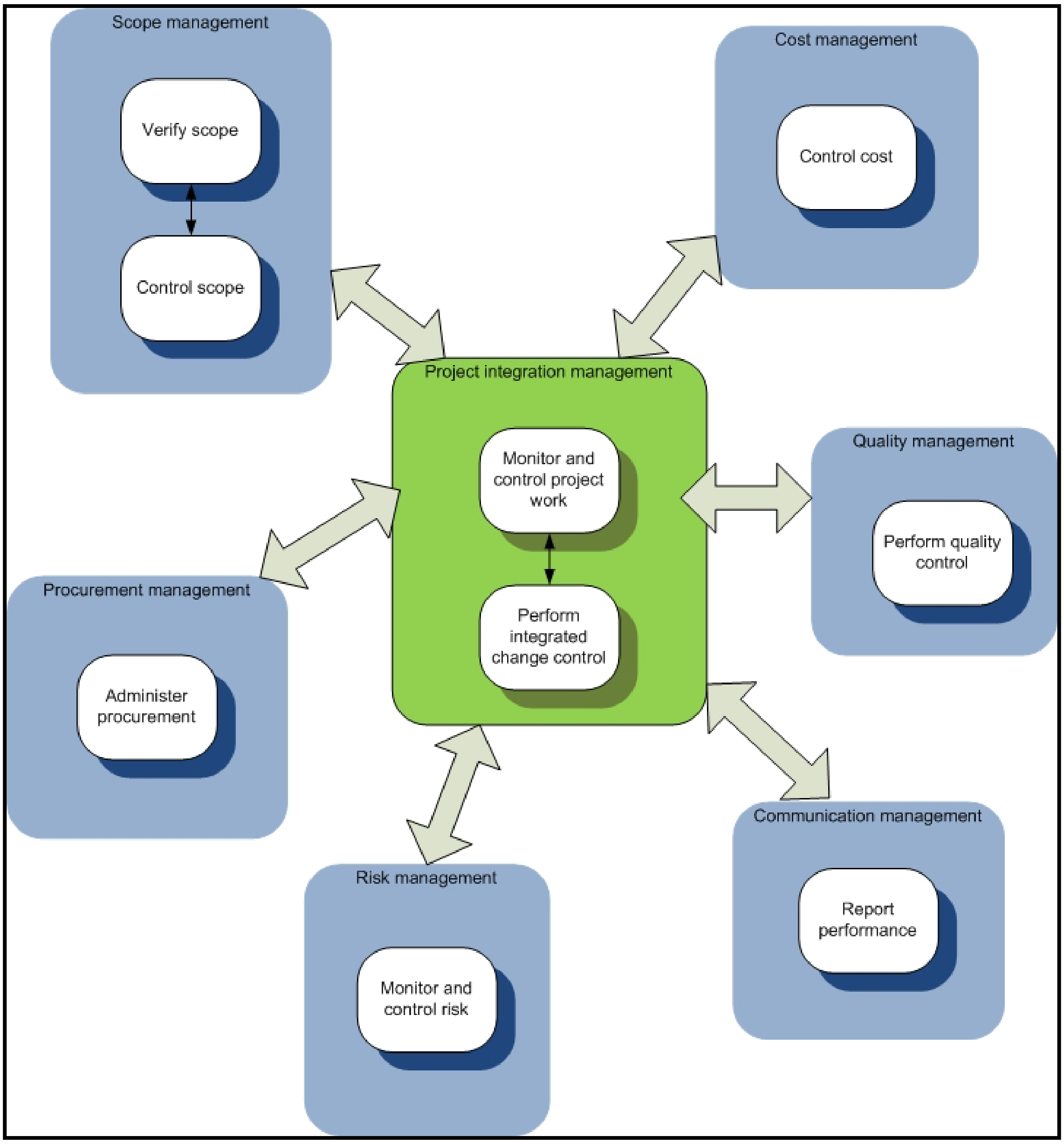


Figure 3.25 -Monitor and controlling process: adapted from (PMI., 2008)

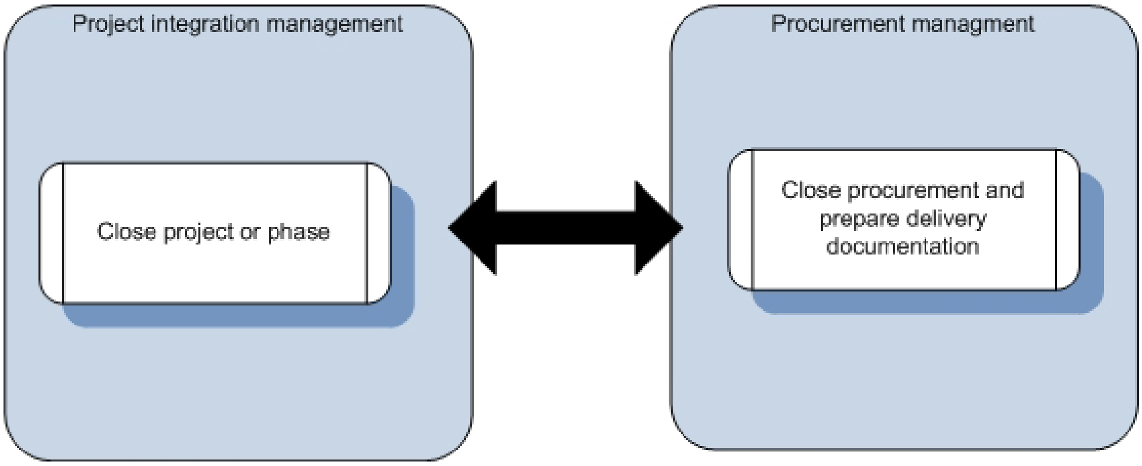


Figure 3.26 -Closing process: adapted from (PMI., 2008)

3.5.2 Project Planning tools in Shipbuilding

There are many commercially available software for shipbuilding production planning and estimation. Some of these software are used as part of the enterprise resource planning (ERP) of the yard with an integrated capability. Individual stand-alone functionality of these software are also quite common for reasons of practicality, simplicity and acquisition cost. As discussed in chapter two (2), customized planning solution has been designed by some of the Korean, Chinese and European Shipyards. We will discuss brief aspects of some of the commercially available software with shipbuilding project planning application in the following section.

3.5.2.1 Safran planner

Project management software from Safran is being used to plan and manage projects, resources and production for both own and subcontractor work at Aker Yards. According to Rinta-Panttila of Aker Yards, Safran's flexibility and capacity were important factors in the purchase decision. Both the project schedule and the resource plan are presented graphically in Safran. Good graphical reports and views are very important because they provide essential information in a concise and easy to read manner. The interactive Gantt editor in Safran, which both Rinta-Panttila and AFY's (Aker Finland Yard) key Safran user Timo Tommila regard as a major plus, help visualize the schedule and resource situation, and it is easy to work out the best schedule and resource plan to speed up work (Safran., 2012).

Discussions with the users of Safran Planner convey very crucial message for those who wish to use it in future. Planning Manager Pertti Rinta-Panttila of Aker Finnyards says that a system like Safran is a must for them. Without it, there will be no ships-not on time at least (Safran.). Pertti Rinta-Panttila also says that when carrying out a large project, resource management is the key to everything and they have to find the best possible way to utilize available resources. To do this Safran is mandatory (Safran.).

Some users mentioned about both usefulness and limitation of using Safran. Mr. Mike Peyton says “Safran seems to have an inherent problem with Longest Path Analysis. It doesn’t export to Excel and it likes to combine data in cells which makes it hard to deal with. Safran does some funky things with zero duration activities with regard to early dates.” “Safran seems to do a good job of being able to handle shortened time periods for histogram displays. Safran’s group and short functionality appears to be more robust and highly customizable”, he also added (PlanningPlanet). Mr. Femi Wuyi, Assistant Planning Manager at Bouygues Construction Nigeria Ltd Abuja, says “I have used both Safran Project Planner & Primavera P6 in my planning works, both are good planning software. Safran has some features that makes it better than MS Project for those that can explore it very well” (Linkedin).

Constructing schedules was once the province of highly trained professionals involving complex tools and specialized jargon. Safran Planner claims that it offers easy-to-use Project planning software that takes the mystery out of project planning. The software claims the following features:

- Fully CPM (Critical Path Method) network
- Resource analyses
- Baseline for schedule comparison
- Multi Project scheduling

- Global data change and update
- Earned value summarized for man hours, cost or time
- Network drawing

With Safran Planner it's a breeze to compose professional Gantt charts. Gantt charts are useful tools for analyzing and planning projects as discussed in section 3.6.2.1.6. When project is underway Safran Gantts are useful for monitoring its progress. It can be seen what should have been achieved at any point in time, identifying deviations and taking remedial action to bring the project back on track. This can be essential for success and profitability. It can be customized for the output for application in user's own definitions. A typical Safran window in shown in Figure 3.27.

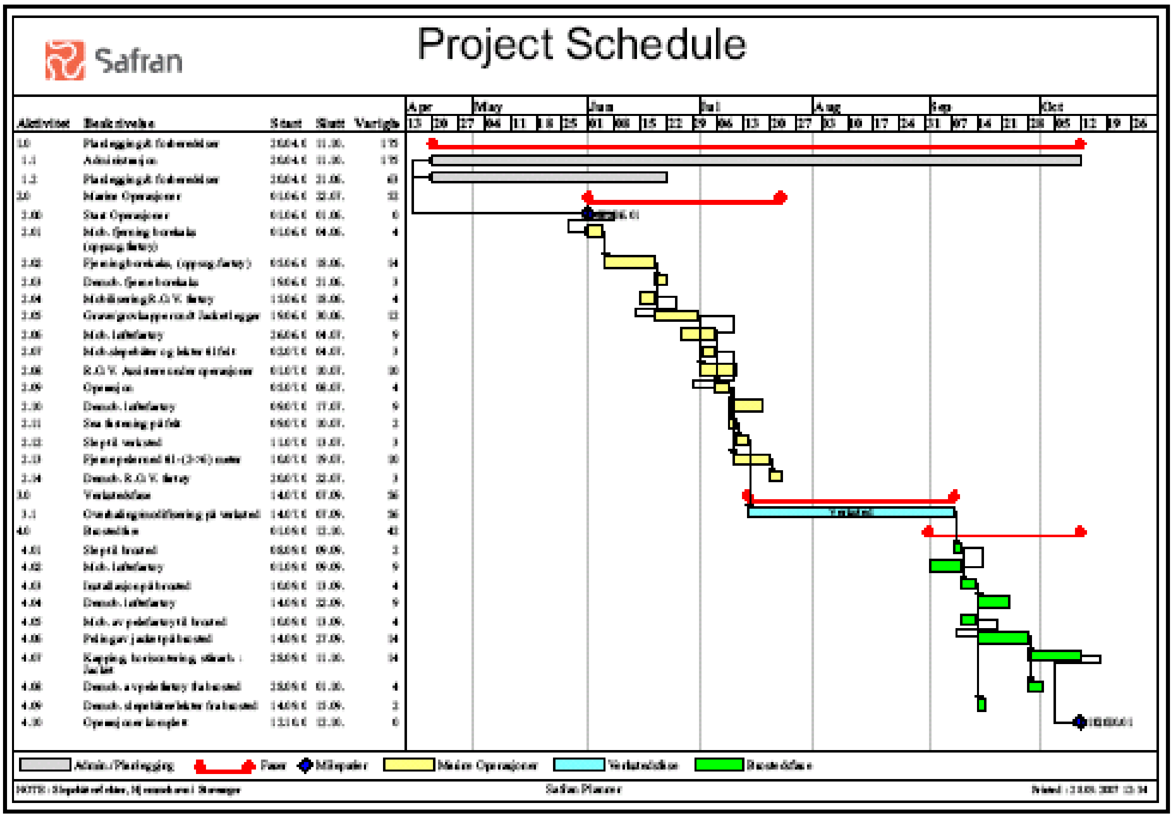


Figure 3.27 -Project schedule in safran planner (Netronic., 2011)

3.5.2.2 Microsoft project

Microsoft Project is the world's most popular project management software developed and sold by Microsoft.

The program, which has many different versions, allows users to:

- Understand and control project schedules and finances.
- Communicate and present project information.
- Organize work and people to make sure that projects are completed on schedule

The application is designed to assist project managers in developing plans, assigning resources to tasks, tracking progress, managing budgets and analyzing workloads. Microsoft Project creates critical path schedules, although a critical chain third-party add-on is available from ProChain and Spherical Angle. Schedules can be resource leveled. The chain is visualized in a Gantt chart (Haughey, 2012).

Resource definitions (people, equipment and materials) can be shared between projects using a shared resource pool. Each resource can have its own calendar which defines what days and shifts a resource is available. Resource rates are used to calculate resource assignment costs which are rolled up and summarized the resource level.

Each resource can be assigned to multiple tasks in multiple plans and each task can be assigned multiple resources. Microsoft Project schedules task work based on the resource availability as defined in the resource calendars. All resources can be defined in an enterprise resource pool and the activities are demonstrated in a Gantt Chart.

Microsoft Project creates budgets based on assignment work and resource rates. As resources are assigned to tasks and assignment work estimated, Microsoft Project calculates the cost equals the work times the rate. This rolls up to the task level, then to any summary tasks and finally to the project level.

Microsoft recognizes different classes of users as they can have differing access levels to projects, views and other data. A typical MS project window in shown in Figure 3.28.

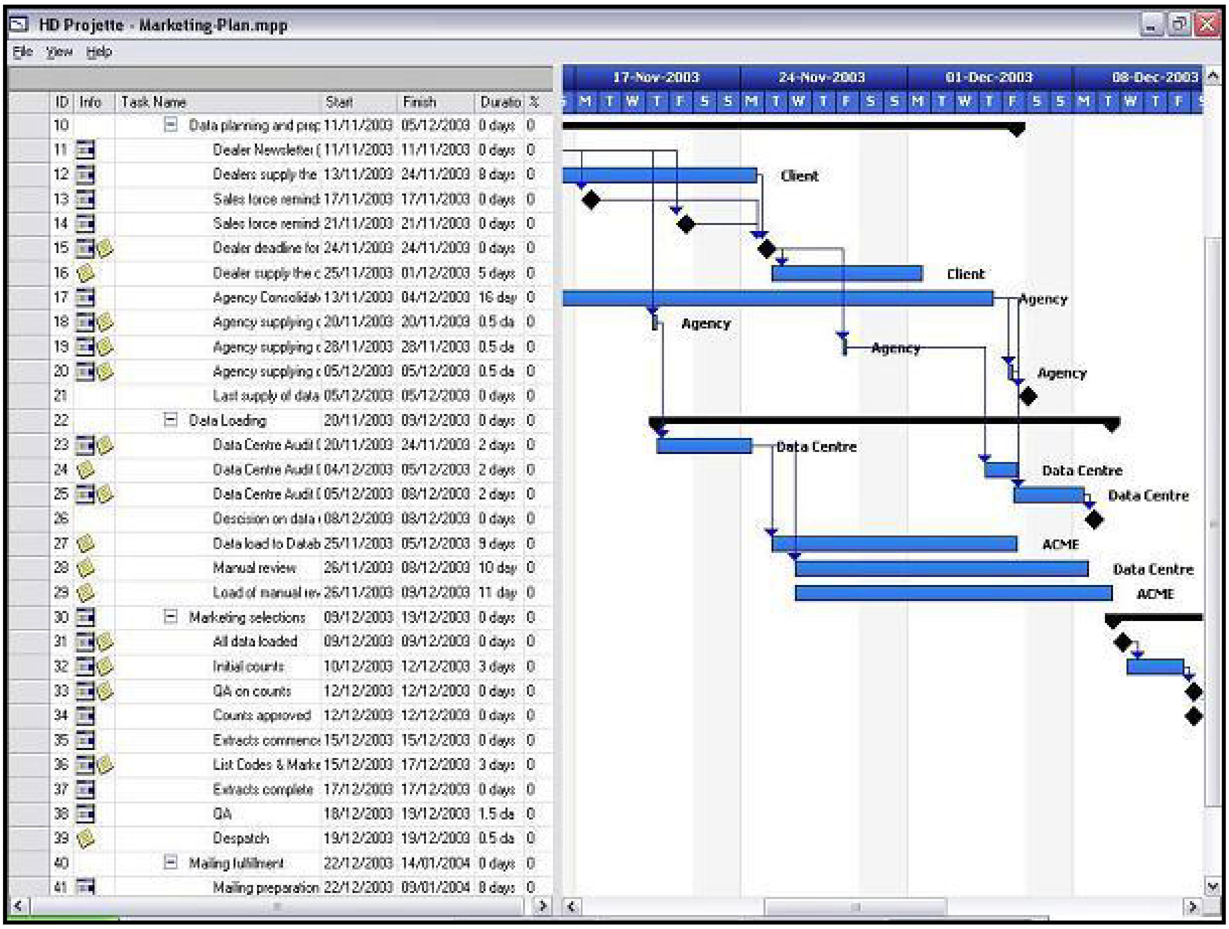


Figure 3.28 -MS Project screenshot (ES., 2012)

3.5.2.3 Primavera

Oracle's Primavera is focused exclusively on helping project-intensive businesses, managing their entire project portfolio lifecycle, including projects of all sizes. Primavera project portfolio management solutions claim to help make better portfolio management decisions, evaluate the risks and rewards associated with projects, and determine whether there are sufficient resources with the right skills to accomplish the work. These solutions provide the project execution and control capabilities needed to successfully deliver projects on time, within budget and with the intended quality and design. A&P Tyne yard, Newcastle upon Tyne uses Primavera solution for project planning (Oracle., 2012).

Primavera has following modules:

1. Primavera P6 Enterprise Project Portfolio Management, 2. Primavera P6 Professional Project Management, 3. Primavera Inspire for SAP, 4.Primavera P6 Analytics, 5. Primavera Risk Analysis, 6. Primavera Earned Value Management, 7. Primavera contract management and business intelligence solution, 8. Primavera Integration Solutions.

Primavera P6 Enterprise project portfolio management is used for planning and scheduling projects while others offer analysis and customized insights into the trend and performance in the project.

P6 Enterprise Project Portfolio Management has following broad features:

- Plan, schedule, and control large-scale programs and individual projects
- Select the right strategic mix of projects
- Balance resource capacity
- Allocate best resources and track progress
- Monitor and visualize project performance versus. plan
- Foster team collaboration
- Integrate with financial management and human capital management systems

A typical window of Primavera P6 is shown in Figure 3.29.

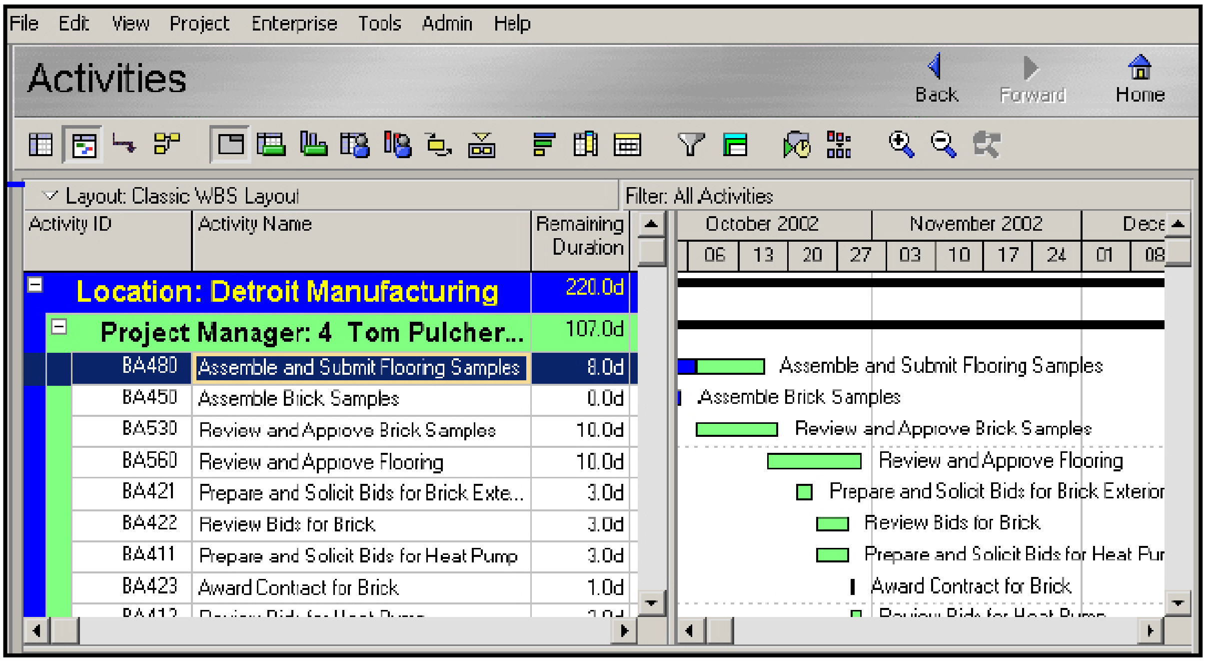


Figure 3.29 -Screenshot of primavera P6 (Dunia, 2012)

3.5.3 Management philosophy in manufacturing

Although there are instances of rigorous process thinking in manufacturing all the way back to the Arsenal in Venice in the 1450s, the first person to truly integrate an entire production process was Henry Ford. At Highland Park, Michigan in 1913 he married consistently interchangeable parts with standard work and moving conveyance to create what he called flow production. Long before the process improvement in automotive industry, in 1799 a genius engineer in England called Marc Brunel produced a processing machine that would automate the production of pulley blocks for Portsmouth Dockyard. Brunel is also credited to design the construction method for Thames tunnel in 1825 (Bagust, 2006). However, Japanese engineers such as Kiichiro Toyoda, Taiichi Ohno, and others at Toyota observed Henry's system in the 1930s, and more intensely just after World War II. It occurred to them that a series of simple innovations might make it more possible to provide both continuity in process flow and a wide variety in product offerings. They, therefore, revisited Ford's original thinking, and invented the Toyota Production System. Production engineers and researcher have proposed many other concepts around manufacturing; Kaizen, 5S, Lean manufacturing, Six-Sigma, lean-sigma, DFSS (Design for Six Sigma), flexible manufacturing, JIT(Just-in-Time) and agile manufacturing are a few to name. A few Shipbuilding industries interestingly adopted and practiced some of these methods.

3.5.3.1 Lean manufacturing method

Lean manufacturing, lean enterprise, or lean production, often simply, "Lean," is a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination. Working from the perspective of the customer who consumes a product or service, "value" is defined as any action or process that a customer would be willing to pay for the core idea of lean is to maximize customer value while minimizing waste. Simply, lean means creating more value for customers with fewer resources.

The term "lean" was coined to describe Toyota's business during the late 1980s by a research team headed by Jim Womack, Ph.D., at MIT's International Motor Vehicle Program. Lean manufacturing is a management philosophy derived mostly from the Toyota Production System (TPS) (hence the term Toyotism is also prevalent) and identified as "Lean" only in the 1990s (Womack *et al.*, 1990). A lean organization understands customer value and focuses its key processes to continuously increase it. The ultimate goal is to provide perfect value to the customer through a perfect value creation process that has zero waste. To accomplish this, lean thinking changes the focus of management from optimizing separate technologies, assets, and vertical departments to optimizing the flow of products and services through entire value streams that flow horizontally across technologies, assets, and departments to customers. Eliminating waste along entire value streams, instead of at isolated points, creates processes that need less human effort, less space, less capital, and less time to make products and services at far less costs and with much fewer defects, compared with traditional business systems. Companies are able to respond to changing customer desires with high variety, high quality, low cost, and with very fast throughput times. Also, information management becomes much simpler and more accurate (Leanorg., 2012). It is not a tactic or a cost reduction program, but a way of thinking and acting for an entire organization.

Businesses in all industries and services, including healthcare and governments, are using lean principles as the way they think and do. Many organizations choose not to use the word lean, but to label what they do as their own system, such as the Toyota Production System or the Danaher Business System. The word transformation or lean transformation is often used to characterize a company moving from an old way of thinking to lean thinking. It requires a complete transformation on how a company conducts business. This takes a long-term perspective and perseverance.

The characteristics of a lean organization and supply chain are described in *Lean Thinking*, by Womack and Dan Jones, founders of the Lean Enterprise Institute and the Lean Enterprise Academy (UK), respectively. *Lean Thinking* remains one of the best resources for understanding "what is lean" because it describes the *thought process,* the overarching key principles that must guide your actions when applying lean techniques and tools.

Womack and Jones recommend that managers and executives embarked on lean transformations think about three fundamental business issues that should guide the transformation of the *entire organization:*

- Purpose: What customer problems will the enterprise solve to achieve its own purpose of prospering?

- Process: How will the organization assess each major value stream to make sure each step is valuable, capable, available, adequate, flexible, and that all the steps are linked by flow, pull, and leveling?

- People: How can the organization insure that every important process has someone responsible for continually evaluating that value stream in terms of business purpose and lean process? How can everyone touching the value stream be actively engaged in operating it correctly and continually improving it?

"Just as a carpenter needs a vision of what to build in order to get the full benefit of a hammer, Lean Thinkers need a vision before picking up our lean tools," said

Womack in his book. "Thinking deeply about purpose, process, people is the key to doing this."

Womack and Daniel T. Jones distilled these lean principles to five steps:

- Specify the value desired by the customer
- Identify the value stream for each product providing that value and challenge all of the wasted steps (generally nine out of ten) currently necessary to provide it
- Make the product flow continuously through the remaining value-added steps
- Introduce pull between all steps where continuous flow is possible
- Manage toward perfection so that the number of steps and the amount of time and information needed to serve the customer continually falls

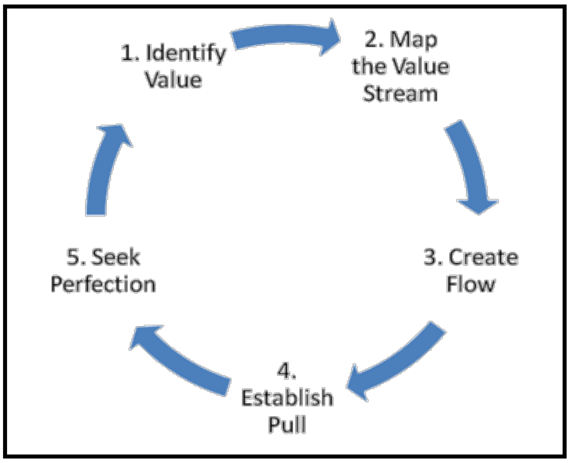


Figure 3.30 -Lean principle (Leanorg., 2012)

3.5.3.2 Six-sigma

Six sigma originated in Motorola in mid 1980s, brought revolution in industries worldwide and has become the long term business strategy to achieve competitive advantage and to excel in operations excellence. Six sigma is widely recognized as a methodology that employs statistical and no-statistical tolls and techniques to maximize an organization's ROI (Return on Investment) through the elimination of defects in process. The perception of Six Sigma has changed drastically from being a statistical tool to being companywide strategy for business process improvement. Organizations have included SIx Sigma as a part of their business strategy and in the strategic review process to become globally competitive. increase market share, and enhance customer satisfaction. It takes us away from" *intuition based* *decision - what we think is wrong, to fact based decision -what we know is wrong".* Six Sigma's success has been attributed to embracing it as an improvement strategy, philosophy and a way of doing business (Antony and Maneesh, 2011).

Six Sigma at many organizations simply means a measure of quality that strives for near perfection. Six Sigma is a disciplined, data-driven approach and methodology for eliminating defects (driving toward six standard deviations between the mean and the nearest specification limit) in any process – from manufacturing to transactional and from product to service.

The statistical representation of Six Sigma describes quantitatively how a process is performing. To achieve Six Sigma, a process must not produce more than 3.4 defects per million opportunities. A Six Sigma defect is defined as anything outside of customer specifications. A Six Sigma opportunity is then the total quantity of chances for a defect. Process sigma can easily be calculated using a Six Sigma calculator (isixsigma, 2012).

The fundamental objective of the Six Sigma methodology is the implementation of a measurement-based strategy that focuses on process improvement and variation reduction through the application of Six Sigma improvement projects. This is accomplished through the use of two Six Sigma sub-methodologies: DMAIC and DMADV. The Six Sigma DMAIC process (define, measure, analyze, improve, control) is an improvement system for existing processes falling below specification and looking for incremental improvement. The Six Sigma DMADV process (define, measure, analyze, design, verify) is an improvement system used to develop new processes or products at Six Sigma quality levels. It can also be employed if a current process requires more than just incremental improvement. Both Six Sigma processes are executed by Six Sigma Green Belts and Six Sigma Black Belts, and are overseen by Six Sigma Master Black Belts.

3.5.3.3 Lean sig-sigma in shipbuilding

The adoption of "lean" automobile manufacturing concepts developed by Toyota has been advocated as a means to achieve large improvements in the performance of various other industries, including shipbuilding. The basic goal of lean production is cost reduction via elimination of unnecessary operations, waiting times, and inventories. Storch and Lim have explored the potential application of one of the Lean principles, flow, to the shipbuilding industry and proposed an approach to move the industry closer to lean manufacturing in terms of flow, and offers a metric by which to determine how close to ideal flow a shipbuilding system is. The basis for the establishment of lean thinking in shipbuilding is the appropriate application of group technology through the use of a product-oriented work breakdown structure (Storch, 1999).

Koenig and Narita described two cases of process improvement in a Japanese shipyard and the extent to which these reflect lean principles. They proposed that if lean production is considered as a general philosophy or set of goals, then the Japanese shipbuilding industry would likely rank ahead of Toyota in terms of achievement. On the other hand, considering the specifically "lean" mechanisms derived from the automobile industry experience, it appears that not all have been applicable to Japanese shipyards (P. C. Koenig *et al.*, 2002).

Under the auspicious role of Norwegian Research Council, following shipyards from Norway participated in the implementation program of lean in shipbuilding: Aker Yards, Kleven Verft and Ulstein Verft. Together they constitute a significant part (app. 75%) of the total Norwegian shipbuilding capacity. Dugnas and Oterhals reported an essential theoretical support towards a better shipbuilding process. Together with the Lean theory review, current activities and plans for implementation of Lean principles at the participating shipyards with a series of recommendations regarding both, theoretical and practical issues leading to further development of the Lean Shipbuilding concept and its application to different shipyards in the Norwegian context (Dugnas and Oterhals, 2008).

The National Shipbuilding Research Program (NSRP) has played a major role in the introduction of Lean Manufacturing to the US shipbuilding base since 1999. NSRP has been involved in Lean projects with resulting successful implementations in US shipyards since 1999. Initial spot improvements have evolved into industry-wide Lean efforts (Bourg, 2006). It was reported that “of the $377M in cost reductions reported by the U.S. shipbuilding industry, over half were from their Lean efforts. As the industry exploits this technology more cost reductions are to be expected” (Whiddon 2005). While application of Lean is expanding in US shipyards, implementation of Six Sigma and its relatively recent integration with Lean remain limited to only a few shipyards. At the same time, Six Sigma and Lean-Six Sigma are embraced by corporations worldwide, from finance to health care, both in manufacturing and transactional processes. Evolution of Lean Six Sigma and DFSS in US shipbuilding is shown in Figure 3.31. During the 2000–2002 period, pilot Six Sigma studies were conducted at Norfolk Naval Shipyard and Northrop Grumman Newport News Shipyard (NGNN). In the summer of 2002 Northrop Grumman Ship Systems (NGSS) began transitioning their Lean program to a Lean Six Sigma (LSS) program in conjunction with the LSS in Shipbuilding project. This project is sponsored by the Office of Naval Research (ONR) ManTech Program and conducted at Advanced Maritime Technology Application Center (AMTAC) at University of New Orleans (UNO). This project has enabled implementation of LSS at NGSS approximately 12 months earlier than originally planned.

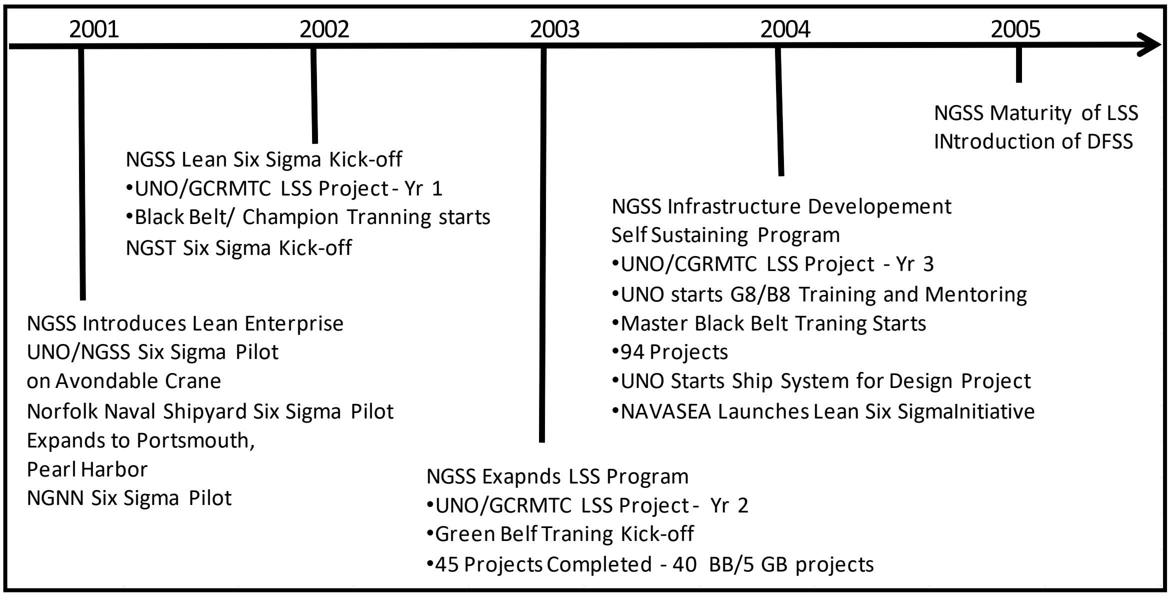


Figure 3.31- Evolution of lean six sigma and DFSS in US shipbuilding (Bourg, 2006)

3.6 An approach to shipbuilding project for getting optimal solution

Small to medium sized shipyards are challenged with the management task of dissimilar projects, unlike big and established shipyards equipped with the state of art facility having major engagement in construction of series, make-to-order ships/ marine vessels. These projects are mostly secured either through formal or informal competitive bidding process. Due to strategic competition, shipyards belonging to small to medium group offer or accept tight deadline for project completion including design deliveries to the satisfaction of the owner's stipulated deadline. Essential it becomes to overlap and integrate all focused disciplines of shipbuilding project, i.e., design, procurement and construction etc., from the day one of the project. Cross functional interaction among disciplines for information, resources and materials poses co-ordination challenge to the management team. Sequence execution in ship construction is mostly influenced by the method of construction, the spatial arrangement of the yard and arbitrary imposition of externalities, while a great consideration is given to simultaneous and ongoing projects.

This proposed method applies Dependency Structure Matrix (DSM) to iterate sequence of project activities based on the relational dependence or interdependence to arrive at an optimum succession. Optimality achieved through this procedure offers best possible sequence and the interrelation of these activities can be further explored to demonstrate type and nature of dependence or interdependence lying therein. Thus, more control and precautionary measures can be taken in advance to minimize disturbance in the project and project teams can be made aware about the cross-functional transfer / exchange of packages (information, resources or materials). While sequential optimality may be a very effective way of safeguarding the project from uncertainties and delay, execution of the activities is required equally to be investigated. Moreover, a best fit or optimum allocation of resources can be arrived at for further reduction of wastes from manufacturing processes. All the activities, listed and iterated through DSM, can be translated and expanded into various executable work processes requiring distinguishable resources, i.e., workers, tools, machines and materials at the least. These work processes may further be fragmented into a number of work stations where tangible jobs are processed towards accomplishing an activity. Work stations are equipped with resources to perform its intended job. It is observed that a shipyard may assign a group of people having assortment of skill sets to execute a task or activity, while the numbers of people, tools, machines and stations allocated with the process are prerogative on the basis of best estimate. This estimate is worked out on the basis of historical performance of the process and expertise of team members in the projection of future task. Human cognitive ability, to project observations and predictions long into the future beyond the immediate situations upon which those are based, is limited and may at times associate high risks of cost overrun and under or over supply of resources in the project. This methodology proposes to introduce discrete event simulation to model and study the process and analyze optimum requirement of resources to accomplish respective task or activity within the time envisaged in the initial planning stage- a testable prediction of future process.

A discrete event simulation technique is proposed to study output measures of the process, i.e., quantified interim units and completion time. Simulation can be used as a strong tool for investigation of any physical process or phenomena. Stand-alone application of simulation technique may not be comprehensively robust to identify optimal arrangement of resource allocation in the process. Therefore, statistical Design of Experiments (DOE) is augmented to find out as to which combination of resource (factor) settings optimizes the process. In this analysis, purposeful changes are made to the inputs (resources or factors) of the process in a series of tests and changes in the preferred response variable are observed & analyzed, while all the tests are carried out in simulated environment. Hereunder, for maintaining congruence in the text, factors, resources and inputs will be used synonymously. In designed experiment each factor is assigned with a number of levels at which the factor is tested. The level of factors is changed simultaneously according to statistical design plan or layout which largely depends on the number of factors under consideration. With application of Design of Experiments, optimality at the local level (OLL) for resource settings in the processing of shipbuilding activities will be achieved.

3.7 Summary

This chapter traversed through project management process, planning process and tools applied in shipbuilding, scheduling techniques, planning techniques, and management philosophies. PERT, CPM and demonstration of project plan in widely used GANTT chart essentially have been studied to analyze the advantages and disadvantages of these techniques. Planning process acts as the driving force in the success of the project goal. The more realistic the planning is made taking feedback and knowledge from project team and historical data, the more likely is an increased chance of the project being implemented within scheduled deadline. Informed leadership in any project and in shipbuilding for that matter is very critical as motivated leaders assigned with component tasks of the project generally champion in pulling all the forces together and carefully marrying the tasks with planning sequences. Till today, it is believed by many that leadership is an inherited or bestowed quality. The debate surrounding the leadership attainment process remains as live as it was yesterday. Nevertheless, project leadership is broadly knowledge based which might even produce more fantastic result if instilled in a born leader. In shipbuilding, project managers and team leaders are trained and made aware of the strategic plan, implementation, procurement, inventory and resource planning in the beginning of the project and periodically to reflect and adjust approaching uncertainties. It is an established norm of the day to consider projects with constrained resources. Budgetary allocation in project always targets value maximization where value is defined as the difference derived by deducting project cost from project's sale proceed from customer, e.g., deduced value by subtracting shipbuilding cost from the value of a ship received from the ship owner. In shipbuilding project, jobs in steel fabrication, pipe fabrication, surface preparation etc. require sets of skills which may be shared among competing tasks of similar nature. For instance, a welding supervisor may be allocated in grouped tasks of sub-assembly jobs carried out simultaneous in multiple sites in a yard. Mobile equipment and human resources should, therefore, be used in the most optimum way in shipbuilding project. While planning and scheduling the sequence of shipbuilding, it is observed that some of the sequences are kept in tandem with each other in spite of the fact that those work groups could have been carried out concurrently. This is done carefully to give way to the other ongoing projects, taking the spatial facility constraint of the yard layout into account. Resource sharing has a far greater significance not only in the timely implementation but also in the arrangement of the project sequences as sharing causes interdependencies among the task sequences. For successful project management, these resource interdependencies should be well reflected in the planning strategy of the project well in advance.

4 Chapter Four. Methodology of Integrated Management Framework

4.1 Introduction

Planning and implementation of a project are considered to be a rather complicated process with a number of components that extend to economic consequences, as much for the executing company as for the owner of the project itself. One of the key issues in the beginning of the project, and also during its implementation process, is to secure the existence of a reliable flow of dependent information and resources among project sequences. The management of that information flow and the co-existence of an efficient decision-making system are considered to be the most important factors of maintaining quality in project management. Dependency and flow of information among the project sequences should be taken into consideration to realize maximum benefit in a resource constrained environment. Project sequence should therefore reflect upon the resource dependencies. From the analysis made in the previous chapter, it may be inferred that none of this method has attributes to project and/or manage resource dependencies which has to be addressed in a methodical way so as to make decisive budgetary program. And also, for the sake of an optimal project efficiency. As mentioned earlier PERT and CPM are not very much prevalent in shipbuilding unless these are demanded by any stakeholder for a very specific purpose. GANTT chart on the other hand can produce the timeline of activity but it does not optimize the activity sequences. Conventional software discussed above mainly reflect the philosophy of these techniques. While the previous chapter has touched upon the standard processes of project management, it has been observed that shipbuilding practices are not any different than these practices. The best practices along with further specialization like the application of lean and sig-sigma may produce desirable outcomes for a yard or project. However, they are only limited to the philosophical transcription. For a small to medium yard, planning sequences are very critical in the sense that alternative sequences may present cost advantage and better utilization of resources and offer an optimum operation. Therefore, after the analysis of the content of methods and techniques in the previous chapter, it may be inferred that there is a need to address sequence iteration of project. The proposed methodology as discussed in this chapter will present a way of creating alternative sequences of project activities and thus an optimal sequence may be established based on dependencies while the conventional management practices can still be applied. As project goes through iterative progression as discussed in section 3.5.1, this proposed method will detail how resource and information can be made the basis to iterate project sequences to derive sequential optimality and, thereby, an effort to deal with this identified sequence issue will be made.

This chapter describes the proposed method to achieve optimality in global level (OGL) and in local level (OLL) of shipbuilding project (see chapter one), components of the methodology and integration framework. This management methodology consists of three principal components, namely Dependency Structure Matrix, Discrete event Simulation and Design of Experiments. An integration framework for managing shipbuilding project incorporating all the three components are discussed and summarized.

4.2 Rationalization of the method

The management of large construction project like shipbuilding and repair or conversion require the use of the related techniques of planning, scheduling and production control. The productivity of the project is dependent on the co-ordination of material, manpower, facilities, capital, and information among others. Managing these resources is the key to efficiency. In Chapter four sections 4.5, it is argued that the best outcome may be reaped from this method being applied in small to medium shipyards which are located in a geographic area where most of the ship building jobs are attempted to be organized and carried out by the builder rather than employed sub-contractors. Small to medium shipyards (SMS) in a growing shipbuilding area usually come across fierce competition in procuring contracts as these yards enjoy almost same level of competitive edges. The author has experienced this phenomenon during his time working with the yard and while participating in competitive tenders. It was consistently found that the range of disclosed price quotations remains within a tiny percentage of winning bid. Unlike the giant shipyards, especially for critical projects like Gas carrier, Cruise ships, OSV etc., who normally settle contract negotiations across the table and the negotiated price may mark a considerable difference from the nearest offer from other yards. Although, the owner's decision is sometimes prejudiced by the reputation, estimated operational risk, historical relation with the yard, delivery schedule, technical excellence of the yard. Hence, price may not be the only factor to be considered. Operational disadvantages for small to medium shipyards in a developing shipbuilding area may display following traits among others:

i) Unfavorable logistic network from the suppliers to the yard

ii) Poor infrastructure of the location

iii) Non-availability of skilled contractors

iv) Scarcity of project finance

v) Complex customs and revenue structure for imported raw materials

vi) Challenge for retention of skilled workers

vii) Lack of training for project management personnel and, therefore, co-ordination and succession of jobs become disorderly

viii) Imbalanced mix of manual and robotic/automatic application

ix) Unstable capital flow which pose cyclic strain on the operational performance

x) Marginal operation due to fierce competition

xi) Diversified project portfolio; as these yards secure works through tenders and therefore get their hands on "all sorts of products" creating management hurdles

A closer study at international yards of various sizes irrespective of location may reveal that the employment of contractors in shipbuilding is fairly a conventional practice. However, contractors base does not flourish on its own but only with the enthusiastic support from the yard. There is a tacit tendency among the SMSs to get most of the jobs done by the yard themselves for the sake of maximization of profit leverage, however, at the risk of exhaustive management control and co-ordination. It is not a surprise to find that these yards are carrying out jobs related to carpentry, foundry or mass production of pipe flanges at the shops within the yard premises. The concept of flexible yard has come forefront in advanced shipbuilding yards, where contractors have the requisite expertise to conduct works in almost all the departments in the shipbuilding project. In this model the yard acts as a facilitator providing support in management, co-ordination and control of the project. SMS's has strategic capacity planning for project implementation considering work flow of current and proposed projects. This strategy serves as a guidance for capacity enhancement, in the face of actual and projected contracts. Due to the operation flexibility being intrinsically bounded by a short range around operating breakeven point, SMSs attempt to avoid prolonged starvation of jobs or interrupted work flow, which is why trait (xi) listed above in this section is prevalent among this yard genre. While trait (viii) listed above is the outcome of a combined effect of the fact that a SMS is in the process of achieving a standard operation. The imbalance is attributed to either the phenomena of the yard being in the development process for its facilities or the availability of cost effective manpower creating a bias towards engagement of workers offsetting the application of automation. Moreover, the cost towards employment of manpower compensating the investment required for automation may have a better suitability from the financial point of view. In the contrary, established yards run on achieved standard that is the process of operation and project management are already evolved to a point of standardization through trial and error over a considerable amount of time. The investment on specific premises for facility development is not an affair to be considered from a short term view. However, these yards are friendly to existing process improvement. Any technological advancement in making the existing machinery or process more efficient finds its way primarily in the major yards. This constant push for innovation appears to be the most significant cause in bringing in any update or improvement to the process of these yards, i.e. the update of software to the robotic welding station. Advanced yards keep abreast state of the art in equipment and machinery unlike SMS, which is in a quandary of making a choice between investment in automation or engagement of manpower. Hypothetically, if it were to keep a record of progress in the development of a SMS, i.e., investments made in automation of equipment over yards lifespan, for any given time, it may be observed that its instantaneous position is lying somewhere in the Spline gradient as shown in Figure 4.1, a reflection of technological investment in SMSs with salient features of phase wise robust and sluggish growth.

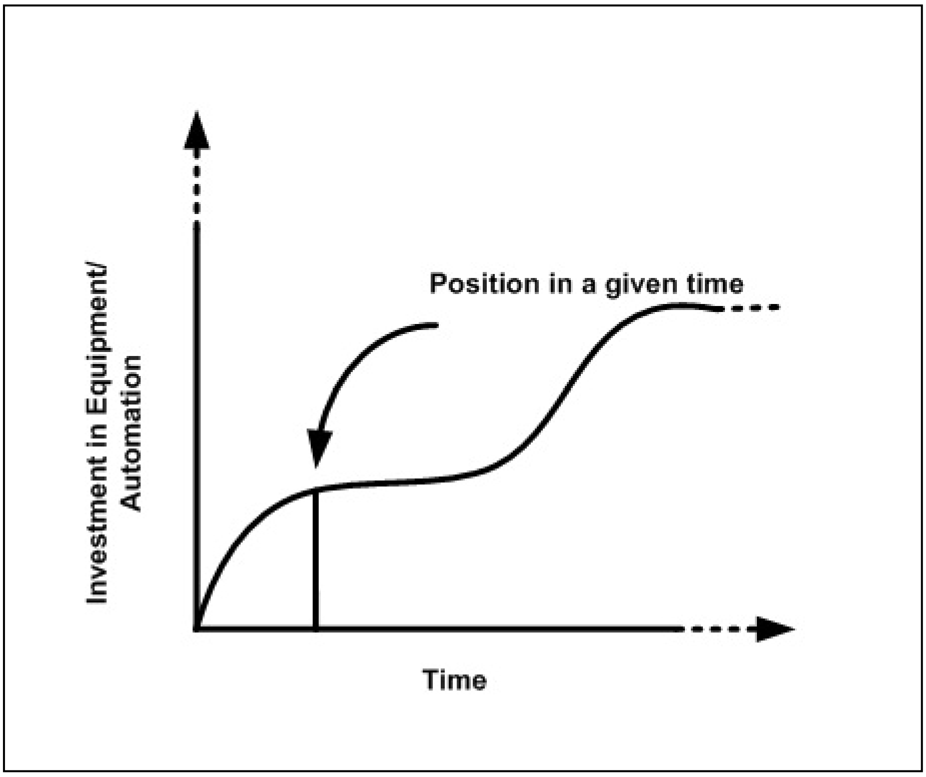


Figure 4.1 -Development pattern of SMS

While this status reflects a yard's present investment climate, it may seemingly be a major question as to how the yard will achieve its efficient operation when the production process is under continuous evolution to reach to a level of stable standard. It is worthwhile to remember that the process and layout of every yard is unique and built over considerable time on an initial master layout. Sometimes, we find that this master layout is put through modification to incorporate various requirements emergent in the production process in the light of present day necessity. With the change in investment made gradually over time, management of individual ship construction project also absorb commensurate adjustments. Concept of management of large project with particular attention to shipbuilding has been discussed in Chapter 3 in detail. Drawing upon the above delineation, It may be conferred that there is a need for the SMS to operate in an optimum efficiency in the context of individual ship construction project, particularly, for the fact that these yards are on constant path of transformation, e.g., Figure 4.1. Also the project has to be completed within the schedule. The proposed method is flexible in nature and addresses the above cited issues around the ship construction project in small to medium shipyards and tries to find an optimal management of the project in terms of project activity sequencing and resource utilization in the corresponding production processes. This method can be applied in any position of the curve in Figure 4.1. It also deals with the project schedule conformity by overlapping design with construction and satisfies concurrent engineering. It may not perhaps be very well-argued to try and find a global optimality for the yard itself consisting of all the ongoing projects as this may become very extraneous in nature and may require more exploitation of resources. If it is maintained that all the individual shipbuilding projects are managed in a project wise global optimality, then the collective synergy of optimally managed projects may assure efficient operation of the yard. In literature, the use of genetic algorithm, neural network, multi-criteria scheduling and many other mathematical applications are observed for finding optimum solution to job shops, but integration of global optimality of project sequence with optimized production requires to be studied and recommended. This method is expected to convey the supposed platform to this integration.

4.3 Proposed optimality method

Figure 4.2 shows a graphical flow chart of the proposed methodology with components having connectivity with each other through steps of collaborative actions and thus produces an integrated framework for achieving optimality in the project management. The objective function of optimality in OGL is time and resources in OLL. However, both of these objective functions connote to reduction of cost. An enlightened discussion is followed in the subsequent sections to demonstrate how all these three components are combined together to produce an approach for shipbuilding project management.

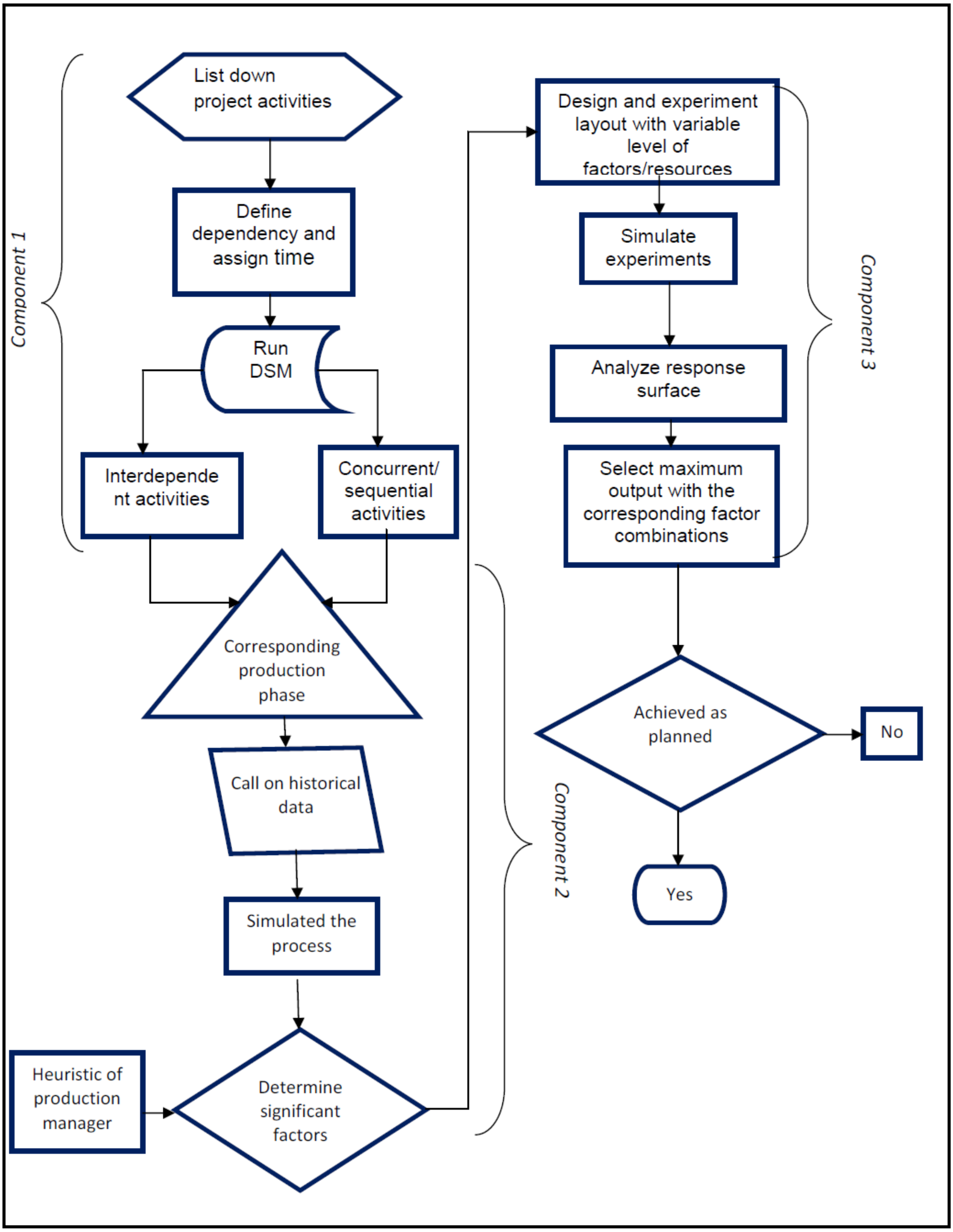


Figure 4.2 -Integrated optimality method

This chapter will present an overview of a novel, integrated and holistic methodology for managing shipbuilding projects for small to medium shipbuilding enterprises. This approach consists of three principal components; (1) Dependency Structure Matrix for optimality in the global level and, (2) Discrete event simulation and (3) Design of Experimentss for optimality a local level of project execution. Furthermore, this management methodology utilizes response surface approach to optimize output measures in the manufacturing process. Planner has to take care of the interaction of the activities in terms of aliasing among them with particular emphasis to interdependency and overlapping of design and construction. Analysis, modeling and sequencing of activities for arriving at optimality in terms of exchange or dependency of information and resources is applied through the application of DSM for the assurance of optimal project management alongside conventional planning tools. DSM offers iteration and allows the modeler to explore the best fit of sequence, can produce concurrent groups of activities and bring about a dependent sequence between different phases like design and construction. Planning falls in the time domain as it is concerned mostly with the interaction and co-ordination between activities. Production of the activities falls in the domain of both time and resource utilization since it is mostly concerned with realization within stipulated time and resources. The attempt is directed as to how to bring about integration between these two domains keeping in view the sequence and optimality. All these three components as embedded in the method as shown in Figure 4.2 will be applied in the case studies in Chapter 5.

4.4 Dependency structure matrix- component one

Dependency Structure Matrix (DSM - also known as the design structure matrix, dependency source matrix, and dependency structure method) is a general method for representing and analyzing system models in a variety of application areas. A DSM is a square matrix (i.e., it has an equal number of rows and columns) that shows relationships between elements in a system. Since the behavior and value of many systems is largely determined by interactions between its constituent elements, DSMs have become increasingly useful and important in recent years (Eppinger and Browning, 2012). Relative to other system modeling methods, a DSM has two main advantages:

- It provides a simple and concise way to represent a complex system.

- It is amenable to powerful analyses, such as clustering (to facilitate modularity) and sequencing (to minimize cost and schedule risk in processes).

The DSM is related to other square-matrix-based methods such as a dependency map, a precedence matrix, a contribution matrix, an adjacency matrix, a reachability matrix, and an N-square diagram, and also related to non-matrix-based methods such as directed graphs, systems of equations, and architecture diagrams and other dependency models. The use of matrices in system modeling can be traced back to the 1960s, if not earlier. However, it was not until the 1990s that the methods received relatively widespread attention (Lindemann., 2009).

4.4.1 Types of DSM

Four different common types of data that can be represented in a DSM have been identified, however, any other type of DSM is possible, too (Browning, 2006).

DSM data types	Representation	Applications
Component-based (Product)	Component relationships	System architecting, engineering and design
People-based (Organization)	Organizational unit relationships	Organizational design, interface management, team integration
Activity-based (Process)	Activity input/output relationships	Process improvement, project scheduling, iteration management, information flow management
Parameter-based (low-level Process)	Design parameter relationships	Low level activity sequencing and process construction, sequencing design decisions

Table 4.1-DSM classification

4.4.1.1 Component based DSM

A component-based DSM documents interaction between elements in a complex system architecture. Different types of interactions can be displayed in the DSM as shown in Table 4.1. Types of interactions will vary from project to project.

Some representative interaction types are shown in the table below (Pimmler and Eppinger, 1994):

Spatial	Needs for adjacency or orientation between two elements
Energy	Needs for energy transfer/exchange between two elements
Information	Needs for data or signal exchange between two elements
Material	Needs for material exchange between two elements

Table 4.2 -Interaction type of component-based DSM

Another comprehensive list for modeling dependencies in a product architecture is provided (Jarratt, 2004) by as shown in Table 4.2.

Mechanical steady state	Components are in physical contact and they impose a steady state mechanical load on each other. This is a symmetrical relationship.
Mechanical dynamic	Components are in contact and interact through a fluctuating force or displacement. This can be a directional relationship.
Spatial	Components are touching or adjacency and orientation are important. This is a symmetrical relationship.
Thermal steady state	There is a steady state temperature difference between the two components. This can be a directional relationship.
Thermal dynamic	There is a fluctuating temperature difference between the two components. This can be a directional relationship.
Electrical signal	A signal passes from one component to the other. This can be a directional relationship.
Electrical earth	There is an electrical earth connection between the two components. This can be a directional relationship.
Electrical dynamic	The physical design or logic driven behavior of one component is connected to the physical design or logic behavior of the other. This can be a directional relationship.

Table 4.3 -Product architecture and component-based DSM

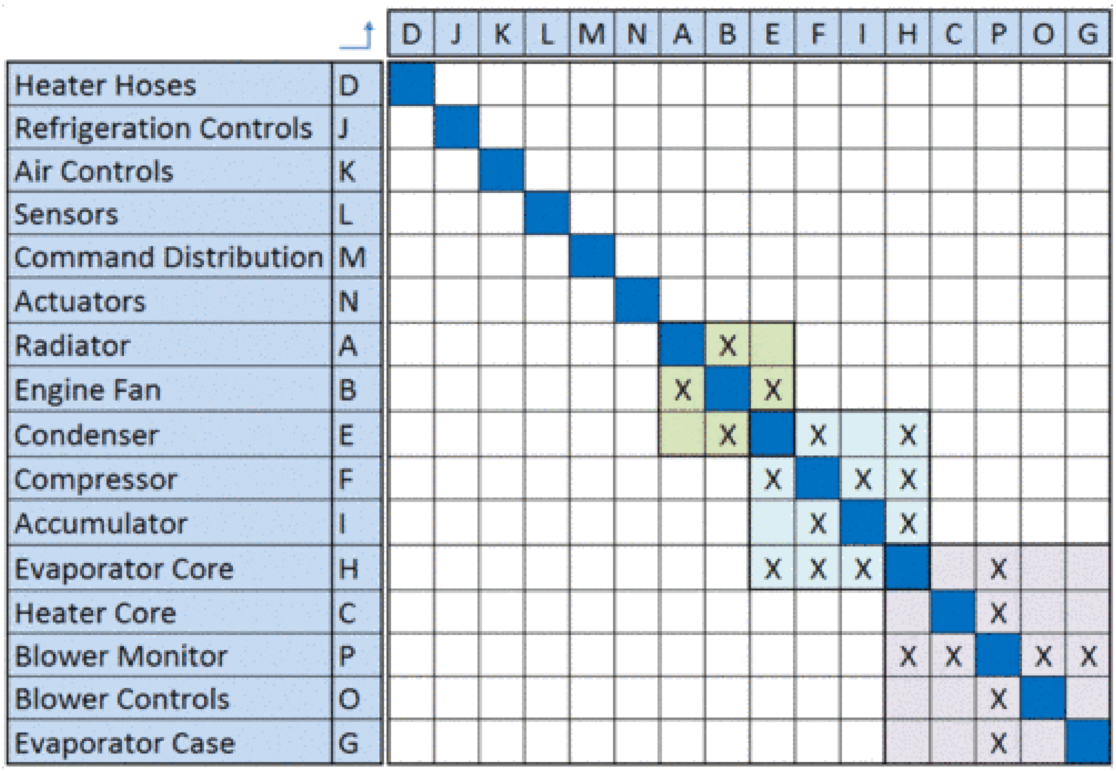
As an example, let us consider the material interaction between components for an automobile Climate Control System as presented in this case, e.g. the engine fan (B) needs transfers material to the condenser (E), as there is an “X” in cell (B, E).

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Radiator	A		X														
Engine Fan	B	X				X											
Heater Core	C																X
Heater Hoses	D																
Condenser	E						X		X								
Compressor	F					X			X	X							
Evaporator Case	G																X
Evaporator Core	H					X	X			X							X
Accumulator	I						X		X								
Refrigeration Controls	J																
Air Controls	K																
Sensors	L																
Command Distribution	M																
Actuators	N																
Blower Controls	O																X
Blower Monitor	P			X				X	X							X	

Figure 4.3 -DSM of climate control system, adapted from (Lindemann., 2009)

The matrix can now be rearranged in order to obtain clusters of highly interacting components while attempting to minimize inter-cluster interactions. This way, the data is not changed, but the matrix rows and columns are only swapped pair-wise to obtain a different matrix layout as shown in Figure 4.4. The obtained groupings represent a useful framework for reorganizing the product architecture and putting the focus on the interfaces among modules.

Clustering the "X" marks along the diagonal of the DSM resulted in the creation of three clusters for the Climate Control System. These clusters represent groups of components that are closely interconnected. They can be used to define modules that can, e.g. be ordered from different system suppliers or that can be used across a series of different refrigerators (small, medium, large volume, for example) as carry-over modules with well-defined interfaces to the other modules or clusters.



		D	J	K	L	M	N	A	B	E	F	I	H	C	P	O	G
Heater Hoses	D																
Refrigeration Controls	J																
Air Controls	K																
Sensors	L																
Command Distribution	M																
Actuators	N																
Radiator	A								X								
Engine Fan	B							X		X							
Condenser	E								X		X		X				
Compressor	F									X		X	X				
Accumulator	I										X		X				
Evaporator Core	H									X	X	X			X		
Heater Core	C														X		
Blower Monitor	P												X	X		X	X
Blower Controls	O														X		
Evaporator Case	G														X		

Cluster 1		Front End Air Chunk
Cluster 2		Refrigerant Chunk
Cluster 3		Interior Air Chunk

Figure 4.4-DSM layout after iteration for automobile climate control system

4.4.1.2 Team-based DSM

This approach is used for organizational analysis and design based on information flow among various organizational entities. Individuals and groups participating in a project are the elements being analyzed (rows and columns in the matrix). A Team-based DSM is constructed by identifying the required communication flows and representing them as connections between organizational entities in the matrix. For the modeling exercise it is important to specify what is meant by information flow among teams. Table 4.3 below, presents several possible ways information flow can be characterized (McCord and Eppinger, 1993).

Flow Type	Possible Metrics
Level of Detail	Sparse (documents, e-mail) to rich (models, face-to-face)
Frequency	Low (batch, on-time) to high (on-line, real)
Direction	One-way to two-way
Timing	Early (preliminary, incomplete, partial) to late (final)

Table 4.4 -Information flow characterization for team-based DSM

Again, the matrix can be manipulated in order to obtain clusters of highly interacting teams and individuals while attempting to minimize inter-cluster interactions. The obtained groupings represent a useful framework for organizational design by focusing on the predicted communication needs of different players.(McCord and Eppinger, 1993) proposed a team-based DSM to analyze the organizational structure necessary for an improved automobile engine development process.

4.4.1.3 Activity-based (task-based) DSM

Figure 4.5 shows a set of tasks in a process. These tasks must work together to fulfill the goal of the overall process. The exchange of dependent factors can thus be represented as a digraph or a DSM.

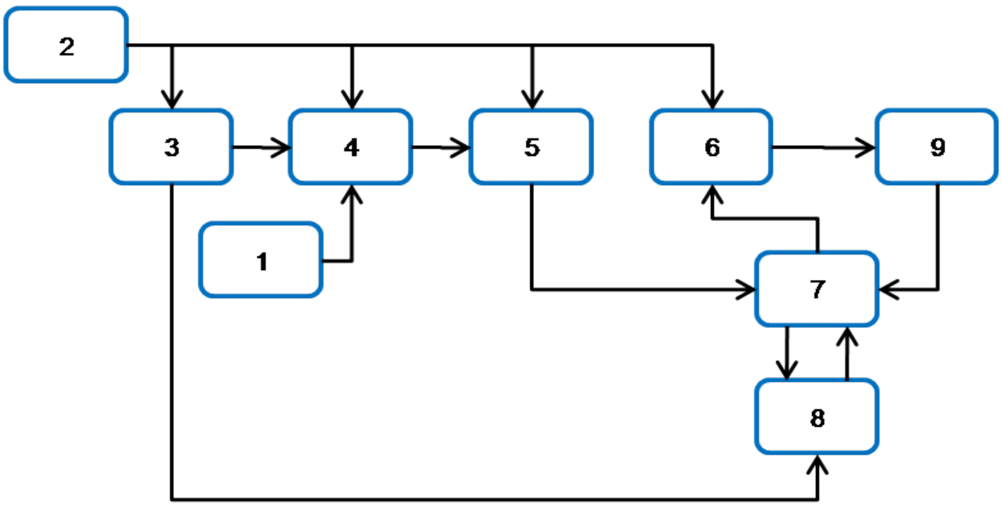


Figure 4.5 -Digraph of example activity, adapted from (Lindemann., 2009)

Three types of task interactions can be observed from the matrix. In the Figure 4.6, tasks 1 and 2 are "independent" since no information is exchanged between them, the same is true for elements 4 and 8. These tasks can be each executed simultaneously (in parallel). Tasks 3, 4, and 5 are engaged in a sequential information transfer and are considered "dependent". These tasks would typically be performed in series. Tasks 7 and 8, however, are mutually dependent on factors. These are "interdependent" or "coupled" tasks often requiring multiple iterations for completion. Ultimately, tasks 6, 7, and 9 are engaged in a cycle.

	1	2	3	4	5	6	7	8	9
1				X					
2			X	X	X	X			
3				X				X	
4					X				
5							X		
6									X
7						X		X	
8							X		
9							X		

Figure 4.6 -DSM layout of activity based example DSM, adapted from (Eppinger and Browning, 2012)

Marked cells below the diagonal represent potential rework loops or iterations in the process. This occurs when an activity is dependent on exchangeable factors from a task scheduled for a later execution. Such scenarios often lead to rework and are undesirable. A number of algorithms have been developed to minimize such instances of iteration (sub-diagonal marked cells) by re-arranging the sequence of tasks in the process. Methods are also available to handle iterations in the process that cannot be eliminated through re-sequencing. Commonly, the basic sequencing algorithms are referred to as “Triangularization”, as the goal is to obtain an “upper triangular matrix” that has preferably no marks below the diagonal. DSM models using simple binary representations display the existence of a dependency between two tasks without providing additional information on the nature of the interactions. However, the nature of interaction may be identified at the beginning of the process sequencing. Further studies have extended the basic DSM configuration by capturing additional facts on the development process. For example, the numerical DSM replaces marks with numbers in the off-diagonal cells to represent the degree of dependency between two tasks (Numerical DSMs). This makes it possible to show, e.g., the probability of a feedback loop and thus prioritize important iterations in the process planning. Resource or material dependence structure can also be modeled with activity-based DSM. Resources in any project are not abundant and sometimes activities sequencing are dependent on the allocation and usage of the resources. Two or more activities may share a resource and produce interdependence among the activities and continue progression.

4.4.1.4 Parameter-based DSM

This type of modeling is used to analyze a design process at the level of parameter relationships. (Black *et al.*, 1990) applied a parameter-based DSM to an automobile brake system design, using the DSM to describe the current practices of a brake system component supplier as shown in Figure 4.7. After sequencing the parameters, in the resultant DSM, Figure 4.8, two blocks (=clusters) of coupled, low-level parameter determinations become apparent.

		1	2	3	4	5	6	7	8	9	10	11	12	13
Customer Requirements	1			X	X	X								
Wheel Torque	2					X	X		X		X			X
Pedal Mech. Advantage	3					X		X		X		X		X
System Level Parameters	4		X	X		X		X	X	X	X	X		X
Rotor Diameter	5			X				X				X		X
ABS Modular Display	6													
Front Lining Coef. of Friction	7					X								X
Piston-Rear Size	8			X		X		X			X	X		X
Caliper Compliance	9						X							
Piston- Front Size	10			X		X		X	X	X		X		X
Rear Lining Coef of Friction	11					X								X
Booster - Max. Stroke	12													
Booster Reaction Ratio	13			X		X		X		X		X	X	

Figure 4.7 -DSM layout of automobile brake system, adapted from

		1	4	2	10	8	3	11	7	13	5	12	9	6
Customer Requirements	1		X				X				X			
System Level Parameters	4			X	X	X	X	X	X	X	X		X	
Wheel Torque	2				X	X				X	X			X
Piston- Front Size	10					X	X	X	X	X	X		X	
Piston-Rear Size	8				X		X	X	X	X	X			
Pedal Mech. Advantage	3							X	X	X	X		X	
Rear Lining Coef. of Friction	11									X	X			
Front Lining Coef. of Friction	7									X	X			
Booster Reaction Ratio	13						X	X	X		X	X	X	
Rotor Diameter	5						X	X	X	X				
Booster - Max. Stroke	12													
Caliper Compliance	9													X
ABS Modular Display	6													

Figure 4.8 -DSM layout of automobile brake system after iteration (Black et al., 1990)

4.4.2 Reading a DSM

The cells along the diagonal of the matrix represent the system elements. To keep the matrix diagram compact, the full names of the elements are often listed to the left of the rows (and sometimes also above in the columns) rather than in the diagonal cells. It is also easy to think of each diagonal cell as potentially having inputs entering from its top and bottom and outputs leaving from its left and right sides. The sources and destinations of these input and output interactions are identified by marks in the off-diagonal cells. Examining any row in the matrix reveals all of the outputs from the element in that row (which are inputs to other elements). Looking down any column of the matrix shows all of the inputs to the element in that column (which are outputs from other elements). For example, in the Figure 4.9, reading across row 2, we see that element 2 provides outputs to elements 3 and 4. Reading down column 5, we see that element 5 receives inputs from elements 1, 3, and 4. Thus, a mark in an off-diagonal cell (e.g., cell 3,5) represents an interaction that is both an input and an output, depending on whether one takes the perspective of its provider (element 3) or its receiver (element 5).

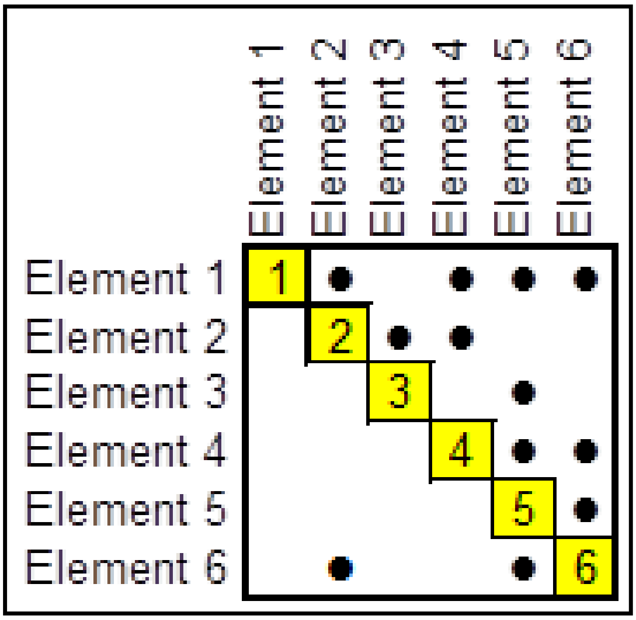


Figure 4.9 - DSM illustration

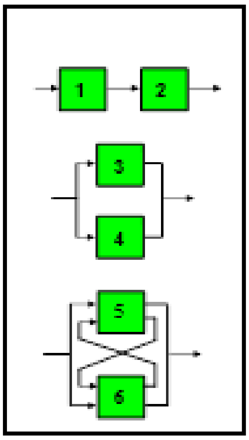


Figure 4.10 -Activity relationship

In Figure 4.10, elements are node-directed link diagram equivalents of portions of the DSM. Elements 1 and 2 form a linear chain or sequence, while elements 3 and 4 are independent, and elements 5 and 6 are interdependent or coupled.

This simple DSM example is called a binary DSM because the off-diagonal marks indicate merely the presence or absence of an interaction. The binary DSM representation can be extended in many ways by including further attributes of the interactions, such as the number of interactions and/or the importance, impact, or strength of each—which might be represented by using one or more numerical values, symbols, shadings, or colors instead of just the binary marks in each of the off-diagonal cells. This extended form of DSM is called a numerical DSM. Additional attributes of the elements themselves may also be included by adding more columns to the left of the square matrix to describe, for example, the type, owner, or status of each element. Additional attributes of the interactions, such as their names, requirements, etc. are usually kept in separate repositories but may be linked to the DSM cells by numerical identification numbers or indices.

Many DSM resources use the opposite convention, the transpose of the matrix, with an element's inputs shown in its row and its outputs shown in its column. (Eppinger and Browning, 2012) developed the following notation for these two conventions:

• IR/FAD convention: DSM with inputs shown in rows, outputs in columns; hence, any feedback marks will appear above the diagonal.

• IC/FBD convention: DSM with inputs shown in columns, outputs in rows; hence, any feedback marks will appear below the diagonal.

4.4.3 Sequencing a DSM

Sequencing is the re-ordering of the DSM rows and columns such that the new DSM arrangement does not contain any feedback marks, thus transforming the DSM into an upper triangular form. For complex engineering systems, it is highly unlikely that simple row and column manipulation will result in an upper triangular form. Therefore, the analyst's objective changes from eliminating the feedback marks to moving them as close as possible to the diagonal (this form of the matrix is known as block triangular). Equally, it is possible to learn about what elements of the system might possibly have to be reworked (e.g. split into two elements or perhaps removed) to achieve a better process architecture.

There are several approaches used in DSM sequencing. However, they are all similar with a difference in how they identify cycles (loops or circuits) of coupled elements. All sequencing algorithms proceed as follows (Eppinger and Browning, 2012):

1. Identify system elements (or tasks) that can be determined (or executed) without input from the rest of the elements in the matrix. Those elements can easily be identified by observing an empty column in the DSM. Place those elements to the left of the DSM. Once an element is rearranged, it is removed from the DSM (with all its corresponding marks) and step 1 is repeated on the remaining elements.

2. Identify system elements (or tasks) that deliver no information to other elements in the matrix. Those elements can easily be identified by observing an empty row in the DSM. Place those elements to the right of the DSM. Once an element is rearranged, it is removed from the DSM (with all its corresponding marks) and step 2 is repeated on the remaining elements.

3. If after steps 1 and 2 there are no remaining elements in the DSM, then the matrix is completely partitioned; otherwise, the remaining elements contain information circuits (at least one).

4. Determine the circuits by one of the following methods:

- Path Searching
- Powers of the Adjacency Matrix Method
- Reachability Matrix Method
- Triangularization Algorithm
- Tarjan's Depth First Search Algorithm

5. Collapse the elements involved in a single circuit into one representative element and go to step 1.

4.4.4 Tearing a DSM

Once a subset of coupled elements has been identified in a DSM, tearing is one way to attempt to determine a sequence for elements in this subset. Tearing is the process of choosing the set of feedback marks that, if removed from the matrix (and then the matrix is re-partitioned), will render the matrix upper-triangular. The marks that we remove from the matrix are called "tears". Identifying those "tears" that result in an upper triangular matrix means that we have identified the set of assumptions that need to be made in order to start process iterations when coupled tasks are encountered in the process. Having made these assumptions, no additional estimates need to be made.

No optimal method exists for tearing, but following two criteria are recommended in literature making tearing decisions (Steward, 1981b):

- Minimal number of tears: the motivation behind this criterion is that tears represent an approximation or an initial guess to be used; it would be rather wise to reduce the number of these guesses used.
- Confine tears to the smallest blocks along the diagonal: the motivation behind this criterion is that if there are to be iterations within iterations (i.e. blocks within blocks), these inner iterations are done more often. Therefore, it is desirable to confine the inner iterations to a small number of tasks.

4.4.5 Banding a DSM

Banding is the addition of alternating light and dark bands to a DSM to show independent (i.e. parallel or concurrent) activities (or system elements). Banding is similar to partitioning the DSM using the Reachability Matrix Method when the feedback marks are ignored. The collection of bands or levels within a DSM constitute the critical path of the system or project (Grose, 1994). *Furthermore, one element or activity within each band is* the critical or the bottleneck activity. Thus, fewer bands are preferred since they improve the concurrency of the system or project. For example, in the DSM shown in Figure 4.11, tasks 4 and 5 do not depend on each other for information; therefore, they belong to the same band. In banding procedure, feedback marks are not considered (i.e. they are ignored in the process of determining the bands).

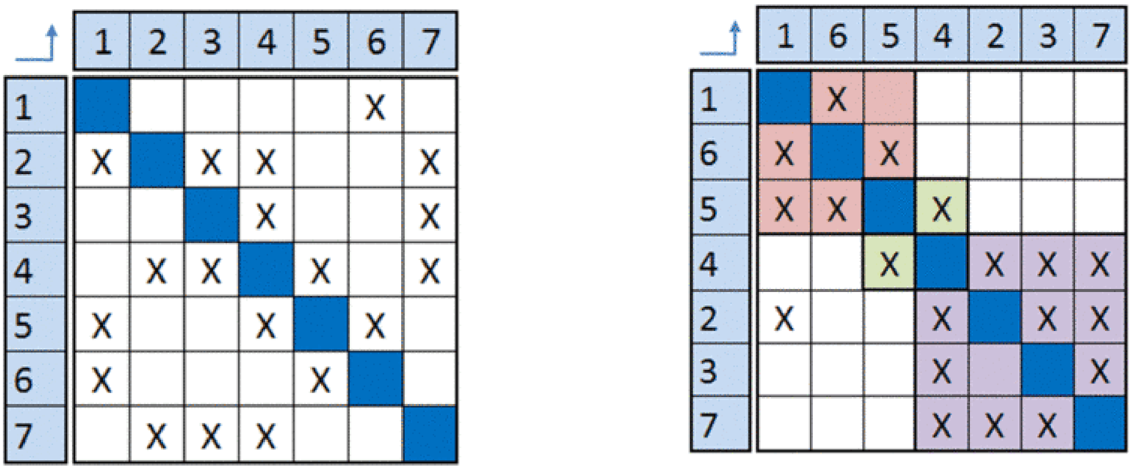
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1		X		X	X	X	X		X			X	X	X
2			X											X
3				X	X				X					X
4									X	X				X
5						X								X
6					X		X	X		X	X	X		X
7										X	X	X		X
8					X				X	X	X			X
9		X												X
10											X	X		X
11										X		X		X
12					X			X					X	X
13					X									X
14														

Figure 4.11 -Banding of DSM

4.4.6 Clustering a DSM

When the DSM elements represent design components (i.e., component-based DSM) or teams within a development project (i.e., people-based DSM), the goal of the matrix manipulation changes significantly from that of sequencing algorithms. The new goal becomes finding subsets of DSM elements (i.e., clusters or modules) that are mutually exclusive or minimally interacting subsets, i.e., clusters as groups of elements that are interconnected among themselves to an important extent while being little connected to the rest of the system. This process is referred to as "Clustering". Figure 4.12 shows two matrices before and after clustering. In other words, clusters absorb most, if not all, of the interactions (i.e., DSM marks) internally and the interactions or links between separate clusters are eliminated or at least minimized as a simple example, let us consider a development process that includes seven participants as shown in Figure 4.16. Interactions between different participants are also shown in the DSM. If several development teams are to be formed within this project, number of teams required and the membership can be formed from this DSM. Figure 4.13 shows a team nomenclature for this example.

Clustering the DSM for this project will provide insights into optimal team formations based on the degree of interactions among participants. Figure 4.14 shows the formed teams on the basis of clustering DSM.



(a) Before iteration (b) After Iteration

Figure 4. 12 -Clustering of DSM

Team 1		Participants 1, 5 and 6
Team 2		Participants 4 and 5
Team 3		Participants 2, 3, 4 and 7

Figure 4.13 -Team nomenclature

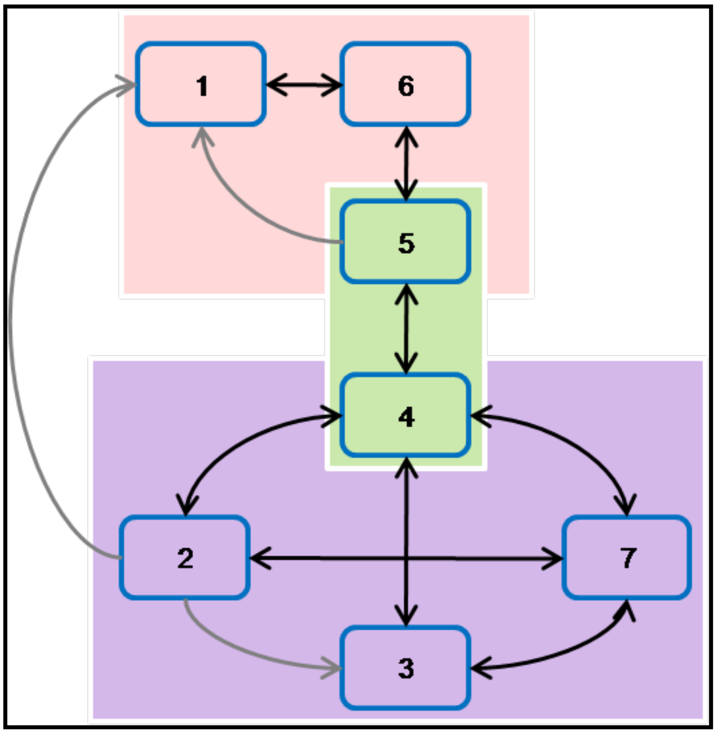


Figure 4.14 -Team formation based on clustering of DSM

4.4.7 DSM against the limitations of PERT and CPM

The traditional approach for project scheduling is the well-known CPM and, when taking a further step, the use of PERT to deal with uncertainty. However, these two traditional approaches have weaknesses in scheduling projects, particularly in terms of modeling iteration (Qian and Goh, 2007). Other tools like Gantt, and IDEF methods do not address problems stemming from project complexity (Yassine and Braha, 2003). They allow project and engineering managers to model sequential and parallel tasks but not interdependent tasks, where a set of tasks is dependent on one another. The DSM method provides this representation capability in a simple and elegant manner.

With regard to the work flow of activities, the CPM approach loses effectiveness when it seeks to deal with iterative processes or handle coupled activities in sequent or parallel activities (Oloufa *et al.*, 2004). Although traditional project management tools like PERT and Gantt charts are useful in sequencing discrete activities or tasks in complex construction projects, they cannot manage the back-and-forth exchange of information that usually occurs in product development and complex projects (Eppinger, 2001). While it is a common practice in shipbuilding to carry out design of the ship overlapping with the construction after couple of months into the project when a single ship project is considered from a unique design afresh. Outfitting design, which comes at a later stage of the project requires information exchange between hull module design and procurement teams. The DSM approach, developed by (Steward, 1981a), is useful in representing complex relationships of dependency caused by information exchange between activities (Yassine and Braha, 2003). Differing from the traditional CPM approach, DSM represents information flows based on workflows in a project, which can handle not only sequential, parallel activities, but also coupled activities (Oloufa *et al.*, 2004). With the use of such a tool for describing information flow, the relationship of information dependency between activities would make analysis and decision making easier (Maheswari *et al.*, 2006). In comparison to all other graph-based tools, the DSM provides a simpler and clearer visual description of complex systems (Sharif and Kayis, 2007) & (Luh *et al.*, 2009). Increased use of DSM can be found in different contexts, from product development, project planning, and systems engineering to organizational design (Browning, 2006). The DSM approach, together with other tools and techniques, could be widely employed to solve different types of problems in various kinds of projects; e.g., DSM can be integrated with quality function deployment (QFD) to support design planning for new product development projects (Hung *et al.*, 2008) be integrated with Cognitive Maps to overcome communication problems and to ease knowledge sharing of design projects; or be integrated with the Monte Carlo Simulation to facilitate change management of construction projects (Z. Y. Zhao and Lv, 2010). In addition, DSM can be transformed to other matrices in different scenarios of project management; e.g., (Avritzer *et al.*, 2010) transformed DSM into a Communication Matrix (COM) to handle coordination issues, and (Senthilkumar *et al.*, 2010) transformed DSM into Design Interface Management Matrices (DIMM) to solve the problem of interface management. The robust technique of the Work Transformation Matrix (WTM), proposed by (Cronemyr *et al.*, 2001), is also an extension of DSM. According to (Mohan, 2002), DSM is useful for identification, definition, recording, and examination of intrinsic system dependencies at different levels from projects to programs, not only in development phases but also in operational phases. However, based on a survey that systematically classified the approaches used in DSM-based process planning, (Karniel and Reich, 2009) identified a gap in the literature regarding “activities sequencing based on DSM and the process modeling literature concerning process verification.” They claimed that, “the DSM itself does not express all the relevant information required for defining process logic. Many logic interpretations are applicable in different business cases; yet, a consistent method of transforming a DSM based plan to a logically correct concurrent process model in the case of iterative activities is lacking.” In addition, DSM requires effort and skilled personnel to estimate information dependency attributes. The estimation efforts have a negative effect on the use of this method (Maheswari *et al.*, 2006). (Luh *et al.*, 2009; Shi and Blomquist, 2012) integrated fuzzy set theory and DSM to solve the problem of vagueness and uncertainty of information dependency for project scheduling.

For shipbuilding project management, traditional tool like CPM, PERT, and similar methods are not very effective since there are always uncertainties in material and component delivery, fabrication, assembly and erection processing time. PERT/CPM assumes that each job has a unique, definable beginning and ending and that all other jobs which must be completed before the job can be started are similarly uniquely defined. So, PERT/CPM network describing the shipbuilding project is directed, unidirectional, acyclic, and does not allow for updating, feedback or adaptation. This introduces severe restrictions which make the approach impractical when jobs and their sequence must often be changed, and one job performance is conditioned on the performance of other job performance (Frankel, 1982). According to (Salimifard *et al.*, 2012), CPM/PERT techniques have been applied in a lot of shipbuilding projects for many years. But these tools suffer from unrealistic assumptions like infinite availability of resources for each activity of the project. These authors said conventional management tools are incapable to resolve conflicts arising from scarcity of resources and resource interdependencies.

4.4.8 Project execution strategies for design and construction overlap

In the conventional method of project execution, design is fully completed before construction starts as illustrated in Figure 4.15.a. As the demand for shorter projects arose, phased construction was introduced. Here, after each design work package is completed, the corresponding construction work package is executed as shown in Figure 4.15.b. (Fazio *et al.*, 1988). Owing to the further demand for shortening project duration, the fast-track method came into existence. In this method, the design phase is overlapped with the construction phase to achieve the time gain as shown in Figure 4.15.c (Huovila *et al.*, 1994). As there was no systematic analysis or procedure for overlapping the phases, there were numerous problems and additional costs associated with the fast-track approach (Huovila *et al.*, 1994).The concurrent engineering concept consists of an organized procedure and methods for achieving the demand of shortened project duration. It is a process where selected activities in the design phase are overlapped, thereby reducing the total duration of the design phase as shown in Figure 4.15.d. At VTT, USA, UK, Korea, Finland and Loughborough University, extensive research is being carried out in implementing the concurrent engineering (CE) concept in construction (Huovila *et al.*, 1994; Huovila *et al.*, 1995; Anumba and Kamara, 1999; Kamara *et al.*, 2001; Malik and Naveed, 2005; Anumba *et al.*, 2007; Bogus and Diekmann, 2011; Tae-Kyung and Chang-Yong, 2014). Concurrent construction (CC) is a combination of the fast-track and CE concepts where there is a shortened design phase and also overlapping with the construction phase as shown in Figure 4.15.e. Even though the CC concept offers potential for maximum reduction in duration, issues of systematic implementation require attention to the detail and competence of core project management team. A comparative analysis of the various execution strategies is shown in Table 4.4. The level of detail required to plan the CE and CC processes is at the activity level. Detailed information about the dependency relationships for the activities is essential for concurrent implementation. Such detailed information will not be available to the planners during planning. One of the challenges in planning a CE process is to decide on the assumptions and the corresponding sequence of execution, that will result in minimum project duration with little risk of errors and rework. Executing a concurrent project with uncertain information and/or assumptions is a key challenge. Once suitable assumptions are determined, the sequence of activities can be generated. DSM can successfully produce an optimal concurrent activity sequence.

Design Structure Matrix (DSM) clusters or marked blocks of interdependent and concurrent activities to optimize sequences and interfaces and thereby ensures optimum completion time. The original layout of sequence of activities is also changed through this clustering. Here optimizing interfaces is equivalent to minimizing interfaces. On the other hand, it is worth pointing out that Work Breakdown Structure (WBS) is a method of production which doesn't exclude the case of DSM. Any identified item in WBS may be used as an input to the DSM. It is possible to integrate a particular process and Work Breakdown Structure with Design Structure Matrix (J. Lee *et al.*, 2010). Moreover, it is important to note that more time is required when sequential scheduling is used.

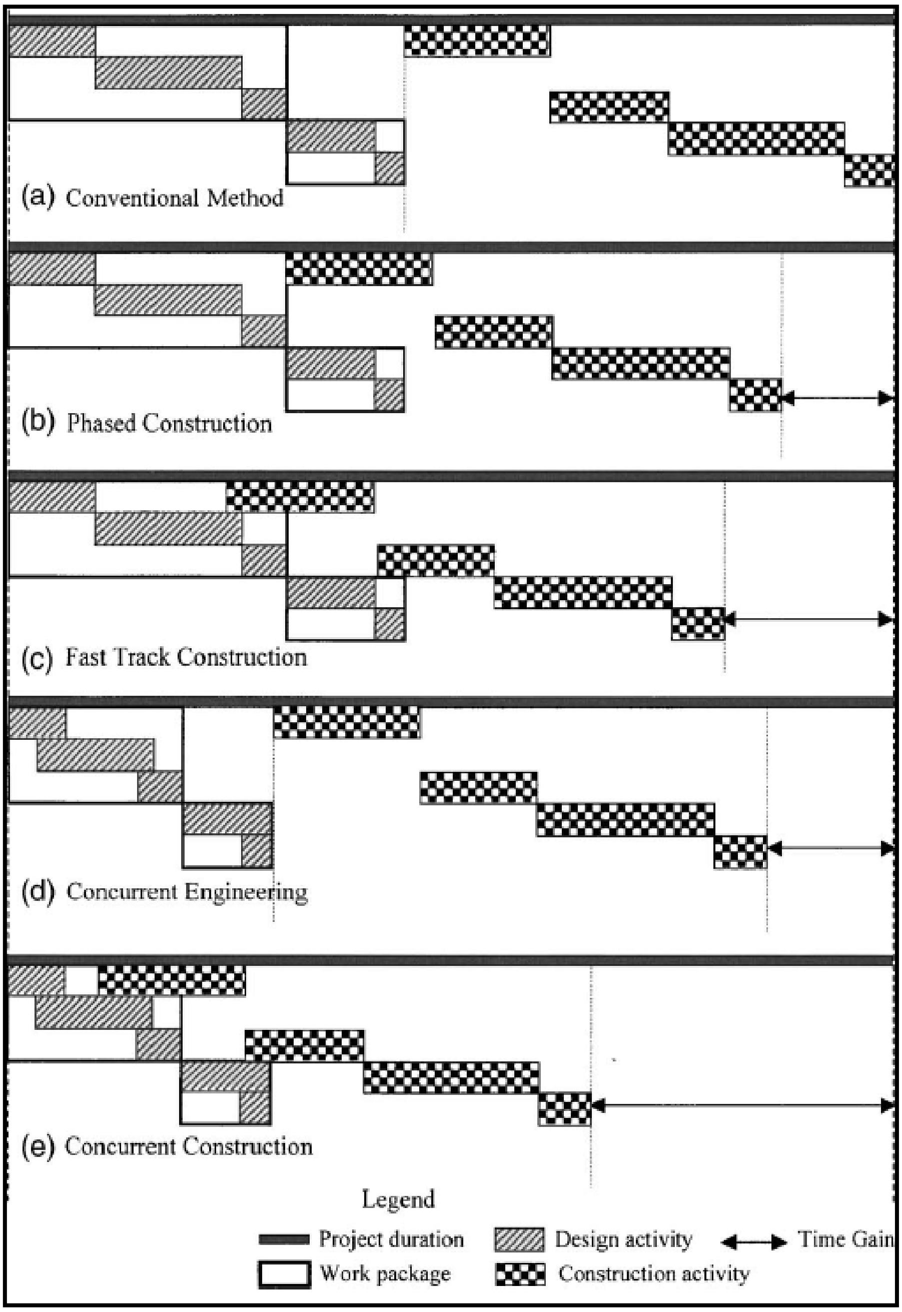


Figure 4.15 -Construction project execution strategy (Maheswari et al., 2006)

Strategy number	**Type of execution model**	**Description**	**Level of detail**
1	Conventional method	Design phase is fully completed followed by construction	Focus is at abstract level—entire phase
2	Phased construction	After each design work package, that particular construction starts	Focus is at second level—work package
3	Fast-track construction	Design work package overlaps with the construction work package	Focus is at second level—work package
4	Concurrent engineering	Design activities overlap among themselves and construction follows this shortened design phase	Focus is at third level—activities
5	Concurrent construction	Design activities themselves overlap and the design phase also overlaps with construction	Focus is at third level—activities

Table 4.5 -Comparison between various execution strategies

4.5 Simulation- component two

Simulation is one of the most important operations research techniques (Lane *et al.*, 1993). It is the process of building and using a time-based visual model which emulates every significant step that occurs in a process and every significant interaction between resources in a process so as to gain insight about the impact of potential decisions on that process. The model shows visually what will happen in the process if changes are made to it and records performance measures of the system under different scenarios. It lets the modeler explore an electronic model of the project or process -whether the project is a factory, or a hospital, or an administrative center, or anything else. With simulation one can quickly try out idea at a fraction of the cost of trying them in the real process in real organization. (Dengiz and Belgin, 2007)have applied discrete event simulation in modeling paint shop. They have designed simulation experiments of the complex paint shop process and optimized resource utilization. Application of simulation in shipbuilding industry has been surveyed and discussed in Chapter 2. However, we will try to discuss the method of simulation process, practiced application algorithm and its relation with system modeling.

simulation is said to be the imitation of the operation of a real-world process or system over time. Whether done by hand or on a computer, simulation involves the generation of an artificial history of a system, and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system. A system can be studied in the ways displayed in Figure 4.16.

The behavior of a system as it evolves over time is studied by developing a simulation model. This model usually takes the form of a set of assumptions concerning the operation of the system. These assumptions are expressed in mathematical, logical, and symbolic relationships between the entities, or objects of interest, of the system. Once developed and validated, a model can be used to investigate a wide variety of “what-if” questions about the real-world system. Potential changes to the system can first be simulated in order to predict their impact on system performance. Simulation can also be used to study systems in the design stage, before such systems are built. Thus, simulation modeling can be used both as an analysis tool for predicting the effect of changes to existing systems, and as a design tool to predict the performance of new systems under varying sets of circumstances.

In some instances, a model can be developed which is simple enough to be solved by mathematical methods. Such solutions may be found by the use of differential calculus, probability theory, algebraic methods, or other mathematical techniques. The solution usually consists of one or more numerical parameters which are called measures of performance of the system (Banks *et al.*, 2005). However, many real-world systems are so complex that models of these systems are virtually impossible to solve mathematically. In these instances, numerical, computer-based simulation can be used to imitate the behavior of the system over time. From the simulation, data are collected as if a real system were being observed. This simulation-generated data is used to estimate the measures of performance of the system.

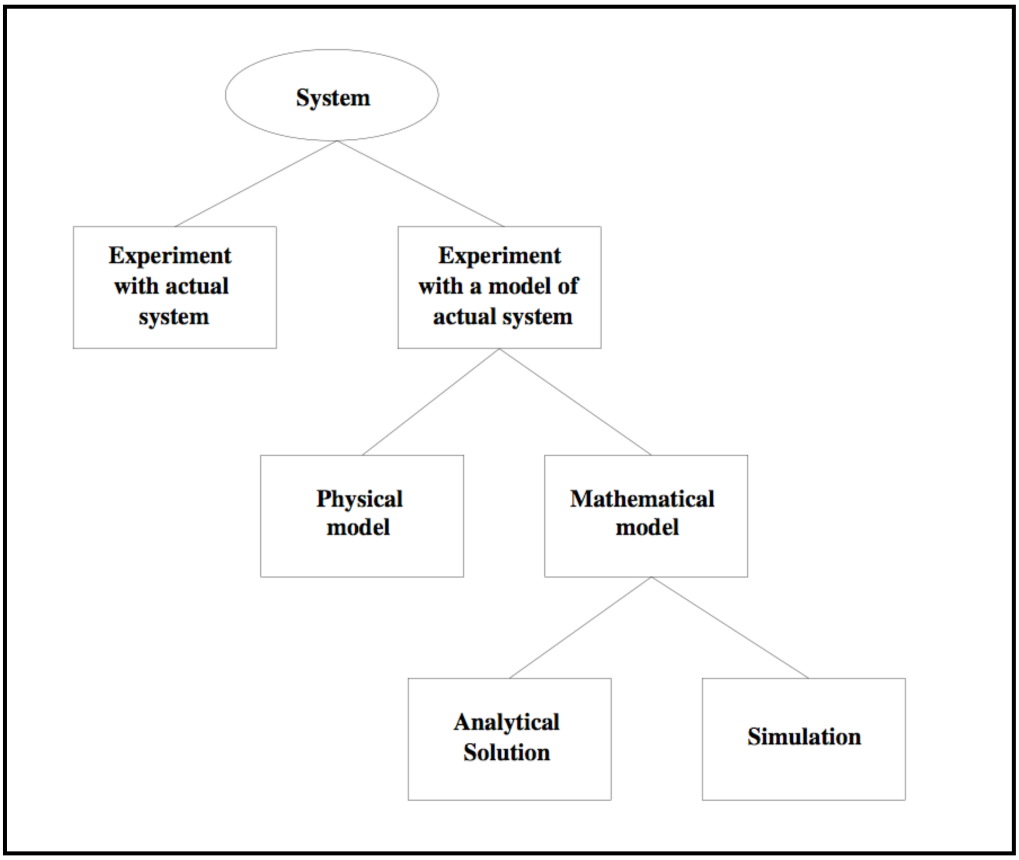


Figure 4.16 -Ways of system study (A. M. Law and Kelton, 2000)

4.5.1 Discrete and continuous systems

Systems can be categorized as discrete or continuous. Few systems in practice are wholly discrete or continuous, but since one type of change predominates for most systems, it will usually be possible to classify a system as being either discrete or continuous (A. M. Law and Kelton, 2000). A *discrete system* is one in which the state variable(s) change only at a discrete set of points in time. A coffee shop is an example of a discrete system since the state variable, the number of customers in the shop, changes only when a customer arrives or when the service provided a customer is completed. Figure 4.17 shows how the number of customers changes only at discrete points in time. For the purpose of the thesis, discrete event systems are analyzed as it can be understood that all the events in construction process of a ship only takes place in discrete event of time.

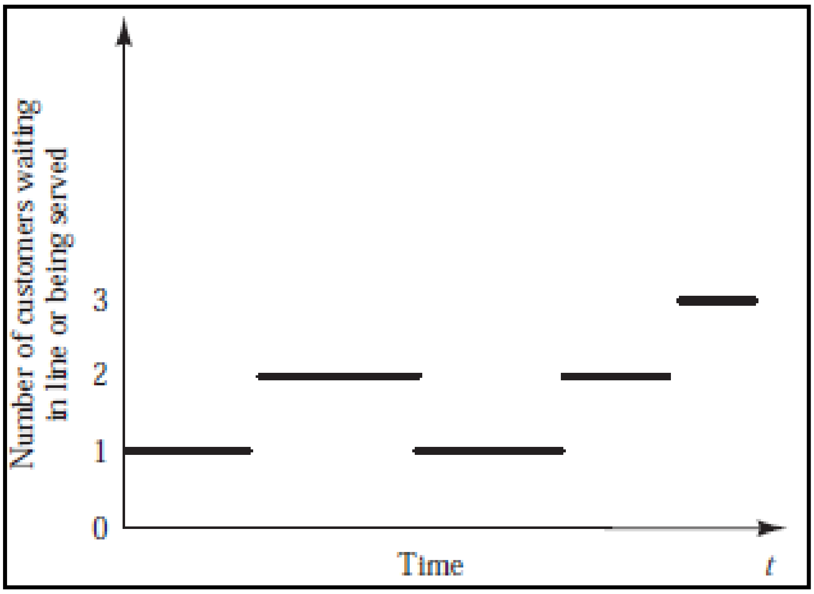


Figure 4.17 -Discrete system state variable (Banks et al., 2005)

A *continuous system* is one in which the state variable(s) change continuously over time. An example is the head of marine diesel oil in the day tank being depleted over a period of observed time. Fuel consumption varies with rotation of engine and applied load.

4.5.2 System model

Sometimes it is of interest to study a system to understand the relationships between its components or to predict how the system will operate under a new policy. Sometimes, it is possible to experiment with the system itself, but, not always. A new system may not yet exist; it may be only in hypothetical form or at the design stage. Even if the system exists, it may be impractical to experiment with it. For example, it may not be wise or possible to double the unemployment rate to determine the effect of employment on inflation. In the case of a of shipyard, reducing the numbers of pipe fitters in a pipe shop to study the effect on the time in the waiting lines may produce a big backlog and

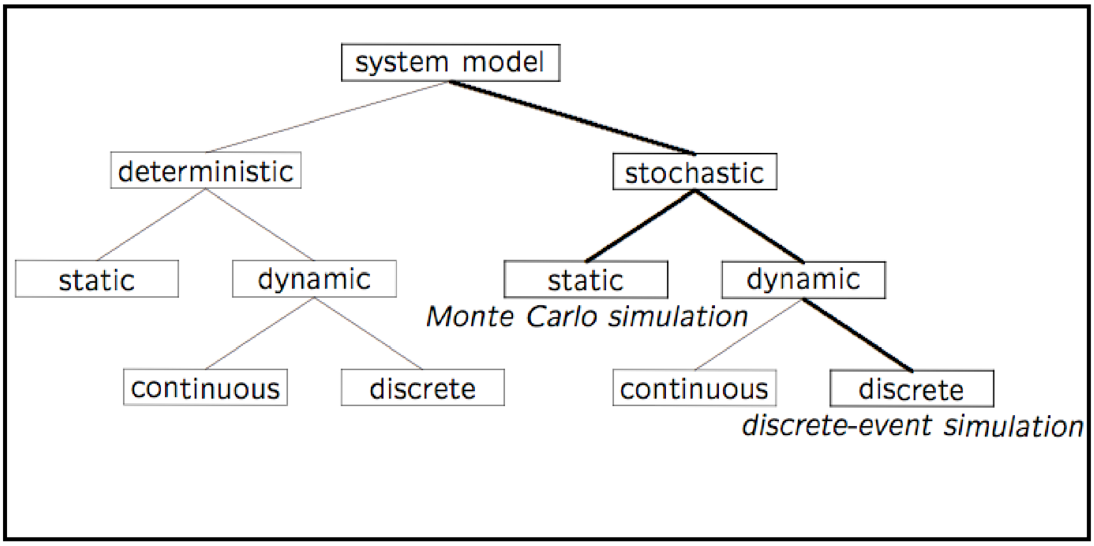


Figure 4.18 -Model taxonomy (A. M. Law and Kelton, 2000)

propagate delay in the project. A pipe shop modeling in the shipyard will be studied in chapter 5. Consequently, studies of systems are often accomplished with a model of a system. Figure 4.18 shows a system model taxonomy where discrete event system simulation represents a dynamic process.

4.5.3 Model classification

Models can be classified as being mathematical or physical. A mathematical model uses symbolic notation and mathematical equations to represent a system. A simulation model is a particular type of mathematical model of a system. Simulation models may be further classified as being static or dynamic, deterministic or stochastic, and discrete or continuous as shown in Figure 4.18. A *static* simulation model, sometimes called a Monte Carlo simulation, represents a system at a particular point in time. *Dynamic* simulation models represent systems as they change over time. Simulation models that contain no random variables are classified as *deterministic*. Deterministic models have a known set of inputs which will result in a unique set of outputs. Deterministic arrivals would occur at the shipyard workstation by the shift pattern of the worker.

A stochastic simulation model has one or more random variables as inputs. Random inputs lead to random outputs. Since the outputs are random, they can be considered only as estimates of the true characteristics of a model. The simulation of pipe shop would usually involve random inter arrival times between a pipe being placed on the bending machine and random service times. Thus, in a stochastic simulation, the output measures—the average number of pipes in the waiting, the average waiting time of a pipe—must be treated as statistical estimates of the true characteristics of the system.

4.5.4 Steps in simulation

Figure 4.19 shows a set of steps to guide a model builder in a thorough and sound simulation study. Similar Figures and discussion of steps can be found in other sources (Shannon, 1975; Gordon, 1978; A. M. Law and Kelton, 2000). The steps in a simulation study are as follows:

Problem formulation: Every study should begin with a statement of the problem. If the statement is provided by the policy makers, or those that have the problem, the analyst must ensure that the problem being described is clearly understood. If a problem statement is being developed by the analyst, it is important that the policy makers understand and agree with the formulation. Although not shown in Figure 4.19, there are occasions where the problem must be reformulated as the study progresses. In many instances, policy makers and analysts are aware that there is a problem long before the nature of the problem is known.

Setting of objectives and overall project plan: The objectives indicate the questions to be answered by simulation. At this point a determination should be made concerning whether simulation is the appropriate methodology for the problem as formulated and objectives as stated. Assuming it is decided that simulation is appropriate, the overall project plan should include a statement of the alternative systems to be considered, and a method for evaluating the effectiveness of these alternatives. It should also include the plans for the study in terms of the number of people involved, the cost of the study, and the number of days required to accomplish each phase of the work with the anticipated results at the end of each stage.

Model conceptualization: The construction of a model of a system is probably as much art as science (Pritsker, 1998). Pritsker provides a discussion of this step. Although it is not possible to provide a set of instructions that will lead to building successful and appropriate models in every instance, there are some general guidelines that can be followed (Morris, 1967). The art of modeling is enhanced by an ability to abstract the essential features of a problem, to select and modify basic assumptions that characterize the system, and then to enrich and elaborate the model until a useful approximation results. Thus, it is best to start with a simple model and build toward greater complexity. However, the model complexity need not exceed that required to accomplish the purposes for which the model is intended.

Data collection: There is a constant interplay between the construction of the model and the collection of the needed input data (Shannon, 1975). As the complexity of the model changes, the required data elements may also change. Also, since data collection takes such a large portion of the total time required to perform a simulation, it is necessary to begin it as early as possible, usually together with the early stages of model building. The objectives of the study dictate, in a large way, the kind of data to be collected.

Model translation: Since most real-world systems result in models that require a great deal of information storage and computation, the model must be entered into a computer-recognizable format. We use the term “program,” even though it is possible to accomplish the desired result in many instances with little or no actual coding. Simulation languages are powerful and flexible. However, if the problem is amenable to solution with the simulation software, the model development time is greatly reduced.

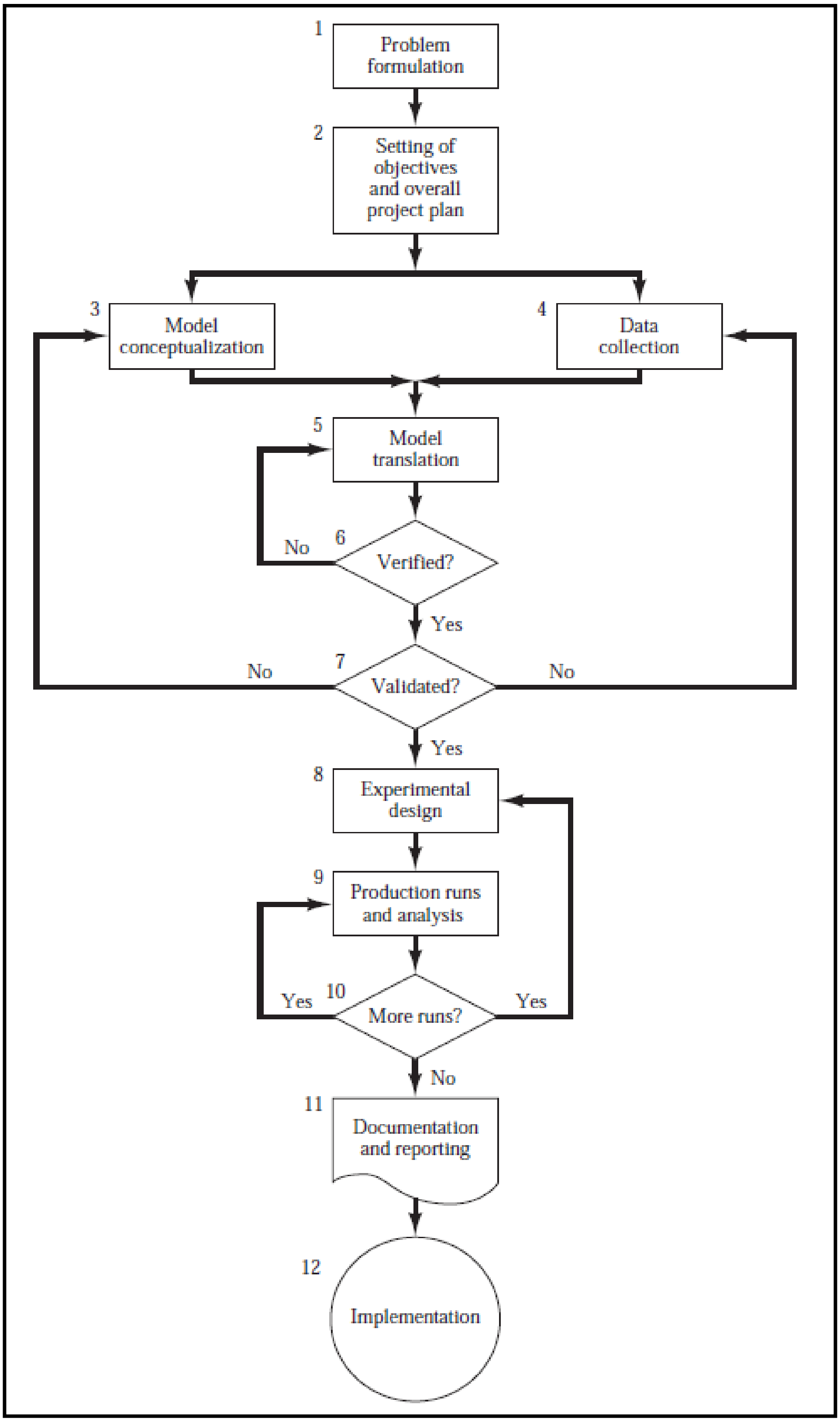


Figure 4.19 -Steps of simulation study (Sarac et al., 2010)

A discrete event simulation software SIMUL8 is used for the investigation of process modeling in chapter 5.

Verification: It pertains to the computer program prepared for the simulation model as to the proper performance. With complex models it is difficult, if not impossible, to translate a model successfully in its entirety without a good deal of debugging. If the input parameters and logical structure of the model are correctly represented in the computer, verification has been completed. For the most part, common sense is used in completing this step. Though some of the software offer intelligent simulation without extra coding and thus debugging becomes redundant.

Validation: Validation is the determination that a model is an accurate representation of the real system. Validation is usually achieved through the calibration of the model, an iterative process of comparing the model to actual system behavior and using the discrepancies between the two, and the insights gained, to improve the model. This process is repeated until model accuracy is judged acceptable.

Experimental design: The alternatives that are to be simulated should be determined. Often, the decision concerning which alternatives to simulate may be a function of runs that have been completed and analyzed. For each system design that is simulated, decisions need to be made concerning the length of the initialization period, the length of simulation runs, and the number of replications to be made of each run.

Production runs and analysis: Production runs, and their subsequent analysis, are used to estimate measures of performance for the system designs that are being simulated.

More Runs design: Based on the analysis of runs that have been completed, the analyst determines if additional runs are needed and what design those additional experiments should follow.

Documentation and reporting: There are two types of documentation; program and progress. Program documentation is necessary for numerous reasons. If the program is going to be used again by the same or different analysts, it may be necessary to understand how the program operates. This will build confidence in the program, so that model users and policy makers can make decisions based on the analysis. Also, if the program is to be modified by the same or a different analyst, this can be greatly facilitated by adequate documentation. (Musselman, 1998) discusses progress reports that provide the important, written history of a simulation project. Project reports give a chronology of work done and decisions made. This can prove to be of great value in keeping the project on course.

4.6 Design of Experiments-component three

The method of experimental design has been widely used in industry for determining factors that are most important in achieving useful goals in a manufacturing process (Fischer *et al.*, 1925; Taguchi and S. Konishi, 1987; Benoist and et al., 1994). Factors influencing the response of the process, under the designer's control, are varied over two or more levels in a systematic manner. Experiments are then performed, according to an orthogonal array to show the effects of each potential primary factor; thus, allowing to perform an analysis that will reveal which of the factors are most effective in reaching our objective and how these factors should be adjusted to optimize it. In the present context of work, the method of experimental design is applied for the optimization of resource allocation in the processing of activities in the shipyard (a detailed application is in the next chapter).

Let us explore basic terminology. The investigation of a system or process is generally considered as the elucidation of some functional relationship:

$$E(y) = f(\varepsilon_1, \varepsilon_2, \dots., \varepsilon_k) \quad (4.1)$$

Connecting the expected value of a response *y* such as the yield of a product with *k* quantitative variables $\varepsilon_1, \varepsilon_2, \dots., \varepsilon_k$, such as temperature and pressure and so on. In what follows, it is convenient not to have to deal with the actual numerical measures of the variable ε_i, but instead to work with coded variables x_i. For example, if at some stage of an experiment the region of interest of a variable ε_i, is defined as $\varepsilon_{i0} \pm S_i$, where ε_{i0} is the center of region, an equivalent x_i can be defined, where;

$$x_i = \frac{\varepsilon_i - \varepsilon_{i0}}{s_i} \quad (4.2)$$

For example, if ε_i, is temperature and the current region of interest is $115^0 \pm 10^0$, then for any setting of temperature we have the equivalent coded value $x_i = (\varepsilon_i - 115)/10$. Furthermore, in Design of Experiments we frequently use the high and low levels of a variable termed -1 and +1 respectively. Hence, for the high level of $\varepsilon_i(125^0)$, $x_i = (125 - 115)/10 = 1$. Experiments are performed by investigators in virtually all fields of inquiry, usually to discover something about a particular process or system. Literally, an experiment is a test (Montgomery, 2001). Montgomery defined an experiment as a test of series of tests in which purposeful changes are made to the input variables of a system so that we may observe and identify the reasons for change in the output response. It is illustrated how the process or system can be represented by the model shown in Figure 4.20.

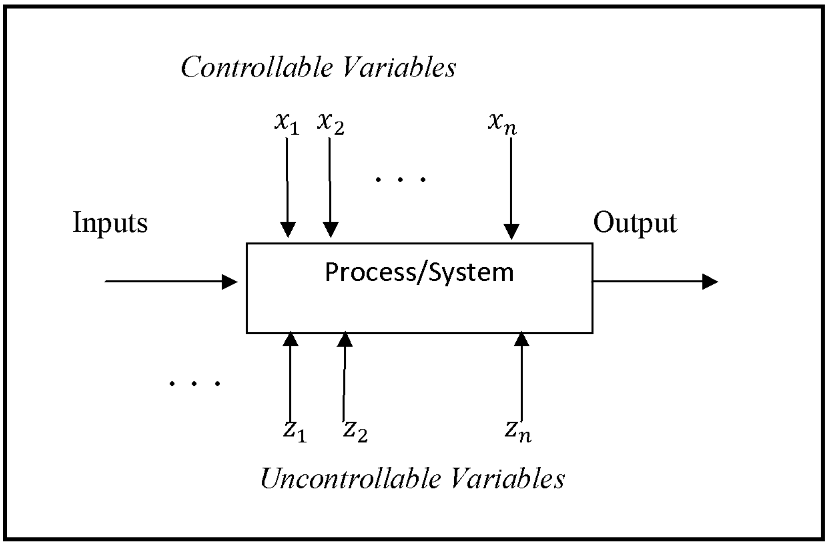


Figure 4.20 -General model of process / system: adapted from (Montgomery, 2001)

The objectives of an experiment may include the following:

1. Determining which variables are most influential on the response *y*,
2. Determining where to set the influential x's so that *y* is almost always near the desired value,
3. Determining where to set the influential x's so that variability in *y* is small,
4. Determining where to set the influential x's so that the effects of the uncontrollable variables $z_1, z_2, \ldots\ldots z_n$ are minimized.

(Montgomery, 2001) discussed how the process or system can be visualized as a combination of machines, methods, people and other resources that transforms some input into an output that has one or more observables responses. Some of the variables $x_1, x_2, \ldots\ldots. x_n$, are controllable whereas other variables $z_1, z_2, \ldots\ldots z_n$ are uncontrollable (although they may be controllable for the purpose of a test).

Montgomery stated that "statistical Design of Experiments refers to the process of planning the experiment so that appropriate data that can be analyzed by statistical methods will be collected, resulting in valid and objective conclusion" (Montgomery, 2001). Three basic principles of statistical DOE can be identified, those being *replication, randomization* and *blocking.* Replication refers to the basic repetition of an experiment. For example, consider the quenching of steel using oil or saltwater. Repetition would consist of treating a specimen by oil quenching and treating a specimen by saltwater quenching. Thus, if five specimens are treated in each medium, five replicated have been obtained. Replication reflects sources of variability both between runs and potentially within runs and has two important properties; (1) it allows an experimenter to obtain an estimate of the experimental error (2), it permits the experimenter to obtain precise estimates of the effect of variables on the output response.

Randomization refers to the random order in which the individual runs or trials of the experiment are to be performed. By properly randomizing the experiment, the effects of extraneous factors may be averaged out. Finally, blocking is a design technique used to improve the precision with which comparison among variables of interest are made. Montgomery started that "blocking is frequently used to reduce or eliminate the variability transmitted form nuisance factors, that is, factors that may influence the experimental response but in which we are not directly interested" (Montgomery, 2001). For example, an experiment on a chemical process may require two batches of raw material to make all the required experimental trials, there could be differences between the batches due to supplier variability. In this case we would consider the batches of raw material as a nuisance factor. To prevent experimental error occurring due to such nuisance factors, the experiment is divided into blocks. Typically, a block is a set of relatively homogenous experimental conditions. In this example each batch of raw material would form a block and then the experimenter divides the observations from the statistical design into groups that are run in each block. Montgomery recommended a general Design of Experiments procedure which included the design of an experiment and the statistical analysis of the resultant data. Indeed, this general procedure is used as a guide in performing statistical Design of Experiments in component 3 of the proposed approach as in Figure 4.2:

1. *Recognition of statement of the problem* – It is important to develop a clear and generally accepted statement of the problem to be addressed,

2. *Selection of the response variable* – Most often, the average and/or the standard deviation of the measured characteristics will be the response variable,
3. *Choice of variable, levels and ranges* – When considering the variables that may influence the performance of a process or system, the experimenter usually discovers that these variables can be classified as *controllable* or *uncontrollable* (or noise) variables. Once the experimenter has selected variables, he or she must choose the ranges over which these factors will be varied and the specific level (such as high and low temperature) at which runs will be made ('run' is essentially one experimental run among a series of runs within a designed experiment),
4. *Choice of Experimental design* – Choice of experimental design involves the consideration of sample size (number of replicates) and the selection of a suitable run order for the experimental trials. A range of experimental designs exist such as factorial designs, fractional factorial designs, central composite designs and D optimal designs, In general, experimental designs are experimental strategies where variable are varied together over their respective ranges and levels in an efficient manner. In the application of this method, factorial design has been selected.
5. *Performing the experiment* – When running the experiment, it is vital to monitor the process carefully to ensure that everything is being done according to plan. Errors in the experimental procedure can adversely affect experimental validity. In this method experimental data is collected from the yard's past processing instances and model is reproduced in a computer simulation. This will work as the basis of further experimentation.
6. *Statistical analysis of the data* – Statistical methods should be used to analyze the data so that results and conclusions are objective rather that judgmental in nature,

7. *Conclusions and recommendations* – Once the data has been analyzed, the experimenter must draw practical conclusions about the results and recommend a course of action.

4.6.1 Factorial designs

A Factorial design is an experimental strategy for investigation the effects of two or more variables in an efficient manner. In each complete trial or replication of an experiment with (regards to a factorial design), all possible combinations of the levels of the variables are investigated. The effect of a variable is defined to be the change in response produced by a change in the level of a variable. This is frequently called a *main effect* because in refers to the primary variables of interest in the experiment. For example, consider the simple factorial experiment in Figure 4.21. This is factorial design with two variables (x_1 and x_2) with both varied at two levels. These levels are simply termed 'low' and 'high' and denoted – and + respectively. The response in *y* due to the change in the levels of the variables x_1 and x_2 is displayed in the corners of the Figure 4.21.

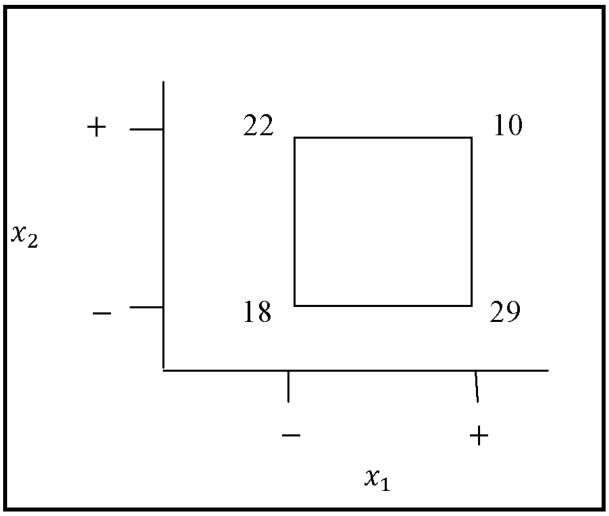


Figure 4.21 -Factorial experiment with interaction

At the low level of variable x_2, the effect of x_1 is = 29 – 18 = 11 and at the high level of variable x_2, the effect of x_1 = 10 – 22 = -12. Because the effect of x_1 depends on the level chosen for variable x_2, we see there is an interaction between x_1 and x_2. The magnitude of the interaction in the average difference in the two x_1 effects, or x_1x_2 = (-12 – 11)/2 = -11.5.

The factorial experiment in Figure 4.21 can be represented using a regression model of the form

$$y=\beta_0+ \beta_1x_1+\beta_2x_2+\beta_{12}x_1x_2 \quad (4.3)$$

This is called multiple linear regression model where we refer to x_i as the predictor, regressor or independent variable and *y* as the response variable. For the purpose of this thesis the term regressor is adopted for the $x_i$variable. The adjective linear is employed to indicate that the model is linear in the parameters $\beta_0, \beta_1, \ldots, \beta_k$, not because *y* is a linear function of the *x'*s. An important objective of regression analysis is to estimate the unknown parameters in the regression model; that is, the regression coefficient β_k. This process is called fitting the model to the data. The technique used in this thesis is called RSM (response surface method) which uses regression models to find out optimum measures of unknown variable is discussed in details in following sections. Variables x_1 and x_2 are in coded scale from -1 to 1 (the high and low levels if variables x_1 and x_2) and x_1x_2 represents the interaction between x_1 and x_2. The estimates of β_1 and β_2 are one-half the value of the corresponding main affects and are given by;

$$x_1 = \frac{\left(\frac{29+10}{2} - \frac{18+22}{2}\right)}{2} = -\frac{0.5}{2} = -0.25$$

(4.4)

$$x_2 = \frac{\left(\frac{22+10}{2} - \frac{18+29}{2}\right)}{2} = -\frac{7.5}{2} = -3.75$$

(4.5)

The interaction parameter β_1= -11.5/2 = -5.75 and finally, the parameter β_0 is given by the average of the four responses, or β_0 = (22+10+18+29)/4 = 19.65. Therefore, the fitted regression model is

$$y = 19.65 - 0.25x_1 - 3.75x_2 - 5.75xx_2 \qquad (4.6)$$

Equation 4.6 can be presented in a three-dimensional graphical representation of the fitted regression model and this three-dimensional plot is called *response surface*. Intuitively, if there are more than three dimensions, i.e., three variables and one response, a response surface cannot be plotted in such a way.

Suppose, the interaction coefficient in (4.6) was negligible, that is β_{12} was small. Dropping this term gives

$$y = 19.65 - 0.25x_1 - 3.75x_2 \qquad (4.7)$$

If Equation 4.7 is plotted, the response surface of the regression model with the interaction coefficient dropped will produce no curvature. Hence the interaction coefficient twists the response surface and is a form of curvature. The concept of interaction between variables is an extremely important concept with regards to robust process design methods.

4.6.2 Response surface methodology

Response Surface Methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes (Myers and Montgomery, 2002). The most extensive applications of RSM are in the particular situations where several input variables potentially influence some performance measure or quality characteristic of the process. Thus performance measure or quality characteristic is called the response. The field of response surface methodology consists of the experimental strategy for exploring the space of the process or independent variables, empirical statistical modeling to develop an appropriate approximating relationship between the yield and the process variables, and optimization methods for finding the values of the process variables that produce desirable values of the response. RSM has emerged as a viable alternative for solving robust process design problems in repose to the limitations of other methods such as Taguchi's (Myers *et al.*, 1992; Montgomery, 2001; Menon *et al.*, 2002). Box and Wilson commented that this methodology was originally developed by Box and his co-workers in the 50's and 60's (Box and Wilson, 1951). Since then RSM has succeeded in many applications. For example, RSM has been utilized for metamodel estimation (Batmaz and Tunali, 2003), in the optimization of center less grinding operations (Dhavlikar *et al.*, 2003), for process development and improvement in the electronics industry (Montgomery *et al.*, 2000), optimizing structural design for space truss platform (Unal *et al.*, 1997), and the optimization of helicopter rotor for low vibration (Ganguli, 2002).

The stages of RSM are follows; First, the preliminary work in which the selection of the input variables (factors) and their levels are carried out. Second stage is the selection of experimental design to obtain minimum variances of the responses and making simulation runs considering the experimental design conditions. Third stage is to build first or higher order regression metamodel and surface fitting (the response surface plot and counter plot of the responses) to obtain approximate responses and the prediction and verification of the model equation. Final stage is the optimization of approximated responses which is called inverse analysis.

In this thesis we will apply statistical modeling to develop an appropriate approximating model between the response *y* and independent variables $\xi_{1,}\xi_2,....\xi_k$

In general, the relationship is

$$y = f(\xi_{1,}\xi_2,....\xi_k) + \varepsilon \qquad (4.8)$$

where the form of the true response function f is unknown and perhaps very complicated, and ε is a term that represents other sources of variability not accounted for in f. Usually, ε includes effects such as measurement error on the response, background noise, the effect of other variables, and so on. Usually, ε is treated as a statistical error, often assuming it to have a normal distribution with mean zero and variance σ^2

Then

$$E(y) = \eta = E[f(\xi_{1,}\xi_2,....\xi_k)] + E(\varepsilon) = f(\xi_{1,}\xi_2,....\xi_k) \qquad (4.9)$$

The variables $\xi_{1,}\xi_2,....\xi_k$ in Equation (4.8) are usually called the natural variables, because they are expressed in the natural units of measurement, such as degrees Celsius, pounds per square inch, etc. In much RSM work it is convenient to transform the natural variables to coded variables $x_{1,}x_2,....,x_k$ which are usually defined to be dimensionless with mean zero and the same standard deviation. In terms of the coded variables, the response function (4.8) will be written as

$$\eta = f(x_{1,}x_2,....,x_k) \qquad (4.10)$$

Because the form of the true response function f is unknown, we must approximate it. In fact, successful use of RSM is critically dependent upon the experimenter's ability to develop a suitable approximation for f. Usually, a low-order polynomial in some relatively small region of the independent variable space is appropriate. In many cases, either a first-order or a second-order model is used. The first-order model is likely to be appropriate when the experimenter is interested in approximating the true response surface over a relatively small region of the independent variable space in a location where there is little curvature in f. For the case of two independent variables, the first-order model in terms of the coded variables is

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \qquad (4.11)$$

The form of the first-order model in Equation (4.11) is sometimes called a main effects model, because it includes only the main effects of the two variables x_1 and x_2. If there is an interaction between these variables, it can be added to the model easily as follows:

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 \qquad (4.12)$$

This is the first-order model with interaction. Adding the interaction term introduces curvature into the response function. Often the curvature in the true response surface is strong enough that the first-order model (even with the interaction term included) is inadequate. A second-order model will likely be required in these situations. For the case of two variables, the second-order model is

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{12} x_1 x_2 \tag{4.13}$$

This model would likely be useful as an approximation to the true response surface in a relatively small region. The second-order model is widely used in response surface methodology for several reasons:

1. The second-order model is very flexible. It can take on a wide variety of functional forms, so it will often work well as an approximation to the true response surface.

2. It is easy to estimate the parameters (the β's) in the second-order model. The method of least squares can be used for this purpose.

3. There is considerable practical experience indicating that second-order models work

well in solving real response surface problems.

In general, the first-order model is

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_k x_k \tag{4.14}$$

and the second-order model is

$$\eta = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum \beta_{jj} x_j^2 + \sum_{i<} \sum_{j=2}^{k} \beta_{ij} x_i x_j \tag{4.15}$$

In some infrequent situations, approximating polynomials of order greater than two are used. The general motivation for a polynomial approximation for the true response function f is based on the Taylor series expansion around the point $x_{10}, x_{20}, \ldots, x_{ko}$.

There is a close connection between RSM and linear regression analysis. For example, consider the model

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon \quad (4.16)$$

The β 's are a set of unknown parameters. To estimate the values of these parameters, we must collect data on the system we are studying. Because, in general, polynomial models are linear functions of the unknown β 's, and this technique is referred to as linear regression analysis.

4.7 Optimality realization in the method

Academic research has made significant contribution in the industry over time, though the transformation of research into immediate application is not always possible. The hindsight of academic research is that it is heavily biased with assumptions that not necessarily replicate the reality of the practice in the industry. Researchers, most of the time, play around numbers and mathematically difficult algorithm of how to create an optimal plan or schedule. This may well imbed assumptions for scenarios in its frame work, but thoughtful insights are revealed for improvement of the process. Applicability might be placed in the sub-ordinate role of importance. The term "Optimal" is relative since no exact and generic solution is available particularly for shipbuilding application. Therefore, optimality in broader terms may not be used uniformly for application across every possible shipyard unless particular conditions specific to the shipyards are considered in the model. This proposed method seconds this notion and suggests to draw upon individualized set-ups dependent data to realize optimality in global and local level of shipbuilding project. It is expected that this methodology would contribute to analyze the planning assumptions with confidence in advance (prior to actual production takes place) for deriving optimality in both planning and production. In reality, optimality in the shipbuilding project management somehow connotes to near-optimality as the process of shipbuilding is very much dynamic in nature and may change in every other trial we conduct in planning and production. On the other hand, shipyard attempts to maintain the delivery schedule with rational certainty. Therefore, optimality is bounded by the space of delivery time. This methodology is expected to offer competent analysis tool and technically achievable solution for optimizing the processes for small to medium shipyards which are in the process of transpiring into more technologically advanced facility with robotics and automation. Or, trying to run in the economically feasible region with less automation and increased human input. The choice between maximum automation, maximum human input and combination of the both to strike a balance is very much dependent on the strategic importance of the yard. Which means the yard's strategic decision makers will analyze the market in which the yard is operating including regional shipping prospect, competition, dynamic shift of products to say the least. Market players of the shipbuilding industry put a lot of efforts to further improve their processes. Therefore, there is a need for a realistic and robust method which will cater to the need of process improvement considering the dynamic environment of shipbuilding projects and the variability across yards. As this methodology incorporates analysis components for process and planning, it is reasonable to say that this may also be well suited in advanced yards to assist in the analysis for further process improvement.

4.8 Context of data collection

As implied in the introduction, data, for analysis of a shipbuilding project, has been collected over time from Ananda Shipyard & Slipways Ltd, located in Bangladesh. It is interesting to see the entrance of Bangladesh, known predominantly as the leading ship scrapping country, in international ship export. Let us have a look at the dynamics of the industry over last century. A century ago, shipbuilding was dominated by Europe, having a world market share of some 80% at the beginning of the 20th century. In the 1950s this position was gradually taken over by Japan, mainly due to a rapid growth of the Japanese economy and a coordinated shipping and shipbuilding program. At the early 1970s, Japan and Europe still dominated the world market with a combined share of some 90%. In the early 1970s South

Korea entered the stage. The country offered lower wages than Japan or Europe and chose to position shipbuilding as a strategic industry. Just as Japan did before, a carefully planned industrial program was successfully initiated, leading to a world market share of 25% by the mid-1990s and a world first position as of 2005. Although having shipyards since the 1940s, China is only becoming a dominant player since the last few decades. The country's economic boom together with the strategic choice to develop heavy industry activities has led to a strong increase in global market share. The share of China has risen rapidly to over 20% of global ship deliveries in 2008 (in CGT). In terms of order book, China surpassed Japan in 2006 as the second largest shipbuilding country in the region thanks to the speculative orders that anticipated a continued growth in shipping demand.

With the emergence of China, it is not expected that this will result in a consolidation in the regional structure of world shipbuilding. New countries were emerging as potential shipbuilding nations, such as Vietnam, India, the Philippines and Brazil to have a share in the burgeoning shipbuilding in the wake of surging world economy. Bangladesh with a rich heritage in shipbuilding dating back to 14th century has renewed its vision and leaped on the bandwagon of the new league and successfully made ship export in 2005. Through the export of multipurpose container vessels to Denmark in 2008 built by Ananda Shipyard & Slipways Ltd., Bangladesh entered in the global league of shipbuilders. Though, the history says that earliest ships exported from this land were wooden boats in 17th century for Sultanate of Turkey and later on wooden ships built in Bangladesh participated in Trafalgar war in 1805 (Mol, 2012). There are 124 registered shipyards, 70% are located in and around the capital city Dhaka and the adjoining city Narayangonj, 20% in Chittagong, 4% in Barisal and 6% in Khulna area. A number of shipyards (12 approximately) are capable to build export quality ships (Islam, 2012). The selected Shipyard has more than thirty years of experience in designing, building and engineering of commercial and naval and service ships, i.e., tug boats, mooring boats, pilot boats, buoy tendering vessels etc. Facility of the yard has been upgraded over the decades keeping a close match with expansion in product market. Availability of cost competitive ship building worker is poised as a boon for the yard while Bangladesh enjoys the advantage of returned workers with high skill level gained from the experience gathered at the yards in countries like

Singapore, UAE, Qatar, Saudi Arabia etc. Investment decision in the high-end equipment and automation has been made historically with careful calculation of sensitivities to the process efficiency in general. Therefore, amount of human input, replaceable with automation, is very much prevalent in this selected yard in comparison with advanced yards. However, this yard is chiefly equipped with plasma-cutting machine, semi-automatic pipe bending machine, automatic shot blasting plant but without an automatic / semi-automatic panel line. Instead, panel shops are armed with an army of workers to do the jobs which could have been managed alternatively by automated panel fitted with robotic welding guns. It is the largest yard in the country in terms of yearly processed steel and employs invariably 3000 personnel to process 60000 tons of steel a year. Design office has access to AVEVA/TRIBON software along with other supplementary like MAXSURF, NAPA etc. Typical production from the yard consists of the following:

- Merchants ships of various types and sizes up to 10000 DWT, i.e., Multipurpose cargo/container vessels, Takers, tug boats, fishing vessels, refrigeration vessel, pilot boats, catamaran, mooring boats, ferry, hydrographic survey vessel, hospital vessel, passenger vessels etc.
- Naval vessels in the genre of replenishing tanker, fast patrol boats, attack boats.
- Cranes, larges hydraulic press, steel truss for bridge, power plant and other heavy industrial products.
- Non propelled marine structures like pontoons, gangway, dredgers etc.

A project was chosen for its one-of-a-kind design and construction feature, a naval fuel replenishing tanker with only 2774 DWT capacity, to analyze data and information for purpose of this research. This is very much representative of the projects that the yard undertakes, i.e., one of a kind design and construction projects won through competitive bidding. This project was awarded after being adjudged as the lowest responsive bid through two stages of qualifying process. Other participating yards from India, South Korea, China, Turkey bid quite close to the wining quotation. Contractual delivery time was eighteen months including the preparation of basic design, construction design, and machinery selections and production, test and trial. It was a challenging project for the yard considering a new design has to be followed and tested as it was not based on any proven design. Therefore, a mammoth task of coordination among multi-disciplinary team and globally distributed vendors was required. Basic design was produced by a design firm based in China while the yard design team had produced detail construction drawings. The project management team had been tasked with the preparation of project plan consisting of master plan and a detailed plan. Master plan listed all the key milestones whereas the detailed plan listed work break downs of the job at shop level. In a weekly meeting, the detail plan is updated according to the work progress at the shop level. However, the yard might perhaps not have successfully implemented overlapping strategy between design and construction to retain control over the progress. With the help of the project management team a number of representative inputs to the detailed plan was selected primarily for the purpose of sequencing analysis, i.e. optimization through iteration.

Since the DSM is a tool that studies the planning process as a system with many interacting elements, it is important to define the boundary of the system in order to focus the research work. Different system definition results in different output of the DSM. Initially, the system elements can be chosen based on the existing project plans, engineers' suggestions, etc. The author has initially defined the initial set of project input elements based on the reading of design documentation and project plan. However, initially defined system elements were then offered to the multidisciplinary team for their review and assigning interactions. A critical review of the list of elements in collaboration with engineering staff or other relevant experts is necessary to glean real interaction dynamics.

Alongside the study of the design and project plan documents, interviewing experienced engineers who are working on the particular project is a good source of further endorsement of the DSM interactions. Interviews are seemed just as important as reading project documents for two reasons. First, not all the knowledge is well captured by design and planning documents. A large amount of information is stored in engineers/ manages' cognition. Second, interviews seem to be an effective means of extracting knowledge from the engineers' mind compared to other methods. Hence, interview may produce an important way to extract the undocumented knowledge from the engineers. The author found that different engineers often had different views on how one element is related to the other and how important the relation was. The causes of the differences could usually be one of the following two a) The interaction was not direct. b) The engineers have different perspectives on the issues due to the difference in their work environment. In this case, the author acted as a mediator.

A final dependency-oriented project plan was discussed in a meeting where the inputs form all the member were discussed and the DSM was constructed based on the majority of the votes or the higher level manager's/ engineers' views. Since the DSM is a tool to analyze the project sequence and seek improvements, it is important that the data is accurate. Having collected the elements and the dependencies, initially, a DSM can be built to represent the basic dependency structure and information/ resource flows between various project elements. DSM provides aid to project managers to understand the planning and organizing better and approach the communication more systematically. Hence, the constructed DSM has been passed to participating engineers and manager to receive comments. This has created, on one hand, transparency about the benefits of building a DSM, as looking at the entire picture of the planning process like never before made project team rethink their current practice, and seek improvements. On the other hand, the collection of comments has further aided the refinement of the structure of the DSM.

4.9 Summary

Work is accomplished in a process as part of the shipbuilding project at the expense of consumed resources and the account of resources needs to be refined so that we can become reasonably more confident on the execution of the concerned work by optimum engagement of resources and budget *inter ali*a. This can be investigated by replicating and simulating models of processes related to activity as laid out in the plan. Determining the optimum number of workstations to be used in the process and workers at some stations is assisted by using simulation optimization approach. In the optimization stage of the study, Response Surface Methodology (RSM) is used to find the optimum levels of considered factors or resources. Simulation model and optimization stage integration are used to analyze both the performance of the current process and determine the optimum working conditions, respectively, with reduced cost, time and effort.

5 Chapter Five. Application and Case Study

5.1 Introduction

The aim of this chapter is to realize proposed methodology using example data from an ongoing shipbuilding project of a yard situated in South Asia. A careful plan for recording data has been designed by a team of three; each from design, project management and fabrication, responsible to co-ordinate with the project personnel. The project was to build a Naval oil replenishing tanker of 2774 DWT capacity with a special installation of UNREP (Underway Fuel Replenishment). This being a small tanker, has incorporated the state of the art design concept and technology, far superior from its commercial counterpart, to outweigh the performance risks in naval movements and exercises. Although the data are predominantly part of the project, collectively, the activity sequencing and process optimization exercise the full range of capabilities of the proposed approach. For the purpose of this thesis, case study documented in this chapter will provide a basis for validating the application of the method in implementation framework of a ship construction project.

5.2 Analysis of component one-sequence optimization

As described in above section, the author has selected a collection of inputs for the purpose of analysis from the detailed planning of the tanker project. This project has inputs in way of work break down having more than three hundred in number. To keep rationality and readability of the thesis, a model has been created with less than fifty inputs. Work break down of a project may not necessarily see universal rule across the projects or yards. Generally, project team breaks down the project in terms of assignable work packages either to a particular group or to a shop to complete the concerned task within a target deadline according to the convenience and maximum clarity for the team. These inputs are put together from the view point of design and production assimilation. The list of the inputs is displayed as a project tree in Figure 5.2. The core of the map is defined by numerical value 226 which is a unique convention symbolizing yard number for this case study. Each entry in the project map has a prefix which represents the sequence of these activities according to the existing project plan. Once the list of the selected activities is compiled, it was again discussed and agreed among the multidisciplinary team. Initial sequence of the inputs is extracted from the design and production planning of the tanker project. But there are intermediate inputs which are not mentioned in order to reasonably model the data within context of the thesis. The idea behind this strategy is that the method should work for any amount of inputs, if the application of the same can be demonstrated with a smaller model. The author has then arranged meetings with the project team to establish the dependency relationship among the inputs or activities. The project team has recommended the dependency structure as shown in the Figure 5.3 based on the exchange of information, resources, materials or tools. Each of the member has expressed respective opinion and ranked relationship on a scale of strength of the dependency. This strength categorization is helpful in understanding the importance of the relationship among activities, particularly when there exists mutual interdependencies between activities. Dependency among the activities in Figure 5.3 is ranked by three strengths. Dependency taxonomy for strength scale is shown in Figure 5.1.

The relationship matrix has much to do with the guesstimates and experience of the project members. A precedence matrix is now developed with strength coding. The activities in the precedence matrix looks seemingly sequential as these are, as discussed earlier, true reflection of activities as executed in real life for the case study project.

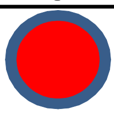
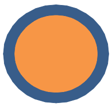
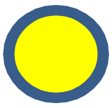
Dependecy Mark	Strength
	High
	Medium
	Low

Figure 5.1 -Dependency taxonomy

Reading across the row in Figure 5.3 reveals that what other activities the activity in that row depends on for information, resources, material or machines. For example, number one entry in Figure 5.3 is dependent on activities 2, 3 and 4 with respective strength marking of dependencies as high, high and medium. Markings below the off-diagonal reveal a sequential dependency which is what a project manager would like to have for better management of resources and avoidance of conflicts. Markings above the leading diagonal reveal mutual dependencies between activities. For example, activities 1, 2, 3 and 4 are mutually dependent on each other. These activities are related to the initial concept design of the tanker which requires high degree of interaction among design team. Dependencies among these entries are mostly for information to be passed between them for collective progression. There are 42 activities listed in the matrix diagram in Figure 5.3 from the case study project's preliminary augmentation consisting principally design development, procurement, surface preparation, pipe and block construction. To achieve a plan overlapped between design and construction activities, it is vital to establish a successive integration between these two domain. Design activities for a make -to -order project similar to the case study requires a considerable time which is consumed mostly as warm up period for the production activities. The Shipyard has followed the process of installing pipes after erecting grand blocks and welding them together. This has supposedly caused more expense of resources than that of installing pipes beforehand in the blocks. Except painting in the grand block, installation of major machineries was conducted once the ship was put together in the dock. The reason as explained by the project team for this inefficient construction process was that the design deliveries were not made available for the equipment to be ordered and to have them at the yard in time keeping in view the schedule for in situ installation of those equipment.

Therefore, production activities should be juxtaposed as far as practicably possible to the immediate design activities having a precedence or dependence relationship. Once this strategy is applied, it will draw production activities closer to design domain by sparsely placing those in the project map and will ensure intertwinement to further reduce project time.

Figure 5.2 - Tree diagram of project activities

The input data or activities from the precedence matrix are now modeled in the Project DSM software which has been kindly provided for the purpose of this research by Project DSM, Carlton South, Vic 3053 Australia. The matrix has now been re-sequenced according to the precedence relationship and an optimal sequence of the activities has been arrived at in figure 5.3, thus dual objectives of minimum iteration and maximum concurrency have been fulfilled.

An iterative block groups together all the activities that are mutually-interdependent on one another for data, information, resources or machines. Therefore, an iterative block encapsulates activities that are linked by dependencies and that are positioned above as well as below the leading diagonal of the DSM. In this respect, all activities in an iterative block are either directly, or indirectly dependent on all other activities in the same block.

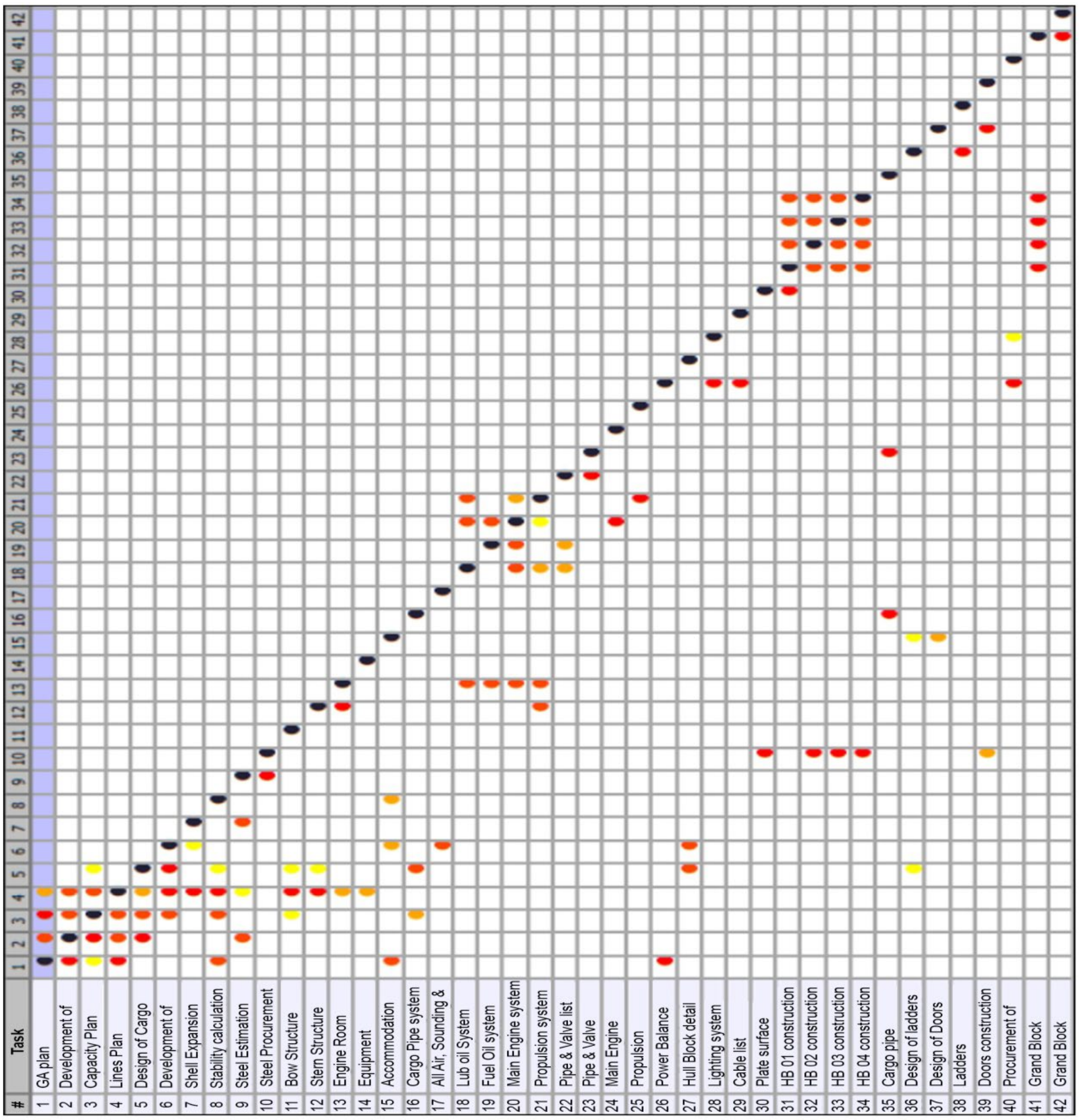


Figure 5.3 -Dependency matrix of activities before optimization

Based on this definition, all 42 activities in the re-sequenced DSM in Figure 5.5 can be grouped into one large iterative block, but perhaps more notably, three localized iterative blocks of highly interdependent activities can be identified. Iterative block 1 in Figure 5.5 encapsulates 5 activities which relate to the design development of the tanker outline solution schema; iterative block 2 encapsulates 4 activities which all relate to the design development of power and propulsion sub system, and iterative block 3 encapsulates 4 activities of Hull block construction. Figure 5.4 displays the iterative blocks derived after processing of activities in DSM optimization.

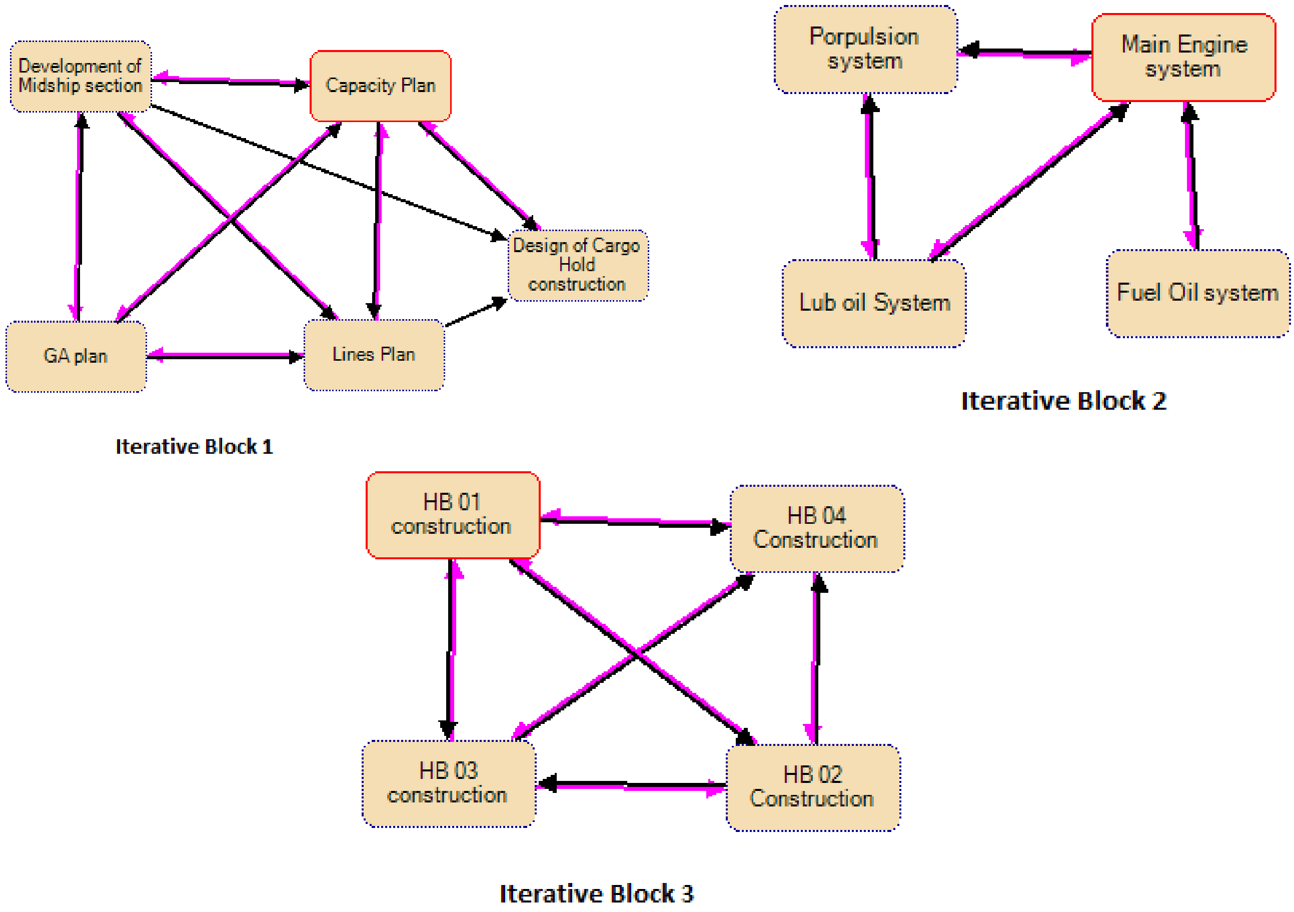


Figure 5.4 -Iterative blocks with purple lines indicating inter-dependencies

Iterative blocks are grouped together and linked with purple lines in the Dependency map in Figure 5.6.

Because the activities grouped together within an iterative block are mutually inter-dependent on one another, it is not possible to derive a sequence of activities which does not result in the need for guesstimates. As an example, consider the 24 possible sequences associated within the 4 activities of the iterative block 2 of Figure 5.5. As can be seen from the 4 partial DSMs from iterative block 2 of Figure 5.5, each of the 24 possible sequences (28-29-30-31, 28-30-29-31, 28-31-29-30, 28-29-31-30, 28-30-31-29, 28-31-30-29, 29-28-31-30, 29-28-31-30, 29-30-31-28, 29-31-28-30, 29-31-30-28, 30-28-29-31, 30-28-31-29, 30-29-28-31, 30-29-31-30, 30-31-28-29, 30-31-29-28, 31-28-29-30, 31-28-30-29, 31-29-28-30, 31-29-30-28, 31-30-28-29, 31-30-29-28) result in the need for guesstimates as indicated by the dependencies above the leading diagonal.

The use of guesstimates implies iteration because, if a guesstimate is found to be unacceptably inaccurate when it is compared with the real and accurate data driven subsequently, then the activities which previously used the guesstimates will have to be re-processed. It is the ability of the Dependency Structure Matrix (DSM) to model interdependencies as well as the iteration which is implied by the use of guesstimates, which makes it an effective technique for modeling project scheduling of activities, However, it is the sub-modeling of iterative blocks and their subsequent interpretation which ensures that the effect of iteration is fully understood such that, ultimately, it is accurately reflected in a schedule of activities. Activities grouped together within an iterative block can be modeled as either (a) sequential activities; or, (b) parallel activities. In a sequential iterative block, activities are processed one after another in the sequence dictated by the DSM. In parallel iterative block, activities are processed concurrently. Ultimately, each iterative block must be resolved into a set of discrete activity occurrences such that resources can be accurately allocated. Ideally the iteration implied by an iterative block is minimized by assigning a team of co-located members of the project to process each activity in the block concurrently. Assuming the concurrent processing of activities, a parallel iteration model can be used to model the activities in an iterative block. However, as will become clearer in the following text, the concurrent processing of activities is not always possible. Therefore, the first decision to make when interpreting the iteration which is implied by iterative block is whether the activities in an iterative block should be processed, and hence modeled, as either sequential activities or parallel activities.

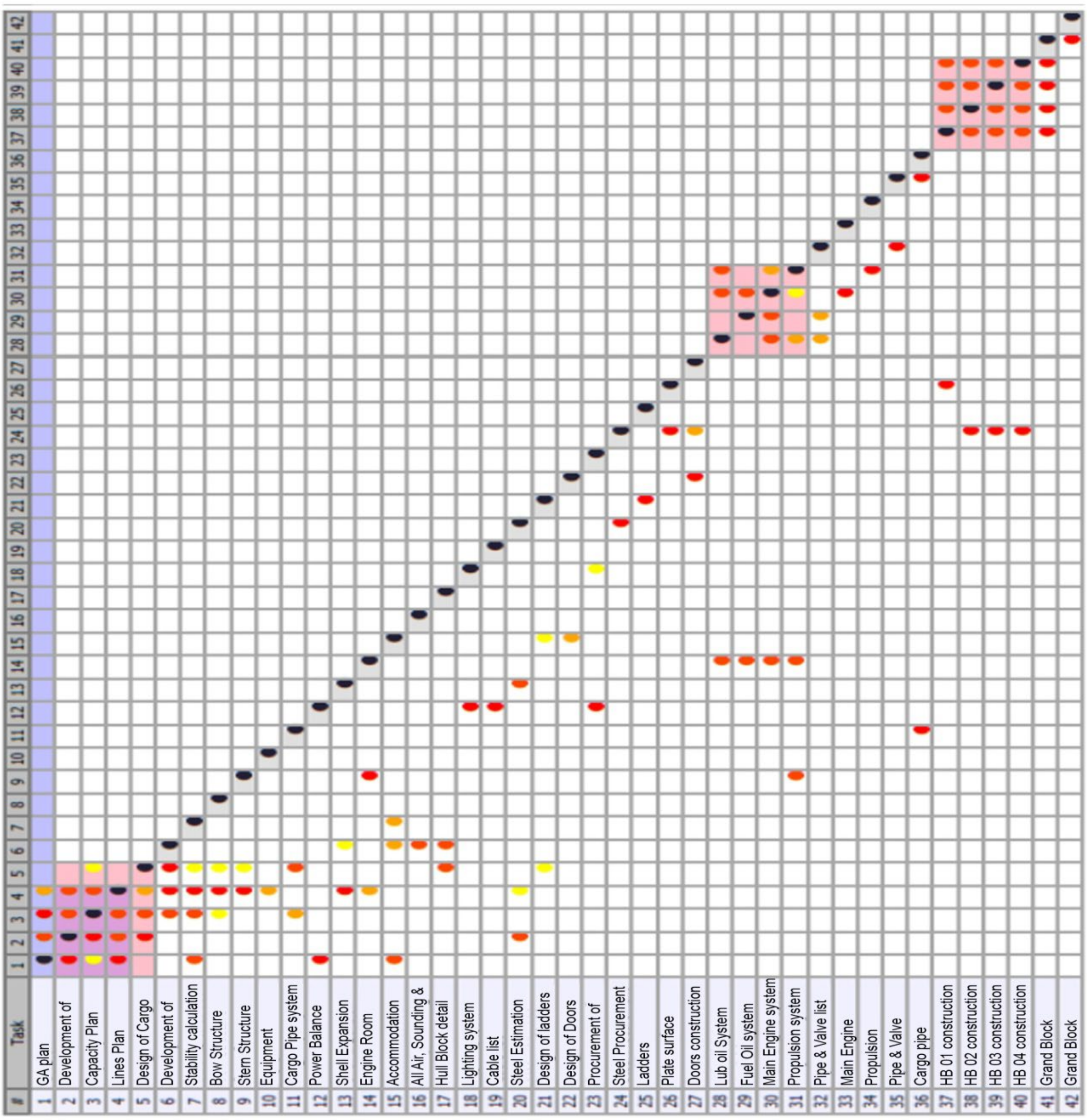


Figure 5.5-Re-sequenced dependency matrix after optimization

5.2.1 Sequential iteration model

Because the number of human resources that would be required to process a large number of activities in parallel is prohibitive, a large iterative block such as the one which encapsulates all the 42 activities of

Figure 5.5, can be processed sequentially and should therefore be modeled using a sequential iteration model.

For the case where a sequential iteration model is considered appropriate, after completion of each activity in an iterative block, if an unacceptable inconsistency between a guesstimate and data is identified, then previously completed activities in the block would be required to be re-processed. Optimally re-sequenced activities in Figure 5.5 are processed taking into consideration the strength of the dependencies. Therefore, activities in a sequential iterative block are processed according to the sequence reflected by the DSM and, whenever necessary, guesstimates are used. Such activities are processed full-time for the predefined duration during their first occurrences and, based on the feedback of real and accurate data from downstream activities, are partially processed, as necessary, intermittently until all the activities in the iterative block have been processed. In the iterative block 1 of Figure 5.5, dependencies as suggested by the project team are for information and resources which indicates that the person(s) who is developing GA is also equally skilled to develop lines plan. It is possible to list the information which are being exchanged between development of GA and Lines plan. By the use of DSM, it is possible to accurately estimate the amount of resources required to process and schedule these activities.

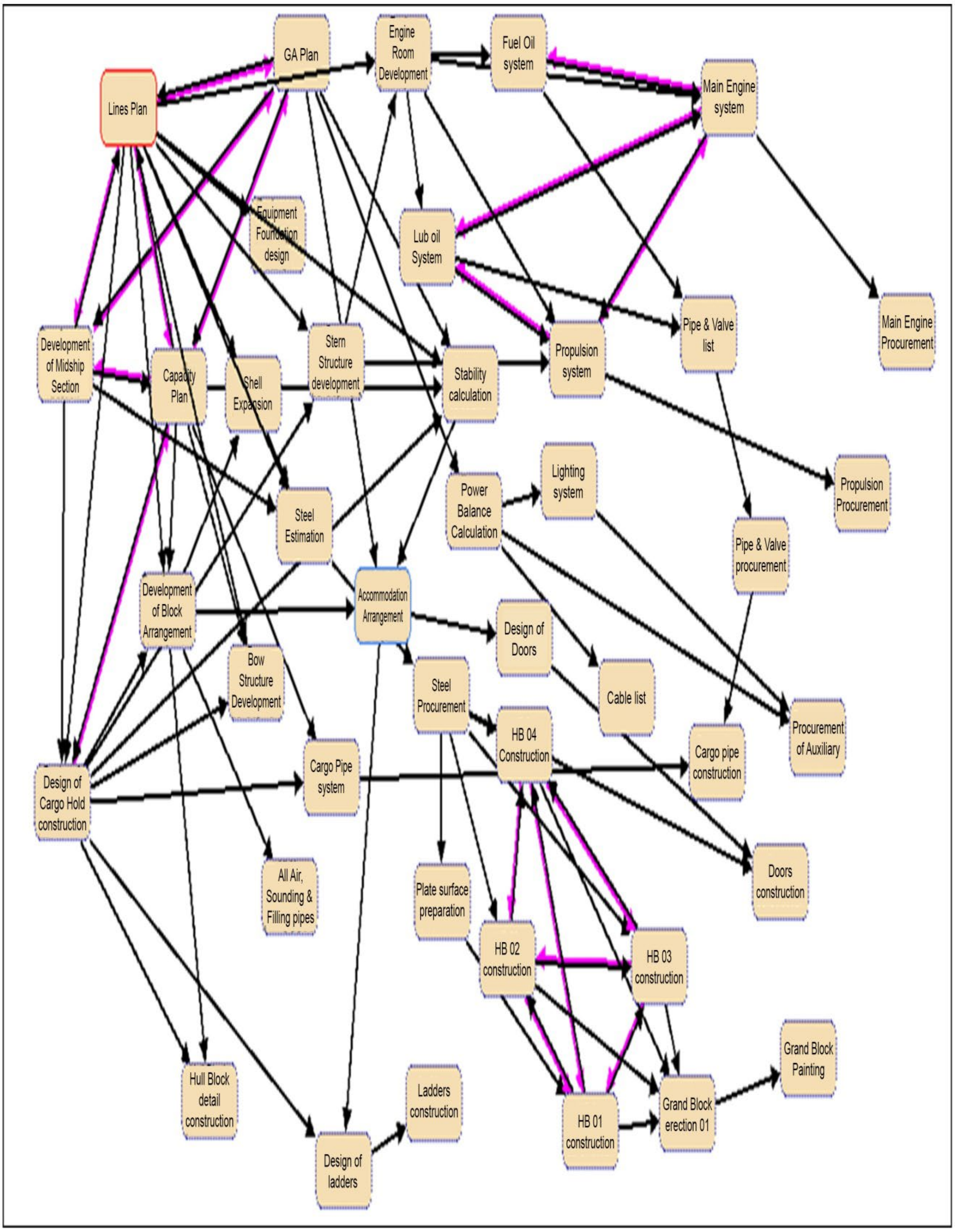


Figure 5.6-Dependency map of activities

5.2.2 Parallel iteration model

For small iterative blocks, which can be visualized in terms of further activity sets like in iterative Block 3 in Figure 5.5, it is more likely that there will be sufficient resources to process activities concurrently. Dependencies among the activities in this block is mainly for human resources and machines. Activity 41, Grand block can only be erected only when all the four hull blocks in activities 37, 38, 39 and 40 are completed. The nature of dependencies among these activities can be further investigated to ascertain how exactly these activities can be scheduled and decision for allocation of resources can be made. For example, if there is only one foreman available to supervise all the four activities in this iterative block and a set of welding and grinding machines are allocated for these activities, it is possible to ensure the exchange of machines in a rotational pattern making sure that progression of all the activities goes in parallel. Therefore, the activities in parallel iterative block should begin and end at the same time, and resources assigned to process the activities should be co-located in order to encourage the efficient and effective integration and exchange of interdependent resources.

In summary, the large iterative block of Figure 5.5 which encapsulates all 42 activities, is processed, and therefore modeled, sequentially according to the optimal re-sequencing. Table 5.1 demonstrates the sequence of activities before and after deriving optimality. The 5 and 4 activities respectively in Block 1 and 2 are modeled as multiple occurrence activities which are processed full-time for their predefined durations during their first occurrences, and on the other hand, activities in iterative block 3 are processed in parallel or concurrently; all beginning and ending at the same times. All other activities outside the iterative block can be processed in sequence as it appears in the DSM, but are required partial re-processing, as necessary, intermittently until all the activities in the DSM in Figure 5.5 have been reprocessed.

Activities	Initial Sequence	Optimal Sequence	Activities	Initial Sequence	Optimal Sequence
GA Plan	1	1	Design of Doors	37	22
Development of Midship section	2	2	Procurement of Auxilliary	40	23
Capacity Plan	3	3	Steel Procurement	10	24
Lines Plan	4	4	Ladders Construction	38	25
Design of Cargo Hold Construction	5	5	Plate Surface Preparation	30	26
Development of Block Arrangement	6	6	Doors Consrtuction	39	27
Stability Calculation	8	7	Lub oil System	18	28
Bow Structure Development	11	8	Fuel oil System	19	29
Stem Structire Development	12	9	Main Engine System	20	30
Equipment Foundation Design	14	10	Propulsion System	21	31
Cargo Pipe System	16	11	Pipe & Valve List	22	32
Pow er Balance Calculation	26	12	Main Engine Procurement	24	33
Shell Exapnsion	7	13	Propulsion Procurement	25	34
Engine Room Development	13	14	Pipe & Valve Procurement	23	35
Accommodation Arrangement	15	15	Cargo Pipe Construction	35	36
All Air, Sounding & Filling Pipe System	17	16	HB 01 Construction	31	37
Hull Block detail Construction	27	17	HB 02 Construction	32	38
Lighting System	28	18	HB 03 Construction	33	39
Cable List	29	19	HB 04 Construction	34	40
Steel Estimation	9	20	Grand Block Erection 01	41	41
Design of ladders	36	21	Grand block Painting	42	42

Table 5.1 -Sequence of activities before and after optimization

By the application of component one of the methodology, it is shown that optimized project planning in combination with recommended standard project management frameworks can uncover hidden dependencies that lead to unnecessary project complexity, rework and risk. This is particularly important if we are focusing on lean production and on eliminating waste from the processes.

While the timing of the project planning activities is determined ultimately by their precedence relationships and availability of resources, the process of deriving an optimal sequence of activities to create Dependency Structure Matrix is invaluable since the DSM represents a priority sequence according to which activities should be considered for processing. Therefore, according to each activity's resources requirements and the availability of resources, activities should be considered for processing in order of priority as they are listed in Figure 5.5.

Once the optimal sequence is derived through DSM, other project planning framework, i.e., Gantt chart, MSP, or any other tools can be applied as well as the resource to complete each activity can be added. While conventional project planning method is applied, the amount of time and resources required to process inter-dependent activities should be given additional consideration. In next section, we will see how the resources required for completion of activities can be used optimally. In brief, component one of the proposed methods by way of application in the case study leads to the following revelations:

- Identify and pinpoint critical task input and dependencies that, if ignored, will lead to substantial rework, delays or even project failure.
- Identify the hidden risks that are built into projects due to sub-optimal project structure.
- Identify all the project tasks and elements that will be affected by potential project rework.
- Identify when and where in a project breakthrough innovation will be necessary to deliver the project outcome.
- Optimize project plan for either shortest project lead time, lowest cost of rework or reduced project complexity.
- Keep track of and manage project assumptions.
- Identify project work that is manageable by project team and the risks and issues that require focused management attention.
- Create 'what if' scenarios to see the effect of different optimization, resourcing and scheduling strategies on project lead time.

5.2.3 Project scheduling with DSM before optimization

In this section we will show the scheduling of each activity before we perform the optimization in local levels. Figure 5.7 and Figure 5.8 exhibit the scheduling of the project under consideration in this thesis before optimization. In order to make the scheduling of this project we have considered the time, shown in Table 5.2, that are usually required for each activity in the shipyard. The time for each activity considered here was taken from the concerned engineers and planners working in the shipyard.

Optimal Sequence	Activity	Time (days)
1	GA plan	120
2	Development of midship section	20
3	Capacity plan	21
4	Lines plan	30
5	Design of cargo hold construction	30
6	Development of block arrangement	31
7	Stability calculation	30
8	Bow structure development	31
9	Stern structure development	35
10	Equipment foundation design	30
11	Cargo pipe system	31
12	Power balance calculation	10
13	Shell expansion	30
14	Engine room development	31
15	Accommodation arrangement	30
16	All air, sounding & filling pipe system	30
17	Hull block detail construction	60
18	Lighting system	31
19	Cable list	17
20	Steel estimation	30
21	Design of ladders	15
22	Design of doors	15
23	Procurement of auxiliary	120
24	Steel procurement	31
25	Ladders construction	20

26	Plate surface preparation	16
27	Doors construction	60
28	Lube oil system	21
29	Fuel oil system	21
30	Main engine system	30
31	Propulsion system	30
32	Pipe & valve list	45
33	Main engine procurement	180
34	Propulsion procurement	180
35	Pipe & valve procurement	46
36	Cargo pipe construction	54
37	HB 01 construction	25
38	HB 02 construction	25
39	HB 03 construction	25
40	HB 04 construction	25
41	Grand block erection 01	15
42	Grand block painting	10

Table 5.2 -Duration of assigned task before optimization

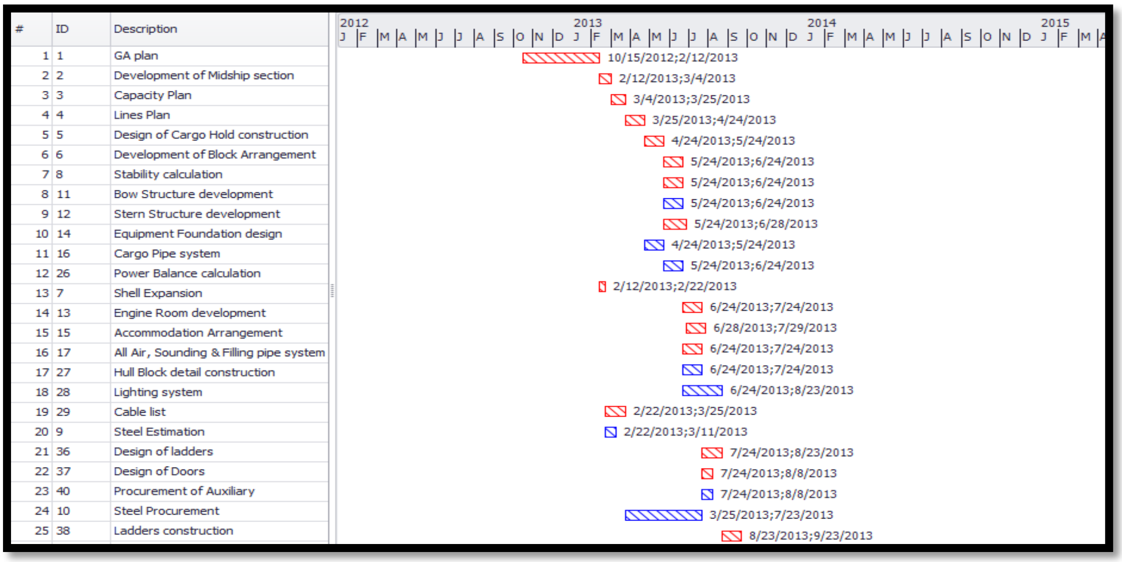


Figure 5.7 -Project scheduling before optimization (Part 1)

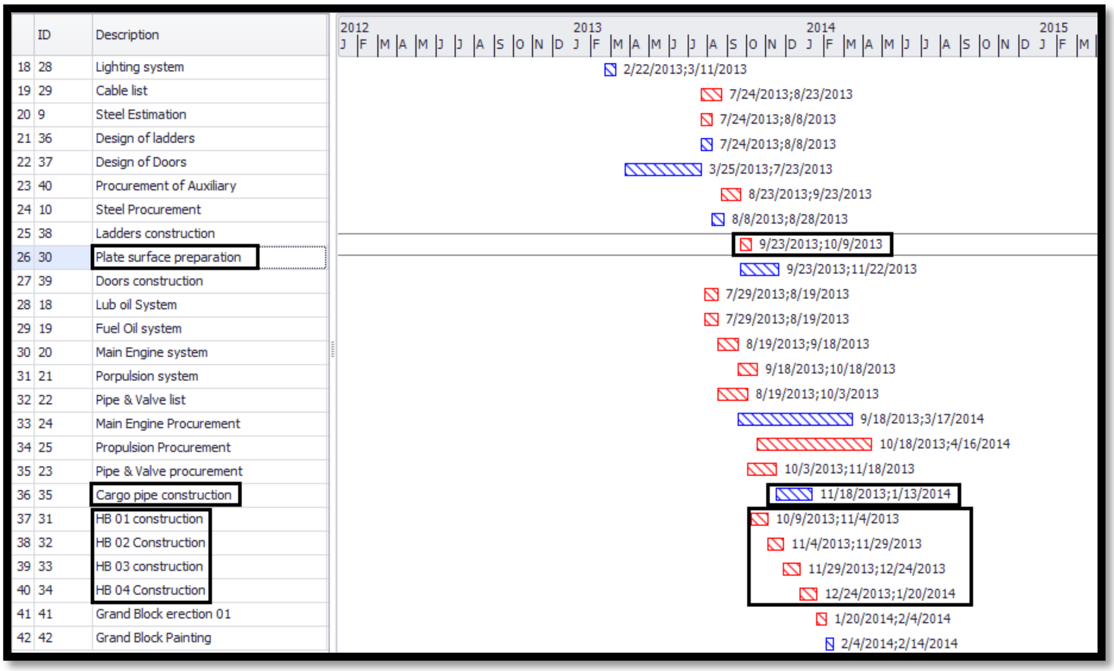


Figure 5.8 - Project scheduling before optimization (Part 2)

5.3 Component two: simulation of activity

Once an optimal project activity sequence is established, as discussed and modeled in the aforesaid section, the next step is to model the production activity simulation. The process can be traced in the method mapping diagram in Figure 4.2. Application of simulation in the manufacturing process is applied across many industries and there is state of the art simulation package available in the market at a reasonable cost. In the forgoing analysis, Discrete Event Simulation (DES) package, Simul8 has been applied to model activity. Discrete Event simulation is the modeling of a system with changes occurring at a finite time. In a shipbuilding production process where complexity, dynamics, and change dominate the environment, it becomes vital to understand systems behavior and the parameters that affect performance. This is particularly important in the development of shipbuilding project plan consisting of future operation and manufacturing; activities in themselves characterized by complexity and variability.

Therefore, modeling of manufacturing process is critical in estimating the resource requirement of the process with embedded process variability alongside estimation based on historical data. Data itself may not produce a holistic understanding of the process until they are investigated in way of applied modeling. DES has the ability to produce a re-producible model of the process entrenched with historical data.

In fact, DES is fundamental to the assessment of manufacturing system or operations management, since many of the measures used are dynamic in nature. It can be narrowed down to the statement that DES is powerful tool to support correct decisions throughout the initial development of manufacturing process and to the repeatable analysis of the process for specific usage. DES thus provides analysis, description and evaluation capabilities of a system or process, and if successfully applied can support collaborative work across project management boundaries such as providing information to decision support mechanism which is outlined in this thesis by applying DES to produce usable information in the decision-making of optimal resource allocation. By these means, simulation can significantly improve system knowledge, shorten development lead time, increase utilization and productivity, and support decision making throughout a project but also throughout an organization. The author has also found that simulation increases the awareness of performance measurements and emphasizes the importance of those measures to the personnel involved in the simulation projects. Simulation can provide users with alternative *'what if' scenarios* for the process under study.

5.3.1 Simulation model of plate surface preparation

Any production phenomenon in shipbuilding can be simulated using DES packages as these processes follow finite time-based change of events. The model which is shown in the following section emanates from the optimally sequenced project activities in Figure 5.9. The activity is called "plate surface" or " surface preparation". This is one of the first activities the project encounters to initiate actual production. The yard receives plates without surface being coated with zinc primer and shot blasted. This activity entails all the plates being processed through surface preparation. 'Surface preparation' activity can further be broken down into manageable work packages consisting of a specific number of plates in each of the sub-activities or the number of plates required to be processed for a block or group of sub-blocks. For the sake of clarity, this is kept as an ungrouped activity in

Figure 5.9. The model in this case study will limit the number of plates being processed over a week time using the existing facility of the yard. This can be extended to any number of weeks as envisaged in the original project plan for the corresponding characterization of the activity. Surface preparation process of this yard in case study is displayed in Figure 5.9. As the yard receives the plates, it stores the pallet of plates in the warehouse or stores. There are a number of stores located in different zones of the yard. Plates are fetched by a fork lift to the shot blasting plant and with help of EOT crane plates are then fed into the shot blasting machine to remove the 'mill scale' from the plates. Sometimes, it is required to re-process a few of those plates through shot blasting plant either because of the high speed of the roller not being sufficient to remove 'mill scale' to the satisfaction of quality control or the rust is too persistent. In both cases, these plates are then fetched by fork lift either to the feeding queue of the blasting machine or to the inspection stage. At his stage these plates are further inspected by the quality department for occasional presence of pitting. It is worthwhile to mention here that most of the time these plates are imported either from far east or from CIS countries. Transportation of these plates take considerable amount of time being spent in the open sea and in the face of variable degree of climatic changes. The erratic intrusion of green water onboard the vessel during the rough sea are quite commonly encountered, anything but pitting phenomena is also quite common among the plates. This is further aggravated by the fact that these plates are stored sometimes couple of months before they are being processed through surface preparation. At inspection stage, quality controller decides on which plate to send to manual grinding or which to surface coating. In the presence of excessive pitting, manual grinding is an option to create a smooth surface at the cost of reduced thickness of the plate. Class society has inclusive guidelines on the allowance of thickness sacrifice on account of pitting correction. Onward grinding stage, all the corrected plates are sent over to surface coating for application of Zinc primer. Primer application concludes the process of surface preparation. All the coated plates then move on the next process of CNC cutting station. Figure 5.9 exhibits the process model of surface preparation.

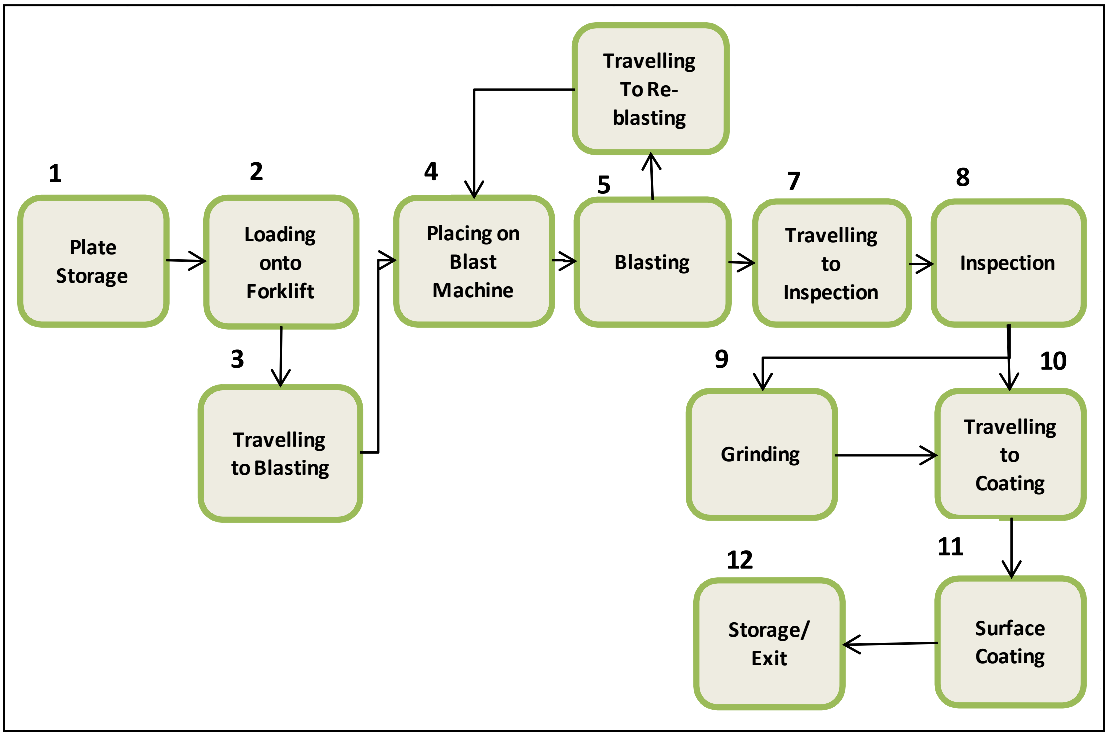


Figure 5.9 -Surface preparation process model

5.3.2 Plate surface preparation model analysis

This model is representative of the general process the yard follows historically. Data of this process has been collected over the span of three weeks and correctness of the data has been confirmed with the process engineers. All the data are extracted from a Naval oil replenishing tanker of 2774 DWT capacity. The yard can handle plates of 2mX6m in size and thickness up to 200 mm. For the particular oil tanker project of this case study, it is assumed that the surface preparation process will be required to handle plates of the same size as with shipyard standard but of variable thickness. However, thickness variation has minimum impact on the process data in regard to the usage for modeling of forecasted scenario of the oil tanker. This surface preparation model has been constructed using the usual data pattern recorded and listed in Table 5.3. A brief description of the process is explained in following pages.

Process Component	Resource(s)	Requirement	Time Distribution (Minutes)	
			Triangular	Uniform
Plate Storage	Loader	2	15-20-30	
Loading	Loader	2		5-7
Travelling Blasting	Forklift	1		7-10
Placing on Blast Machine	EOT Crane	1	3-4-12	
	Blasting Helper	1-2		
Blasting	Blasting Operator	3		18-22
Travelling to Re-Blasting	Forklift Operator	1		4-7
	Blasting Helper	1		
Travelling Inspection	Forklift Operator	1		3-7
	Blasting Helper	1		
Inspection	Inspector	1	3-4-7	
	Forklift Operator	1		
Grinding	Grinder	2-3	40-50-70	
Travelling Coating	Forklift Operator	1		7-12
Surface Coating	Painter	2	45-50-60	

Table 5.3 -Surface preparation model data

Plate Storage: Plates are stored in different locations in the yard. As the surface preparation process starts right plates with class markings are sorted out in the store for onward transportation. Generally, two loaders are assigned in the store who help to sort the plates and keep them in the queue. Time required for this process follows a triangular distribution. According to (A. M. Law, 2007), triangular distribution approach is used to model task times based on a few actual data and also expert opinions. When concerned team members of the process was asked about the time it takes, they opined that most of the instances this sorting process takes 20 (twenty) minutes, but sometimes it can be done optimistically as early as within 15 (fifteen) minutes and at times it might take as long as 30 (thirty) minutes.

This sorting process consists of identification of the right marking of the plates, removing them from the pallet and keeping them in the queue for onward loading.

Loading: Minimum two loaders are required to help load these plates on to the forklift. Response for the time required for the process was not triangular rather bounded by a lower and upper limit. Therefore, uniform distribution has been attributed. Generally, three plates are loaded on in the forklift each time as the forklift used for the process has a fixed 2 (two) ton capacity.

Travelling Blasting: Once the plates are loaded, irrespective of the location of the store in the yard, travelling takes a uniform distribution time. Forklift used in travelling between store and blasting renders a dedicated service for this operation only.

Placing on Blast Machine: This process requires an EOT crane and minimum 1 (one) or maximum 2 (two) Basting helpers depending on weight of the plate or the availability of the helper(s). Required time follows a triangular distribution.

Blasting: Blasting process requires 3 (three) Blasting operator, one of them is stationed in the control room, one look after the shot spray and flow and the other one looks after the roller and ensure that plates are not colliding with side of the machine. This process time usually takes a uniform distribution. Blasting machine can only hold 3 (three) plates on the roller bench at exit before forklift arrives and loads the plates.

Travelling to Re-Blasting: In some instances, blasted plates are required to be sent through the blasting process once more due to the presence of tough mill scale or the mill scale not being removed due to the high speed of the roller. It is estimated that about 10% (ten) of the plates are usually required to be sent through re-blasting. It requires a forklift to carry the plate back to feed in queue of the blast machine and 1 (one) helper to help load it onto the forklift. It takes a uniform distribution of time.

Travelling to Inspection: Once the plates are blasted about 90% (ninety) plates are fetched by forklift to inspection center where and inspector further investigates the quality of the shot and the presence of pitting. With the help of blasting helper plates are loaded onto the forklift. Time distribution is uniform.

Inspection: This process requires a forklift and one inspector to carry out the inspection as because the plates are required to be turned around for both sides inspection. Pitting is common phenomena encountered by the yard. Over the last couple of years about 40% (sixty) percent of the plates were infected with pitting of some degree. These plates are sent then unloaded and sent through manual grinding for rectification. This is done according to the guideline of class society. Inspection follows a triangular distribution.

Grinding: Plates infected with pitting are processed through this center and usually 2 (two) to 3 (three) grinders are placed at this center depending on the extent of restoration requirement. Time taken to process the work at this center follows a triangular distribution. Once the grinding operation is completed plates are then fetched to next station for surface coating.

Travelling Coating: Plates passed by quality control inspection for surface coating and those from grinding operation are then fetched by forklift to paint station. This requires forklift and generally it takes a uniform distribution to fetch these plates to surface coating.

Surface Coating: This is the last active step of surface preparation process. Plates are applied with primer coating at this stage with air spray gun or roller by the assigned painter(s). This process takes a triangular distribution time.

With all the above data being ingrained in the surface preparation model, a simulation model is created to replicate the real process scenario. Figure 5.10 exhibits the simulation of this model. This model follows a shift of 8 (eight) hours pattern starting from 8 o'clock in the morning and is run for a week. There is a warm up period before any data is started to be collected. Warm-up period helps the model to get adjusted with the distribution over a time period and thus ensures close replication of real-time process productivity.

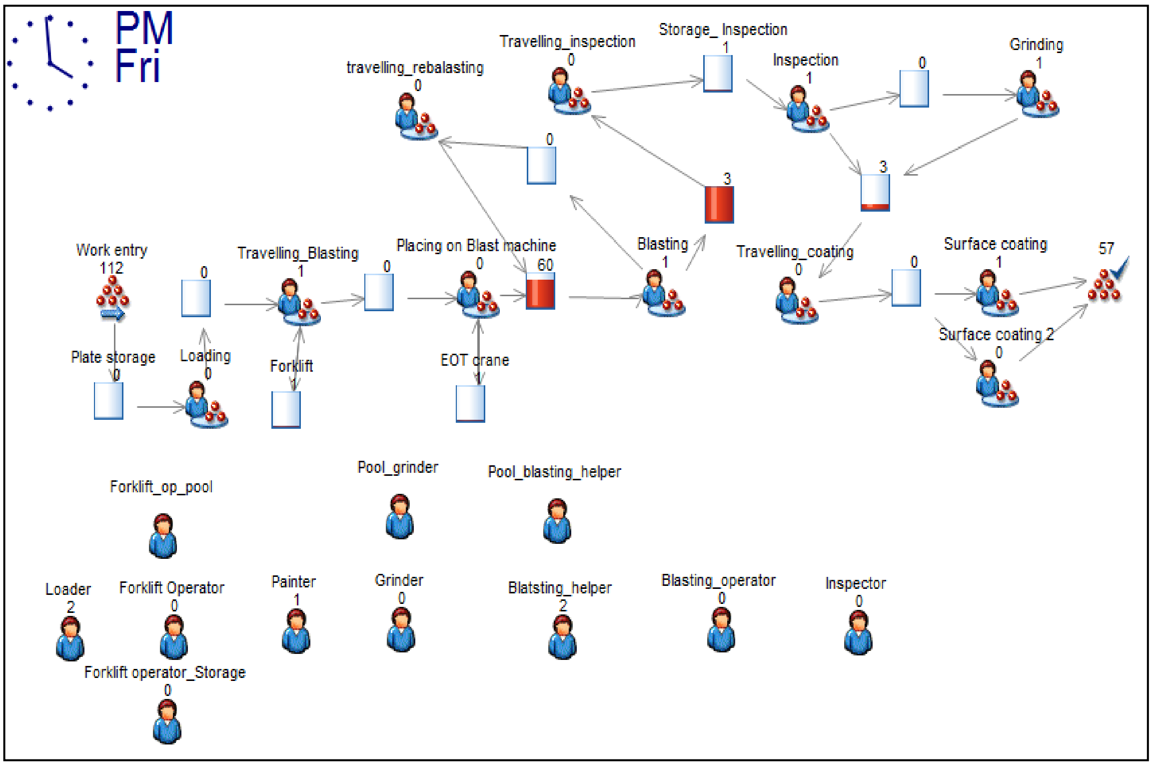


Figure 5.10 -Simulation model of surface preparation

For the purpose of verification and validation, a comparison between the model and the real data from the process reveal that this model closely replicates reality. It can be seen in Figure 5.10 that a total of 57 (fifty-seven) plates are processed every week, whereas the process engineer confirms that this combination of resources can produce around 60 (sixty) plates a week on a single shift basis.

5.3.3 Simulation model of block construction

Block construction is one of the most important activities in a shipbuilding project. Construction of block usually is split into two sub-activities namely sub-assembly and final assembly. Blocks placed in the parallel middle body of the ship, have been considered here. Block construction process of this yard in the case study is displayed in Figure 5.11. After receiving the plates from the surface preparation shop they are taken to Computer Numerical Control (CNC) machine shop of the yard. There are a number of CNC machines in that particular shop. Plates are fetched by a fork lift to CNC machine shop and with help of EOT crane plates are then fed into the CNC machine. Then plates are cut into a number of members required to construct a block. All the members produced by the CNC machine are then taken to the subassembly shop. In order to produce a block, the workers of the yard perform several types of tasks in both subassembly and final assembly shop. These tasks include mainly grinding, fitting, welding, inspection and painting (only in final assembly shop). At the time the plates are brought into the sub-assembly shop the grinders start grinding the plates. After doing sufficient grinding operation the plates are inspected to see whether there has been enough grinding made to proceed to next task. The plates are then fitted for the welding operation. Next, the welded plates are grinded again to smooth out the edge before taking them to the final assembly shop. Generally, the workers are advised to make three sub-assembly groups to do all the jobs required to produce blocks in the yard. Each sub-assembly groups perform the same sequence of tasks mentioned above but in different parts of the block. Figure 5.11 exhibits the process model of block construction.

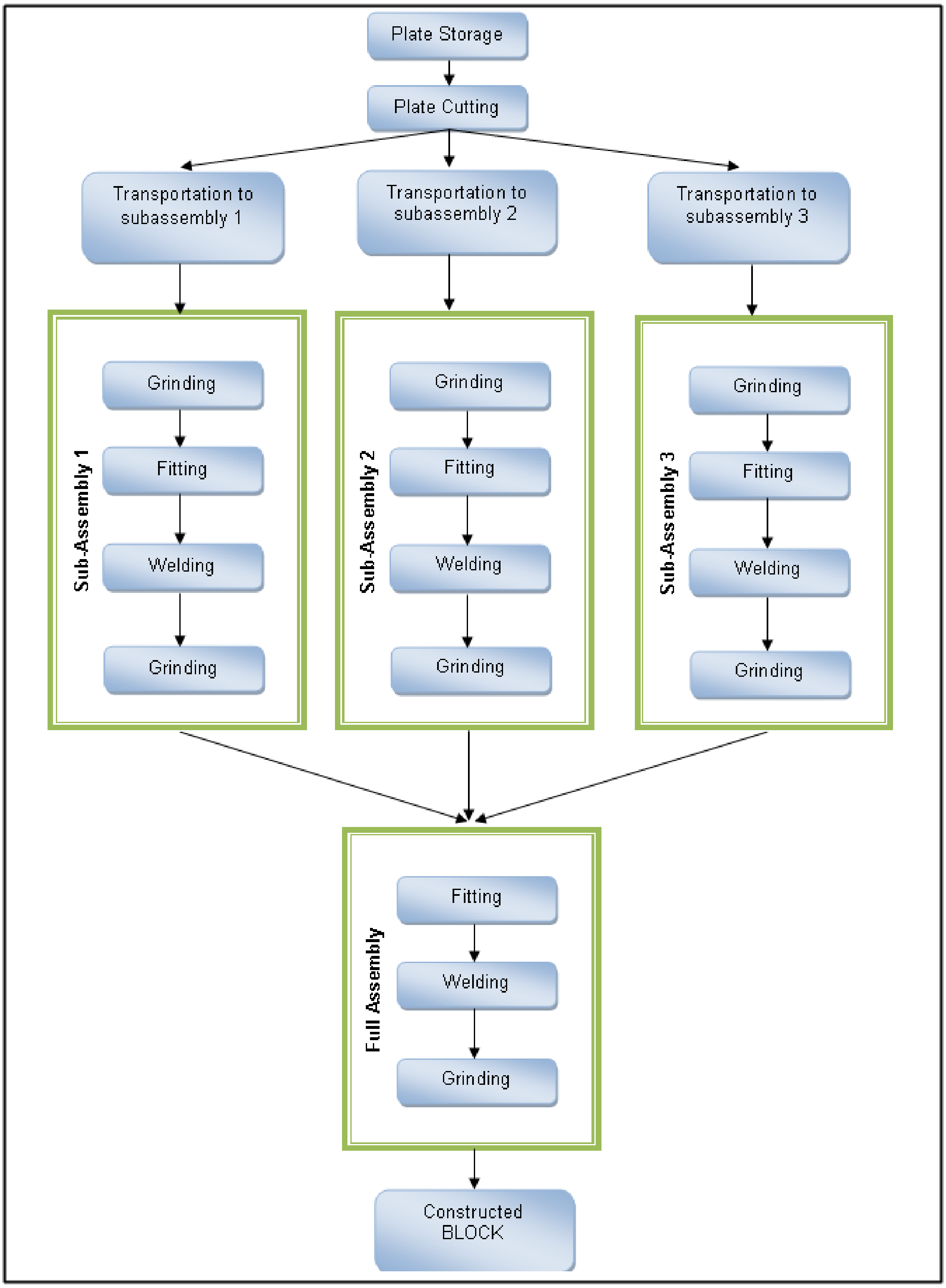


Figure 5.11 - Block construction process model

5.3.4 Block construction model analysis

This model is another representative of the general process the yard follows historically. Similar to the surface preparation model analysis, data of this process has been collected over the span of two weeks and correctness of the data has been confirmed with the process engineers. Information of the blocks are collected from the Naval fuel replenishment tanker. There are a total 72 blocks in this ship. This model has been analyzed using similar kind of blocks from the parallel middle body, which are forty (40) in numbers. This block construction model has been constructed using the standard data pattern recorded and listed in Table 5.4.

Process Component	**Resources**	**Total Requirement**	**Triangular Time Distribution (Minutes)**	
			Resource Variation	**Distribution**
Cutting of Plates	CNC Machine	1	CNC Speed 1	170-171-172
			CNC Speed 2	215-216-217
			CNC Speed 3	300-301-302
Travelling to Subassembly	Forklift	1	Forklift	20-21-22
Grinding at Subassembly	Grinder	4-8	Grinder (4)	6-7-12
			Grinder (6)	4-5-8
			Grinder (8)	3-4-8
Fitting at Subassembly	Fitter	6	Fitter (6)	2-3-4
Welding at Subassembly	Welder	4-8	Welder (4)	7-8-15

			Welder (6)	5-6-9
			Welder (8)	4-5-8
Fitting at Final Assembly	Fitter	6	Fitter (6)	60-70-80
Welding at Final Assembly	Welder	4-8	Welder (4)	4320-4500-5000
			Welder (6)	2880-3200-3600
			Welder (8)	2160-2500-3000
Grinding at Final Assembly	Grinder	4-8	Grinder (4)	2880-3200-4000
			Grinder (6)	1920-2300-2500
			Grinder (8)	1440-1600-1800

Table 5. 4 -Block construction model data

Cutting of plates: Plates are stored in CNC shop after the surface preparation procedure has been done. In the yard, there are five CNC machines out of which two are gas cutting machines and the other three can perform both gas cutting and plasma cutting operation. We considered one CNC machine in our model. Plates are placed in the CNC machines to be cut into members. Generally, 1 to 40 members can be produced from a plate depending on the design of members and the size of the plates. Time required for this process follows a triangular distribution. Every CNC machine has its own speed depending on the thickness of plates. So the speeds of the machine vary according to the plate thickness. From the machine manual, we have chosen three types of speed and then we calculated the time required to cut a single plate. Even though different plates will take different cutting time on the basis of dimensions and design of members, we have averaged out speeds on account of dimensions. The triangular distribution of times has been given in the Table 5.4.

Travelling to subassembly: The members required to build a block are taken to the sub-assembly shop by forklift. There are five forklifts in the yard but we considered one forklift in our model since other forklifts will remain busy for some other jobs. As mentioned earlier, three plates are loaded on the forklift each time as the forklift used for the process has a fixed 2 (two) ton capacity. The time taken by a forklift to arrive at the sub-assembly facility is usually 20 minutes. We have considered triangular time distribution for the forklift which is 20-21-22, where 20, 21, 22 minutes are minimum, frequent and maximum time requirement for the forklift.

It has been mentioned earlier that the workers are advised to make three sub-assembly groups to do all the jobs required to produce blocks in the yard. These three groups are tank top, inner bottom and others consisting of frames, girders etc. Each sub-assembly group performs the same sequence of tasks namely, grinding, fitting, welding, and inspection.

Grinding at subassembly: Once the members arrive at the sub-assembly shop, the grinders of each sub-assembly group start grinding operation on each member. Members, after being produced from plates, contain rough edges which are required to be levelled. Usually, a total of four to eight grinders for the three groups (not each group) are required to perform the grinding operations depending on the volume of edged members. It has been confirmed from the process engineers that it takes nearly 6 to 8 days for the grinders to perform the grinding operation required in the sub-assembly shop. We then calculated the time needed for a grinder to do grinding work. We considered triangular time distribution for assigning the time for the grinders. It is important to mention that we considered an average grinding time for each grinder. In the model the numbers of grinders have been varied ranging from four to eight (Three types considered: 4, 6, & 8). The triangular distributions of time are given in Table 5.4.

Fitting at subassembly: Once the grinding operation is done, members are fitted according to the design to perform the welding operation. In block construction, the fitting operation doesn't take much time. Usually, a total of six fitters for the three groups (not each group) are required to perform the fitting operations. We have considered triangular time distribution for assigning the time for the fitter and this time is an average fitting time. In the model, we didn't vary the numbers of fitters since fitting time is not much significant in block construction.

Welding at sub-assembly: In block construction, welding operation carries a great importance. When the fitters get their job done, welders then involve themselves in welding the members. Generally, a total of four to eight welders for the three groups (not each group) are required to perform the welding operations. Process engineers of the yard confirmed that it takes near about 6 to 8 days to carry out the welding operation in the sub-assembly shop. We then calculated the welding time needed for a welder. Triangular time distribution has been considered here for assigning the time for the welders. The numbers of welders have been altered ranging from four to eight (three types considered: 4, 6, & 8), which is same as the number of grinders. Table 5.4 shows the time distribution of welding.

Grinding at sub-assembly: After the welding operation is done, the grinders again start their jobs since the welded joints carry lots of dust, rough surfaces etc. which are required to be removed. The same number of grinders and grinding time have been set this time as mentioned in the earlier section.

Fitting at final assembly: In the sub-assembly work shop, the mentioned three groups finish their task for all the parts required to make a block. The tank top, inner bottom, longitudinal, frames etc. are taken to the final assembly zone. The fitters start their fitting operation to the parts made from sub-assembly. This job is similar to the job mentioned in the 'Fitting at sub-assembly' section. Same number of fitters (six) is assigned here to perform the task.

Welding at final assembly: The welders do the same job as they do in the sub-assembly. Engineers working in the yard informed that usually four to eight welders are required to perform the welding job in order to make the final block. We calculated the required welding time for the full block (not for each member) by averaging out the times. We have put triangular distribution of time in our model. The distributions of time are given in Table 5.4.

Grinding at final assembly: After the welding operation is done in final assembly, the grinders again start their job for the last time. As previously mentioned, grinding operation should be carried out on the welded parts since they contain dust, rough edges etc. It has been suggested by the process engineers that around four to eight grinders are required in the final assembly. The calculated time is an average time and we put triangular distribution of time in our model (Table 5.4).

With all the above data being obtained in the block construction model, a simulation model is created to replicate the real process scenario. Figure 5.12 exhibits the simulation of this model. This model follows a shift of 8 hours pattern starting from 8 o'clock in the morning and is run for 25 days (simulation time) which is the average time required to build a single block. We then run the model to produce 40 blocks since the ship we considered has 40 blocks in the parallel middle body and the run time was 500000 minute.

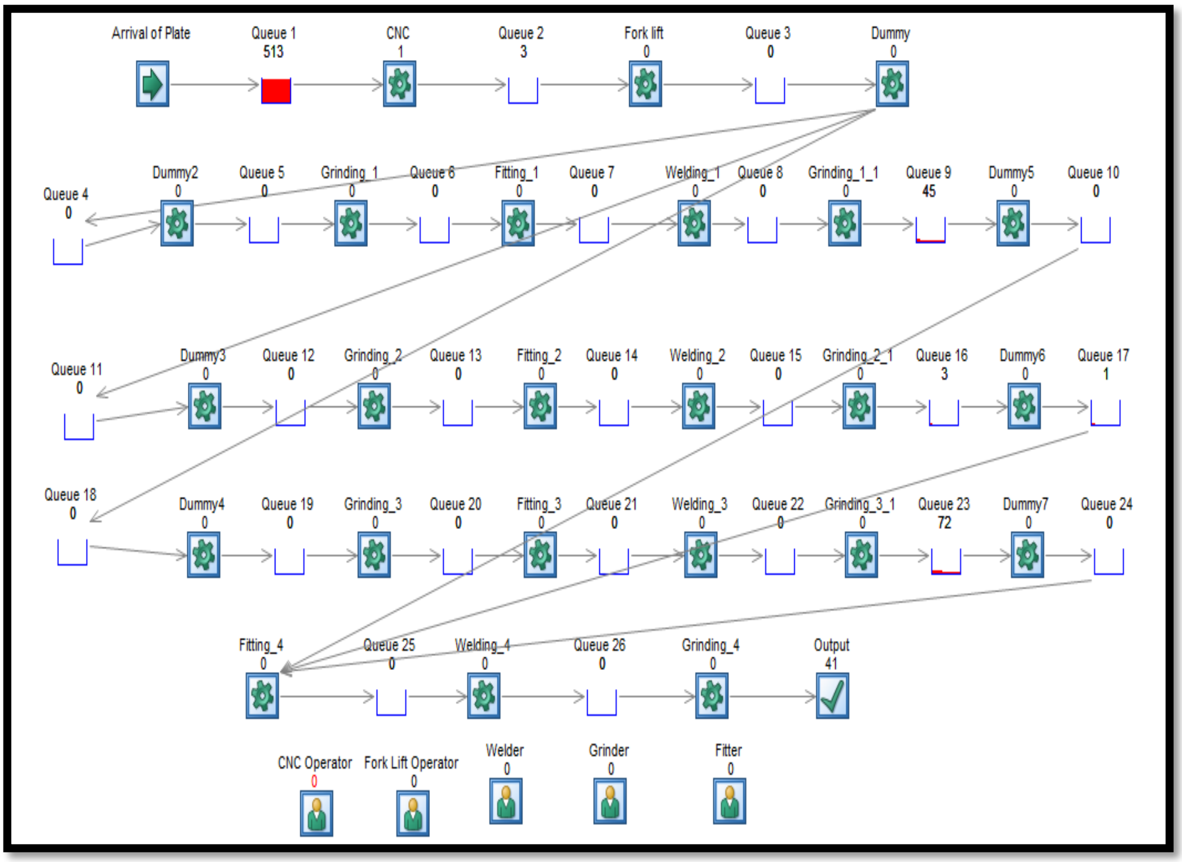


Figure 5.12-Simulation model of block construction

A comparison between the model and the real data from the process reveals that this model closely replicates reality. It can be seen in Figure 5.12 that a single block is built in 25 days, whereas the process engineer confirms that generally the shipyard takes around 25 days to produce a block on a single shift basis.

5.3.5 Simulation model of pipe spool production

Production of pipe spool carries vital importance in shipbuilding industry. The shipyard under this study deals with pipes ranging from DN-5 to DN-800. Since the classification of pipes is many, we have selected pipes ranging from DN-5 to DN-300 and categorized them into three groups: DN-5 to DN-32, DN-40 to DN-80 and DN-100 to DN-300. Pipe spool production in this case study is displayed in Figure 5.13. After receiving the pipes from the storage, they are taken to pipe cutting shop where there are a number of pipes cutting machines. It is worth mentioning that usually six groups of labours each consisting of 3 members (1 fitter, 1 junior fitter & 1 helper) and a group of 4 welders are assigned to work for the total pipe spool production. All of these workers are engaged in activities starting from pipe cutting to pipe welding. After the pipes of various standards are cut, pipes are transported to either automatic bending machine or manual bending machine depending on the standard of pipes. All the pipes having bent by the bending machine are then inspected for quality assurance. After the quality checking is made, pipes are prepared for welding operation. Figure 5.13 exhibits the process model of pipe spool production.

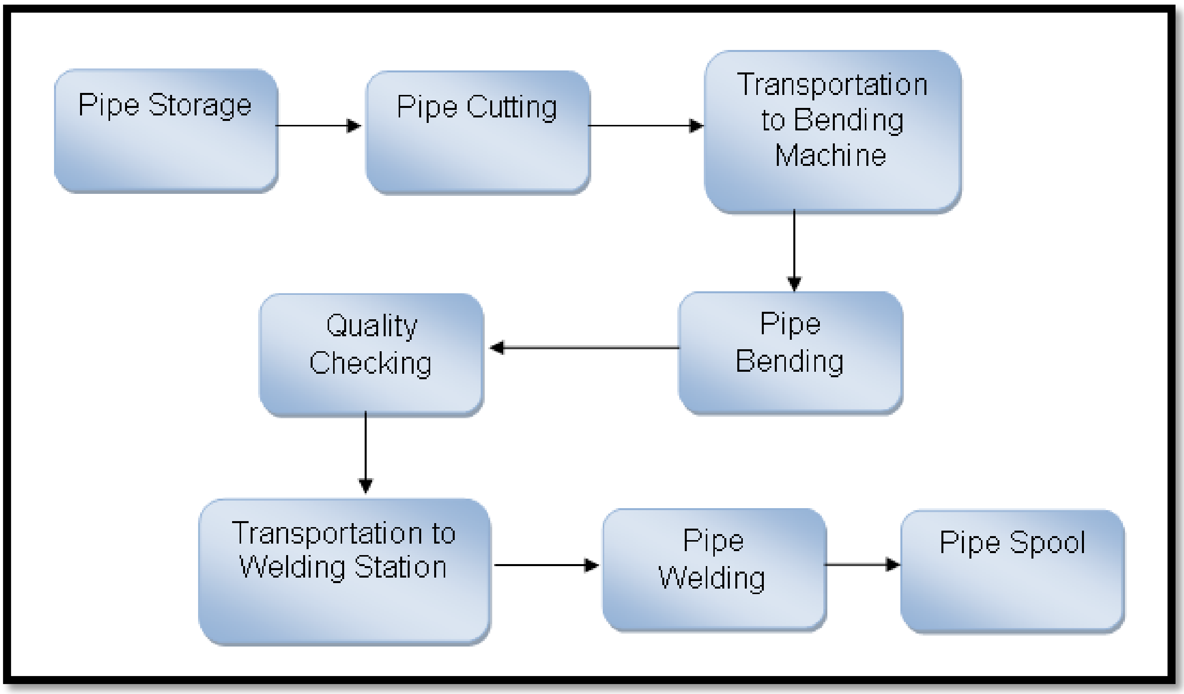


Figure 5.13 - Pipe spool production process model

5.3.6 Pipe spool production model analysis

This is another example of the general process of the shipyard. Same as surface preparation and block construction model analysis, data have been collected and confirmed with engineers working in the yard. The pipe spools are considered from the Naval oil tanker and there were approximately 2500 pipe spools in that ship. In the case study, we have considered the number of pipes produced per week in the shipyard. The recorded data are listed in Table 5.5.

Process Component	**Resources**	**Resource Required**	**Triangular Time Distribution (Minutes)**	
			Resource Assigned	**Distribution**
Pipe Cutting	Cutting Machine	3	3	20-25-30
	Helper	3	5	
	Fitter		5	
	Junior Fitter		5	
			Total: 15	
	Helper	3	6	

	Fitter		6	
	Junior Fitter		6	
			Total: 18	
	Helper	3	7	
	Fitter		7	
	Junior Fitter		7	
			Total: 21	
Transportation to Bending Machine	Helper	2	5	10-12-15
	Fitter		5	10-12-15
	Junior Fitter		5	10-12-15
			Total: 15	
	Helper	2	6	10-12-15
	Fitter		6	10-12-15
	Junior Fitter		6	10-12-15
			Total: 18	
	Helper	2	7	10-12-15
	Fitter		7	10-12-15
	Junior Fitter		7	10-12-15
			Total: 21	
Pipe Bending	Automatic Bending Machine	1	1	40-50-60
	Manual Bending Machine	1	1	20-25-30
		2	2	
		3	3	
	Helper	3	5	
	Fitter		5	

	Junior Fitter		5	
			Total: 15	
	Helper	3	6	
	Fitter		6	
	Junior Fitter		6	
			Total: 18	
	Helper	3	7	
	Fitter		7	
	Junior Fitter		7	
			Total: 21	
Quality Checking	Checker	1	1	4-5-6
Transportation to Welding Station	Helper	2	5	10-12-15
	Fitter		5	10-12-15
	Junior Fitter		5	10-12-15
			Total: 15	
	Helper	2	6	10-12-15
	Fitter		6	10-12-15
	Junior Fitter		6	10-12-15
			Total: 18	
	Helper	2	7	10-12-15
	Fitter		7	10-12-15
	Junior Fitter		7	10-12-15

			Total: 21	
Pipe Welding	Welder	3-5	Welding Station 1	55-60-65
			Welding Station 2	95-100-105
			Welding Station 3	175-180-185
			Welding Station 4	355-360-365
			Welding Station 5	475-480-485
			Welding Station 6	755-760-765

Table 5.5 -Pipe spool production model data

Cutting of pipes: Pipes are taken to the pipe cutting shop from storage. In the yard, there are several pipe cutting machines, however, the fabrication groups usually use three of them. That's why three cutting machines are considered in our model. As mentioned earlier, six groups of people (each group comprised of 1 junior fitter, 1 helper and 1 fitter) work for total pipe spool production. It is confirmed from the process engineers that on an average 3 people from fabrication groups are required for each pipe cutting operation. Even though six groups (18 members) are assigned in the yard, but for the purpose of optimization we have both increased (21 members) and decreased (15 members) the total number of people in fabrication groups (resources) in our model from which the required three people have been selected. Time required for this process follows a triangular distribution since the dimensions of pipes vary significantly. We have chosen the cutting time needed to cut pipes in an average manner, though different pipes will take different cutting time on the basis of dimensions. Thus, calculated average times of cutting are 20, 25 and 30 minutes for DN-5 to DN-32, DN-40 to DN-80 and DN-100 to DN-300 respectively. The triangular distribution of each of the times has been given in Table 5.5.

Transportation to bending machine: The pipes are taken to the bending machine by the help of fabrication groups. Generally, two people from fabrication groups are required to transport each pipe from the cutting machine to the bending machine. Similar to the pipe cutting operation, the number of people in fabrication group have been increased and decreased to 21 and 15 respectively. We have considered triangular time distribution for the transportation which is 10-12-15, where 10, 12, 15 minutes are minimum, frequent and maximum time requirement for the transportation.

Bending of pipes: Once the pipes arrive at the bending machine facility the fabrication groups start bending of the pipes. In the yard pipes are required to be either bent or joint by elbow after being cut in the cutting machines. Two types of bending machines are used: automatic bending machine and manual bending machine. The yard has a maximum of three manual bending machines where pipes below DN-65 are bent. Rest of the pipes is bent in the automatic bending machine (one in number). In general, three people from fabrication groups are required to perform the bending operations. No additional bending operator is needed for this job as the assigned fitters or helpers usually carry out this bending operation. To optimize the total process, we have assigned different number of people in fabrication groups (15, 18 & 21). Process engineers of the yard mentioned that the triangular time distribution for automatic bending machine is 40, 50, 60 minutes and for manual machines is 20, 25, 30 minutes which are required to bend DN-5 to DN-32, DN-40 to DN-80 and DN-100 to DN-300 respectively. We considered triangular time distribution here which is shown in Table 5.5.

Quality checking: In the yard, generally one quality inspector is assigned to check whether the pipes have been bent in accordance with the design. The quality checker takes around 4-6 minutes to perform the checking operation.

Welding at sub-assembly: In pipe spool production, similar to block construction, welding operation carries a vital importance. Once the quality inspector has his job done, welders then involve themselves in welding the flange with the pipes. Generally, four welders are required to perform the welding operations in the pipes. In our model, we have increased the number of welders to 5 and decreased to 3 to get the optimal benefit. Process engineers of the yard opined that welding time varies significantly based on the dimensions of the pipe. For this particular welding operation, we have selected six welding stations each of which is responsible for welding particular size of pipes. Triangular time distribution has been considered in Table 5.5 to assign the time for the welding.

A simulation model is generated to replicate the real process scenario of pipe spool production. Figure 5.14 shows the simulation of this model. This model follows a shift of 8 hours pattern starting from 8 o'clock in the morning and is run for 6 days.

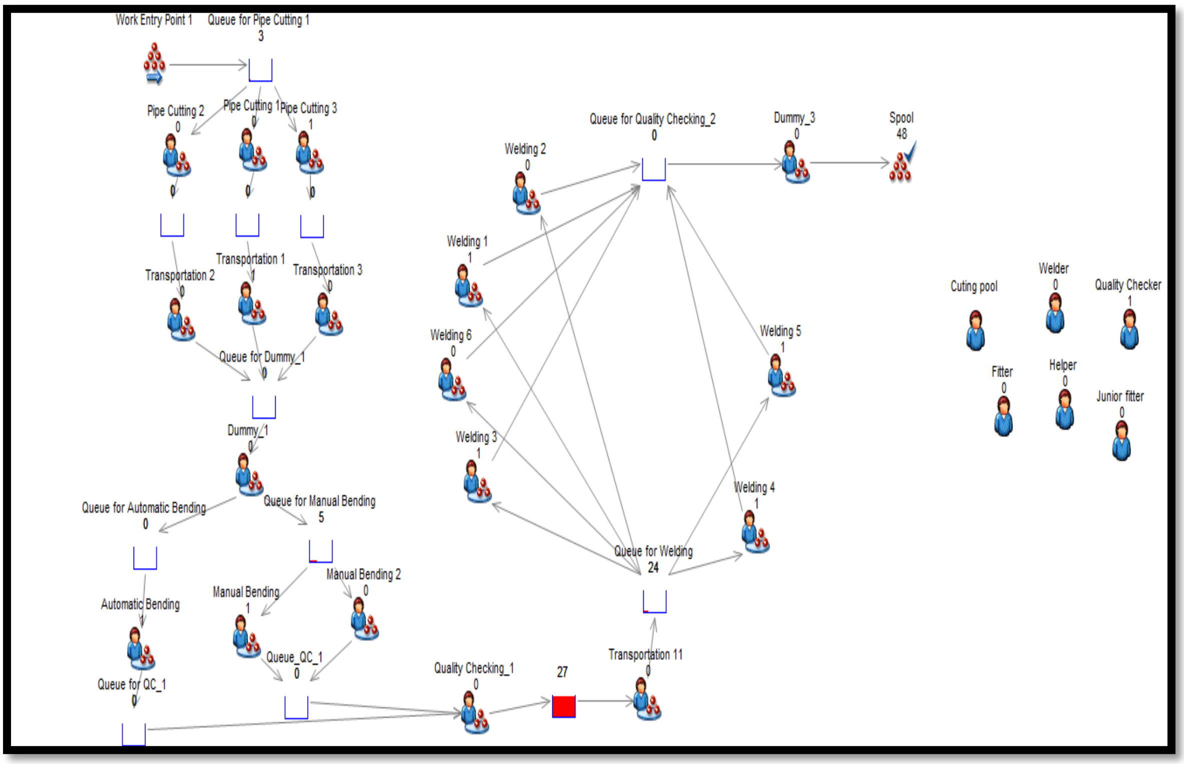


Figure 5.14-Simulation model of pipe spool production

A comparison between the model and the real data from the process reveals that this model closely replicates reality. It can be seen in Figure 5.14 that our model can produce 48 spools per week, whereas the process engineer confirms that production of spools ranges from 40 to 45 per week on a single shift basis.

5.4 Component three: Design of Experiments optimization

As discussed in chapter 4, Design of Experiments is a method of optimization where careful changes are made to the factors responsible in the variation of output and thus on ascertaining the interaction effect of the factors, a desired output is achieved. It also helps to identify the impact of the any factor under study on the outcome of the process. Simulation of any process of system can reveal underlying characteristics and may answer question to "what if" but it does not optimize the process.

A study is carried out to select the input variables (factors) and their levels. As it is not possible to identify the effect of all variables, it is important to determine the variables that have significant effects on the response or output. Screening simulation experiments are used to identify the variables (factors) to be optimized. For this problem, these factors are determined based on both the performance measure of the simulation model (average number in queue statistics) and the opinion of the process engineers. Process knowledge is very important in the successful implementation of the method.

5.4.1 Design of Experiments for plate surface preparation

This section will describe the Design of Experiments for the plate surface preparation model. The factors as identified are as follows:

- Speed of the Blast Machine (Blasting Speed)
- Number of Forklifts (Forklift)
- Number of Surface coating workstation (Painter_surf_coating)

Factors	Min Level	Max Level	Centre Pt	Min Code	Max Code	Centre Pt code
Blasting Speed, x_3	0.2 m/minute	0.4 m/minute	0.3 m/minute	-1	1	0
Forklift, x_2	1	3	2	-1	1	0
Painter_surf_coating, x_1	1	5	3	-1	1	0

Table 5.6-Factor levels and codes for Design of Experiments (plate surface)

Next important issue is the determination of factor levels that are related to the physical and economic conditions of the process.

Table 5.6 exhibits the allowable and assignable resources for this particular tanker project and their levels for the process and the coding for Design of Experiments. A Design of Experiments combined with a 2^3 full factorial experimental design is used to show the relationship between response function that represent process output and factors that represent process inputs in which a response of interest is influenced by factors and the aim is to optimize this response. In other words, the aim of this Design of Experiments is the determination of the optimum operating setting of number of workers in the surface coating workstation, number of forklifts and the speed of the blast machine.

Std Order	Run Order	Center Pt	Blocks	Painter_surf_coating	Forklift	Blasting speed
1	1	1	1	-1	-1	-1
8	2	1	1	1	1	1
2	3	1	1	1	-1	-1
10	4	0	1	0	0	0
3	5	1	1	-1	1	-1
4	6	1	1	1	1	-1
6	7	1	1	1	-1	1
9	8	0	1	0	0	0
5	9	1	1	-1	-1	1
7	10	1	1	-1	1	1

Table 5.7- Layout of 2^3 full factorial design (plate surface)

Layout of the 2^3 full factorial design, 2 (two) levels and 3 (three) factors, is shown in Table 5.7, where all the three factors have been kept at all possible level combinations. Two central points are added to estimate the experimental error and to investigate the fitness of the meta-model and the presence of curvature in the interaction of the factors. In Table 5.7, Std order stands for standard order, which is, another way, a random order of the experiment generated by MINITAB software used for Design of Experiments analysis. This random order is generated to avoid biasness in the experiment. Run order is the sequence of the experiments.

Std Order	Run Order	x_1	x_2	x_3	Plates (output)
1	1	-1	-1	-1	46
8	2	1	1	1	103
2	3	1	-1	-1	51
10	4	0	0	0	77
3	5	-1	1	-1	47
4	6	1	1	-1	54
6	7	1	-1	1	60
9	8	0	0	0	78
5	9	-1	-1	1	46
7	10	-1	1	1	47

Table 5.8-Output values of 2^3 full factorial design (plate surface)

Once the layout of the full factorial is derived, simulation runs are carried out according to the factor level combinations suggested by the layout, considering all configurations of the factor levels through each of the Design of Experiments. Table 5.8 exhibits all the response values (number of plates) produced in the simulations over a week time with different factor levels suggested by design layout in Table 5.7. Appendix A of this thesis has listed and displayed all the ten simulation runs of Table 5.8.

Figure 5.15 shows the analysis window of the 2^3 full factorial Design of Experiments of surface preparation process.

Full Factorial Design

```
Factors:   3   Base Design:         3, 8
Runs:     10   Replicates:             1
Blocks:    1   Center pts (total):     2


All terms are free from aliasing.
```

Factorial Fit: Plates versus Painter_surf_coa, Forklift, Blasting speed

Estimated Effects and Coefficients for Plates (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		56.750	3.540	16.03	0.004
Painter_surf_coating	20.500	10.250	3.540	2.90	0.101
Forklift	12.000	6.000	3.540	1.69	0.232
Blasting speed	14.500	7.250	3.540	2.05	0.177
Painter_surf_coating*Forklift	11.000	5.500	3.540	1.55	0.260
Painter_surf_coating*Blasting speed	14.500	7.250	3.540	2.05	0.177
Forklift*Blasting speed	10.000	5.000	3.540	1.41	0.293
Ct Pt		20.750	7.916	2.62	0.120

```
S = 10.0125     PRESS = 13925.4
R-Sq = 93.93%   R-Sq(pred) = 0.00%   R-Sq(adj) = 72.67%
```

Figure 5. 15 -2^3 full factorial design analysis (plate surface)

If we recall equation 4.12 in chapter 4, we can produce a first order model of the above analysis. The equation was:

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 \quad (4.12)$$

Therefore, the first order metamodel is built for the approximation from the analysis as follows:

Plates=56.750+10.250(x_1) + 6(x_2) + 7.25(x_3) + 5.5(x_1*x_2) + 7.25(x_1*x_3) + 5(x_2*x_3) …… (5.1)

If we look at the p (confidence probability) values of all the factors and the interaction terms of the factors, we can conclude that painter_surf_coating is the most significant term with lowest p value having the greatest impact on the output value in this surface preparation process. That means the value of the number of painter has most contribution in determining the number of plates in the process. Next important factors are blasting speed and the interaction term paint_surf_coating*Blasting Speed having the same p value. This signifies that both of these terms have significance on the value of output. Number of forklift is the third most important term according to the p value. Rest of the interaction terms in Figure 5.15 has impact on the output value in the order of their p values. So far, we have discussed about the significance of the factor according to the p values. Now we will look into how significant they are from the Figure *5.16*. We can see that all the three graphs have rightward ascent, which stands out the fact that as all the factors are changed from their minimum value to the maximum values, the output also increases gradually. Painter_surf_coating has the steepest gradient which is why this factor is the most significant factor.

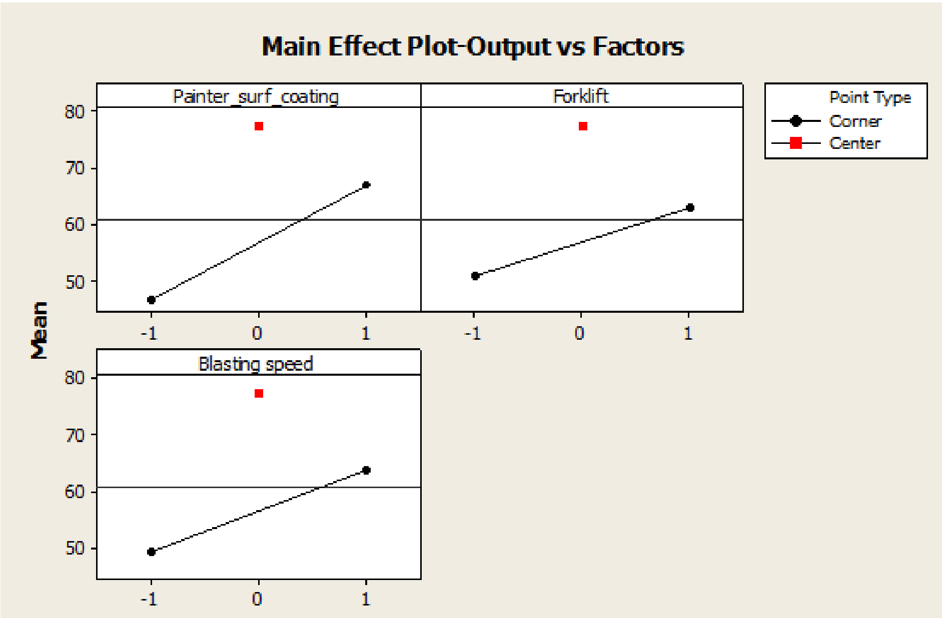


Figure 5.16 -Main effect plot- output vs. factors (plate surface)

Figure 5.17 displays how the significance of the interaction of the factors affect the output variable.

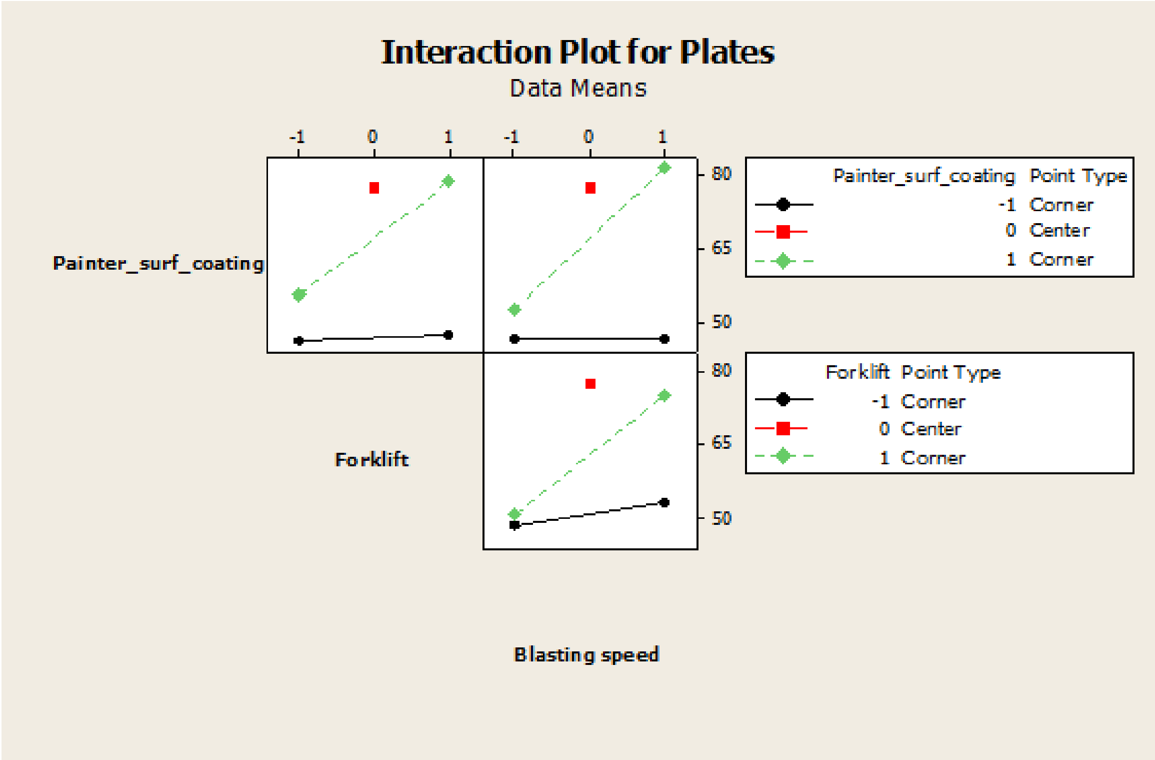


Figure 5.17 -Interaction of factor plots (plate surface)

It can be interpreted that as the painter_surf_coating and forklift are increased to the maximum the output value goes up, but contribution of forklift is not very significant as long as the interaction of these two are concerned. In the case of the interaction plot of Painter_surf_coating and Blasting speed, the output value goes up as the number of painter goes from minimum value to maximum value but contribution of blasting speed in not significant. Likewise, the interaction plot between Forklift and Blasting speed reveals that as both of these factors increase the output value also increases and both of the factors are significant. We can see from Figure 5.17 that there is no curvature in the interaction plot, therefore, the impact of interaction of the factors follows a linear relationship with the output value. However, as the R^2 (pred) statistics in

8 is 0% (Zero), and all the p values of three factors being greater than 0.05 (confidence level) and thus being statistically non-significant, this first order model is not sufficient to optimize this process. Therefore, a second order response surface (RSM) model will now be analyzed to achieve further improvement of the metamodel. The layout of the experiment used is called Box-behnken and it is

displayed in Table 5.9. The difference between this experimental design and 2^3 full factorial L-8 design is that a center point is now added to the design.

StdOrder	RunOrder	Painter_surf_coating, X_1	Forklift, X_2	Blasting Speed, X_3
1	1	-1	-1	0
3	2	-1	1	0
2	3	1	-1	0
13	4	0	0	0
12	5	0	1	1
11	6	0	-1	1
14	7	0	0	0
15	8	0	0	0
4	9	1	1	0
10	10	0	1	-1
8	11	1	0	1
9	12	0	-1	-1
5	13	-1	0	-1
7	14	-1	0	1
6	15	1	0	-1

Table 5.9 -Box-behnken L-15 layout for response surface analysis (plate surface)

Once the layout of the Box-behnken design is derived, simulation runs are carried out according to the factor level combinations suggested by the layout, considering all configurations of the factor levels through each of the Design of Experiments. Table 5.10 exhibits all the response values (number of plates) produced in the simulations over a week time with different factor levels suggested by design layout in Table 5.9. All the 15 (fifteen) simulations snapshots are attached in Appendix A.

StdOrder	RunOrder	X_1	X_2	X_3	Plates
1	1	-1	-1	0	46
3	2	-1	1	0	47
2	3	1	-1	0	59
13	4	0	0	0	79
12	5	0	1	1	102
11	6	0	-1	1	60
14	7	0	0	0	80
15	8	0	0	0	78
4	9	1	1	0	78
10	10	0	1	-1	54
8	11	1	0	1	102
9	12	0	-1	-1	53
5	13	-1	0	-1	46
7	14	-1	0	1	47
6	15	1	0	-1	50

Table 5.10 -Output values of Box-behnken design (plate surface)

Figure 5.18 displays the analysis of Box-behnken designed experiments for surface preparation model. We can see that all the factors have now got p values less than 0.05. This means that all the terms of the models are statistically significant. As both R^2 (pred) and R^2 (adj) have now higher values more than 70% (seventy), this fitted meta model can now satisfactorily be used for optimizing the process. From Figure 5.18, we can see that both painter_surf_coating and Blasting speed are the most significant factors on the output variable with both having lowest p values. The next important terms are the second order term of painter_surf_coating and interaction term of Painter_surf_coating*Blasting Speed with both them having a p value of 0.002. The third most important factor is Forklift.

Box-Behnken Design

```
Factors:       3     Replicates:     1
Base runs:    15     Total runs:    15
Base blocks:   1     Total blocks:   1

Center points: 3
```

Response Surface Regression: Plates versus Painter_surf, Forklift, Blasting Speed

```
The analysis was done using coded units.

Estimated Regression Coefficients for Plates

Term                                  Coef  SE Coef       T      P
Constant                            79.000    2.540  31.106  0.000
Painter_surf_coating                12.875    1.555   8.279  0.000
Forklift                             7.875    1.555   5.064  0.004
Blasting Speed                      13.500    1.555   8.680  0.000
Painter_surf_coating*              -13.750    2.289  -6.006  0.002
  Painter_surf_coating
Forklift*Forklift                   -7.750    2.289  -3.385  0.020
Blasting Speed*Blasting Speed       -4.000    2.289  -1.747  0.141
Painter_surf_coating*Forklift        4.500    2.199   2.046  0.096
Painter_surf_coating*Blasting Speed  12.750    2.199   5.797  0.002
Forklift*Blasting Speed             10.250    2.199   4.660  0.006


S = 4.39886    PRESS = 1520.5
R-Sq = 98.21%  R-Sq(pred) = 71.92%  R-Sq(adj) = 95.00%
```

Figure 5.18 -Analysis of Box-behnken experimental design (plate surface)

A second order response surface model can be constructed from Figure 5.18 and it follows from equation 4.15 in chapter 4:

$$\eta = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum \beta_{jj} x_j^2 + \sum_{i<} \sum_{j=2}^{k} \beta_{ij} x_i x_j \qquad (4.15)$$

Therefore, the second order model of surface preparation process is as follows

$$Plates=2.54+1.555x_1+1.555x_2+1.555x_3+2.289x_1^2+2.289x_2^2+2.289x_3^2+2.199x_1x_2+2.199x_1x_3+2.199x_2x_3 \quad (5.2)$$

We can see a significant improvement of the model this time with all the p values of contributing three factors being less than 0.05, and with improved R^2 statistics. This model is analyzed with available limited data. Therefore, a normality check of data is important. A normality checks of the data produced by the simulation runs is carried out and it reveals that all the data are normal. It can be best explained by the following few figures. Figure 5.19 shows the histogram of residual in the model. Residual value can be defined as a value which is either added or subtracted from the fitted metamodel to arrive at the actual value of the simulation run. The shape of the histogram symbolizes bell shape and therefore normal.

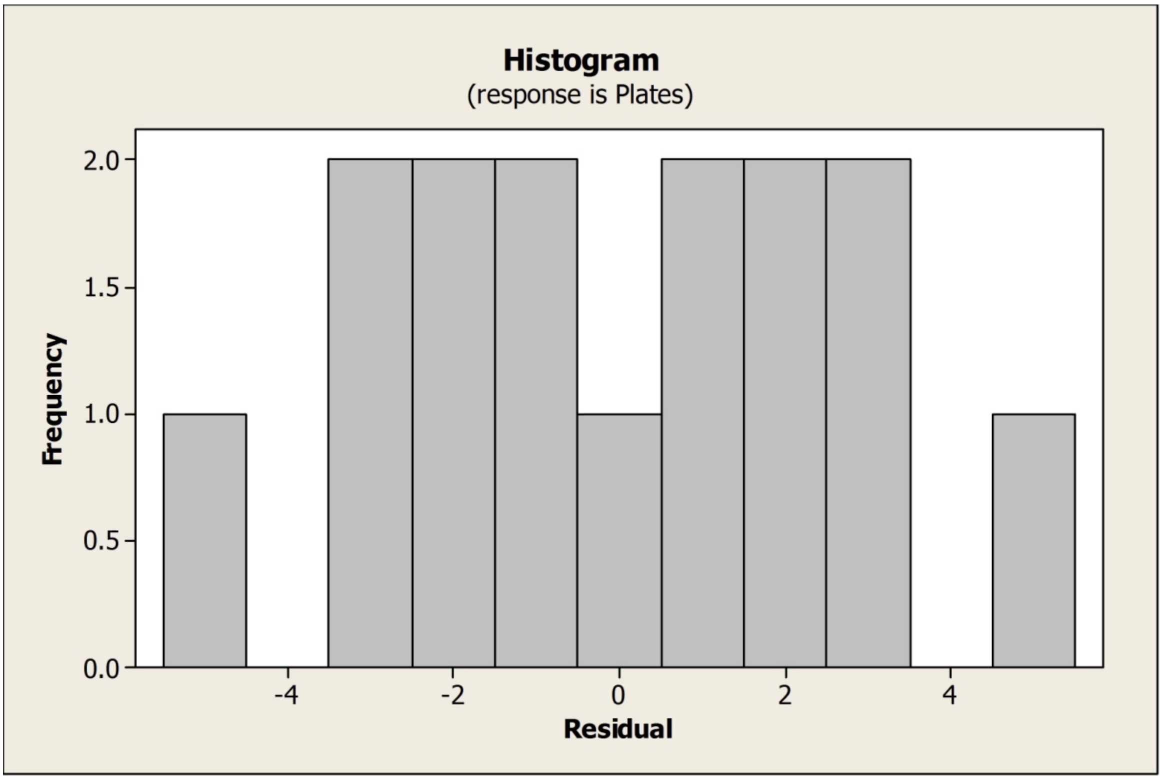


Figure 5.19 -Histogram of residual values (plate surface)

Figure 5.20 suggests that all the residual data follows a normal probability pattern with gradual ascent around a mean value. This graph testifies the normality of the data.

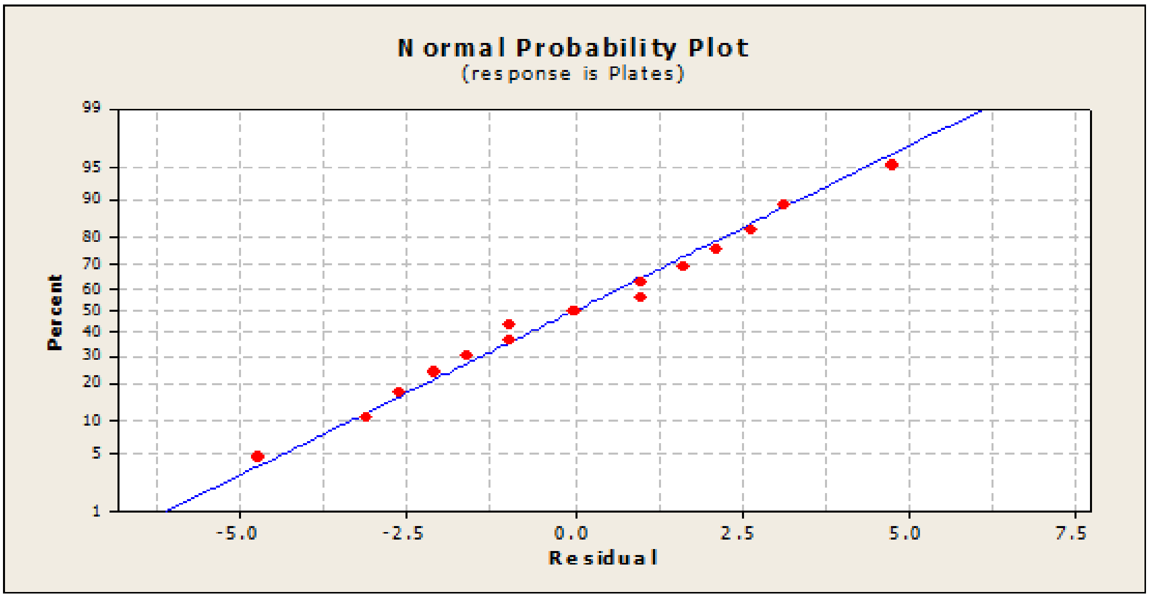


Figure 5.20 -Normal probability plot (plate surface)

After, the procedural check for model fitness and normality of the data, we can deduce that this model is the right fit for our purpose of optimization analysis. A response surface model is produced with the model equation 5.2. This is displayed in Figure 5.21. There are three graphs in the Figure 5.21, each of them being the response (output) surface for the different levels of factor setting. In the first graph both painter-surf_coating and forklift are varied while keeping blasting speed held at center point (0.3 m/ minute). If we look at the produced surface carefully, it is seen that the maximum height of the response surface is around 80 (eighty), and this can be achieved keeping both Painter_surf_coating and Forklift at their higher levels and blasting speed at the center point. For the second graph, forklift is held constant at its center point and for the third graph Painter_surf_coating is held at its center point, and like the first graph, corresponding maximum response values can be determined from the graph. While this graph is of interest for maximum response (values), it can also be used to located any predefined response values and their corresponding optimum factor levels.

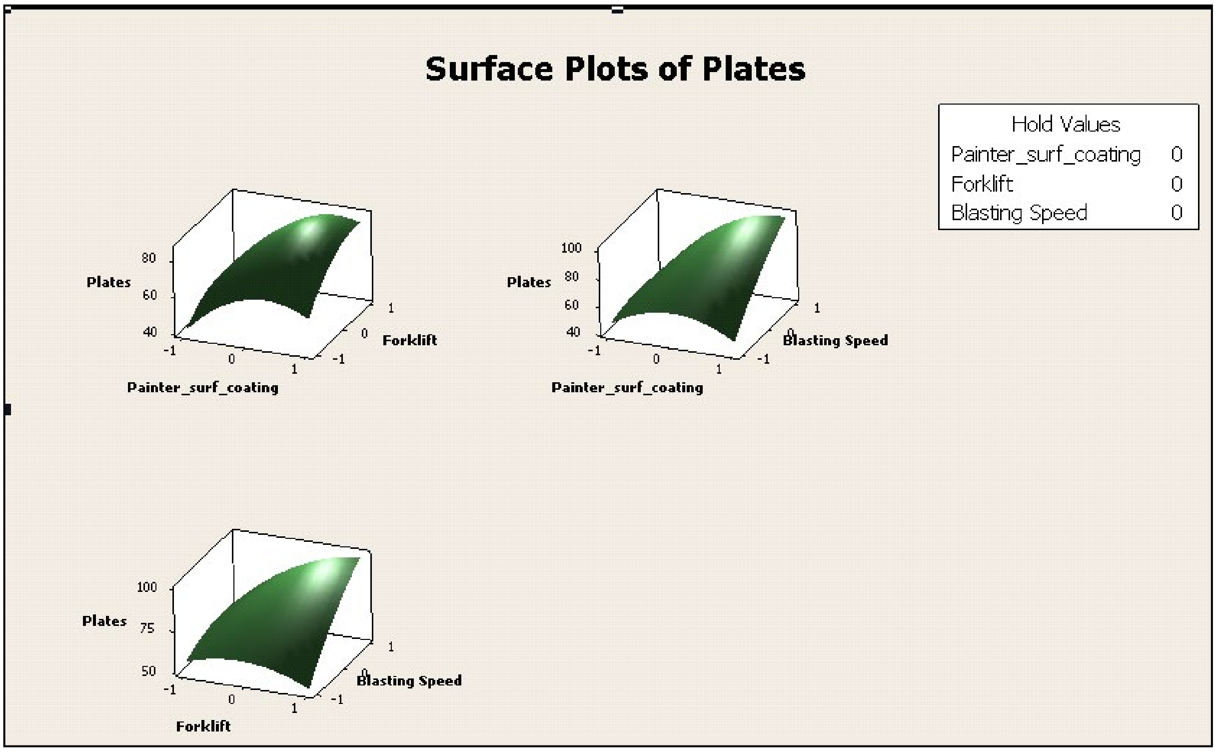


Figure 5.21 -Response surface plots (plate surface)

For the purpose of locating optimum factor levels, a response optimizer is used to find out best fitting of response and corresponding optimum factor levels. Figure 5.22 is the snapshot of response optimizer. It has been considered that the plate surface preparation model following its entry in initial optimality in Global Level (OGL) activity sequence, requires to process, for instance, 75 (seventy-five) plates over a week time in a single shift pattern.

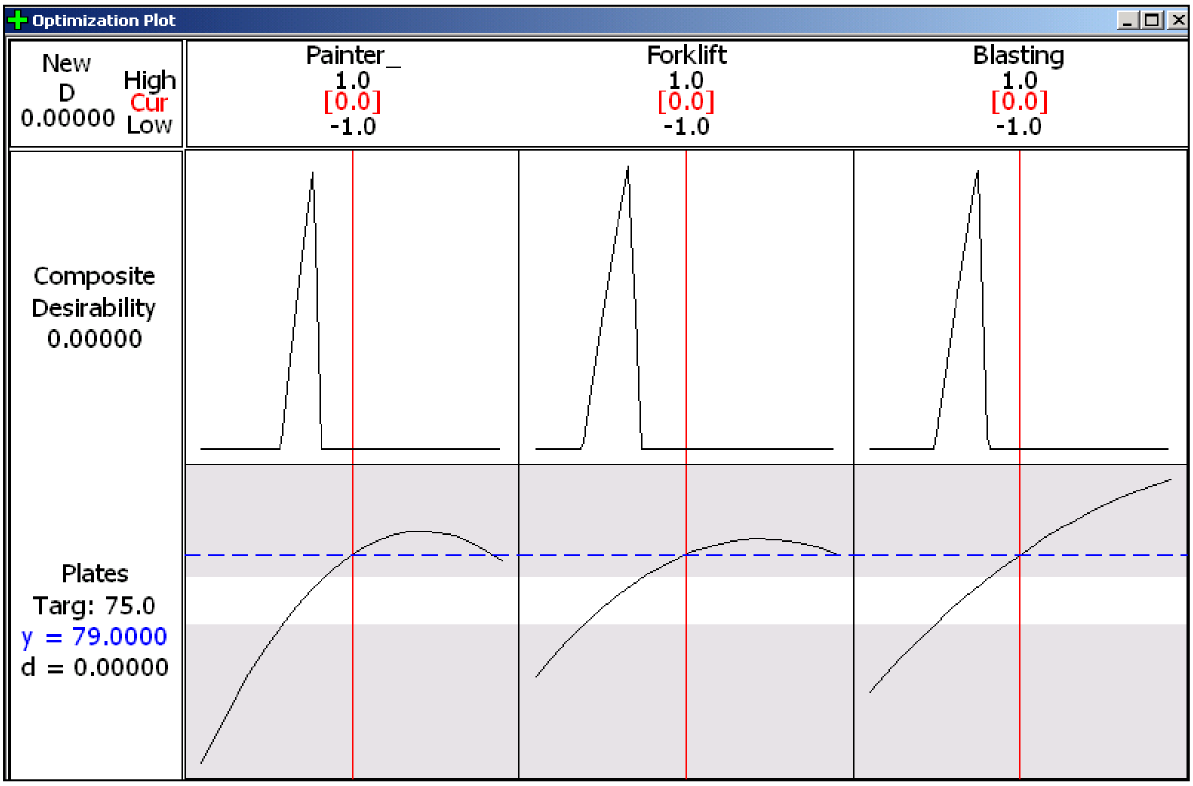


Figure 5.22 -Response optimizer (plate surface)

A search for optimality, as in Figure 5.22, in the local level (OLL), i.e., at the corresponding operation level of the activity " Plate Surface" listed in Figure 5.5, for a desired 75 (seventy five) units of plates reveals that all three factors should be kept at the center point, and that is Painter_surf_coating, $x_1 = 3$, Blasting Speed, $x_2 = 0.3$ m/ minute, and Forklift, $x_3 = 2$, to achieve optimal resources allocation for this output value.

From the Figure 5.22, a maximum output of 79 (seventy-nine) plates is possible to be produced with this optimum level setting of these three significant factors.

Going back to the Figure 5.5, optimal sequence of activities, it is now possible to adjust intended number output from the activity, if there is any change to the initial assumption in the value assigned before conducting the search for optimality. Also, initial resource allocation for this activity may also be adjusted. Therefore, integration, as envisaged in Figure 4.2 in chapter 4, of both Optimality in Global

Level (OGL) project activity sequencing and Optimality in Local Level (OLL) for corresponding resource allocation in realizing that particular activity is established.

5.4.2 Design of Experiments for block construction

This section will describe the Design of Experiments for the block construction model. The significant factors according to production engineers are as follows:

- Time for CNC Machine to cut a plate (CNC Speed)
- Number of Welder (Welder)
- Number of Grinder (Grinder)

Factors	Min Level	Max Level	Centre Pt	Min Code	Max Code	Centre Pt Code
CNC Speed, X_4	300 minute/plate	170 minute/plate	215 minute/plate	-1	1	0
Welder, X_5	4	8	6	-1	1	0
Grinder, X_6	4	8	6	-1	1	0

Table 5.11 -Factor levels and codes for Design of Experiments (block construction)

Table 5.11 shows the allowable and assignable resources and their level for the process and the coding for Design of Experiments. A Design of Experiments combined with a 2^3 full factorial experimental design is used to show the relationship between response function that represent process output and factors that represent process inputs in which a response of interest is influenced by factors and the aim is to optimize this response, number of blocks constructed over specific time, in effect, is the response in this case.

Std Order	Run Order	Centre Pt	Blocks	Welder (X_4)	Grinder (X_5)	CNC Speed (X_6)
9	1	0	1	0	0	0
6	2	1	1	1	-1	1
1	3	1	1	-1	-1	-1
10	4	0	1	0	0	0
5	5	1	1	-1	-1	1
7	6	1	1	-1	1	1
3	7	1	1	-1	1	-1
8	8	1	1	1	1	1
4	9	1	1	1	1	-1
2	10	1	1	1	-1	-1

Table 5.12 - Layout of 2^3 full factorial design (block construction)

Layout of the 2^3 full factorial design, 2 (two) levels and 3 (three) factors, is shown in Table 5.12, where all the three factors have been kept at all possible level combinations. Two central points are added to estimate the experimental error and to investigate the fitness of the meta-model and the presence of curvature in the interaction of the factors.

Std Order	Run Order	Welder (X_4)	Grinder (X_5)	CNC Speed (X_6)	No. of. Blocks (Output)
9	1	0	0	0	61
6	2	1	-1	1	48
1	3	-1	-1	-1	40
10	4	0	0	0	61
5	5	-1	-1	1	48
7	6	-1	1	1	59
3	7	-1	1	-1	41
8	8	1	1	1	87
4	9	1	1	-1	41
2	10	1	-1	-1	41

Table 5.13 -Output values of 2^3 full factorial design (block construction)

Once the layout of the full factorial is derived, simulation runs are carried out Table 5.13 exhibits all the response values (number of blocks) produced in the simulations. Appendix B of this thesis has listed and displayed all the ten simulation runs of Table 5.13. Figure 5.23 shows the analysis window of the 2^3 full factorial Design of Experiments of block construction process.

Full Factorial Design

```
Factors:   3   Base Design:        3, 8
Runs:     10   Replicates:            1
Blocks:    1   Center pts (total):    2


All terms are free from aliasing.
```

Factorial Fit: No. of Blocks (O versus Welder (X4), Grinder(X5), ...

```
Estimated Effects and Coefficients for No. of Blocks (Output) (coded units)

Term                        Effect    Coef  SE Coef      T      P
Constant                            50.625    2.563  19.75  0.003
Welder (X4)                  7.250   3.625    2.563   1.41  0.293
Grinder(X5)                 12.750   6.375    2.563   2.49  0.131
CNC speed(X6)               19.750   9.875    2.563   3.85  0.061
Welder (X4)*Grinder(X5)      6.750   3.375    2.563   1.32  0.319
Welder (X4)*CNC speed(X6)    6.750   3.375    2.563   1.32  0.319
Grinder(X5)*CNC speed(X6)   12.250   6.125    2.563   2.39  0.139
Ct Pt                               10.375    5.732   1.81  0.212


S = 7.25   R-Sq = 94.66%   R-Sq(adj) = 75.99%
```

Figure 5.23 -2[3] full factorial design analysis (block construction)

If we again recall equation 4.12, we can produce a first order model of the above analysis. The equation was

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 \qquad (4.12)$$

Therefore, the first order metamodel is built for the approximation from the analysis as follows:

$$Blocks = 50.625 + 3.625\,(x_4) + 6.375(x_5) + 9.875(x_6) + 3.375(x_4 * x_5) + 3.375(x_4 * x_6) + 6.125(x_5 * x_6) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.3)$$

The p (confidence probability) values of all the factors and the interaction terms of the factors state that CNC speed is the most significant term with lowest p value having the greatest effect on the output value. That means the value at which the CNC machine cuts the plates has most contribution in determining the number of blocks. Next important factor is ‘Grinder’ term having the second lowest p value and the interaction term ‘Grinder*CNC Speed’ is the third important factor. This says that both of these terms have significance on the value of output. Rest of the interaction terms has impact on the output value in the order of respective p values.

Now, we will discuss on how much each factor is significant when their values go from the lowest to highest. From the Figure 5.24 we can see that all the three graphs have rightward ascent, which stands out the fact that as all the factors are changed from their minimum value to the maximum values, the output also gets increased gradually. CNC Speed has the steepest change in values which is why this factor is the most significant factor.

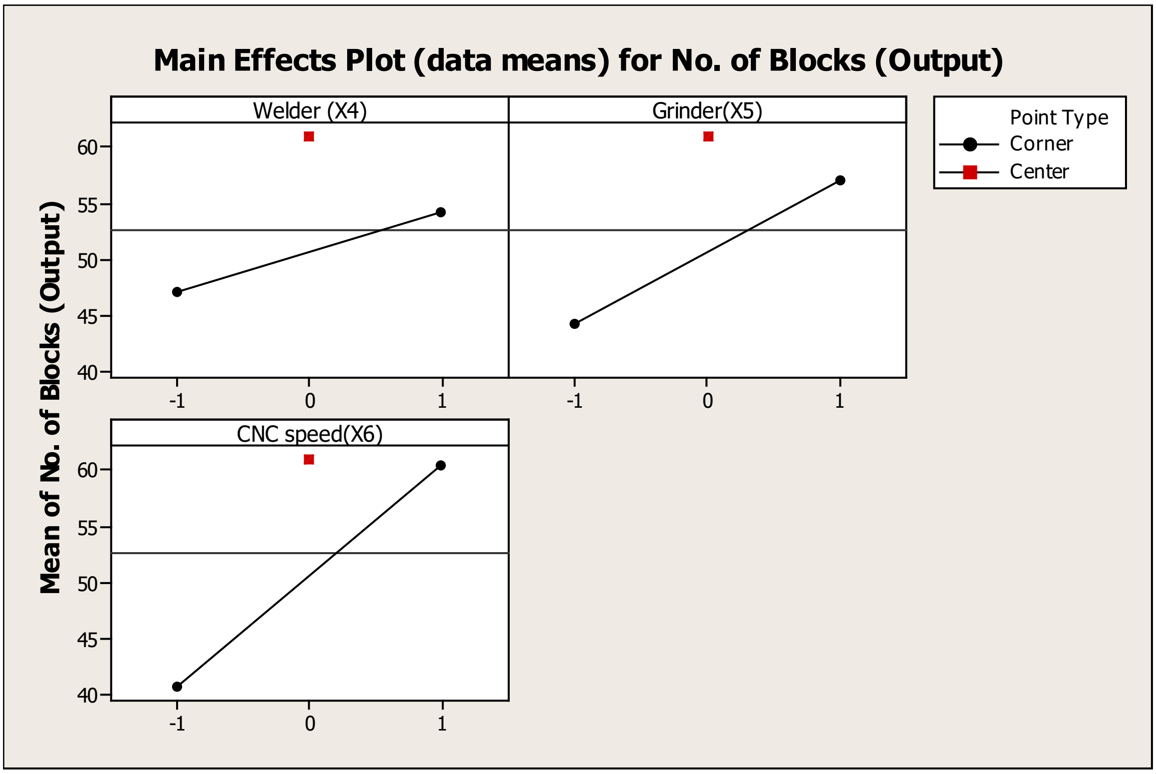


Figure 5.24 -Main effect plot- output vs. factors (block construction)

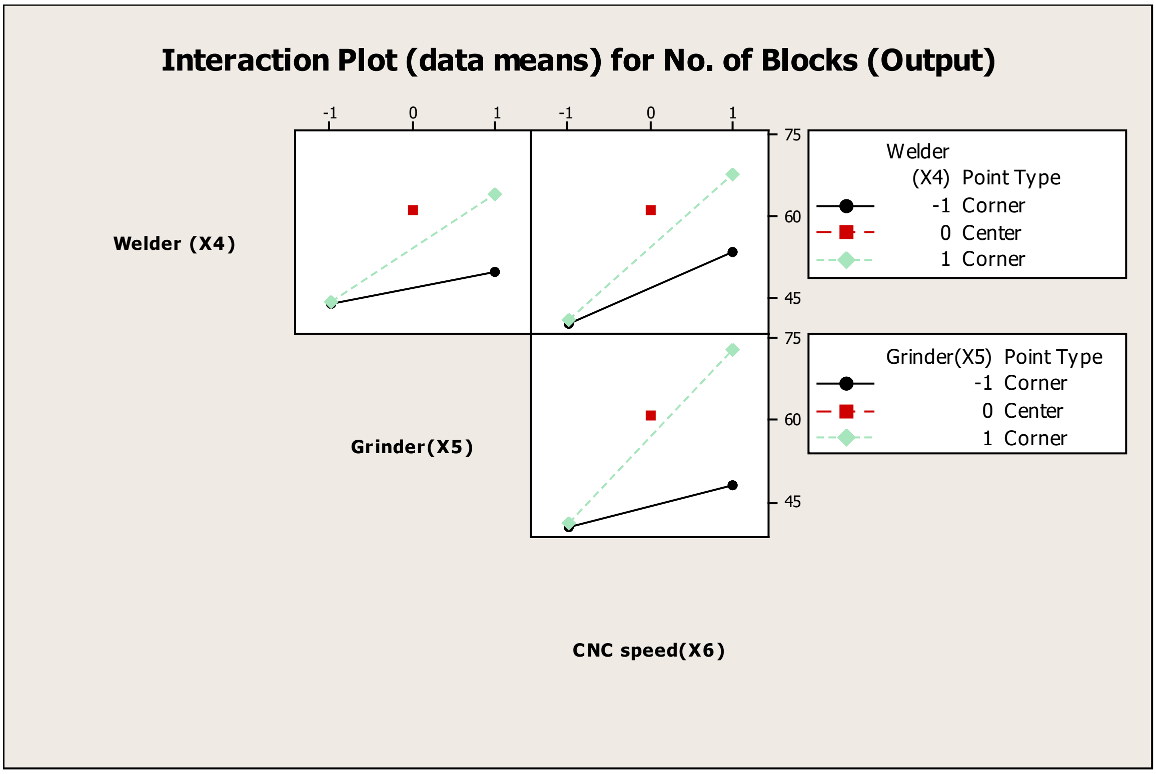


Figure 5.25 - Interaction of factor plots (block construction)

Figure 5.25 displays how the significance of the interaction of the factors affect the output variable. From the interaction between welder and grinder it can be interpreted that for the minimum value of welder (-1), when the value of grinder varies from -1 (minimum) to +1 (maximum), the output (black) gets increased. For the maximum value of welder (+1), when the value of grinder varies from -1 (minimum) to +1 (maximum), the output also gets increased (green) but the output amount is greater than the previous one in this interaction. From the interaction between welder and CNC speed it can be explained that for the minimum value of welder (-1), when the value of CNC speed varies from -1 (minimum) to +1 (maximum), the output (black) gets increased. For the maximum value of welder (+1), when the value of CNC speed varies from -1 (minimum) to +1 (maximum), the output (green) also gets increased but the output value is much greater than that of the interaction between welder and grinder. The most significant interaction is between grinder and CNC speed. Even though the output gets increased when we vary the CNC speed from minimum to maximum for the minimum value of grinder, but it gives us the highest output when the variation of CNC speed from -1 to +1 for the maximum value of grinder.

However, all the p values being greater than 0.05 (confidence level) and thus being statistically non-significant. So, a second order response surface method (RSM) will now be investigated. Figure 5.25 says the interaction of the factors follows a linear relationship with the output value. The layout used is called Box-behnken and it is displayed in Table 5.14.

Std Order	Run Order	Welder (X_4)	Grinder (X_5)	CNC Speed
3	1	-1	1	0
7	2	-1	0	1
14	3	0	0	0
13	4	0	0	0
5	5	-1	0	-1
15	6	0	0	0
11	7	0	-1	1
10	8	0	1	-1
8	9	1	0	1
1	10	-1	-1	0
12	11	0	1	1
2	12	1	-1	0
4	13	1	1	0
6	14	1	0	-1
9	15	0	-1	-1

.

Table 5.14 -Box-behnken L-15 layout for response surface analysis (block construction)

Std Order	Run Order	Welder (X_4)	Grinder (X_5)	CNC Speed (X_6)	Block
3	1	-1	1	0	58
7	2	-1	0	1	58
14	3	0	0	0	61
13	4	0	0	0	61
5	5	-1	0	-1	43

15	6	0	0	0	61
11	7	0	-1	1	49
10	8	0	1	-1	41
8	9	1	0	1	87
1	10	-1	-1	0	48
12	11	0	1	1	87
2	12	1	-1	0	48
4	13	1	1	0	62
6	14	1	0	-1	41
9	15	0	-1	-1	41

Table 5.15 -Output values of Box-behnken design (block construction)

Table 5.15 exhibits all the response values (number of blocks) produced in the simulations carried out according to the layout suggested by Box-behnken. All the 15 (fifteen) simulations snapshots are attached in Appendix B.

Box-Behnken Design

```
Factors:       3    Replicates:     1
Base runs:    15    Total runs:    15
Base blocks:   1    Total blocks:   1

Center points: 3
```

Response Surface Regression: No. of Block versus Welder (X4), Grinder(X5), CNC Speed (X6)

The analysis was done using coded units.

Estimated Regression Coefficients for No. of Blocks (Output)

Term	Coef	SE Coef	T	P
Constant	61.000	2.540	24.019	0.000
Welder (X4)	3.875	1.555	2.492	0.055
Grinder(X5)	7.750	1.555	4.983	0.004
CNC speed(X6)	14.375	1.555	9.243	0.000
Welder (X4)*Welder (X4)	-2.125	2.289	-0.928	0.396
Grinder(X5)*Grinder(X5)	-4.875	2.289	-2.130	0.086
CNC speed(X6)*CNC speed(X6)	-1.625	2.289	-0.710	0.510
Welder (X4)*Grinder(X5)	1.000	2.199	0.455	0.668
Welder (X4)*CNC speed(X6)	7.750	2.199	3.524	0.017
Grinder(X5)*CNC speed(X6)	9.500	2.199	4.319	0.008

S = 4.399   R-Sq = 96.8%   R-Sq(adj) = 91.1%

Figure 5.26 -Analysis of Box-behnken experimental design (block construction)

Figure 5.26 displays the analysis of Box-Behnken designed experiments for block construction model. We can see that four of the factors have p value less than 0.05, one factor has p value very close to 0.055 and for the others p value is more than the confidence level. This means that the terms having p value less than 0.05 are statistically significant. As both R^2 (pred) and R^2 (adj) have higher values more than 70% (seventy), this fitted meta model can now satisfactorily be used for optimizing the process. From Figure 5.26, we can see that the most significant factor is 'CNC speed' having p value of 0.000. The second most significant factor is 'grinder' term which has a p value of 0.004. The third, fourth and fifth important factors are 'Grinder*CNC speed', 'Welder*CNC speed' and 'Welder' respectively.

A second order response surface model can be constructed from equation 4.15 in chapter 4.

$$\eta = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum \beta_{jj} x_j^2 + \sum_{i<} \sum_{j=2}^{k} \beta_{ij} x_i x_j \qquad (4.15)$$

Therefore, the second order model of block construction process is as follows

$$Blocks = 61.000 + 3.875(x_4) + 7.750(x_5) + 14.375(x_6) - 2.125(x_4)^2 - 4.875(x_5)^2 - 1.625(x_6)^2 + 1.000(x_4 * x_5) + 7.750(x_4 * x_6) + 9.500(x_5 * x_6) \ldots \ldots (5.4)$$

We can see a significant improvement of the model this time with four of the total p values being less than 0.05 and one factor being very close to the confidence level and with improved R^2 statistics.

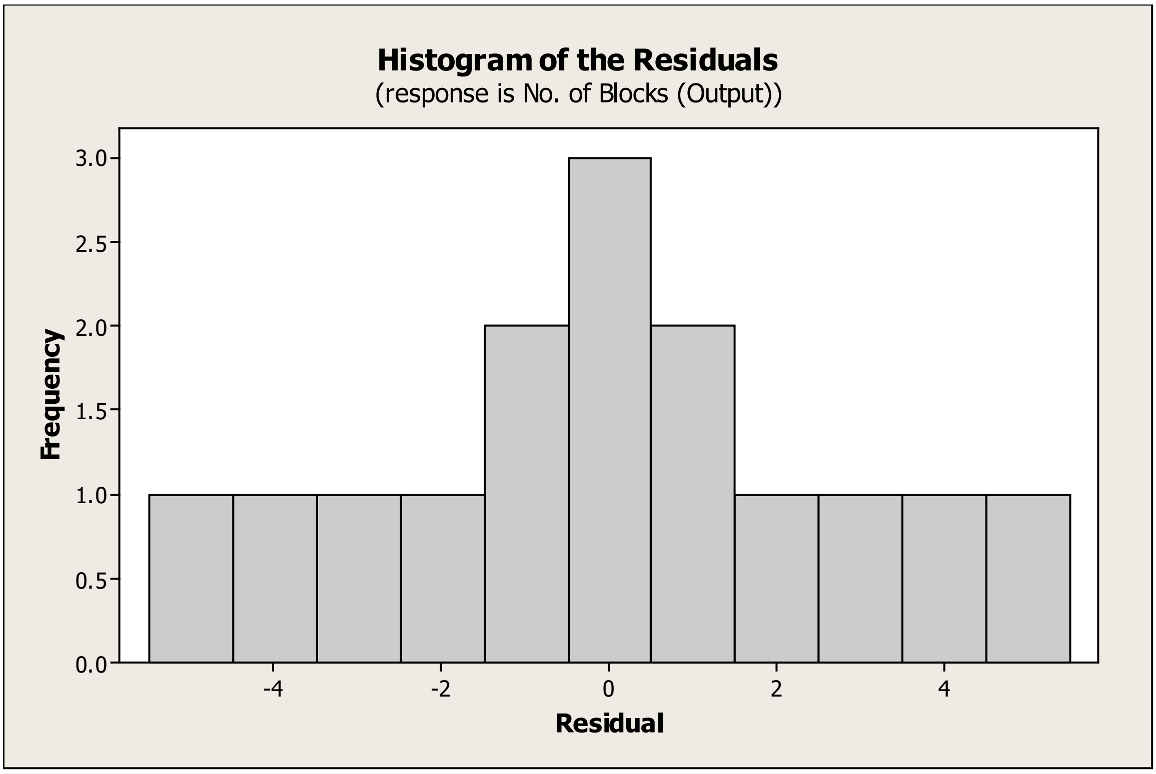


Figure 5.27 -Histogram of residual values (block construction)

Similar to the plate surface preparation model, a normality check of data for the block construction model is important. A normality check of the data produced by the simulation runs is carried out and it reveals that all the data are normal. Figure 5.27 shows the histogram of residual.

Figure 5.28 suggests that all the residual data follows a normal probability pattern with gradual ascent around a mean value. This graph testifies the normality of the data.

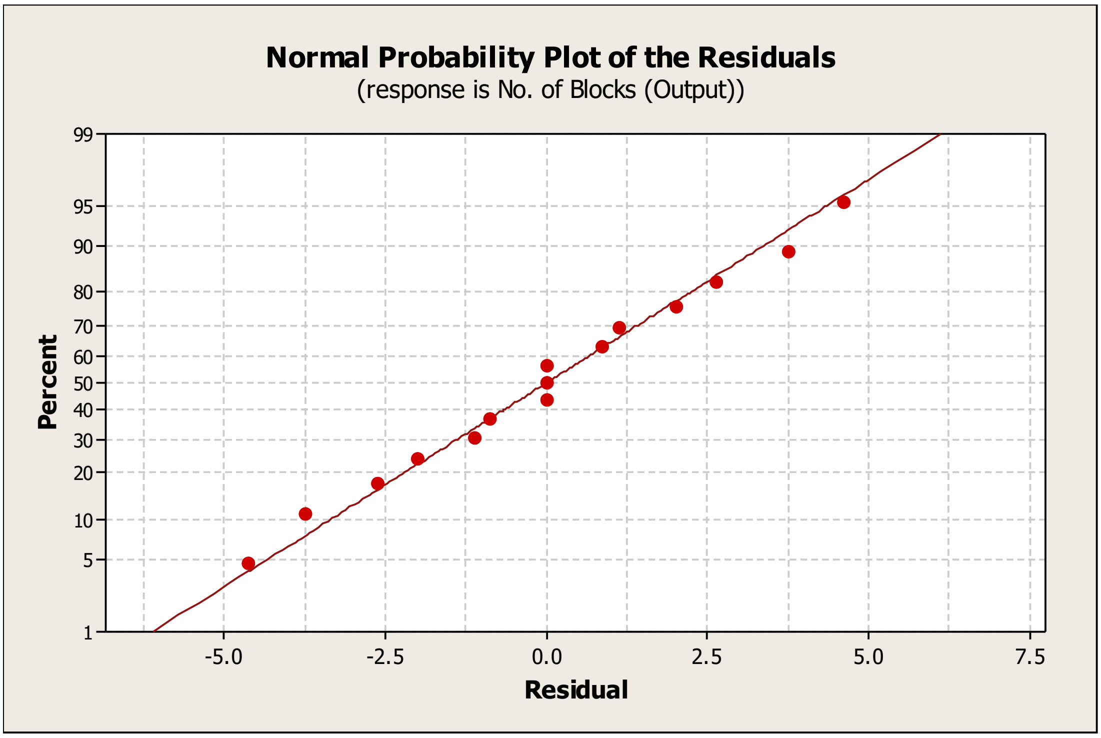


Figure 5.28 -Normal probability plot (block construction)

Therefore, it is statistically satisfied that this model of block construction is appropriate for the optimization process. A response surface model is produced with the model equation 5.4 and displayed in Figure 5.29, Figure 5.30 & Figure 5.31, each of them being the response (output) surface for the different levels of factor setting. In the first graph (Figure 5.29) both welder and grinder varied while keeping CNC speed held at center point (215 minute/plate). It can be interpreted that the maximum height of the response surface is around 70, and this can be achieved keeping both welder and grinder at their higher levels and CNC speed at the center point. For the second graph (Figure 5.30), grinder is kept constant at its center point and for the third graph (Figure 5.31) welder is held at its center point, and like the first graph, corresponding maximum response values can be determined from the graph. While this graph is of interest for maximum response (values), it can also be used to located any predefined response values and their corresponding optimum factor levels.

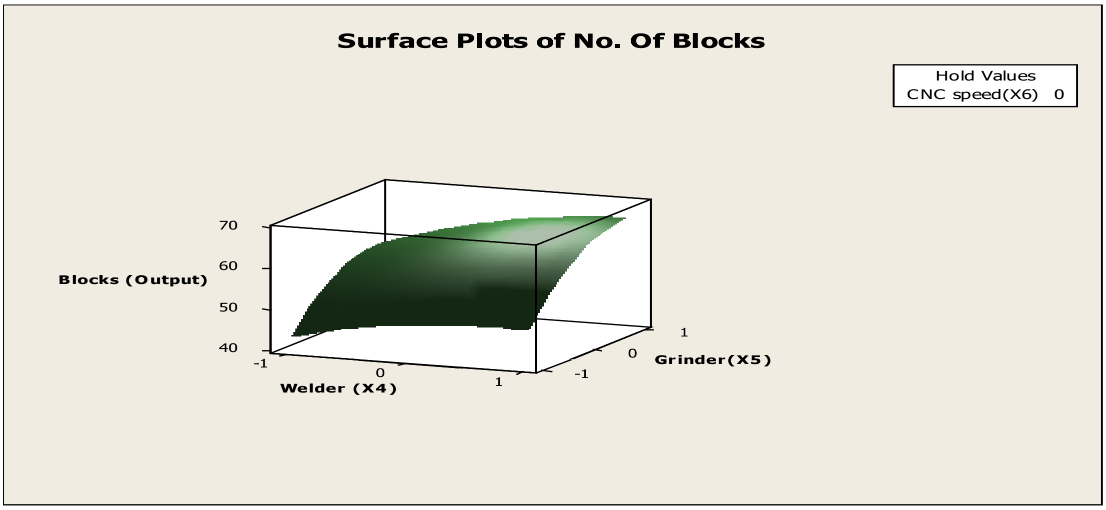


Figure 5.29 -Response surface plots of blocks vs. welder, grinder (block construction)

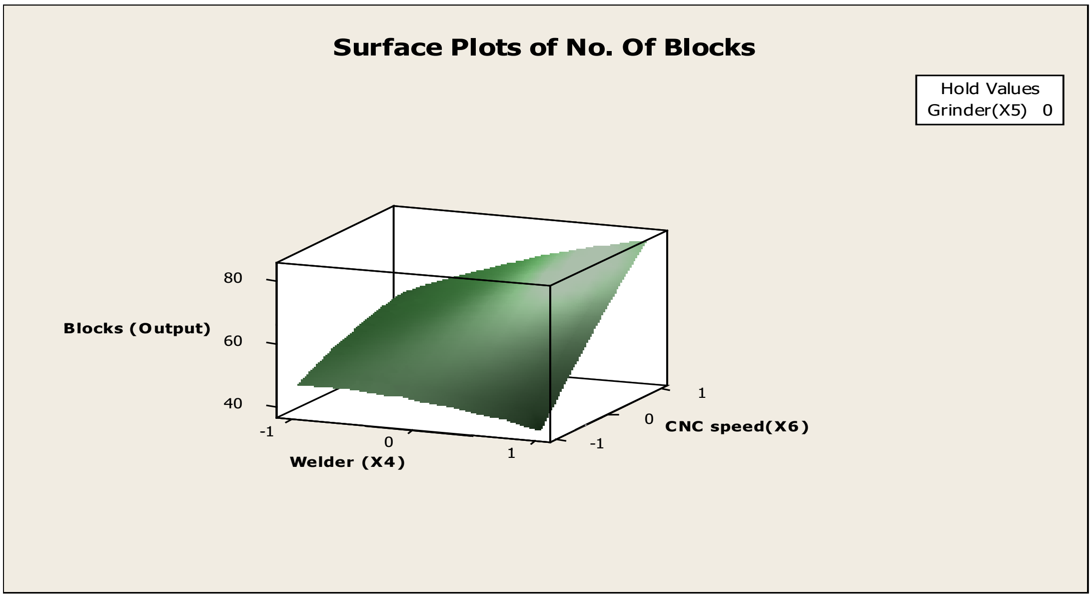


Figure 5.30 - Response surface plots of blocks vs. welder, CNC speed (block construction)

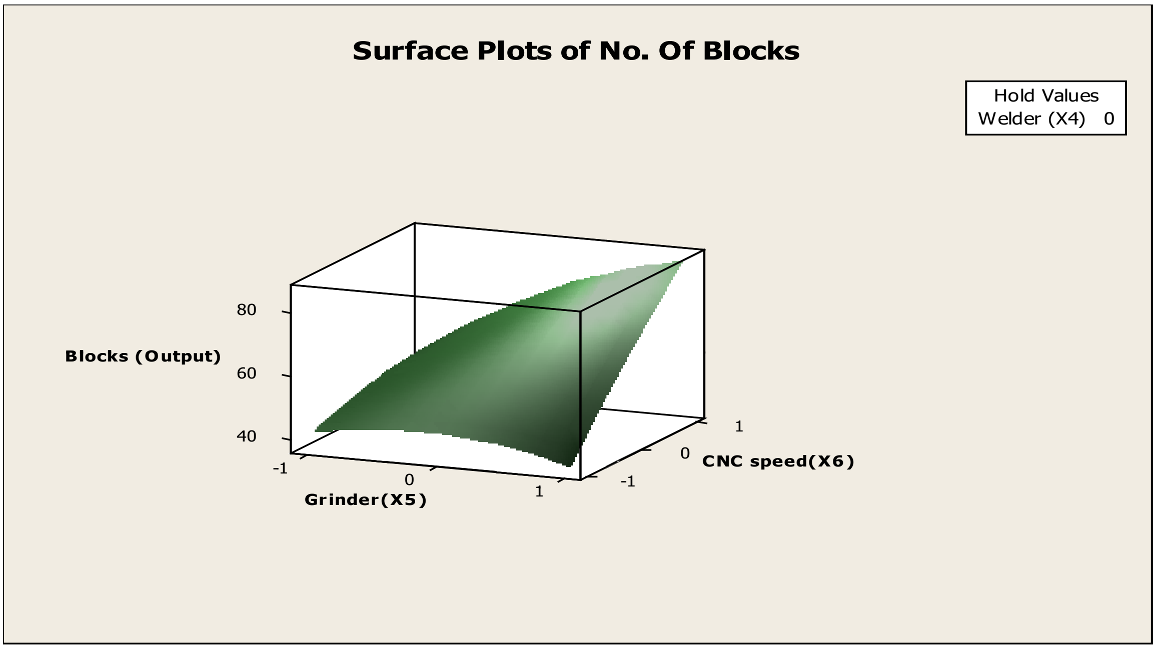


Figure 5.31 - Response surface plots of blocks vs. grinder, CNC speed (block construction)

A response optimizer is used to find out best fitting of response and corresponding optimum factor levels for the purpose of locating optimum factor levels.

Figure 5.32 gives us the understanding of response optimizer. The response surface optimizer provides a tool of getting targeted number of outputs depending on the optimal value of each factor. We set a target of 45 blocks for a single shift pattern.

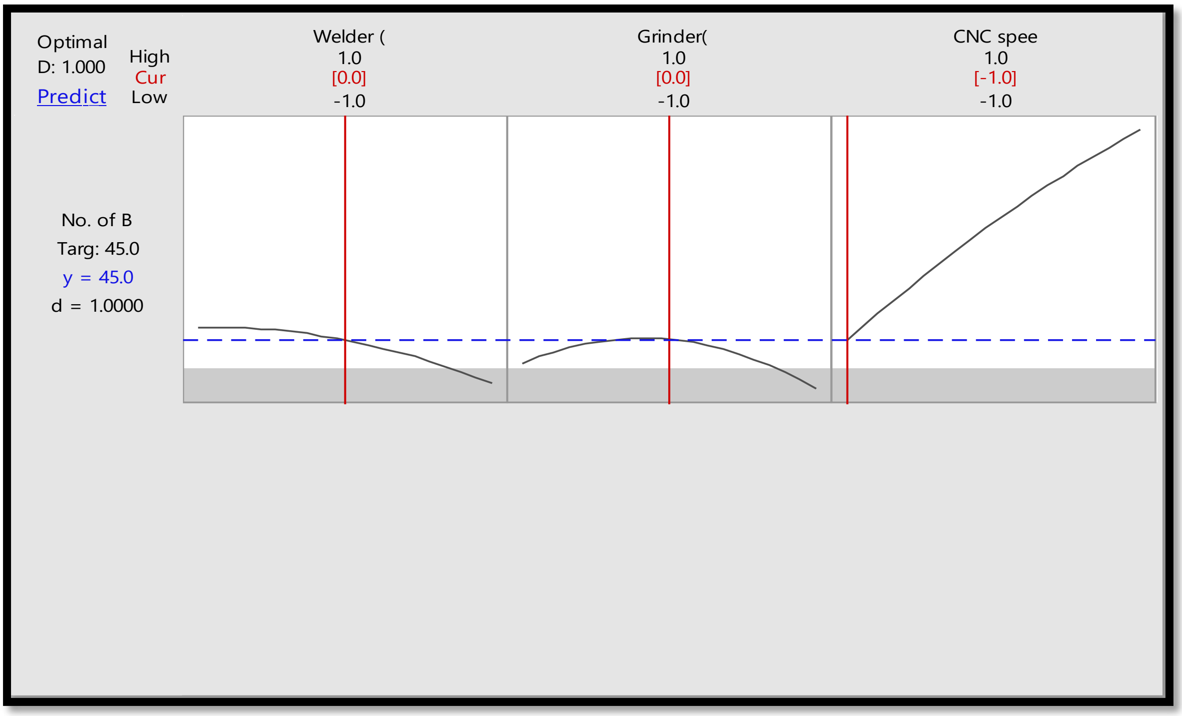


Figure 5.32 -Response optimizer for a target of 45 blocks (block construction)

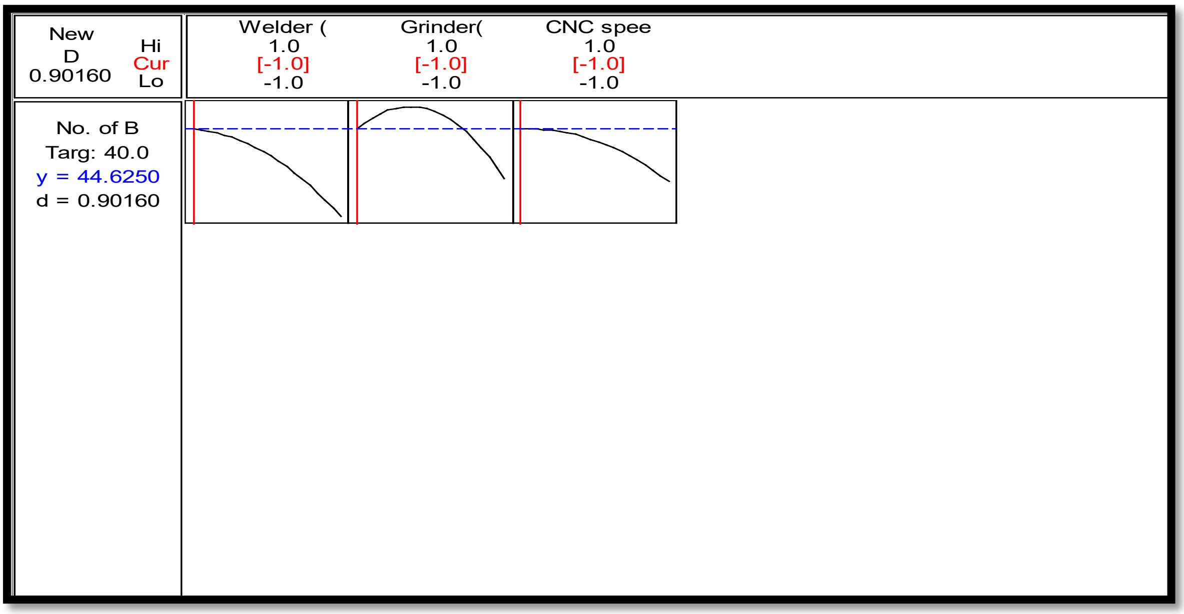


Figure 5.33- Response optimizer for a target of 40 blocks (block construction)

We can see that the desired number of blocks (45) requires the optimal setting of factors of welder, $x_4 = 6$, grinder, $x_5 = 6$, and CNC speed, $x_6 = 300$ minute/plate. Therefore, these are the optimally allocated resource values for welder, grinder, CNC speed. Another example is shown in Figure 5.33. This one gives us the total number of outputs based on the settings of factors (elder, grinder, CNC speed) that are used in actual practice at the shipyard. The model produces near about 45 blocks taking the optimal setting of factors (welder (x4) = -1, grinder (x5) = -1, CNC speed (x6) = -1) whereas 40 blocks are usually produced in reality with these settings. Therefore, response surface optimizer allows us to optimize the factor setting for a targeted number of outputs. It is now possible to adjust intended number of outputs in the project activity layout for any change to the initial assumption of value assigned before conducting the search for optimality. It is worth pointing out that both optimality in global level of project activity sequencing and in the local level for corresponding resource allocation are established.

5.4.3 Design of Experiments for pipe spool production

This section is dedicated for the Design of Experiments for the pipe spool production model. The factors to be considered as per the recommendation of engineers are as follows:

- Total Number of Fitter, Junior Fitter and Helper (Fabrication groups)
- Number of Bending machines (Bending Machines)
- Number of Welder (Welder)

actors	Min Level	Max Level	Centre Pt	Min Code	Max Code	Centre Pt Code
Fabrication groups, X_7	15	21	18	-1	1	0
Bending Machines, X_8	2	4	3	-1	1	0
Welders, X_9	3	5	4	-1	1	0

Table 5.16-Factor levels and codes for Design of Experiments (spool production)

Table 5.16 shows the assignable resources and their level for the process and the coding for Design of Experiments. A Design of Experiments combined with a 2^3 full factorial experimental design is used to show the relationship between response function that represent process output and factors that represent process inputs in which a response of interest is influenced by factors and the aim is to optimize this response, number of pipe spool produced over specific time, in effect, is the response in this case.

Std Order	Run Order	Centre Pt	Blocks	Fabrication groups (X_7)	Bending Machines (X_8)	Welder (X_9)
4	1	1	1	1	1	-1
9	2	0	1	0	0	0
7	3	1	1	-1	1	1
3	4	1	1	-1	1	-1
5	5	1	1	-1	-1	1
6	6	1	1	1	-1	1
8	7	1	1	1	1	1
2	8	1	1	1	-1	-1
10	9	0	1	0	0	0
1	10	1	1	-1	-1	-1

Table 5.17 - Layout of 23 full factorial design (spool production)

Table 5.17 shows layout of 2^3 full factorial design, 2 (two) levels and 3 (three) factors, is shown in, where all the three factors are set at all possible level combinations. Similar to the other models described before, two central points are added to estimate the experimental error and to investigate the fitness of the meta-model and the presence of curvature in the interaction of the factors.

Std Order	Run Order	Centre Pt	Blocks	Fabrication groups (X_7)	Bending Machines (X_8)	Welder (X_9)	Output (Spool)
4	1	1	1	1	1	-1	36
9	2	0	1	0	0	0	48
7	3	1	1	-1	1	1	48
3	4	1	1	-1	1	-1	34
5	5	1	1	-1	-1	1	47
6	6	1	1	1	-1	1	70
8	7	1	1	1	1	1	68
2	8	1	1	1	-1	-1	36
10	9	0	1	0	0	0	48
1	10	1	1	-1	-1	-1	35

Table 5.18 -Output values of 23 full factorial design (spool production)

Table 5.18 exhibits all the response values (number of spool) produced in the simulations. All the ten simulations have been displayed in Appendix C of this thesis. Figure 5.34 shows the analysis window of the 2^3 full factorial Design of Experiments of pipe spool production process.

Full Factorial Design

```
Factors:   3   Base Design:        3, 8
Runs:     10   Replicates:            1
Blocks:    1   Center pts (total):    2
```

All terms are free from aliasing.

Factorial Fit: Output (Spool vs. Fabrication Group, Bending Machine, Welder)

Estimated Effects and Coefficients for Output (Spool) (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		46.7500	0	*	*
Fabrication Group (X7)	11.5000	5.7500	0	*	*
Bending Machine (X8)	-0.5000	-0.2500	0	*	*
Welder (X9)	23.0000	11.5000	0	*	*
Fabrication Group (X7)* Bending Machine (X8)	-0.5000	-0.2500	0	*	*
Fabrication Group (X7)*Welder (X9)	10.0000	5.0000	0	*	*
Bending Machine (X8)*Welder (X9)	0.0000	0.0000	0	*	*
Fabrication Group (X7)* Bending Machine (X8)*Welder (X9)	-1.0000	-0.5000	0	*	*
Ct Pt		1.2500	0	*	*

S = 0   R-Sq = 100.00%   R-Sq(adj) = 100.00%

Figure 5.34 -23 full factorial design analysis (spool production)

Recalling equation 4.12 allows us to produce a first order model of the above analysis. The equation was

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 \qquad (4.12)$$

Therefore, the first order metamodel is built for the approximation from the analysis as follows:

$$Blocks = 46.75 + 5.75\,(x_7) - 0.25\,(x_8) + 11.5\,(x_9) - 0.250\,(x_7 * x_8) + 5.00(x_7 * x_9) - 0.5\,(x_8 * x_9 * x_7) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.3)$$

Figure 5.35 shows us the main effect plot for the pipe spools produced. Two of the graphs (Fabrication group vs. Output & Welder vs. Output) have their output increased when the factors are changed from their minimum value to the maximum values. The factor "Welder" has the steepest gradient in values which is why this factor is the most significant factor. But it is seen from the third graph (Bending Machine vs. Output) that there is a slight decrease in the production of spool while we increase the number of bending machines. The reason behind it is that when the bending machine gets increased, more people of fabrication groups get busy in bending the pipes which consequently reduces the number of people in fabrication groups in other stations (pipe cutting and transportation). It is to be mentioned that the time required for bending the pipes is quite longer than that of cutting and transportation. So, there is a shortage of number of people in those stations which ultimately decreases the production of pipe spool.

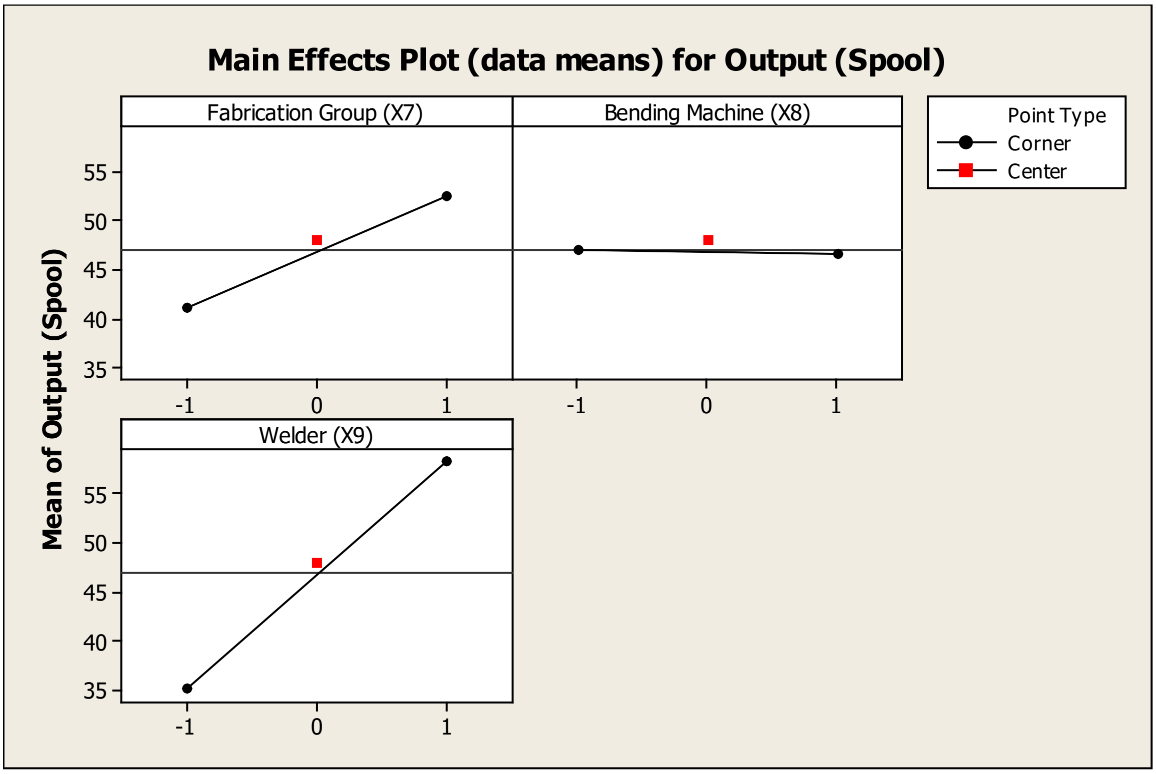


Figure 5.35 -Main effect plot- output vs. factors (spool production)

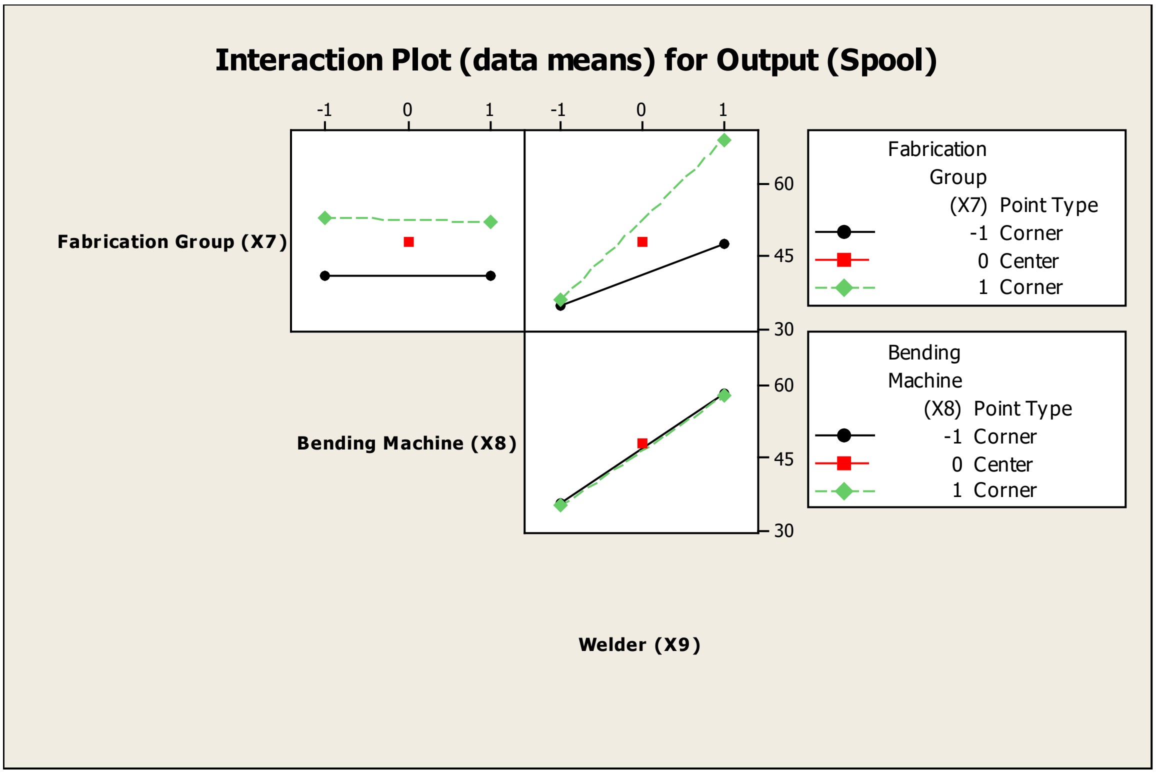


Figure 5.36 - Interaction of factor plots (spool production)

Figure 5.36 displays how the significance of the interaction of the factors affects the output variable. From the interaction between fabrication groups and bending machine, it can be interpreted that for the minimum value of fabrication groups (-1), when the value of bending machine varies from -1 (minimum) to +1 (maximum), the output (black) remains constant. For the maximum value of fabrication groups (+1), when the value of bending machine varies from -1 (minimum) to +1 (maximum), the output gets decreased (green). From the interaction between fabrication groups and welder it can be explained that for the minimum value of fabrication groups (-1), when the value of welder varies from -1 (minimum) to +1 (maximum), the output (black) gets increased. For the maximum value of fabrication groups (+1), when the value of welder varies from -1 (minimum) to +1 (maximum), the output (green) also gets increased but the output value is much greater than the previous one and this is the most significant interaction since it gives us the highest possible output. The interaction between bending machine and welder reveals that for both minimum and maximum value of bending machine, we get same number of increased output when the number of welders gets increased from its minimum to maximum value.

Figure 5.34 states that the p (confidence probability) values of any of the factors can't be determined from this factorial design which proves that this one is statistically non-significant. So, a second order Response Surface Method (RSM) is required to be investigated. The layout used is called Box-behnken and it is displayed in Table 5.19.

Std Order	Run Order	Fabrication Group (X_7)	Bending Machine (X_8)	Welder (X_9)
3	1	-1	1	0
10	2	0	1	-1
9	3	0	-1	-1
12	4	0	1	1
11	5	0	-1	1
8	6	1	0	1
5	7	-1	0	-1
2	8	1	-1	0
15	9	0	0	0
13	10	0	0	0
1	11	-1	-1	0
6	12	1	0	-1
7	13	-1	0	1
4	14	1	1	0
14	15	0	0	0

.

Table 5.19 -Box-behnken L-15 layout for response surface analysis (spool production)

Std Order	Run Order	Fabrication Group (X_7)	Bending Machine (X_8)	Welder (X_9)	Output (Spool)
3	1	-1	1	0	39
10	2	0	1	-1	36
9	3	0	-1	-1	36
12	4	0	1	1	58
11	5	0	-1	1	57
8	6	1	0	1	69
5	7	-1	0	-1	35
2	8	1	-1	0	57
15	9	0	0	0	48
13	10	0	0	0	48
1	11	-1	-1	0	41
6	12	1	0	-1	36
7	13	-1	0	1	48
4	14	1	1	0	57
14	15	0	0	0	48

Table 5.20 -Output values of Box-behnken design (spool production)

Table 5.20 exhibits all the response values (number of spool) produced in the simulations carried out according to the layout suggested by Box-behnken. All the 15 (fifteen) simulations snapshots are attached in Appendix C.

Box-Behnken Design

```
Factors:        3     Replicates:     1
Base runs:     15     Total runs:    15
Base blocks:    1     Total blocks:   1

Center points: 3
```

Response Surface Regression: Output (Spool vs. Fabrication Group, Bending Machine, Welder)

```
The analysis was done using coded units.

Estimated Regression Coefficients for Output (Spool)

Term                                   Coef  SE Coef       T      P
Constant                            48.0000   1.1619  41.312  0.000
Fabrication Pool (X7)                7.0000   0.7115   9.838  0.000
Bending Machine (X8)                -0.1250   0.7115  -0.176  0.867
Welder (X9)                         11.1250   0.7115  15.636  0.000
Fabrication Pool (X7)*               0.3750   1.0473   0.358  0.735
  Fabrication Pool (X7)
Bending Machine (X8)*                0.1250   1.0473   0.119  0.910
  Bending Machine (X8)
Welder (X9)*Welder (X9)             -1.3750   1.0473  -1.313  0.246
Fabrication Pool (X7)*               0.5000   1.0062   0.497  0.640
  Bending Machine (X8)
Fabrication Pool (X7)*Welder (X9)    5.0000   1.0062   4.969  0.004
Bending Machine (X8)*Welder (X9)     0.2500   1.0062   0.248  0.814

S = 2.012   R-Sq = 98.7%   R-Sq(adj) = 96.2%
```

Figure 5.37-Analysis of Box-behnken experimental design (spool production)

Figure 5.37 displays the analysis of Box-behnken designed experiments for spool production model. The figure shows that three of the factors have p value less than 0.05. This means that the terms having p value less than 0.05 are statistically significant. As both R^2 (pred) and R^2 (adj) have higher values more than 70% (seventy), this fitted meta model can now satisfactorily be used for optimizing the pipe production process. From this figure we can see that the most significant factors are ‘Welder (X9)’ and ‘fabrication group (X7)’ having p value equal to 0.000.

The second most significant factor is ‘Fabrication group (X7) * Welder (X9)’ term which has a p value of 0.004.

A second order response surface model can be constructed from equation 4.15 in chapter 4.

$$\eta = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum \beta_{jj} x_j^2 + \sum_{i<} \sum_{j=2}^{k} \beta_{ij} x_i x_j \qquad (4.15)$$

Therefore, the second order model of pipe spool production process is as follows

$$Blocks = 1.1619 + 0.7115\ (x_7) + 0.0.7115\ (x_8) + 0.7115\ (x_9) + 1.0473\ (x_7)^2 + 1.0473\ (x_8)^2 + 1.0473(x_9)^2 + 1.0062\ (x_7 * x_8) + 1.0062\ (x_7 * x_9) + 1.0062\ (x_8 * x_9) \ldots\ldots\ldots\ldots \,(5.4)$$

A significant improvement of the model is obtained this time with three of the total p values being less than 0.05 and with improved R^2 statistics.

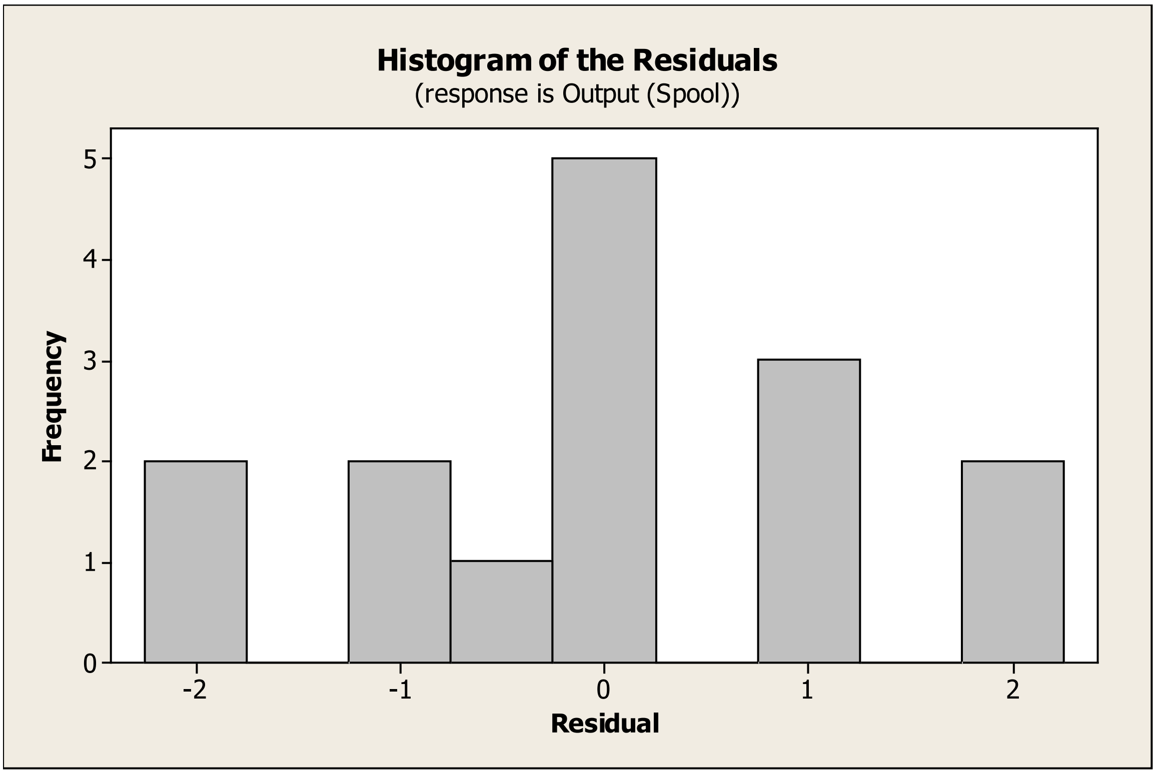


Figure 5.38 -Histogram of residual values (spool production)

A normality check of data for the pipe spool production model is important. A normality check of the data produced by the simulation runs is carried out and it reveals that all the data are normal. Figure 5.38 shows the histogram of residual.

Figure 5.39 suggests that all the residual data follows a normal probability pattern with gradual ascent around a mean value. This graph testifies the normality of the data.

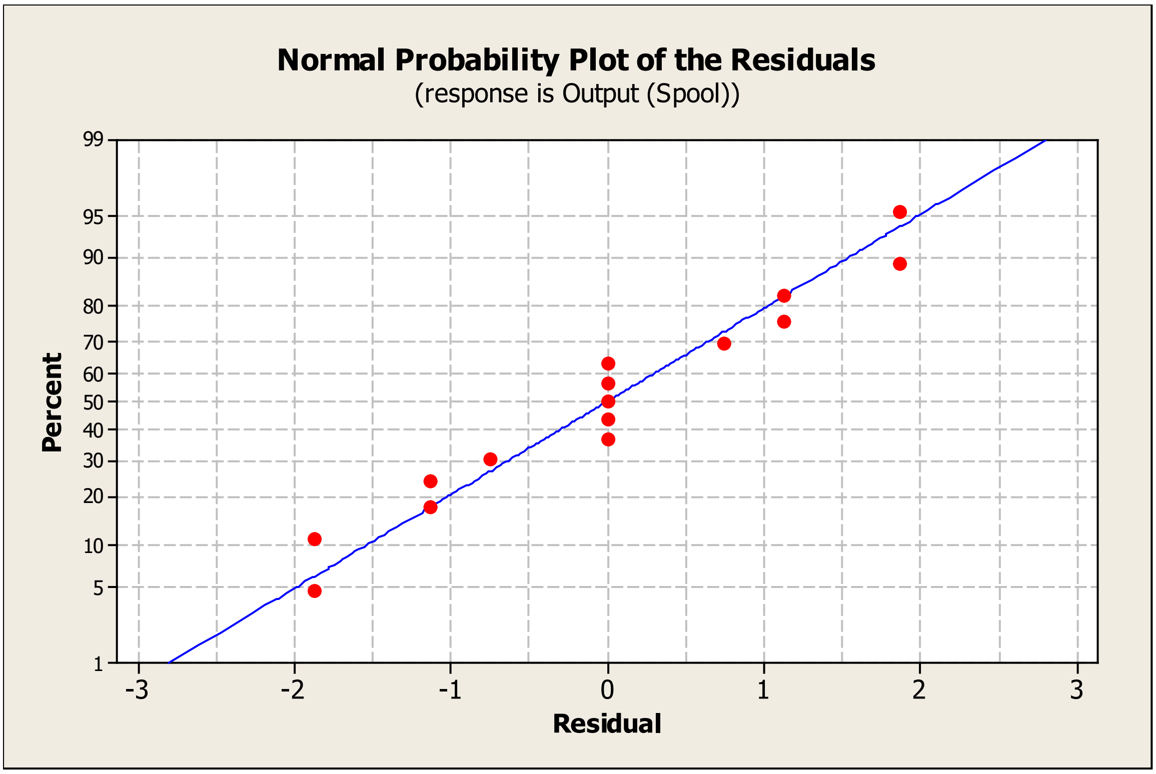


Figure 5.39 -Normal probability plot (pipe spool production)

Therefore, it is statistically confirmed that this model is good enough for the optimization process. A response surface model is produced with the model equation 5.4 and displayed in Figure 5.40, Figure 5.41, and Figure 5.42. Each of the figures shows the response (output) surface for the different levels of factor setting. In the Figure 5.40, both welder and bending machine are varied while keeping the fabrication group constant at center point. It can be interpreted that the maximum height of the response surface is around 58, and this can be achieved keeping both welder and bending machine at their higher levels and fabrication group at the center point. In the Figure 5.41, welder is kept constant at its center point and in Figure 5.42 bending machine is held constant at its center point. Similar to the first graph, corresponding maximum response values can be determined from the graph. While this graph is of interest for maximum response (values), it can also be used to locate any predefined response values and their corresponding optimum factor levels.

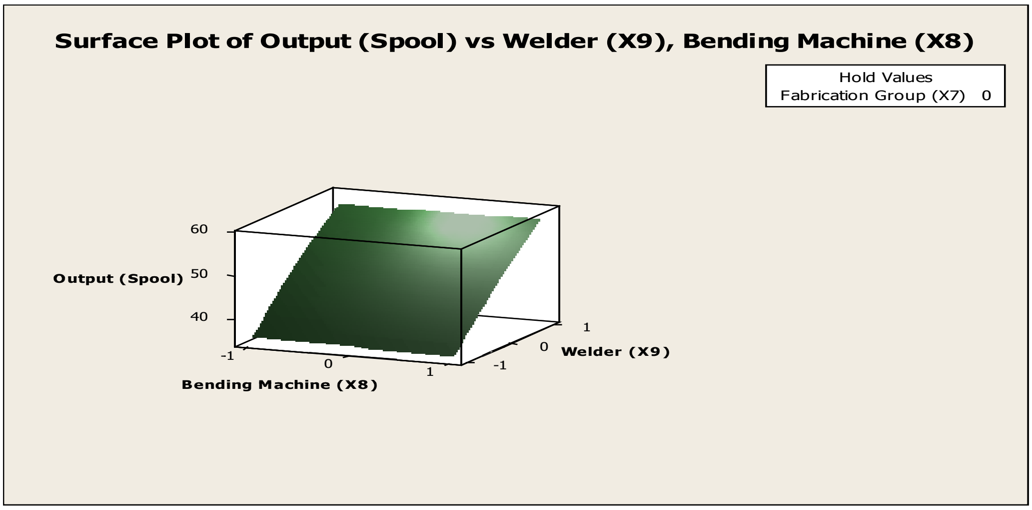


Figure 5.40 -Response surface of spool vs. welder, bending machine (spool production)

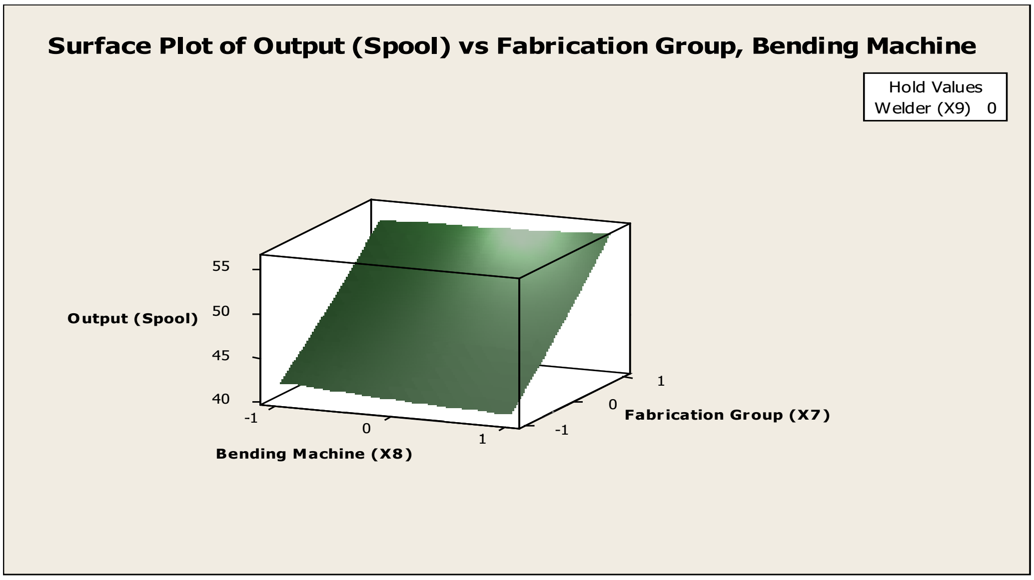


Figure 5.41 -Response surface of spool vs. fabrication groups, bending machine (spool production)

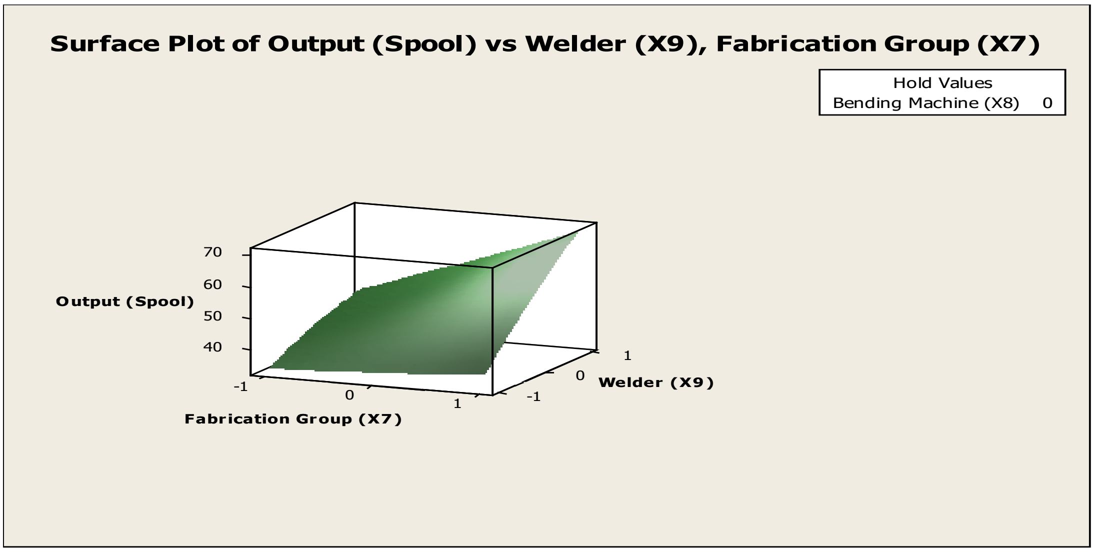


Figure 5.42 -Response surface of spool vs. welder, fabrication pool (spool production)

For the purpose of locating optimum factor levels, a response optimizer is used to find out best fitting of response and corresponding optimum factor levels. Figure 5.43 exhibits the response surface optimizer. It provides a tool for getting targeted number of outputs depending on the optimal value of each factor. We set a target of 58 spools for a single shift pattern.

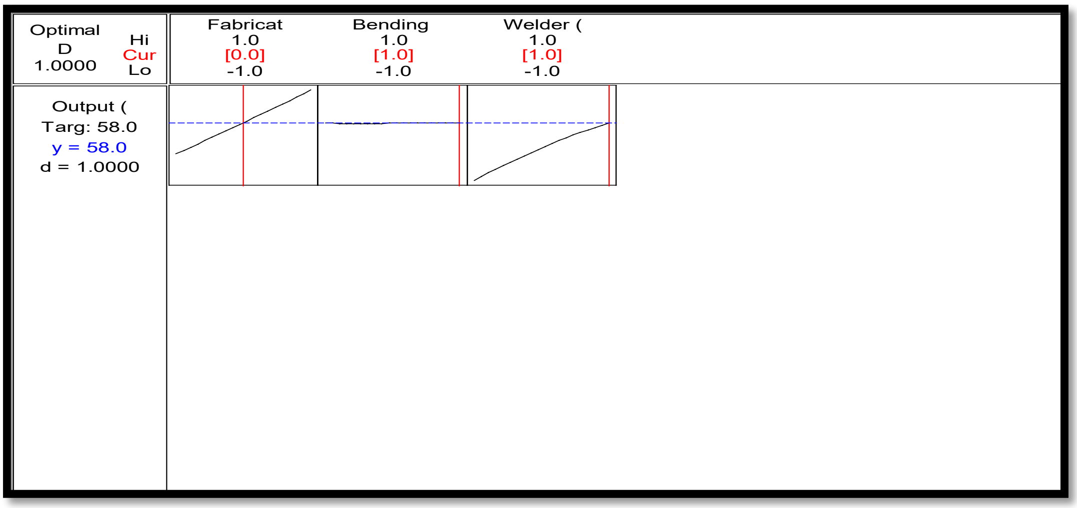


Figure 5.43 -Response optimizer for a target of 58 spools (spool production)

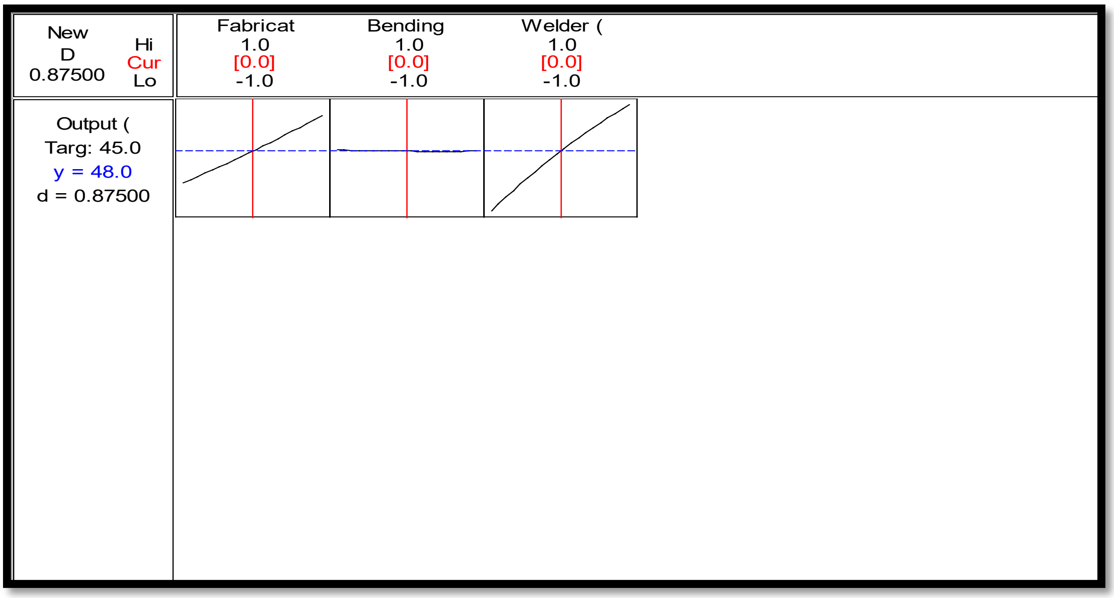


Figure 5.44 - Response optimizer for a target of 45 spools (spool production)

It can be interpreted from Figure 5.43 that the optimal setting of factors of fabrication groups, x_7 = 18, bending machine, x_8 = 4, and welder, x_9 = 4 gives us a total of 48 spools. Therefore, these are the optimally allocated resource values for fabrication groups, bending machine and welder.

Another example is shown in Figure 5.44. This one gives us the total number of pipe spool based on the settings of factors (welder, fabrication group, bending machine) that are used in actual practice at the shipyard. The model produces near about 48 spools taking the optimal setting of factors (fabrication group (x7) = 18, bending machine (x8) = 3, welder (x9) = 4) whereas 45 spools are usually produced in reality with these settings.

we can conclude that both global level and local level optimality for corresponding resource allocation are established.

5.5 Optimized project scheduling with DSM

The effect of optimization in three local levels, plate surface preparation, construction of blocks and production of pipe spools is incorporated into the project scheduling. The initial time required by the shipyard has been replaced by the optimized time for these three local levels. The process of getting the optimized time is described in Table 5.21.

Item	Description
Task	**Plate surface preparation**
Details	Each block requires 40 plates on average. A total of 4 hull blocks are considered in the scheduling. So, we need 40x4 = 160 plates.
Resource requirements	Blasting Speed: 0.3m/min Forklift: 2 Painter: 3
Time (Before optimization)	Shipyard produces 60 plates per 6 days. In accordance with that it takes 16 days to complete 160 plates considering this resource setting.
Time (After optimization)	Model produced 79 plates considering this resource setting. So13 days are required in this optimal case.
Task	**Construction of blocks**
Details	Shipyard produces 40 blocks placed at parallel middle body of the ship considering that each block takes 25 days to be completed
Resource requirements	Welder: 4 Grinder: 4 CNC speed: 300 min/plate
Time (Before optimization)	25 days required considering this resource setting
Time (After optimization)	22 days are required considering this resource setting as the model produced 45 blocks instead of 40.
Task	**Production of pipe spools**
Details	Cargo pipe construction requires 400 pipes on average.
Resource requirements	Bending Machine: 3 Fabrication Group: 18

	Welder: 4
Time (Before optimization)	Shipyard produces 45 pipes per 6 days. In accordance with that it takes 54 days to complete 400 pipes considering this resource setting.
Time (After optimization)	Model produced 48 pipes considering this resource setting. So 50 days are required for this optimal setting.

Table 5.21 - Process of getting optimized time

Table 5.22 shows the optimized time for plate surface preparation, block construction and pipe spool production. It is to be mentioned that Table 5.2 gives us the duration for each activity before optimization.

Optimal Sequence	Activity	Time (days)
1	GA plan	120
2	Development of midship section	20
3	Capacity plan	21
4	Lines plan	30
5	Design of cargo hold construction	30
6	Development of block arrangement	31
7	Stability calculation	30
8	Bow structure development	31
9	Stern structure development	35
10	Equipment foundation design	30
11	Cargo pipe system	31
12	Power balance calculation	10
13	Shell expansion	30
14	Engine room development	31
15	Accommodation arrangement	30

16	All air, sounding & filling pipe system	30
17	Hull block detail construction	60
18	Lighting system	31
19	Cable list	17
20	Steel estimation	30
21	Design of ladders	15
22	Design of doors	15
23	Procurement of auxiliary	120
24	Steel procurement	31
25	Ladders construction	20
26	Plate surface preparation	13
27	Door construction	60
28	Lube oil system	21
29	Fuel oil system	21
30	Main engine system	30
31	Propulsion system	30
32	Pipe & valve list	45
33	Main engine procurement	180
34	Propulsion procurement	180
35	Pipe & valve procurement	46
36	Cargo pipe construction	50
37	HB 01 construction	22
38	HB 02 construction	22
39	HB 03 construction	22
40	HB 04 construction	22
41	Grand block erection 01	15
42	Grand block painting	10

Table 5.22 - Optimized time for project activities

Figure 5.45 and Figure 5.46 represent the project scheduling after the optimization is carried out.

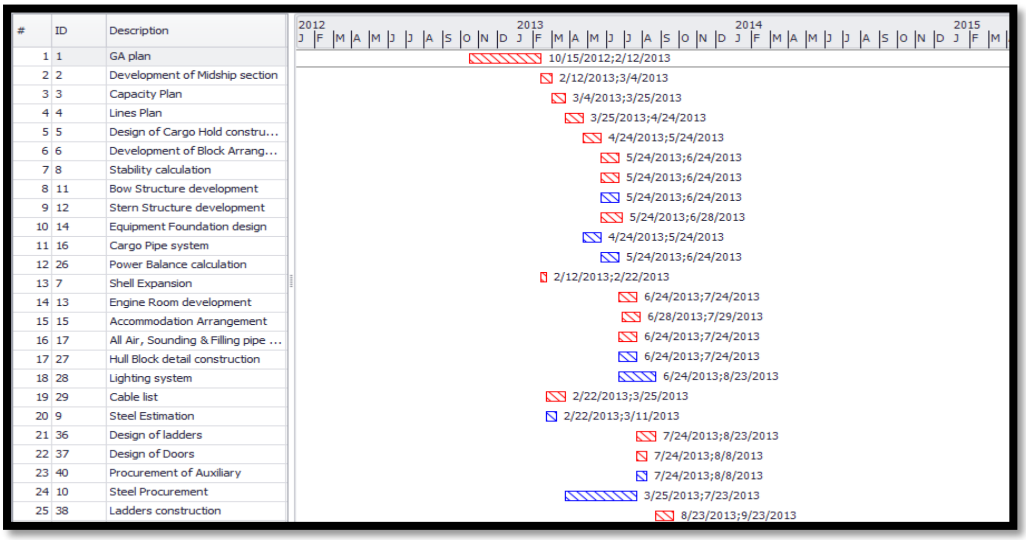


Figure 5.45 -Project scheduling after optimization (Part 1)

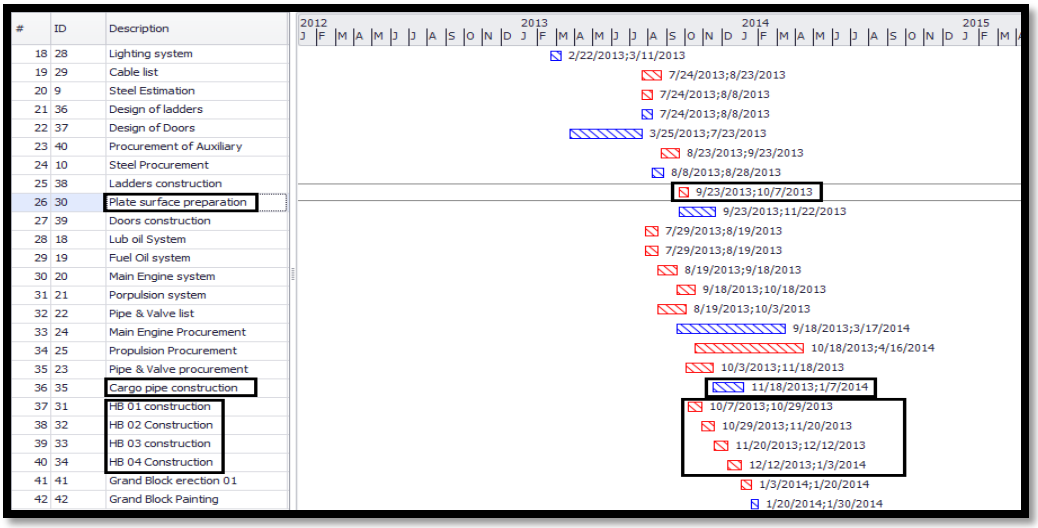


Figure 5.46 -Project scheduling after optimization (Part 2)

5.6 Cost analysis in a shipbuilding project

Cost analysis of a project is of vital importance for any industry, like shipbuilding, since it can provide whether a project or activity will be or has been worthwhile. It is used to help people make decisions on major issues. Cost analysis informs the progress of an activity and how it should proceed or be revised, based on the benefits and costs identified (Holland, 2012). Cost analysis is a technique that is used to determine options that provide the best approach for the adoption and practice in terms of benefits in labor, time and cost savings (Wikipedia). In this thesis we will present cost analysis for the three models: block construction, plate surface preparation and spool production

5.6.1 Cost analysis of block construction model

Analysis of cost lets us understand and identify which of the available variables are crucial for a project to be economically successful. For the block construction model, we have selected three major variables that put significant effect on the overall cost of a block construction.

Table 5.23 will define the cost items, functional items and considered functional items for the block construction model cost analysis.

Cost Items	Functional Items	Considered Functions
Welding	Number of Welder, Electricity, Welding Rod, Welding Machine	Number of Welder
Grinding	Number of Grinder, Electricity, Grinding Machine	Number of Grinder
CNC machine cutting	CNC Machine, Operator Salary, Electricity	Electricity

Table 5.23 -Identified major variables for cost analysis (block construction)

The mathematical equations for all the cost functions are given below:

$$Welding = f(Number\ of\ Welder, Electricity, Welding\ Rod, Welding\ Machine\ )$$

$$Grinding = f(Number\ of\ Grinder, Electricity, Grinding\ Machine\ )$$

$$CNC\ Machine\ Cutting = f(CNC\ Machine, Operator\ Salary, Electricity\ )$$

It is important to note that we will consider only those functional items that are of great importance in cost analysis of block construction model. Therefore, three functional items, number of welders, number of grinder and electricity, have been given priority in the analysis.

Table 5.24 will show us the value specified for each of the variables we considered in the cost analysis.

Variable	Expression	Numerical Value
Cost per welder per day	X1	BDT 300
Number of welders	Y1	4, 6, 8
Cost per grinder per day	P1	BDT 250
Number of grinders	Q1	4, 6, 8
CNC machine electricity cost per day	M1	BDT 2520
Percentage of CNC machine running time	N1	See Table 1.1
Number of days	D1	1000
Number of blocks	B1	Varies between 41 to 87
Average weight of each block	A1	23 Ton

Table 5.24 -Functional variable and their values (block construction)

The relation between the cost item and its function is described below:

$$Total\ welding\ cost, W1 = X1\ \times Y1 \times D1$$

$$Total\ grinding\ cost, G1 = P1\ \times Q1 \times D1$$

$$Total\ CNC\ Machine\ Cutting\ Cost, E1 = M1\ \times N1 \times D1$$

$$Total\ Cost\ per\ tonnage, C1 = \frac{(W1 + G1 + E1)}{(A1 \times B1)}$$

Welder	Grinder	Percentage of CNC running time	Blocks	Welding Cost (BDT)	Grinding Cost (BDT)	CNC Cost (BDT)	Total Cost per tonnage (BDT)
4	4	0.6996	40	1200000	1000000	1762992	4307.6
4	8	0.6942	41	1200000	2000000	1749384	5248.55
8	4	0.7014	41	2400000	1000000	1767528	5479.88
8	8	0.6942	41	2400000	2000000	1749384	6521.08
4	4	0.8313	48	1200000	1000000	2094876	3890.28
8	4	0.8313	48	2400000	1000000	2094876	4977.24
4	8	0.8313	59	1200000	2000000	2094876	3901.89
6	6	0.7426	61	1800000	1500000	1871352	3685.92
8	8	0.8313	87	2400000	2000000	2094876	3245.81

Table 5.25 -Cost analysis for different number of factors (block construction)

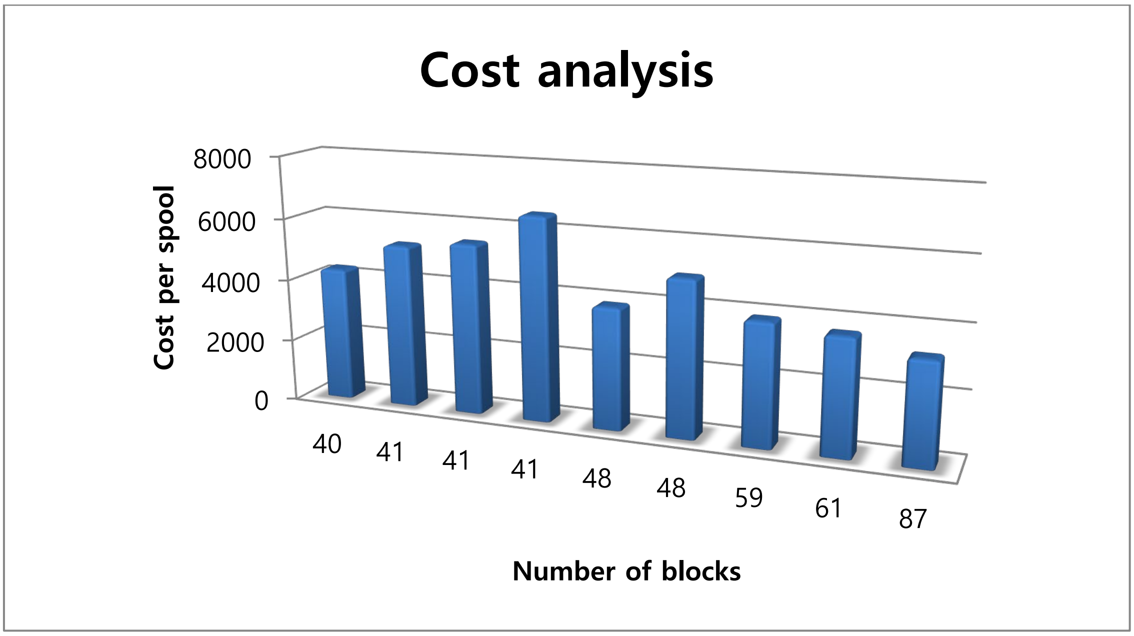


Figure 5.47 - Bar chart showing the cost per tonnage of blocks

Table 5.25 and Figure 5.47 show that least amount of cost is required for the production of 87 blocks. This means assigning maximum number of welders (8), grinders (8) and maximum CNC speed would give us lowest monetary unit per tonnage of blocks.

5.6.2 Cost analysis of plate surface preparation model

We have selected three major variables that put significant effect on the overall cost of plate surface preparation.

Table 5.26 will define the cost items, functional items and considered functional items for the plate surface preparation model cost analysis.

Cost Items	Functional Items	Considered functions
Surface coating	Number of painters, paint	Number of painters
Forklift	Number of forklifts, forklift operator, fuel	Number of forklift operator
Blasting	Blasting Machine, blasting machine operator, electricity	Electricity

Table 5.26 -Identified major variables for cost analysis (plate surface)

The mathematical equations for all the cost functions are given below:

$$Surface\ Coating = f(Number\ of\ painter, paint)$$

$$Forklift = f(Number\ of\ Forklift, Forklift\ operator, Fuel\ )$$

$$Blasting = f(Blasting\ Machine, Blasting\ Machine\ Operator, Electricity\ )$$

Most significant functional items, number of painters, number of forklift operator and electricity, have been given priority in the analysis.

Table 5.27 will show us the value specified for each of the variables we considered in the cost analysis.

Variable	Expression	Numerical Value
Cost per painter per day	X2	BDT 300
Number of painters	Y2	1, 3, 5
Cost per forklift operator per day	P2	BDT 250
Number of forklift operator	Q2	1, 2, 3
Blasting machine electricity Cost per day	M2	BDT 18360
Percentage of blasting machine running time	N2	See Table 1.1
Number of days	D2	6
Number of plates	B2	Varies between 46 to 103
Average weight of each plate	A2	0.75 Ton

Table 5.27 -Functional variable and their values (plate surface)

The relation between the cost item and its function is described below:

$$Total\ surface\ coating\ cost\ , W2 = X2\ \times Y2 \times D2$$

$$Total\ forklift\ cost, G2 = P2\ \times Q2 \times D2$$

$$Total\ blasting\ cost, E2 = M2\ \times N2 \times D2$$

$$Total\ Cost\ per\ tonnage, C2 = \frac{(W2 + G2 + E2)}{(A2 \times B2)}$$

Painter	Forklift operator	Percentage of Blasting running time	Plates	Surface Coating Cost (BDT)	Forklift Cost (BDT)	Blasting Cost (BDT)	Total Cost per tonnage (BDT)
1	1	0.4894	46	1800	1500	53912.3	1658.32
1	1	0.4894	46	1800	1500	53912.3	1658.32
1	3	0.4894	47	1800	4500	53912.3	1708.15
1	3	1.0	47	1800	4500	110160	3303.82
5	1	0.5003	51	9000	1500	55113.04	1715.37
5	3	0.5042	54	9000	4500	55542.67	1704.75
5	1	0.5519	60	9000	1500	60797.3	1584.38
3	2	0.7276	77	5400	3000	80152.41	1533.37
5	3	1.0	103	9000	4500	110160	1600.77

Table 5.28 -Cost analysis for different numebr of factors (plate surface)

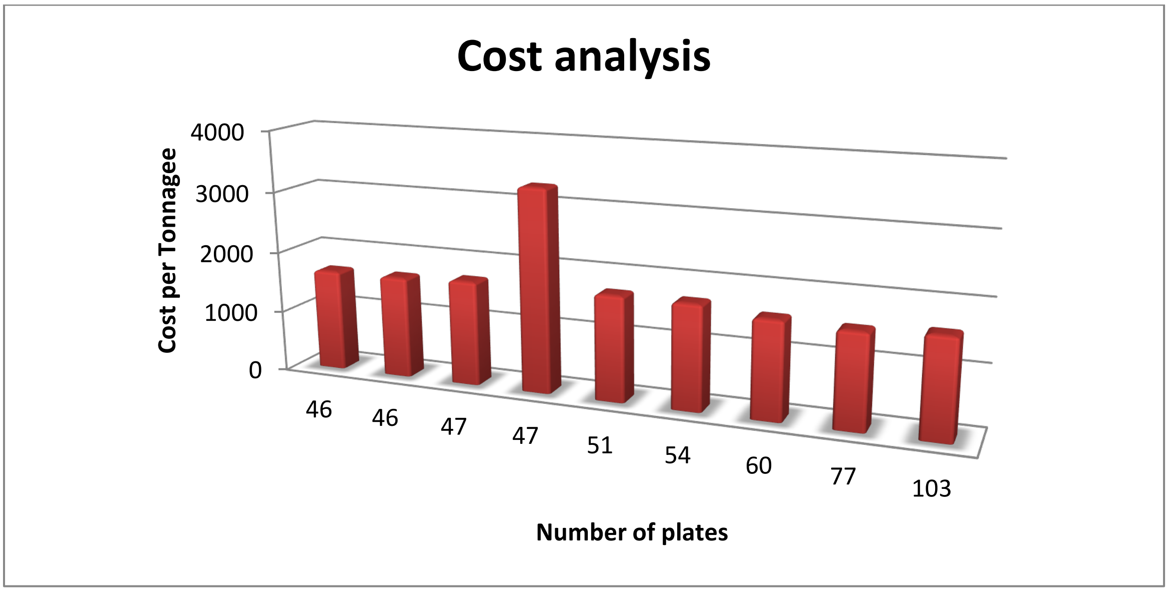


Figure 5.48 - Bar chart showing the cost per tonnage of plates

Table 5.28 and Figure 5.48 show that least amount of cost is required for the 77 plates. This explains that assigning center point value for the number of painters (3), forklift operators (2) and blasting speed would give us lowest monetary unit per tonnage of plates.

5.6.3 Cost analysis of pipe spool production model

We have selected three major variables that put significant effect on the overall cost of spool production.

Table 5.29 will define the cost items, functional items and considered functional items for the pipe spool production model cost analysis.

Cost Items	Functional Items	Considered Functions
Welding	Number of Welder, Electricity, Welding Rod, Welding Machine	Number of Welder
Fabrication Group	Fabrication group member (Total number of fitters, junior fitter, helper)	Fabrication group member
Bending	Automatic Bending Machine, Electricity	Electricity

Table 5.29 -Identified major variables for cost analysis (spool production)

The mathematical equations for all the cost functions are given below:

$$Welding = f(Number\ of\ Welder, Electricity, Welding\ Rod, Welding\ Machine\ )$$

$$Fabrication\ group = f(Total\ number\ of\ fitter, junior\ fitter, helper\ )$$

$$Bending = f(Automatic\ Bending\ Machine, Electricity\ )$$

Most significant functional items, number of welders, number of fabrication group member and electricity, have been given priority in the analysis.

Table 5.30 will show us the value specified for each of the variables we considered in the cost analysis.

Variable	Expression	Numerical Value
Cost per welder per day	X3	BDT 300
Number of welders	Y3	3, 4, 5
Cost per member in fabrication group per day	P3	BDT 250
Number of fabrication group member	Q3	15, 18, 21
Automatic bending machine electricity Cost per day	M3	BDT 6480
Percentage of automatic bending machine running time	N3	See Table 1.1
Number of days	D3	6
Number of spools	B3	Varies between 34 to 70

Table 5.30-Functional variable and their values (spool production)

The relation between the cost item and its function is described below:

$$Total\ welding\ cost\ , W3 = X3\ \times Y3 \times D3$$

$$Total\ fabrication\ group\ cost, G3 = P3\ \times Q3 \times D3$$

$$Total\ bending\ cost, E3 = M3\ \times N3 \times D3$$

$$Total\ Cost\ per\ spool, C3 = \frac{(W3 + G3 + E3)}{(B2)}$$

Welder	Fabrication Member	Percentage of automatic Bending machine running time	Spools	Welding Cost (BDT)	Fabrication Group Cost (BDT)	Bending Cost (BDT)	Total Cost per spool (BDT)
3	15	0.5094	34	5400	22500	31200	917
3	15	0.4766	35	5400	22500	30988	885
3	21	0.441	36	5400	31500	39757	1104
3	21	0.441	36	5400	31500	39757	1104
5	15	0.4766	47	9000	22500	34588	735
4	18	0.4263	48	7200	27000	36962	770
5	15	0.575	48	9000	22500	35226	733
5	21	0.4639	68	9000	31500	43506	639
5	21	0.4465	70	9000	31500	43393	619

Table 5.31 -Cost analysis for different numebr of factors (spool production)

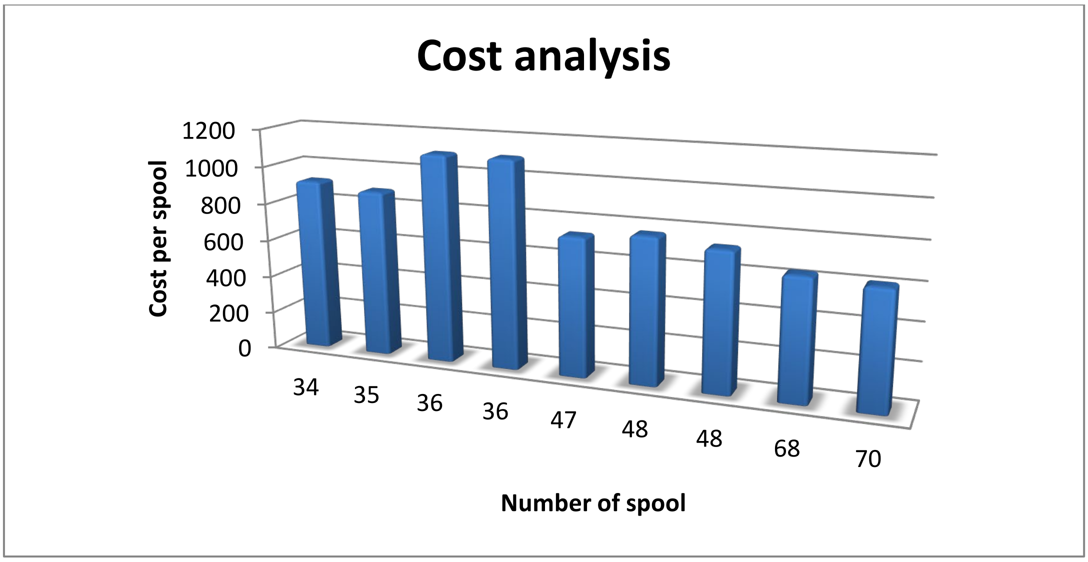


Figure 5.49 - Bar chart showing the cost per spool

Table 5.31 and Figure 5.49 show that least amount of cost is required for the production of 70 spools. This describes that assigning highest number of welders

(5) and fabrication group members (21) and lowest number of bending machines will provide us minimum cost per spool.

5.7 Validation and verification of the method

Proper validation and verification of any results increase the significance of the analysis made by the researchers. In this thesis we followed qualitative validity approach, rather than quantitative, for the validation of the results. Qualitative research approaches are diverse, consisting of a variety of philosophical paradigms, such as interpretivism, phenomenology, semiotic, ethnographic, critical theory symbolic interactionism and others (Anney, 2014). Qualitative validation research considers four criteria, namely, dependability, credibility, transferability and confirmability (Guba and Lincoln, 1981). These four criteria are described briefly.

1. Credibility: It states that the results of qualitative research are credible or believable from the perspective of the participant in the research (Social research methods). Credibility establishes whether the research findings represent valid and truth information drawn from the participants' original data and is a correct interpretation of their original views (Anney, 2014).

2. Transferability: Transferability says that the results of qualitative research can be transferred or generalized to other contexts or settings with other respondents (Anney, 2014)**.** The qualitative researcher can enhance transferability by doing a thorough job of describing the research context and the assumptions that were central to the research. The person who wishes to "transfer" the results to a different context is then responsible for making the judgment of how sensible the transfer is (Social research methods).

3. Dependability: Dependability refers to the stability of findings over time (Bitsch, 2005). Dependability involves participants evaluating the findings and the interpretation and recommendations of the study to make sure that they are all supported by the data received from the informants of the study (Anney, 2014)**.**

4. Confirmability: Qualitative research tends to assume that each researcher brings a unique perspective to the study. Confirmability refers to the degree to which the results of an enquiry could be confirmed or corroborated by others (Social research methods). Confirmability is concerned with establishing the data and interpretations of the findings are not thoughts of the inquirer's imagination, but are clearly derived from the data (Tobin and Begley, 2004). This criterion states that data collection and analysis procedures can be conducted by a 'data audit' and then judgments about the potential for bias or distortion can be made.

Out of the four criteria mentioned above, the "Confirmability" is the one that has been considered in this thesis. All the data collected for analysis purpose were further verified with the concerned process engineer for accuracy. Optimized project sequence derived in Figure 5.5 were discussed with a multidisciplinary team from design and production and the produced layout map of project plan was analyzed by the team. It has been confirmed unanimously that this method would be of benefit to the effort for improvement in project management. Simulation runs were tested against output estimates from real process, and were found to be in close match with each other. While three example processes of surface preparation and block construction and pipe spool preparation from the activities in the optimized project sequence have been analyzed for optimum resource allocation, all other activity having a process of discrete event can be replicated and optimum resources required for a target output can be analyzed. Together these three processes of surface preparation, pipe production and block construction are claimed to represent in the range of 30%-50% work content in terms of spent man-hours in shipbuilding project depending on the type and size of the project. Processes of these types, which also are listed in global project plan as broken-down activities, in order of manageable work content, estimated to be completed within a predefined time are somewhat repeatable across different projects. For instance, plate surface preparation process and block construction process across different projects may remain almost the same. However, changes may take place in terms of targeted output in a predefined time or spatial arrangement of the workstations involved in the process or the inclusion of any new facility or equipment due to investment may alter the process from the previous one. For example, inclusion of automated pre-wash of plates and rolling before blasting will change this process for plate surface preparation. Therefore, once the simulation models of these processes are constructed, any further recreation of those models for any other project or for different requirement of the same project may be accomplished with little effort of alteration to the model. That essentially enables these simulation models to be reused at the expense of minimum further endeavor. All other activities without any definite process of discrete event work flow in the shop floor may be simulated and optimized without needing the application of Design of Experiments. All the activities in outfitting and installation process, for instance, may be simulated and time-based estimation of resources may be conducted for targeted progression. Analysis of outfitting and installation are not in the scope of work of this thesis for understandable nature of prolonged data collection and voluminous simulation. Nonetheless, this novel method of managing shipbuilding project requires to be verified by the people involved in the project for validation upon all the components being sequentially analyzed with the real-life data. This has duly been done in this case study and the method received insightful confirmation from project team.

5.8 Relation between case study and project management

The case study described in this chapter will be compared to various process groups of project management to see which areas the case study covers. In chapter two we discussed the difference between project management, production management, process management and scheduling. In this section we would like to make a relationship between this case study and the project management to clarify that our case study satisfies the criteria of project management.

Item	Project Management	Relation with case study
Definition	✓ Project management focuses on results, with clear goals and detailed plans for managing finances and manpower. ✓ Project is a unique endeavor with a beginning and an end undertaken to achieve a goal. ✓ Organizational function of planning, organizing, securing and managing resources.	✓ According to the definition, project management deals with the organizational function of planning, organizing and managing resources. In our case study the objective of using the dependency structure matrix (DSM) is to make planning and organizing of resources based on the interdependency among the activities to optimize the resources.

	✓ Applies processes and knowledge over time ✓ Aligns cross-functional teams to complete projects (Answers; Edelenbos and Klijn, 2009; AIPMM, 2013)	✓ The use of simulation regarding the plate surface preparation is also a part of planning activities. The aim is to get a proper sequence that will help optimizing the resources in the shipyard.
Important Task	✓ Maximize revenue ✓ Lead product development activities ✓ Reduce development cost ✓ Maximize profit ✓ Deliver high quality (AIPMM, 2013)	✓ Optimized project activity plan and subsequent processes have the ability to reduce cost and maximize profit.
Focus	Controlling the project phases according to five features: the quality of the content, cost, time, organization and information (Edelenbos and Klijn, 2009)	✓ Review of initial activity plan, and optimization have clearly set a path for improvement for overall quality of the project, cost and organization.
Framework	✓ Initiate ✓ Plan ✓ Execute ✓ Monitor/Control ✓ Close (AIPMM, 2013)	✓ After the project initiation, plan has been adopted, optimization has been executed, cost and time improvement have been monitored.
Constraints	✓ Scope (Quality) ✓ Cost ✓ Schedule(Time) (Wikipedia)	

Table 5.32- Relation between case study and project management

5.9 Summary

This chapter culminates in elaborating the proposed method in bringing about optimality in individual shipbuilding project in the context of ever-changing circumstances in small to medium shipyard located in the developing shipbuilding area, and drawing in particular inference from South Asia. This chapter has started with illuminating the key questions as to the relevance of optimality application in shipbuilding project. Thereafter, application of data collected from an ongoing project has been made in each component of the method. Dependency structure matrix has been proposed and used to bring about optimality in Global Level of project management, and activities of design and construction were overlapped, wherever possible, arranged in parallel depending on inter-dependency or in sequence depending on the strength of dependency. Thus, an optimal project sequence can be established with minimum iteration of jobs, and keeping project completion time optimum. By doing so, uncertainty or risk of the project in question can be visualized in advance and due consideration to ward off risks can be rendered to the project. Strength of this method lies in the concept that optimality achieved through the application of DSM can accommodate dependency relationship of any nature between activities ranging from finance, to resource in way of human skill and tools, and even to arbitrarily imposed dependency to make way to spatial arrangement for other projects in the yard. To delve further into the optimal boundary of operation, activities are extrapolated in real shop floor function and with the help of succeeding components, optimal resource allocation to execute respective activity has been demonstrated. Simulation technique has been used in exhibiting how an activity can be replicated in its actual operative domain in computer environment. A discrete event simulation software has been used for this purpose. Simulation allows us investigating into the operation of activity without requiring to conduct experimentation in actual process, and thus makes way to saving against unsustainable expenditure. Design of Experiments (DOE) has been proposed to optimize resource allocation to an activity under investigation. A 2^3 full factorial design is constructed and the meta-model is analyzed for its sufficiency of fitness. Subsequently, Box-behnken design layout is constructed and corresponding simulation runs are conducted to complement analysis of 2^3 full factorial design. Significant improvement has been achieved by this second order analysis and the derived meta-model has been used to find the optimum setting of factors in achieving desired response (output) from the process. Plate surface preparation process, block construction process and pipe spool production were used as examples for the analysis. In quest of optimum factor or resource setting for desired output, all other activities listed in the optimized project sequence having a process of discrete event phenomena can be analyzed following the procedure shown in this method. In chapter 6, limitation of this method and its future research course will be outlined along with the recapitulation of all the chapters we have come across so far.

6 Chapter Six. Conclusions

6.1 Contribution

It is believed that a bridge between academic research and its application in the shipbuilding industry has been established through this methodology. The aim of the research is to provide small to medium shipyards operating in a flexible environment of evolution, change, and competition- a strategy for modeling and optimizing sequence of activities of shipbuilding project and resources utilized in accomplishing those activities. So that, a project can be managed and controlled in an effective manner. This helps to ensure that production cost can be minimized, product quality can be maximized and, perhaps most importantly, project completion time can be reduced by taking many uncertainties of project in consideration during the course of optimization procedure.

In today's highly competitive environment of rapid technological changes, change in demand of ship types, and overall volatility of shipping market, it has been concluded that the best opportunities for gaining competitive advantage lie in the improvement of performance of the yard and, in particular, reduced project cost. As a result, engineering firms like shipyards are increasingly adopting new initiatives aimed at reducing completion time. One of the most popular of such initiative is concurrent engineering.

Concurrent engineering is defined as the concurrent and faster processing of design and production activities supported by the improved integration and communication of data, information, knowledge, and resources. Whilst it is accepted that the application CE principles can go a long way reducing project completion time, it may be iterated that, like all new initiatives, there are costs as well as benefits to be considered. This method is suitable to implement CE principles in shipbuilding project.

In many advanced yards, sub-contractors, suppliers and vendors carry out many of the jobs like block construction, prefabrication, accommodation module construction, pipe spool construction etc., in some cases, simultaneously either at their own premises distributed geographically or at the yard premises. While these yards or other engineering companies seem to believe that their performance will be improved through the application of initiatives of concurrent engineering. However, small to medium yards operate in a different environment in terms of challenges faced by both of these genres. A detailed discussion has been attempted in section 4.5 and in section 5.2 regarding the operating conditions of SMSs in developing shipbuilding area with special accentuation to South Asia. Small to medium shipyards organize as much work as possible to retain an economy of scale in the project. This self-reliance has been influenced by significant bearing of the disadvantages these yards' experience and a sense of "more work more margin" prevailing in the view of the management. Due to the transitional conditions in terms of equipment and facility acquisition being contiguous to this yard type, it is of utmost importance to find out a conciliate zone of operation per shipbuilding project. It has been stressed in this thesis that an optimal approach may be adopted for the best practice and for the congruence in the management of shipbuilding projects.

A large number of management modeling techniques exist, which are discussed in chapter 3 in detail. Having examined some of the popular techniques for modeling project processes, it has been concluded that, whilst most techniques satisfy conventional conjecture-based planning, only Dependency Structure Matrix satisfies the requirement of deriving an optimal project sequence with maximum concurrency based on the inter-relationship between activities.

Prior to the creation of project activities, a clear understanding of the project's design and production phases is required. In this respect, ignoring needless complexity and by revealing the most appropriate, essential project elements and their inter-relationships, a model can be used to gain clear understanding and its processes. Project activities and their sequences are based on the dependence, independence and inter-dependence caused by many factors including but not limited to data, knowledge, resources, logistics, design, supplies, spatial arrangement for multiple projects in the yard and arbitrary job sequence as deemed best by the project management team to maximize construction ease. Design has been regarded as interwoven in the broad project plan to make sure that production can take place as soon as a design delivery is ready for dissemination to successive processes. Considering all the dependencies a specific design activity may have on other project activities for a smooth progression of the project. As a matter of practicality, any activity of the project will have a dependency on other activities but some of these dependencies are feeble and some of them are strong. In this thesis, it has been proposed that this strength of dependences or inter dependences should be the determining factor in shaping out the optimal sequence of activities. In conventional approach to project plan, these dependency strengths are not considered in advance and in as detailed as proposed in this strategy. There are many benefits in considering this dependency relationship in advance. This will reveal all the probable risks surrounding this dependency relation between activities and lead to a clear understanding into the dynamics of sequences. Project management team can give appropriate attention to the strength of dependencies and can systematize the complexity of relation. Any prerequisite provision required either to steer clear of or to complement this dependency may possibly be contemplated by the project team in advance and therefore uncertainty in the project cropping up later in the succession would be reduced considerably. As the sequence of activities is in the core to the nature of flow of a project into progression, it is therefore proposed that the sequence of activities should be optimized in the domain of this very important fact of dependency relationship- which are primarily for data, knowledge, tools or resources. Component one of this proposed methodology provides the first step in optimizing the project sequence. Once all the activities are listed in the matrix with a denomination of strengths of dependency relation between activities, it is then optimized with the help of the Triangularization Algorithm based approach. This approach will consider all the dependencies and their strengths and essentially will produce an optimized layout of sequences with maximum concurrency of activities. Thus, this method, through the application of component one, not only satisfies concurrent engineering principle but also produces an optimized project plan.

In order for the project plan to be effective, this must be based on activity durations which are accurate. If these durations are not accurate then the schedule will not reflect reality and, consequently, this key management and control mechanism will be delusive. In order for activity durations to be accurate, they must be based on processes which are stable and subject to small variability. As a result, it has been concluded that systematic approach to the management of project processes, which are stable and subject to contained variability is of fundamental importance of the proposed modeling strategy. It is to be used to attain maximum advantage. In a conventional management approach, project activity durations are merely a best estimate based on previous experiences gathered from other projects. Sometimes, these estimates are made more buoyant with the commitment of extra resources envisaged by project team in order to achieve the pace required for project execution. In this thesis, it has been proposed that the time required for the completion of activity or the amount of activity to be completed within a predefined time should preferably be based on an analytical approach. The elementary outline of the approach is achieved both through the application of component two and through the combined application of component two and three of the proposed methodology. Once an optimally sequenced list of activities is created, then the activity duration estimated primarily by the project team is required to be verified analytically as much as possible against the intended extent of activity-based work. Shipbuilding processes, such as plate surface preparation, plate cutting, block construction, pipe construction being carried out in the shops, follow somewhat standard procedures across all the projects. This thesis proposes that activities containing such works in the original project plan are required to be analyzed further so that an intended work can be conducted with the use of optimal number of resources, and therefore, after the analysis original plan can either be adjusted or resource planning can be made harmonious to the activity requirement. To this effect, an activity is extrapolated to envisioned processes it would have to be aligned with. For accomplishment of task, it would require resources to be utilized. It is proposed that for the best interest of the project undertaken by the small to medium shipyards operating in an ever-developing environment, each activity of the project derived through work break down structure should use optimum resources.

Simulation technology has been explored in many forms across the industry for years. This is a proven method of process analysis. Process data for activity can be collected from other similar projects and then be used for analysis of projects under consideration as shipbuilding processes are somewhat similar in a specific yard across the different projects and the variability is an unavoidable reality. Activity simulation suggests important insights into the process and offers an easy understanding to point out important factors in the process. Statistical analysis in way of Design of Experiments (DOE) is proposed to analyze and find out an optimum setting of resources required to execute an activity. Simulation answers to the questions of “what if” scenarios but it cannot optimize the activity process for a certain objective function. Design of Experiments and more specifically Response Surface Method (RSM) creates the opportunity of analyzing and optimizing the process for a specific response function or output. There are different experimental layouts proposed in the literature. In this thesis, a full factorial experimental design is first deployed and then the sufficiency of the derived model is checked as to whether the produced model can explain the variations in the process accurately. Further experimental design is employed if the first order model is insufficient. A second order model is thus produced through further experimentation and analysis. By extension, response surfaces are also produced. This model can then be used to ascertain an optimum combination of factors or resources required to accomplish the intended tasks contained in the corresponding activity. Starting from the global level optimization of the sequence of project activities this methodology attempts to further optimizes resources required to realize those activities through the application of Discrete Event Simulation (DES) and Design of Experiments.

One of the conclusions drawn from the experience with industrial case study is that, the matrix-model, and the project work break down based activity upon which it is based, should be created from the scratch whenever the proposed activity modeling strategy is first used. It should always be remembered that dependencies are at the core of the modeling strategy. Existing modeling techniques such as PERT or CPM or other project management platform are limited in their representation of dependencies. The scope of modification of an existing project work break-down structure, and the subsequent creation of matrix model based on an existing plan, tends to be limited, in that, assumptions beyond the knowledge of the researcher are already built into the model.

Returning to the aim of the thesis, it has been endeavored to establish the methodology through chronological presentation in the preceding chapters. The first chapter presented the introductory background behind the motivation and idea of author's undertaking of the thesis to propose a solution towards the aim. The second chapter discussed the literature search for allied works in the domain of simulation and project process. The third chapter introduced a detailed presentation of conventional project management techniques and a search for a desired method, the fourth chapter concentrated on the elaboration and explanation of solution approach proposed in the thesis and the fifth chapter exhibited the validation and verification of the proposed method by employing the same in a small to medium shipyard's ongoing project as a case study. Through these detailed presentations of the chapters a methodology to manage shipbuilding project through integrated optimality, particularly for small to medium shipyards is established and explained. The author would like to substantiate that this proposed methodology is a novel approach in its attempt to integrate global level shipbuilding project activity management and the subsequent realization of works in shop floor through optimization.

By incorporating industrial case study into the research, further valuable insight has been gained into some of the practicalities of the approach recommended in this thesis. As a result of feedback from the yard personnel, as well as engineers, designers and planners from a range of yard departments associated with the case study project, the proposed methodology has been developed to reflect some of the requirements voiced by the industry. However, the best way of truly validating the strategy is through its full application to a shipbuilding project in a small to medium yard located in developing area from the scratch and is to be addressed as part of an ongoing research. Through the presentations in the preceding chapters, it was attempted chronologically to work toward the implementation of the aim of the thesis of proposing a methodology for optimally managing shipbuilding project at both global and local levels at small to medium shipyards in developing shipbuilding area. The objectives as listed in section 1.5 in Chapter 1 have, thus, been achieved through establishing this methodology.

6.2 Limitation of the method

1. Each run of a model is usually the result of a random experiment and is thus only an estimation of the studied parameters (mean waiting times in a queue, probability of saturating the system, etc.). This is not the case for analytic models

that give exact values of these parameters. As a consequence, simulation results may be difficult to interpret. Since most simulation outputs are essentially random variables (they are usually based on random inputs), it may be hard to determine whether an observation is a result of system interrelationships or randomness.

2. Model building requires special training. It is an art that is learned over time and through experience. Furthermore, if two models are constructed by two skilled individuals, they may have similarities, but it is highly unlikely that they will be the same.

3. The ability to create a model that accurately represents the system to be simulated is not immediately apparent. Real systems are extremely complex and a determination must be made about the details that will be captured in the model. Some details must be omitted and their effects lost or aggregated into other variables that are included in the model. In both cases, an inaccuracy has been introduced and the ramifications of this must be evaluated and accepted by the model developers and the process engineers.

4. The availability of data to describe the behavior of the system may be difficult to harness. It is common for a model to require input data that is scarce or unavailable. This issue must be addressed prior to the design of the model to minimize its impact once the model is completed.

5. Development of a simulation model requires time and important resources. Skimping on resources for modeling and analysis may result in a simulation model or analysis that is not sufficient for the task.

6. Once a model has been developed, the flexibility of the tool and its acceptance can lead to pernicious effects: for example, an unjustified trust in the accuracy of results calculated. This fact is reinforced by the visual aspect of animations, etc. that reduce the distance between the model and the process simulated.

7. In processing activity sequence, it is rather appeared that the window of dependency structure matrix requires tedious attention to underpin any sequence of dependency relation between activities, if the number of activity increases.

8. Relational dependency established in this thesis is based on the opinion received from the personnel involved in the project management. Much of the bearing of this process is dependent on their previous experience in other projects and on the guesstimates conceived by the team effort. During the implementation of the project, the nature and dynamics of relational dependency may change due to the possible induction of uncertainty or changes in the work scope through design modification. However, this limitation may be overcome by periodical modeling of sequences to the requirement of adjustment.

9. Application of Design of Experiments requires extensive study in the field of applied statistics. Development of resources in this special knowledge area and their retention may pose some degree of challenges to the yards intending to practice this method of project management.

10. This method requires competent knowledge in three distinctive fields such as project management with ship production knowledge, expertise in discrete event simulation and applied statistics for realizing the benefit of the proposed management modeling method through a holistic approach. Assimilation of this conceptual knowledge among a team or in a person involved in the project may be challenging, if not impossible, to garner, and at the expense of substantial cost.

11. When applying the method in a yard with sole objective of optimizing the project processes, a manager will tend to favor the use of the more experienced members of the project team who are usually the most efficient. This practice has serious implications for the company in the medium to long term in that, the lesser experienced members do not receive enough of the on-the-job training which is necessary in order to develop their own skills.

However, against the above limitation it can be argued that it is possible to develop packages that contain models that only need input data or a very little modification across different projects for their operation. Such models have the generic tag — "templates ".

It is also possible to develop output analysis capabilities within simulation packages for performing very thorough analyses. Simulation can be performed faster today than yesterday, and even faster tomorrow. This is attributable to the advances in hardware that permit rapid running of scenarios. It is also attributable to the advances in many simulation packages. For example, some simulation software contains a library of objects for modeling material handling such as fork lift trucks, conveyors, and automated guided vehicles.

6.3 Potential further direction of work

Whilst valuable feedback has been derived through the use of the shipyard case study, further application of the proposed management method needs to be undertaken. This is to be addressed by an ongoing research project based at a small to medium shipyard involving the construction a ship starting from the design phase. Whilst the management method has been demonstrated within the thesis using an oil tanker, it is considered that the method is equally applicable to modeling management strategy of any other vessel's construction process, although further research with the wider range of ship types constructed at different yards would indicate whether this expectation is justified.

The simulation work in the thesis has been focused on the production process, but one area of further work could be focused on the development of research into studying and improving the outfitting process. Outfitting and installation works on board a ship or in a block is normally carried out by estimating man-hour requirement. It may be investigated whether each of the activity derived through work break down of the project can lead to the application of Design of Experiments by making no-tangible parameters as response function other than tangible work item. The case study used in this thesis emanates from plate surface preparation, and uses a tangible plate count as response function in the application of Design of Experiments for optimizing resources. In contrast, as the outfitting and installation do not have a regular process of input and output or a flow of work as in work shop, resource requirement in outfitting and installation can be optimized through Design of Experiments by taking time, for instance, as a response function.

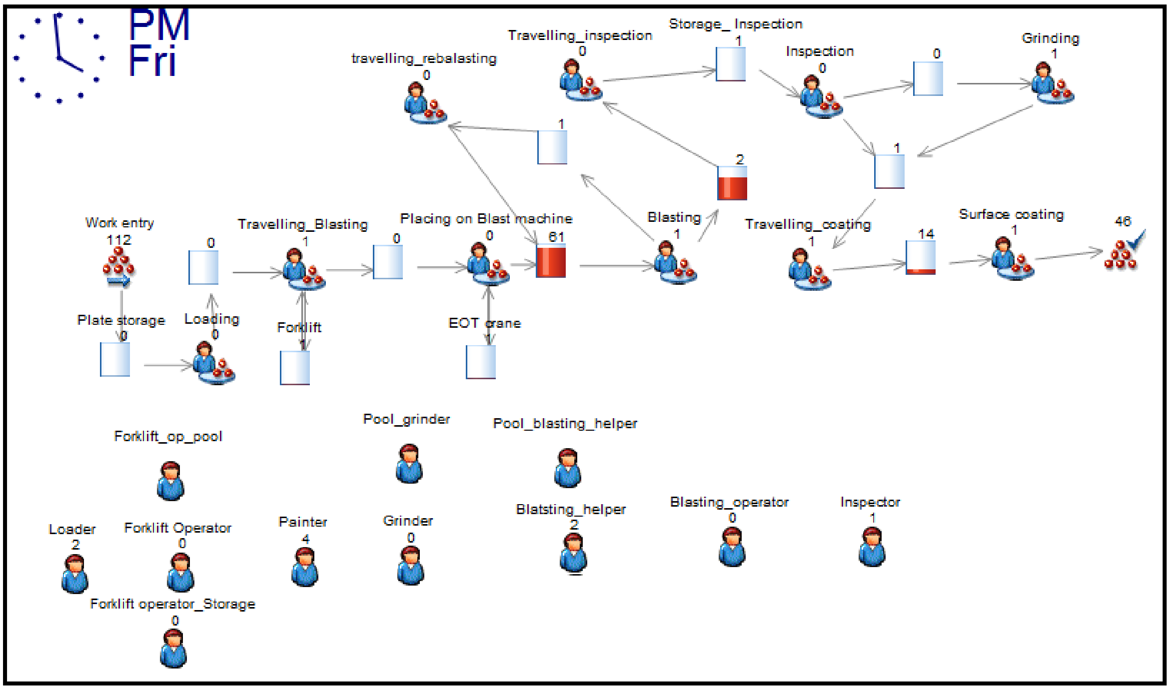
While the idea behind the method is to derive optimal construction for a project in a small to medium shipyard which goes through continuous evolution in terms of investment characteristics, it should be stressed whether the achievement by the application of the method is quantifiable through introducing a measuring yard stick. The author believes that research into value stream mapping of the optimal sequences coupled with optimized resource allocation should be undertaken in order to establish a quantification in the improvement in contrast to conventional management method.

Because a work breakdown structure has significant impact on the success of the modeling of the method, more work needs to be undertaken in order to develop the approach, in particular, research into the viability of defining activities in terms of their inputs, outputs, standard procedures, experience and technical uncertainties.

In terms of modeling activity sequence and their data dependencies, the representative example used in the thesis consists of 42 (forty-two) activities. As the number of activities increases it may be necessary to use a hierarchical approach to the creation of the set of inter-related dependency structure matrices. For a specific yard, it may also be possible to derive a set of generic models which cover the range of the vessels it produces, and which can simply be customized for a new specification. As ship construction projects undertaken by SMSs are, in most of the cases, made to order, i.e., project with a newly developed design, taking many months for completion, it is possible that optimal dependency structure matrix can be constructed targeting a specific period of the whole project timeline and all the matrices thus produced may be integrated as the project progresses. This way of producing time bounded optimal DSMs in groups may lead to an improvement to the management of long activity list in DSM window.

While the thesis proposes a novel method to manage shipbuilding projects in small to medium shipyards in developing shipbuilding area, this method has been tested for individual project at a specific yard without much attention to the resource conflicts between multiple projects. Therefore, a model across the spectrum of the ongoing projects in a specific yard might be worth of investigation to find an optimum balance among all the ongoing projects.

Appendix A



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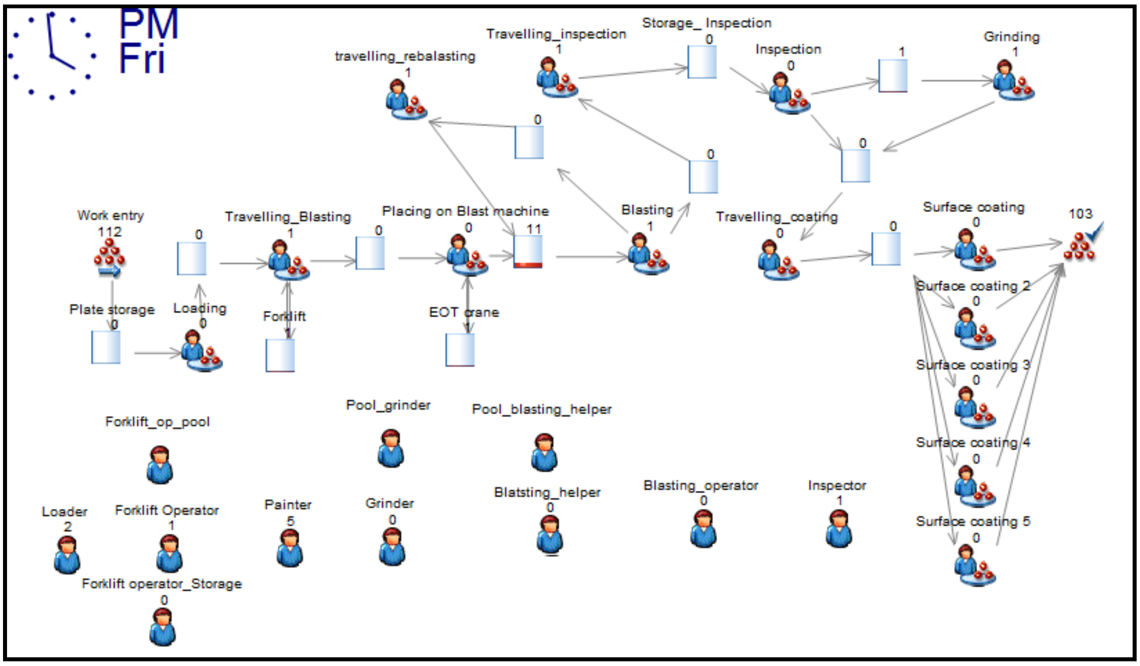

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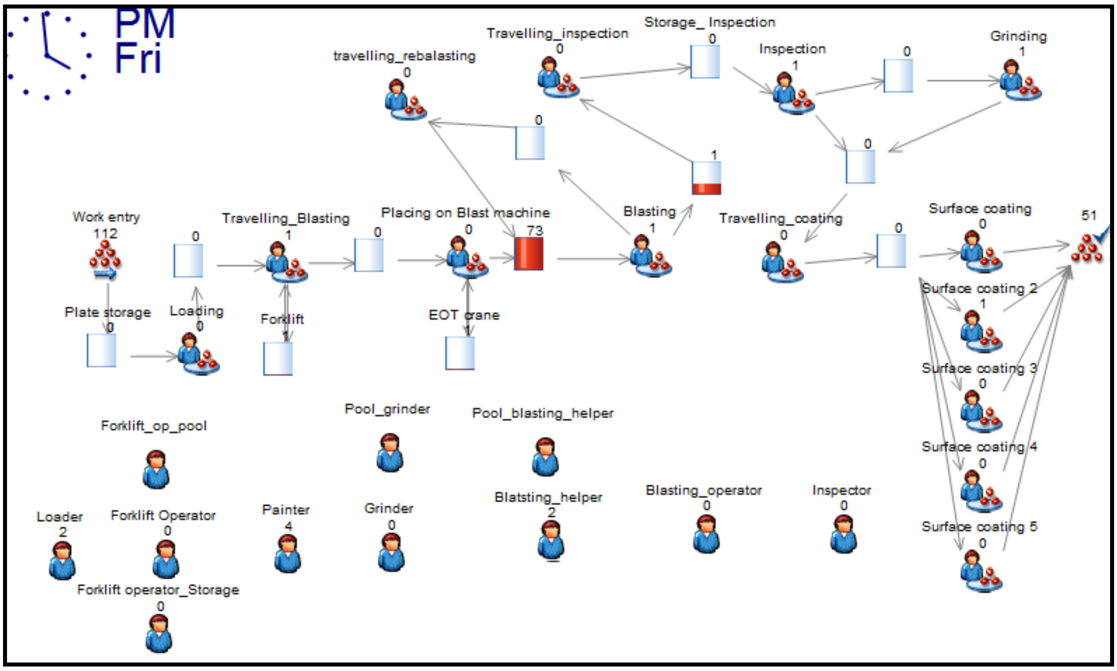

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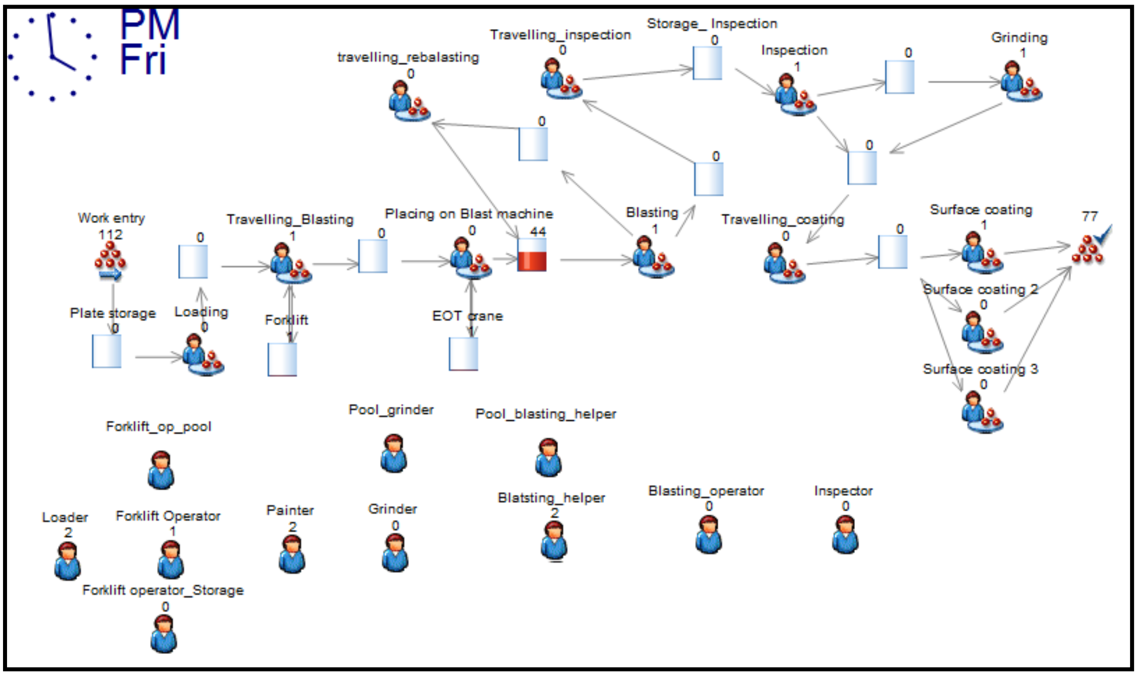

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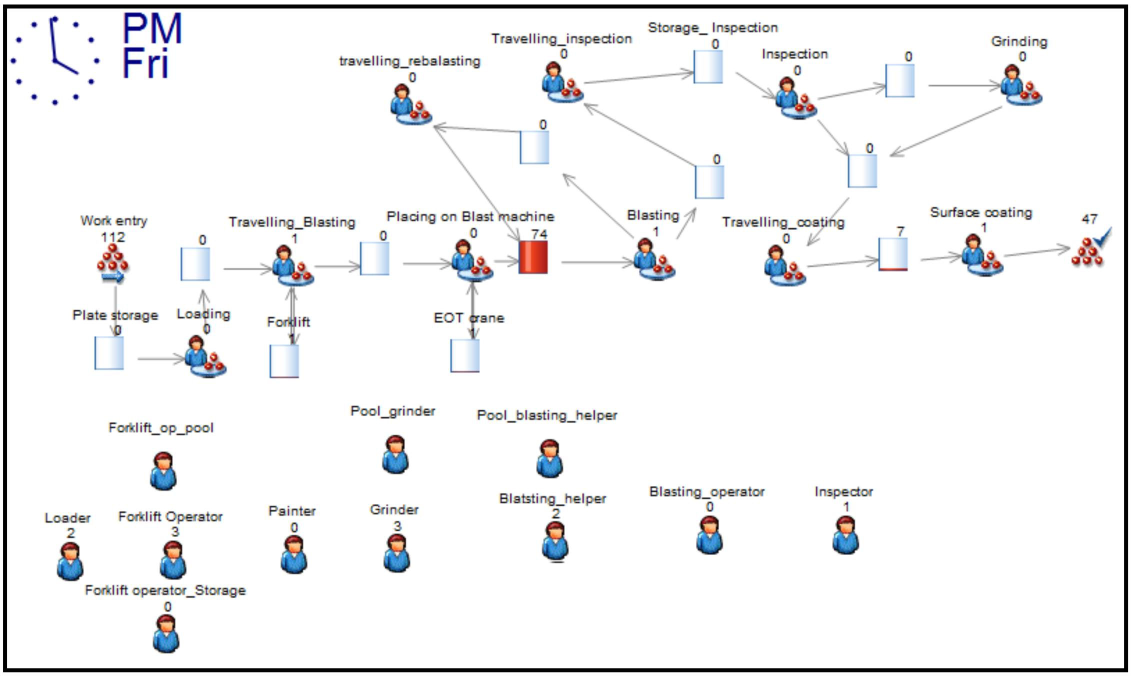

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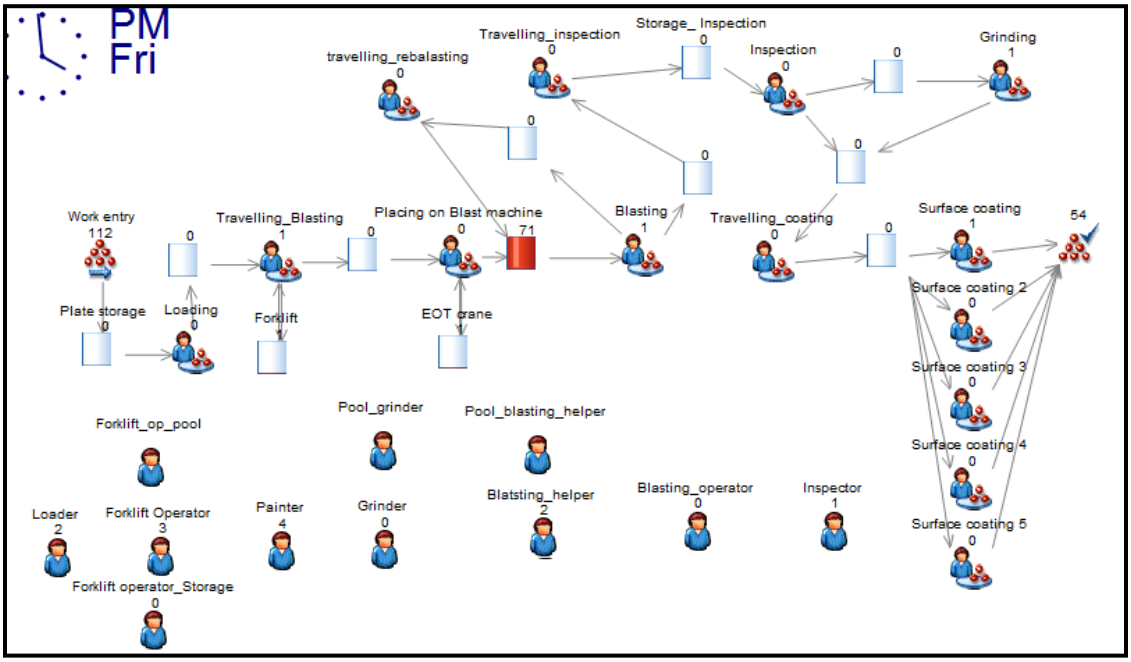

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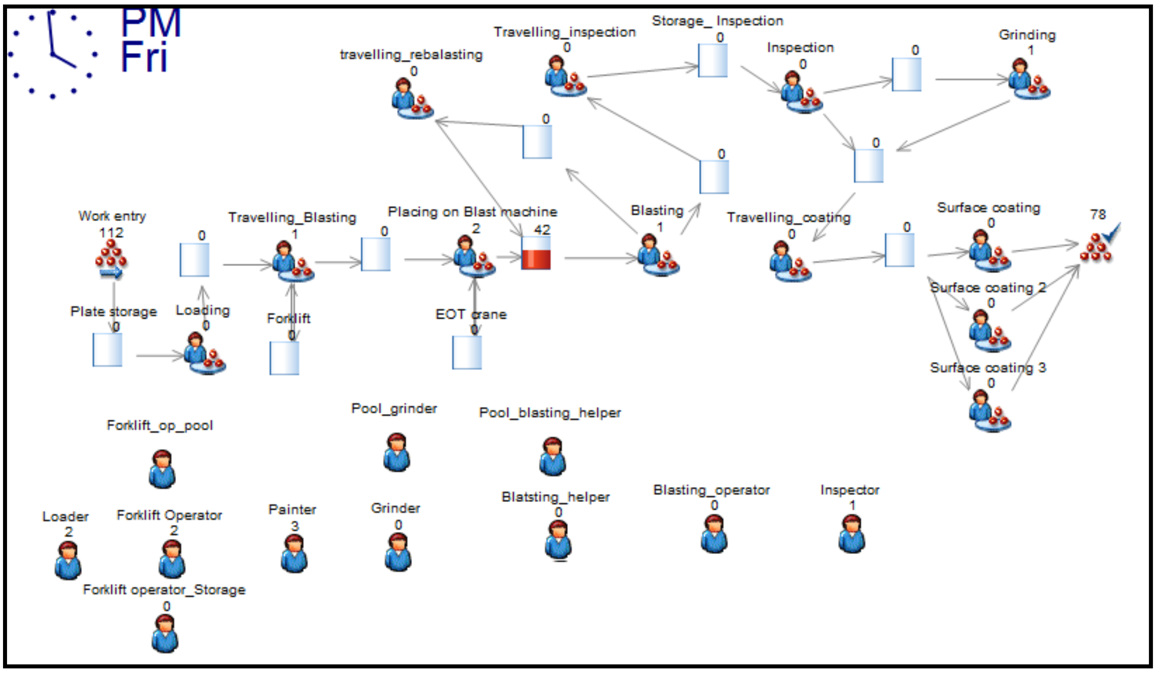

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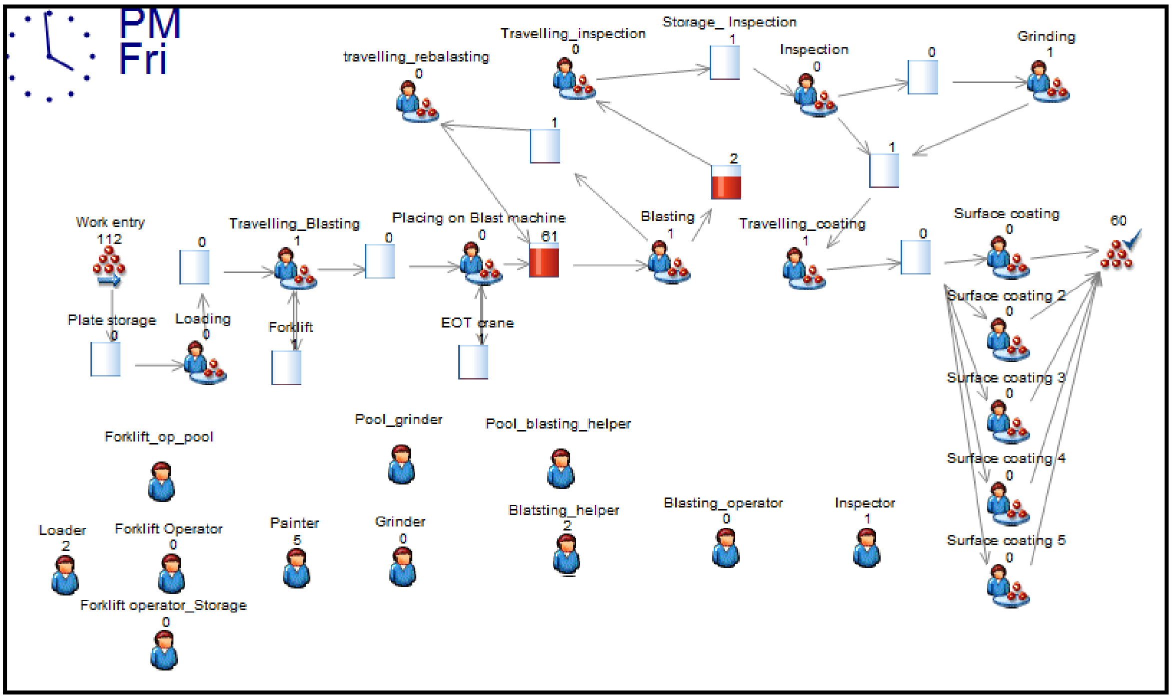

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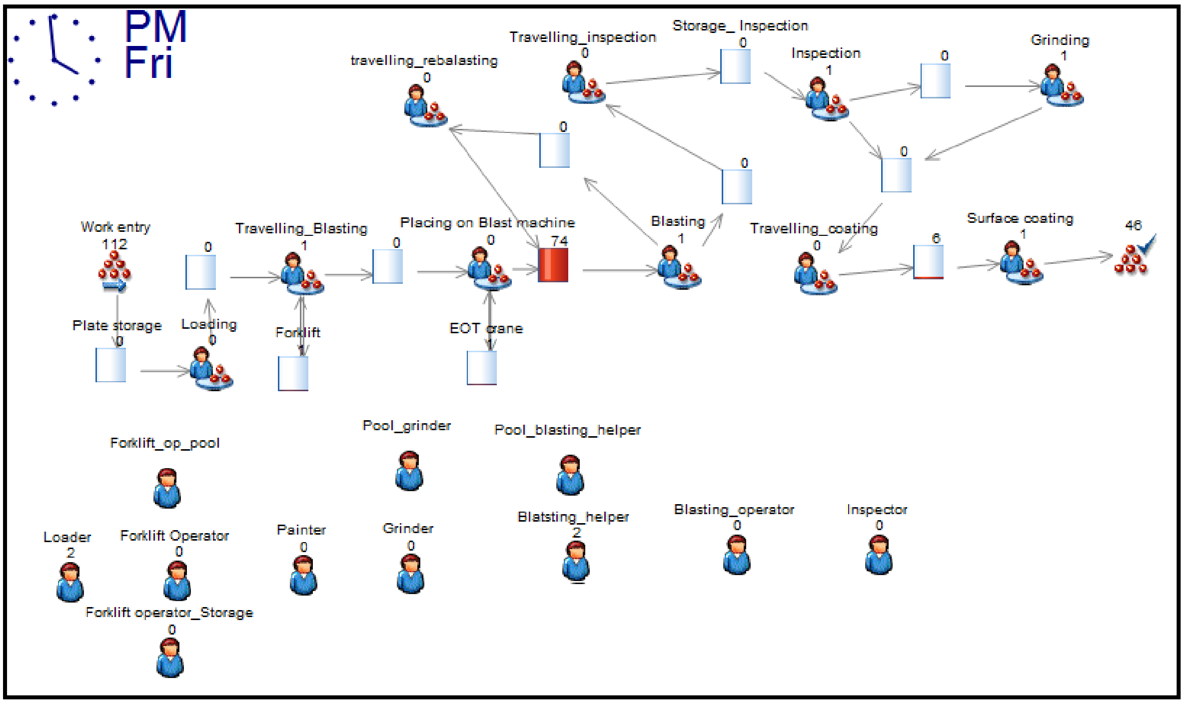

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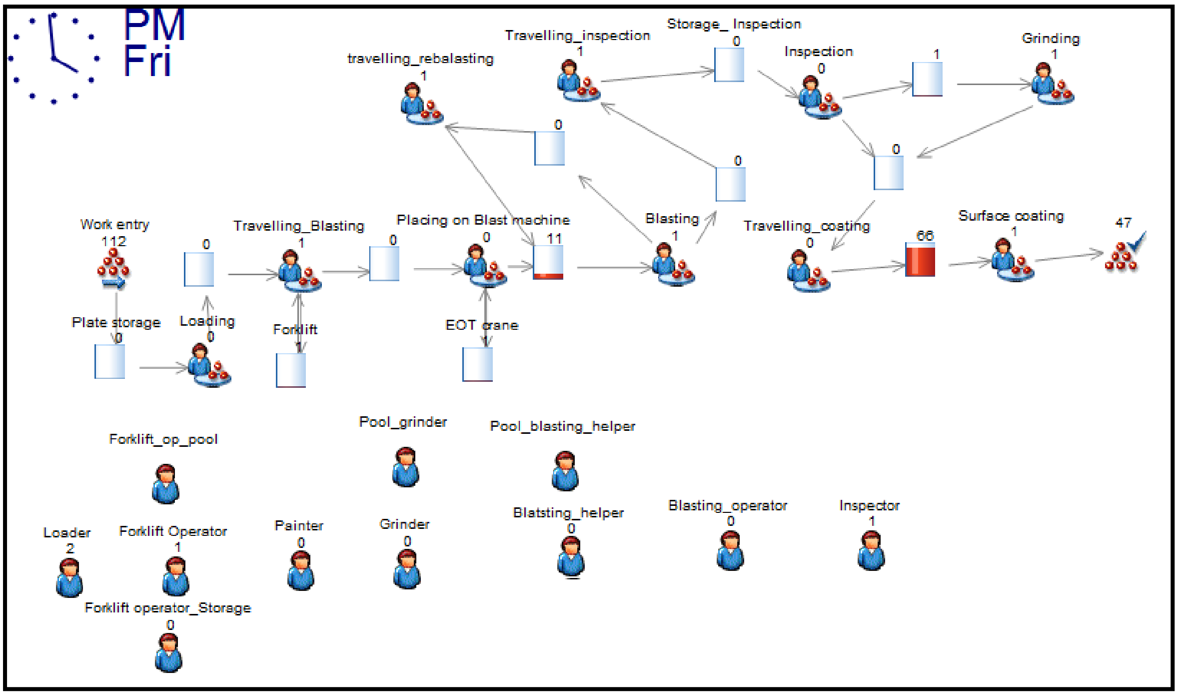

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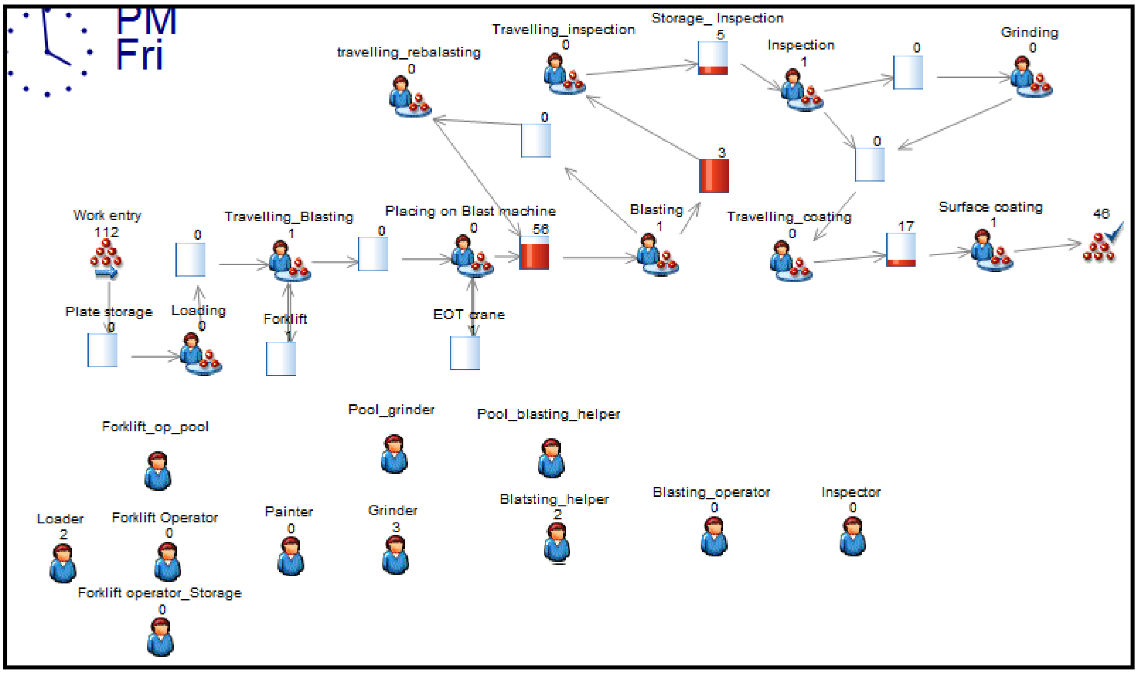

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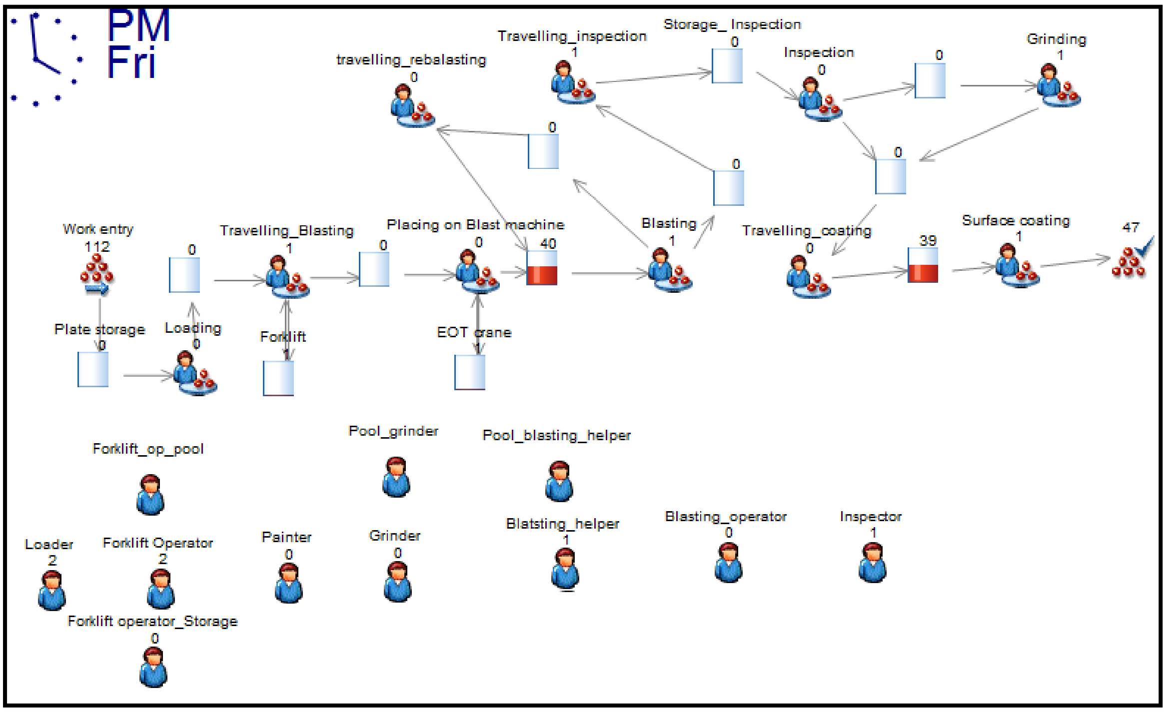

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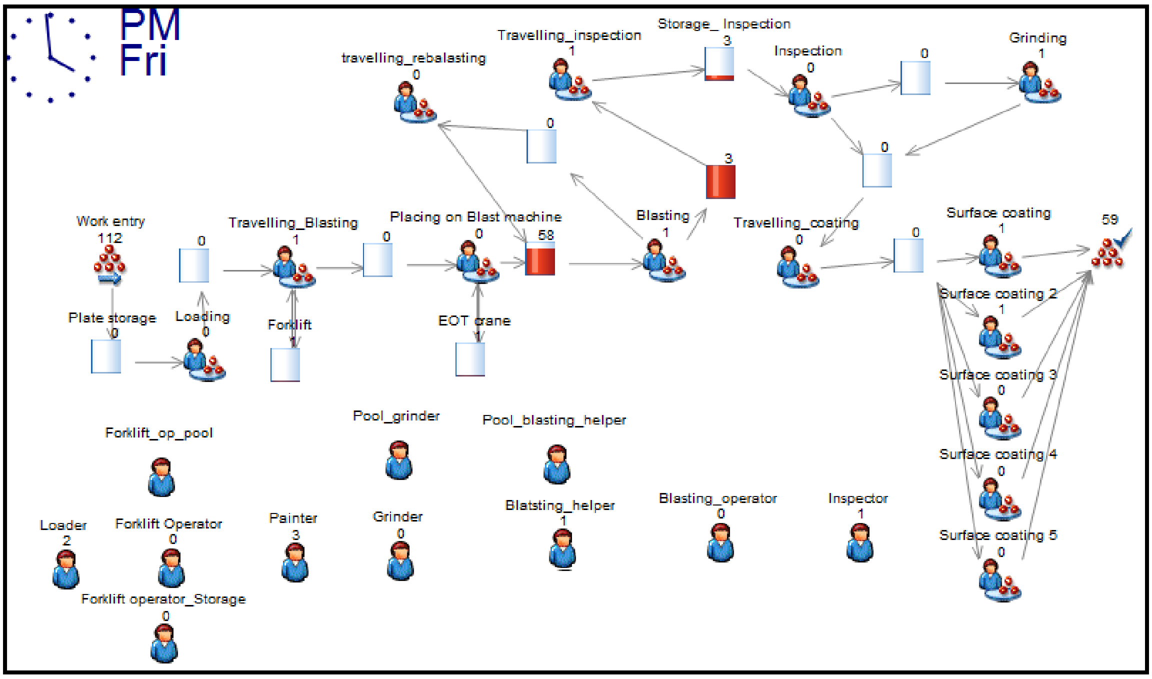

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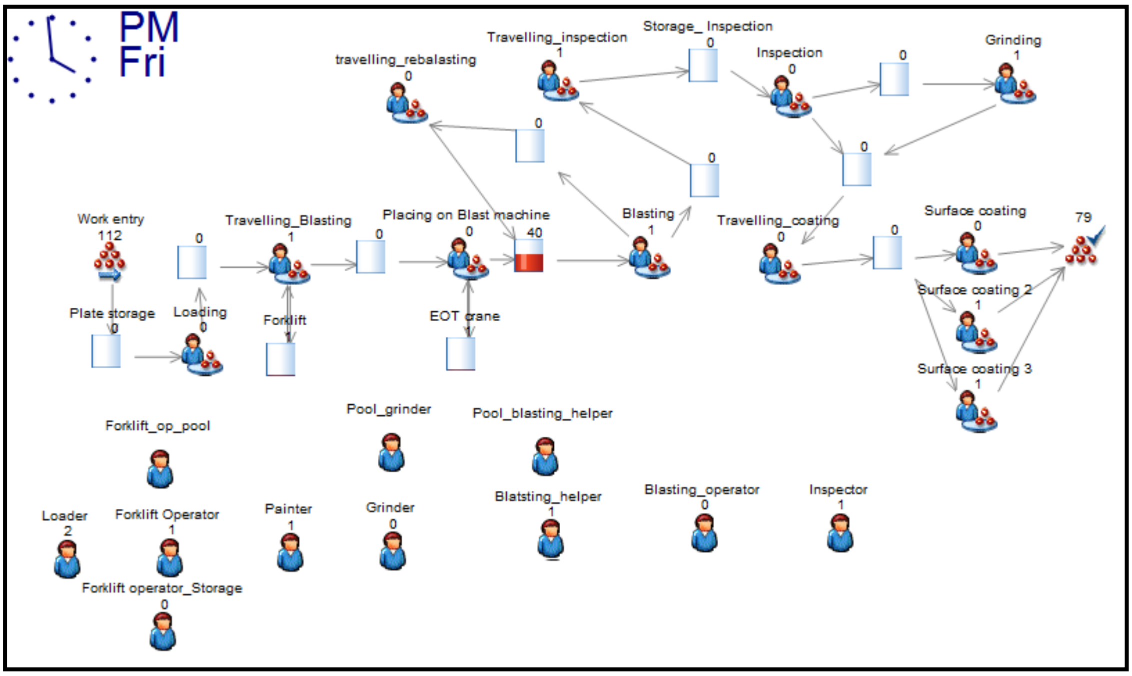

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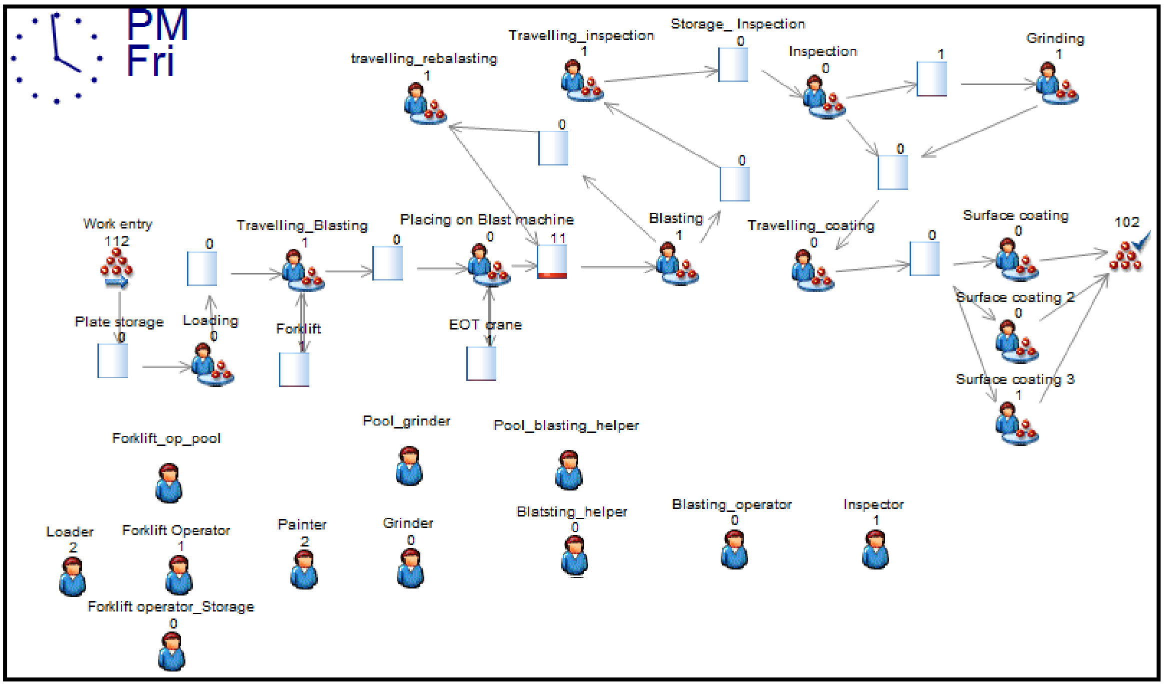

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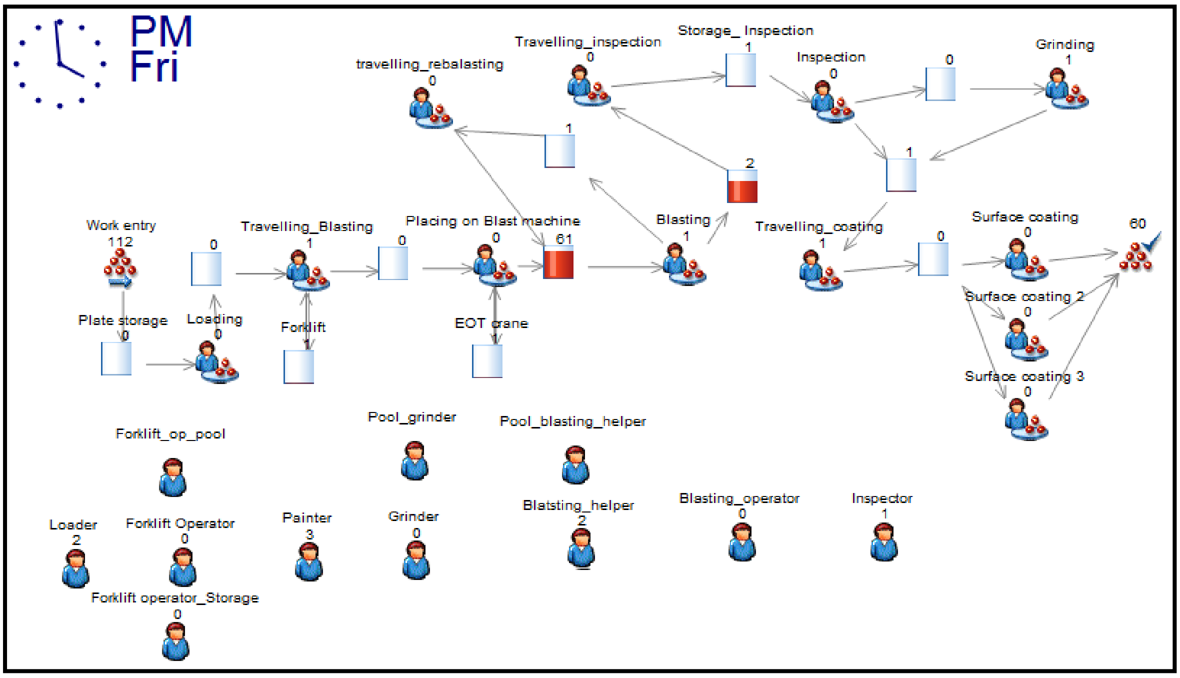

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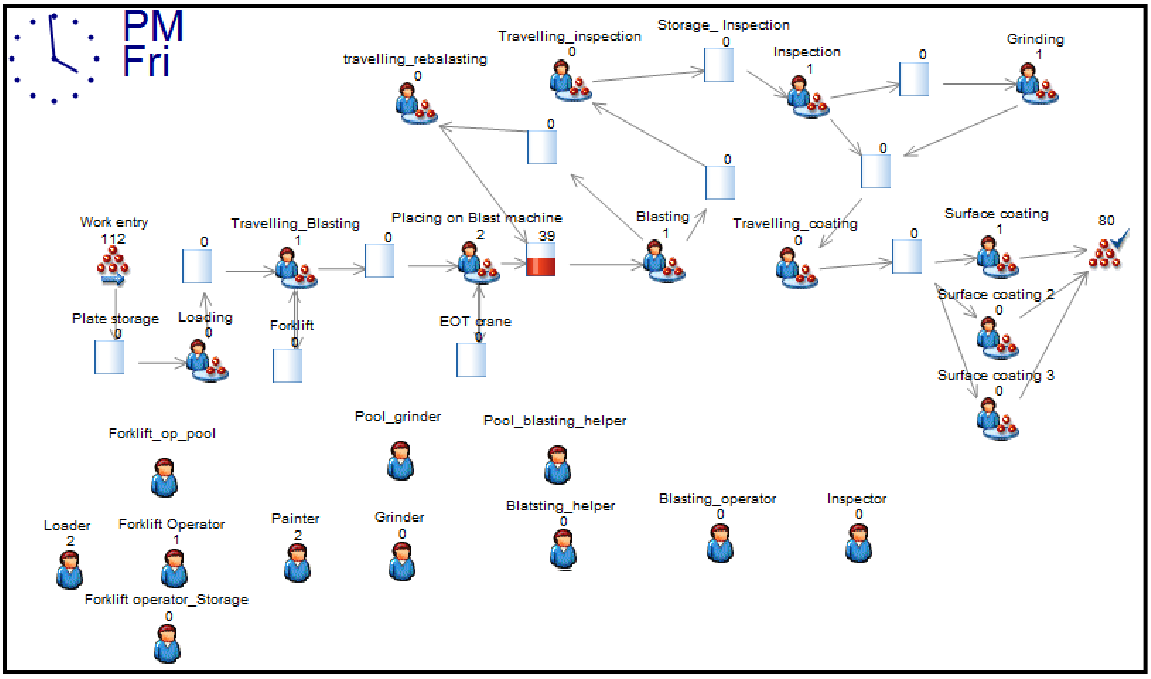

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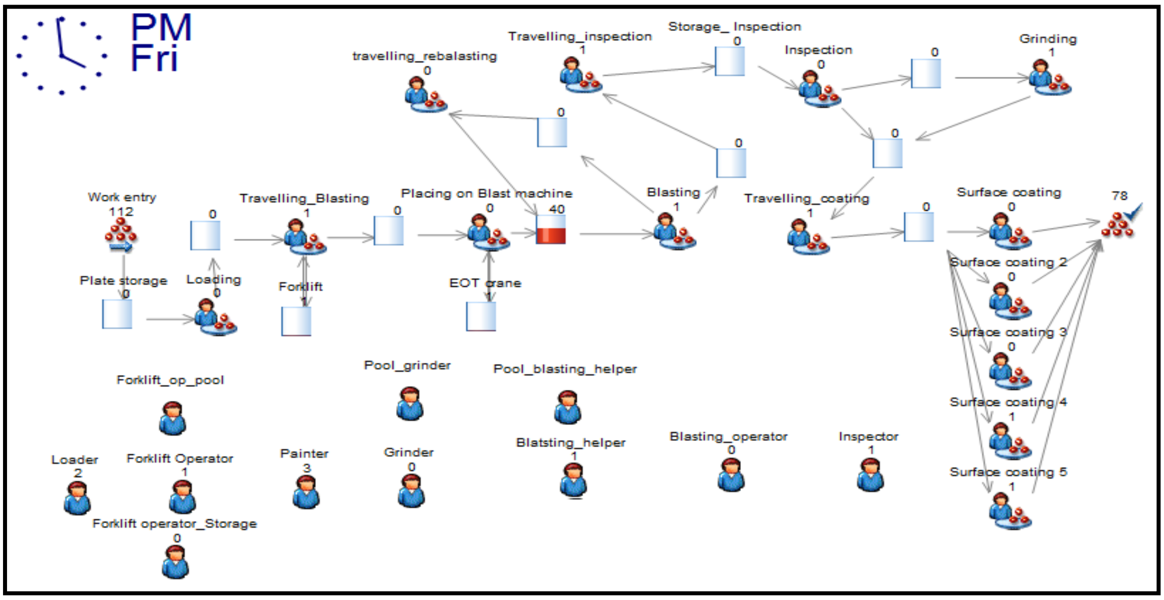

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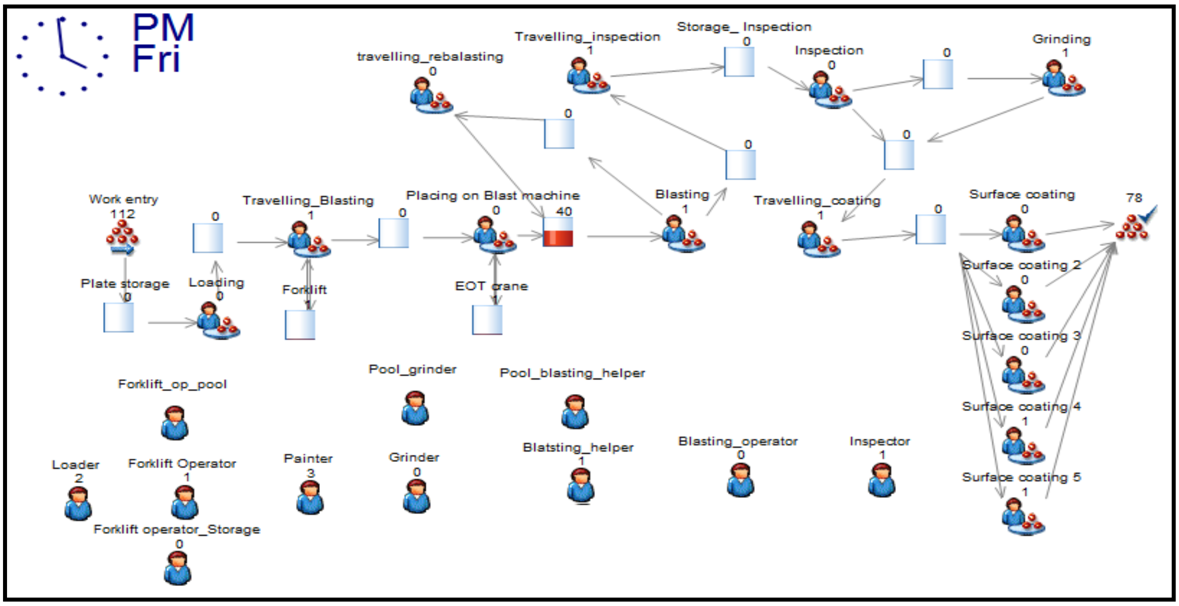

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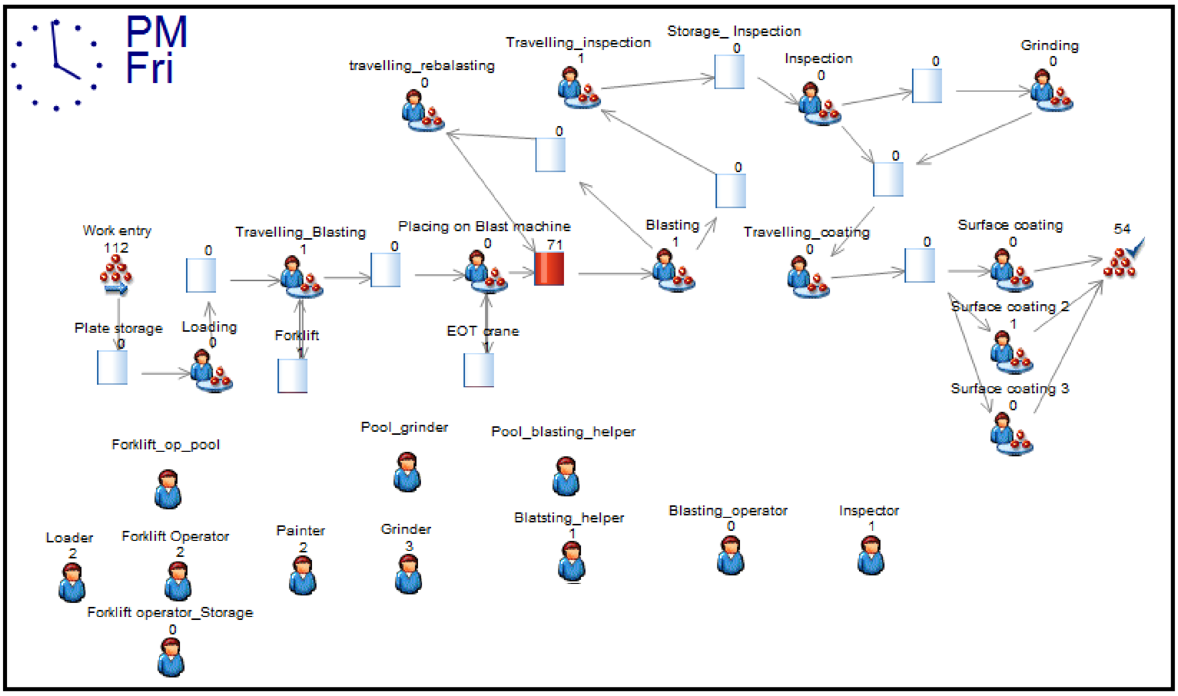

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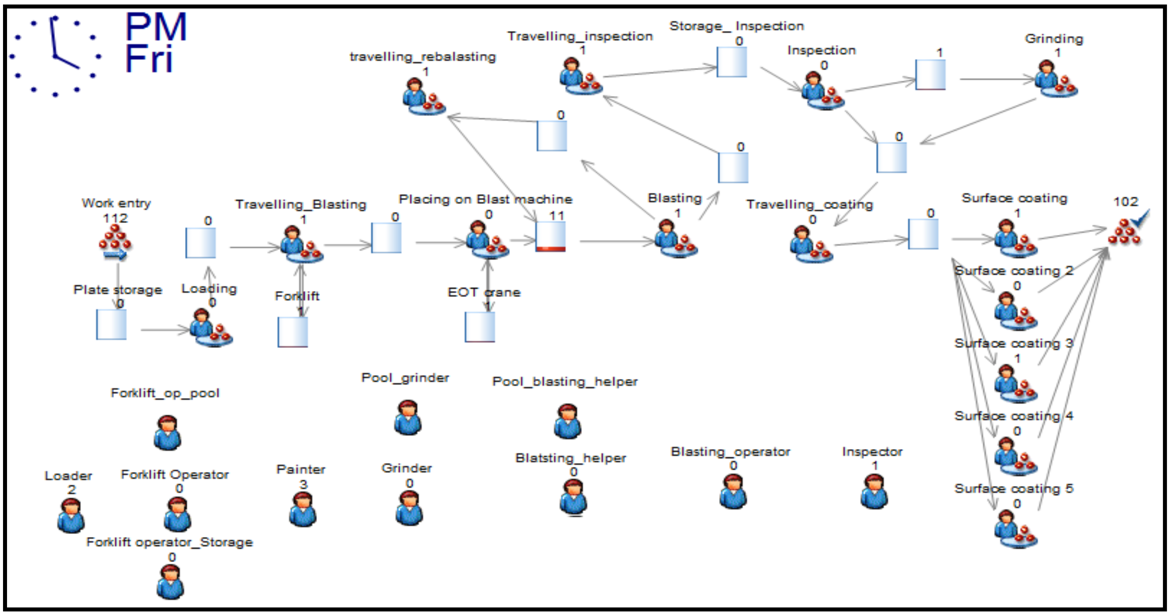

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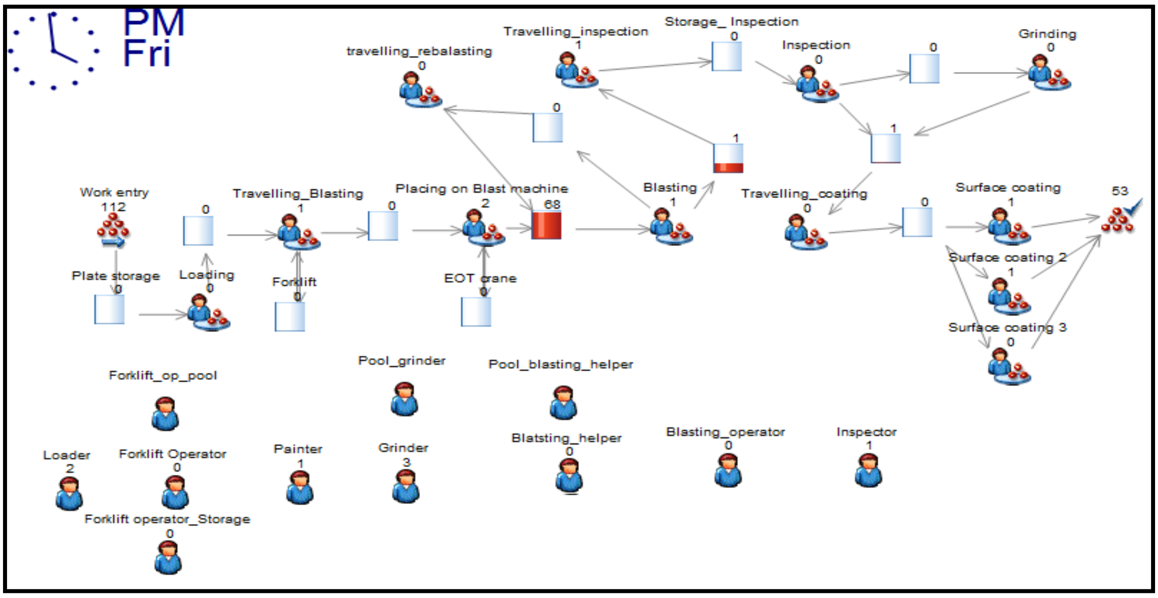

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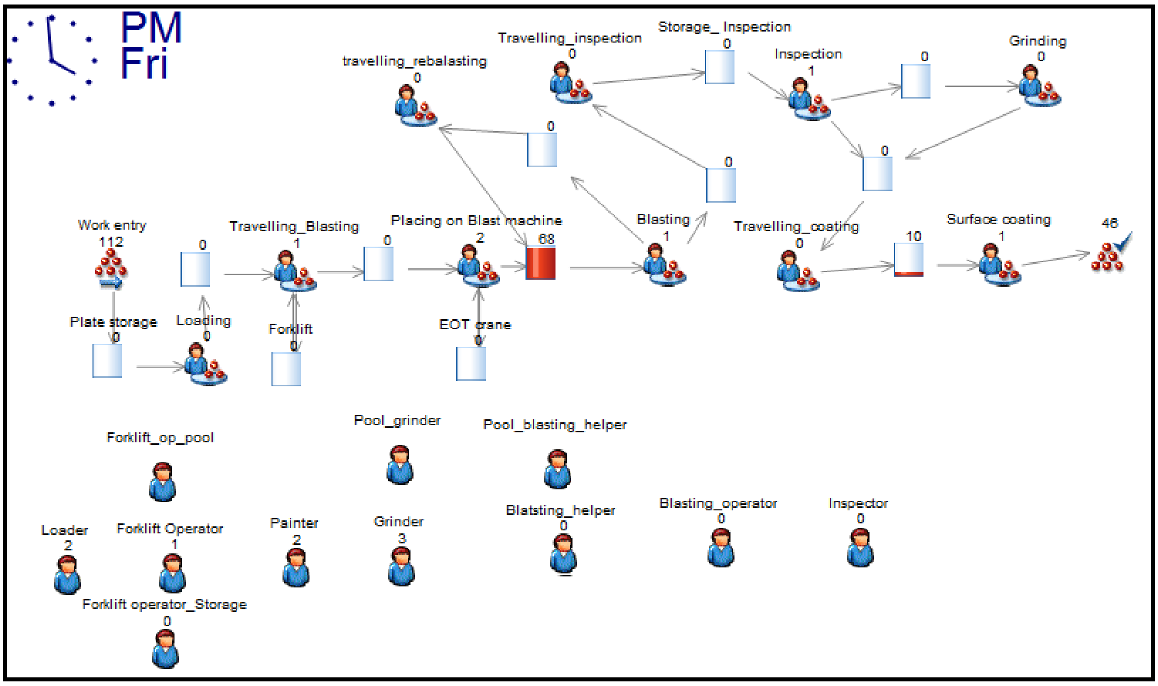

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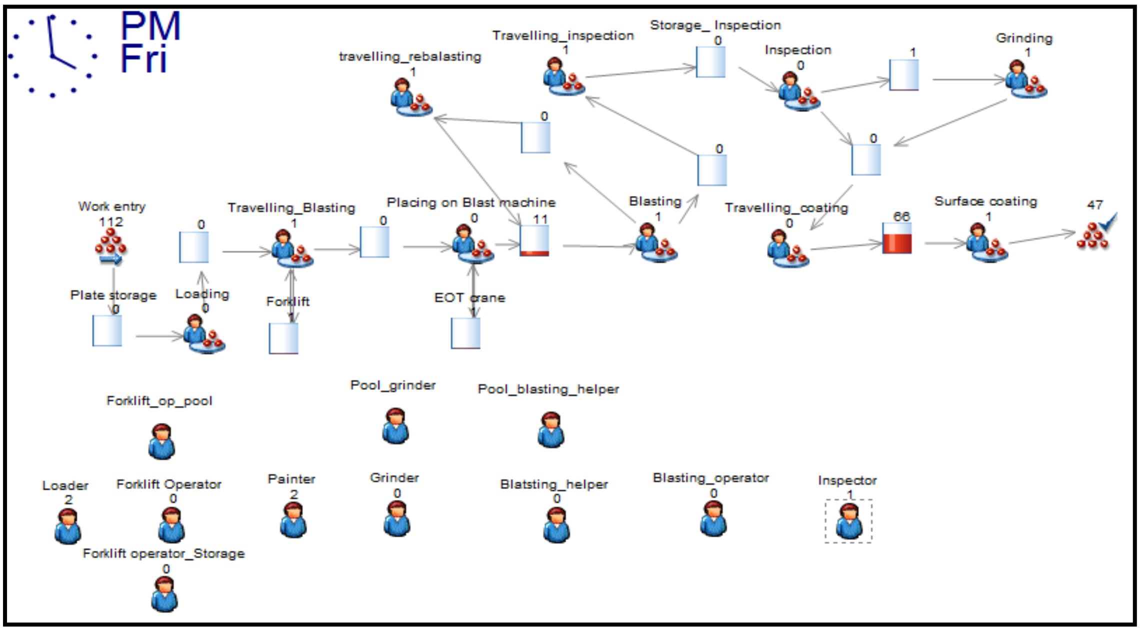

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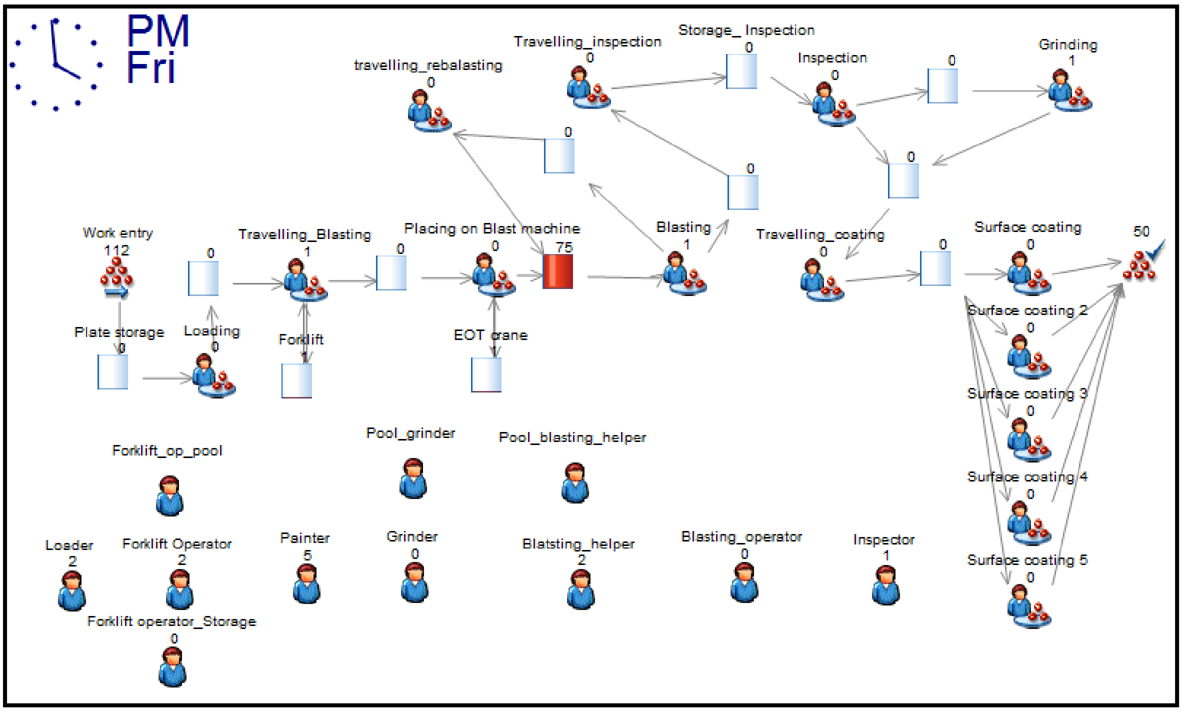

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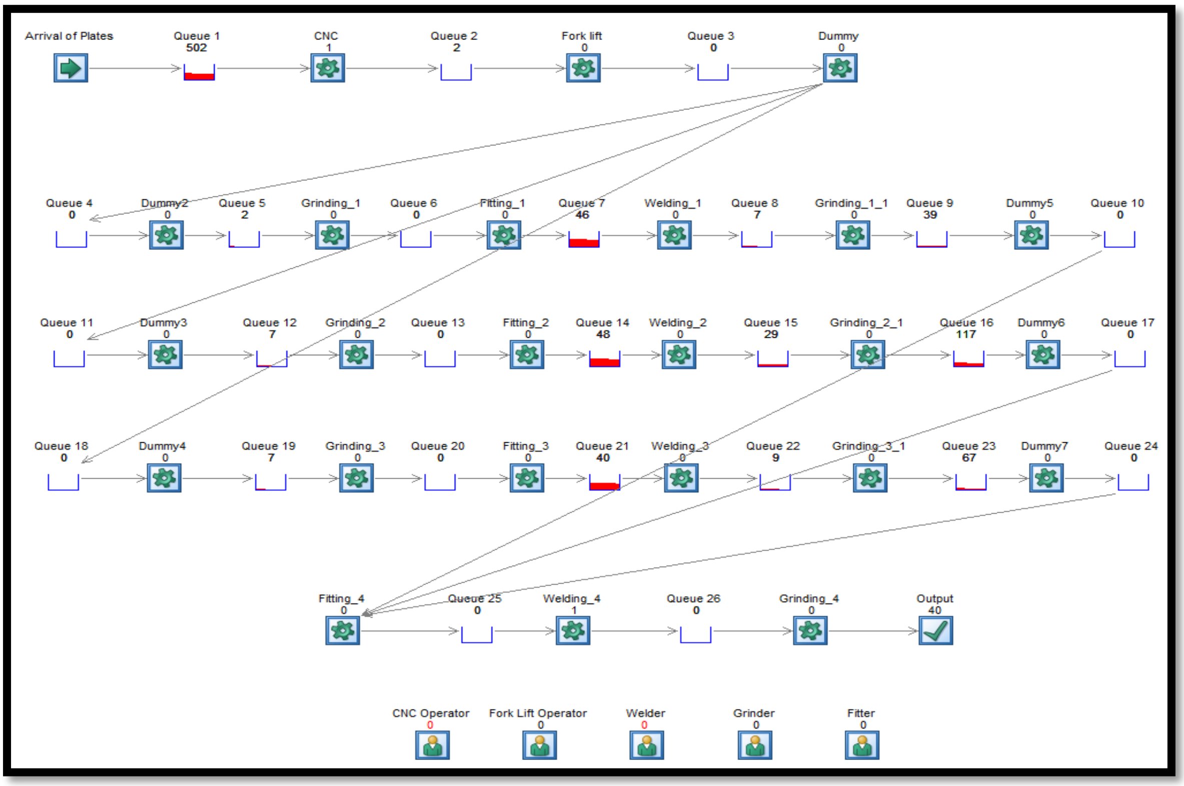
Appendix B



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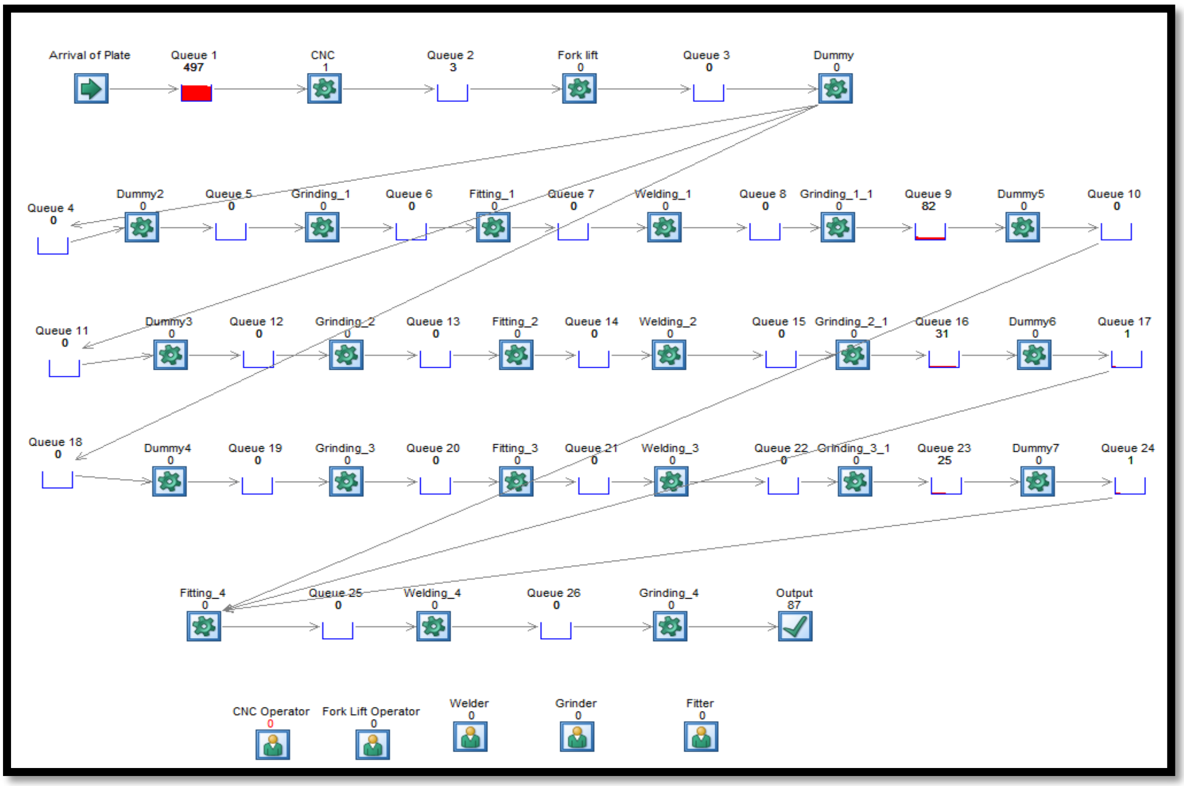

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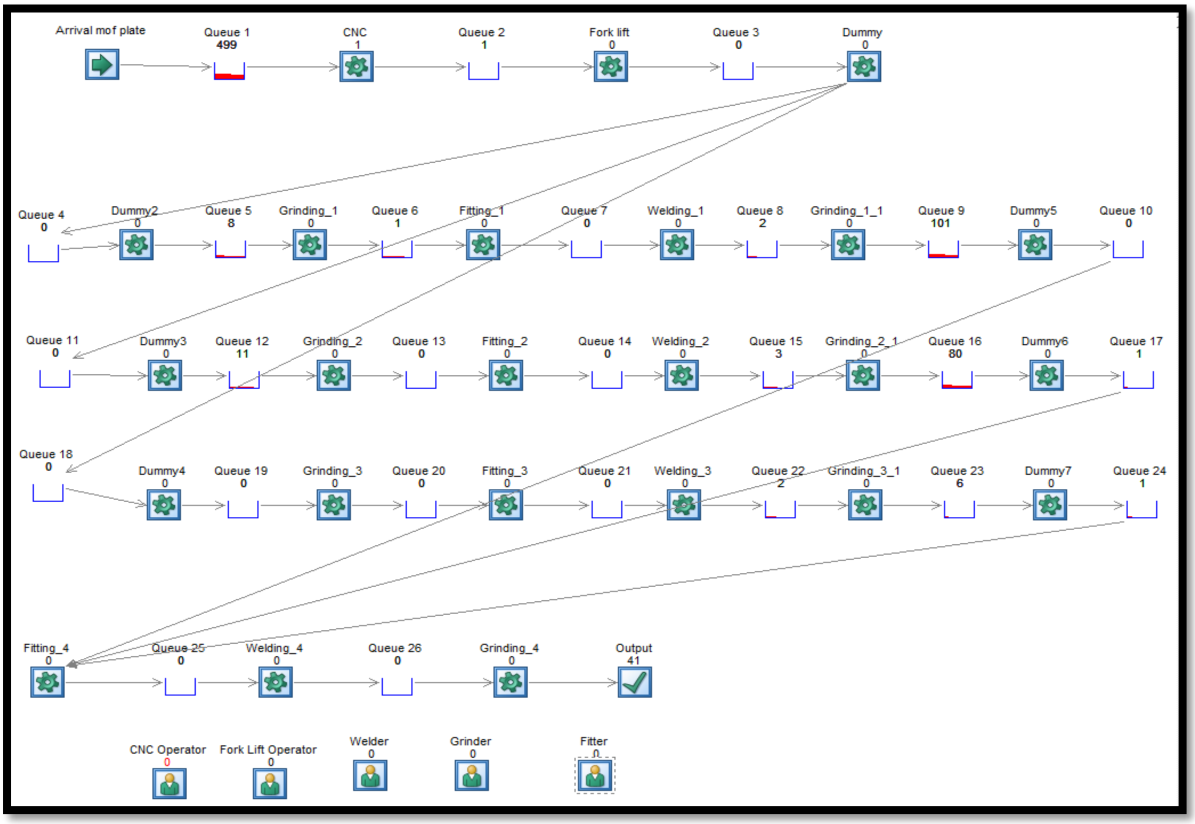

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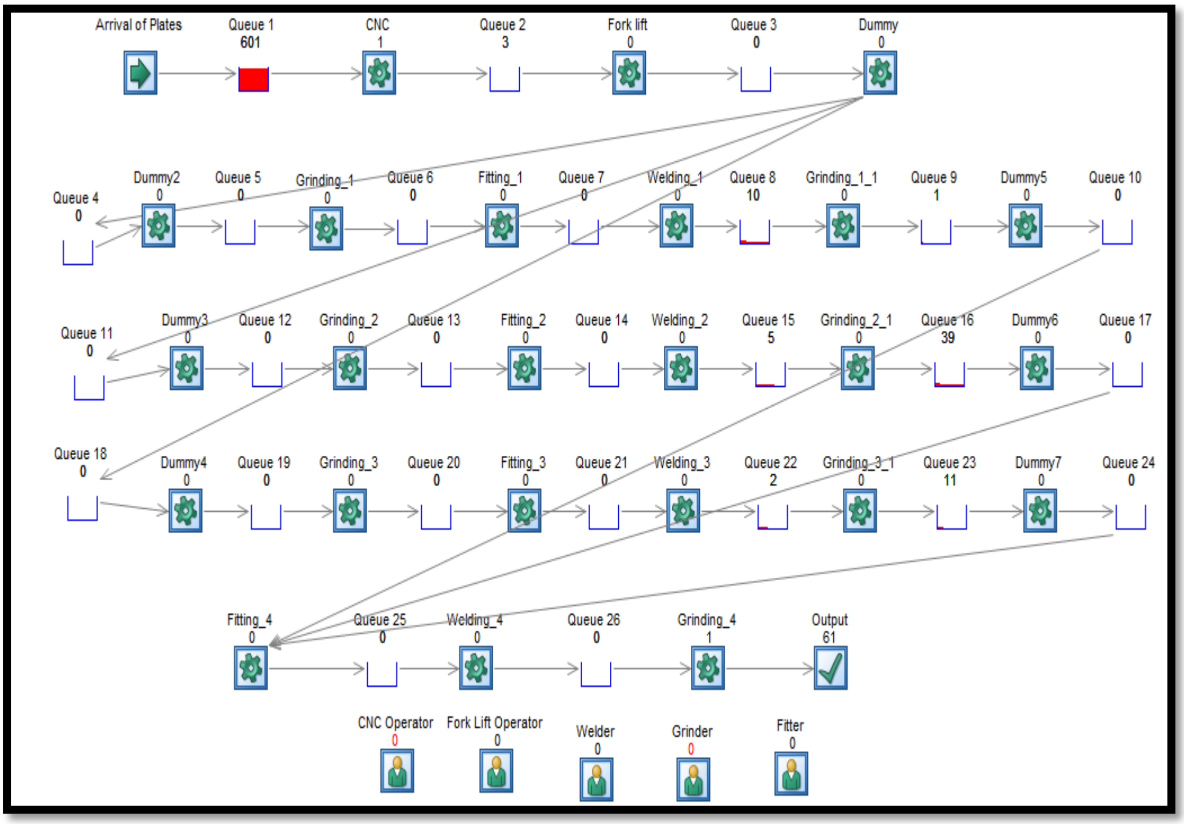

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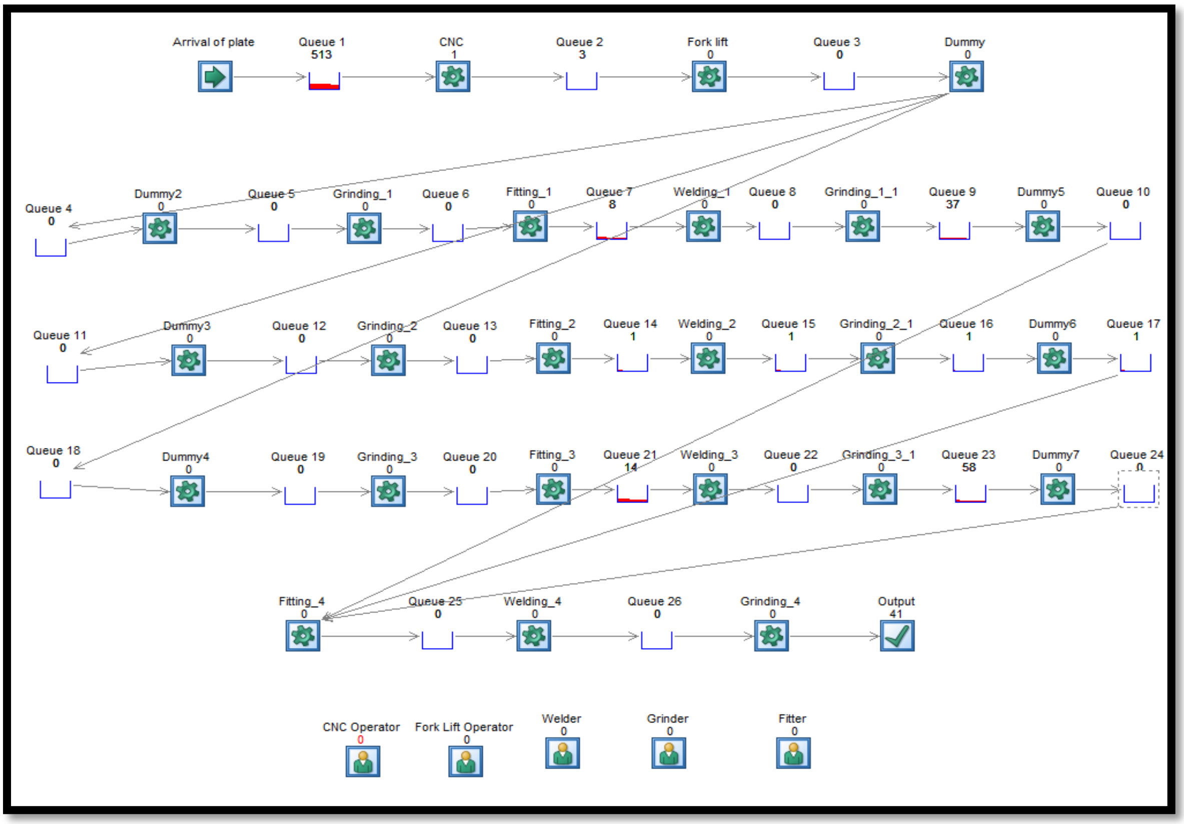

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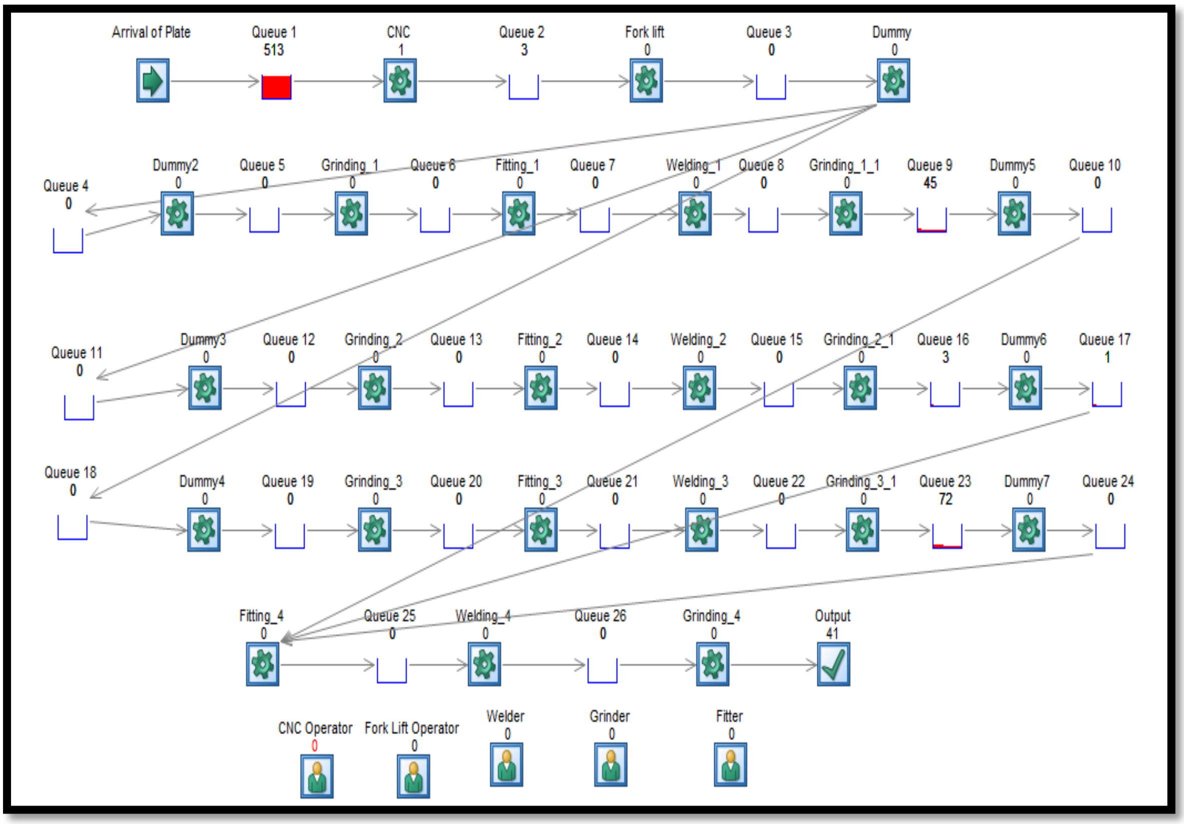

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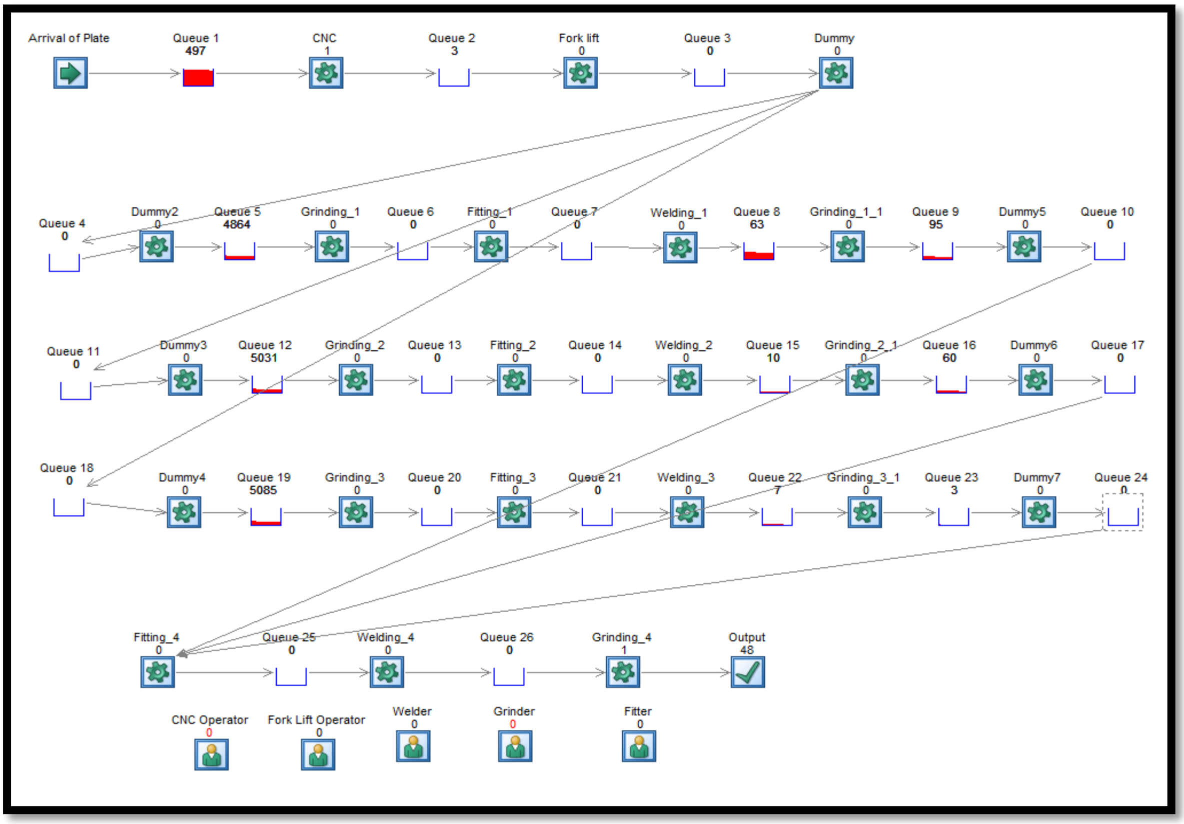

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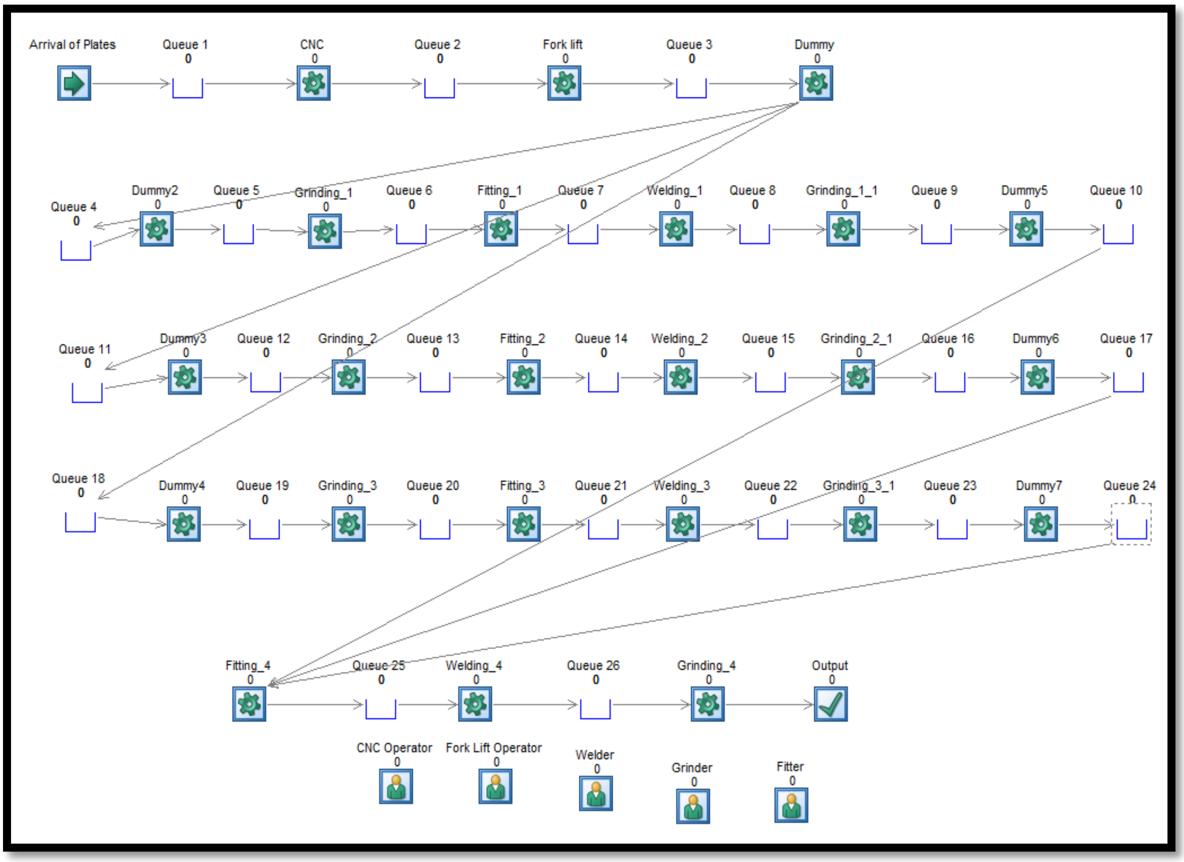

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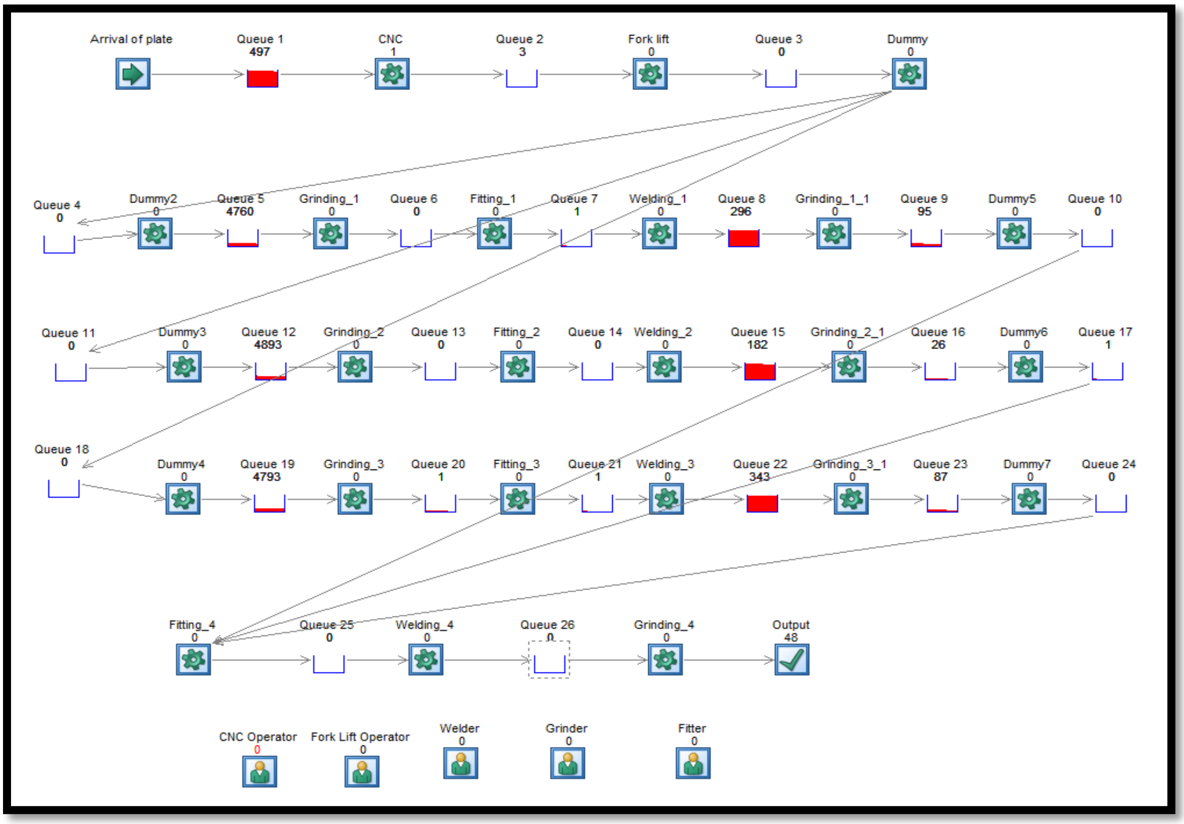

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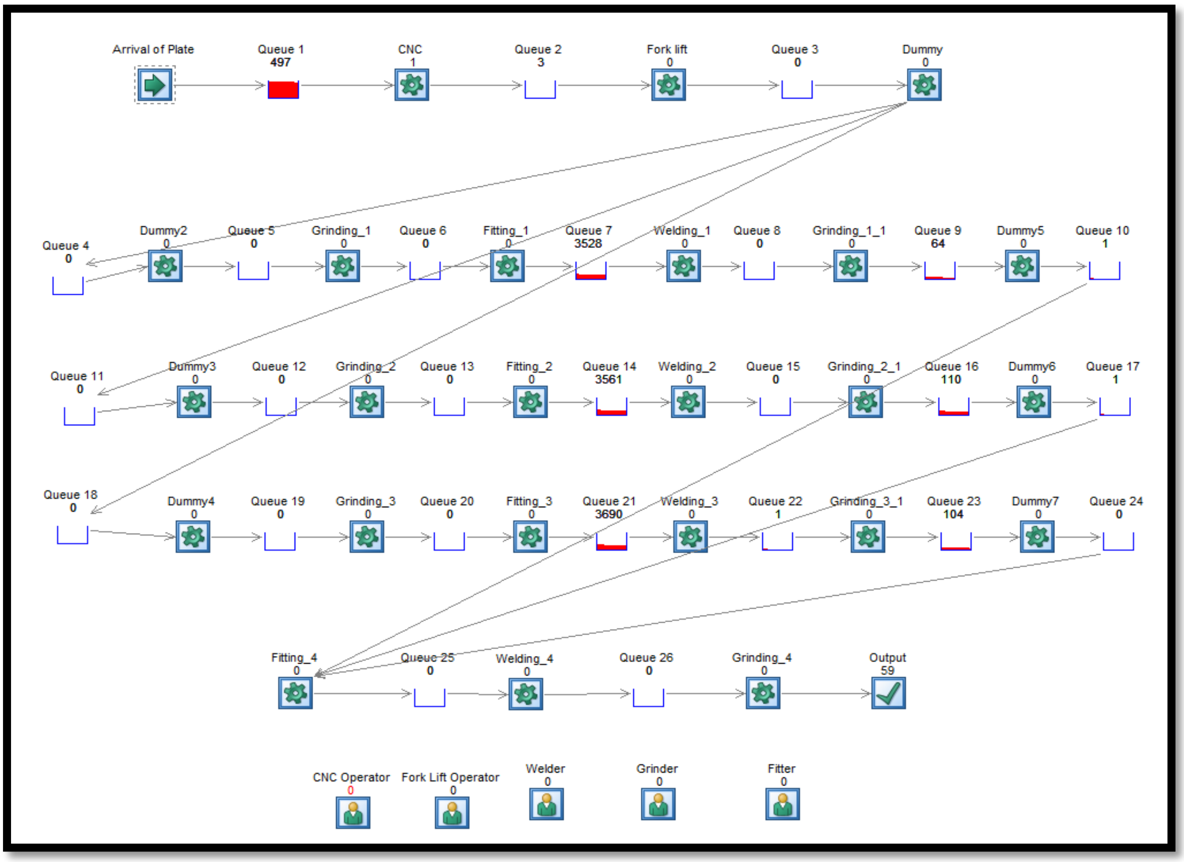

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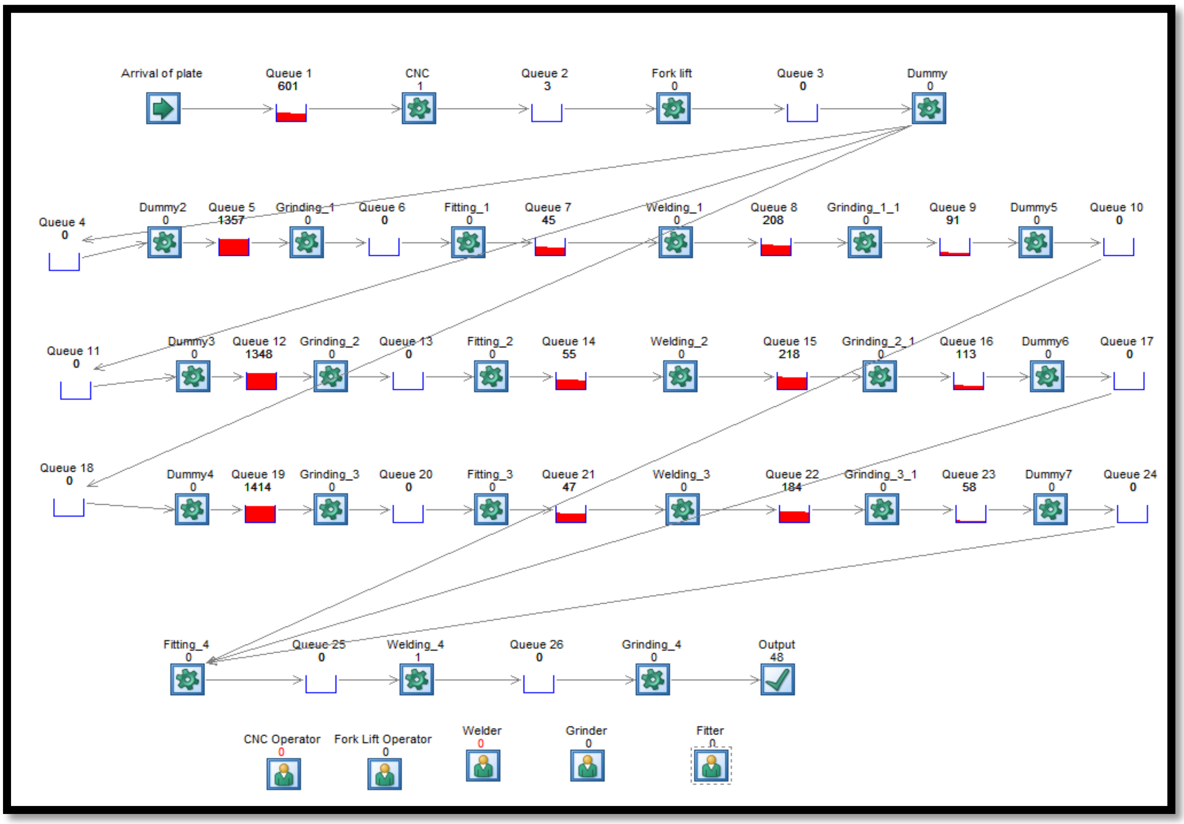

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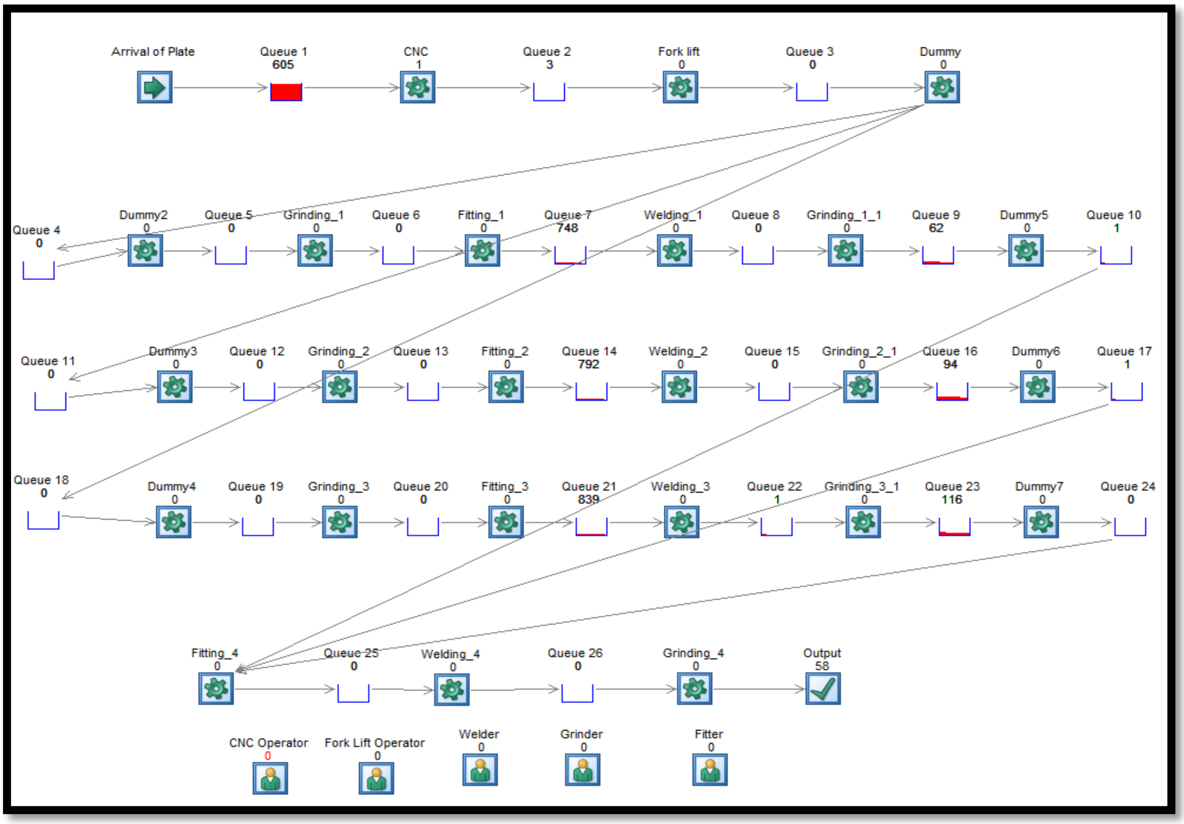

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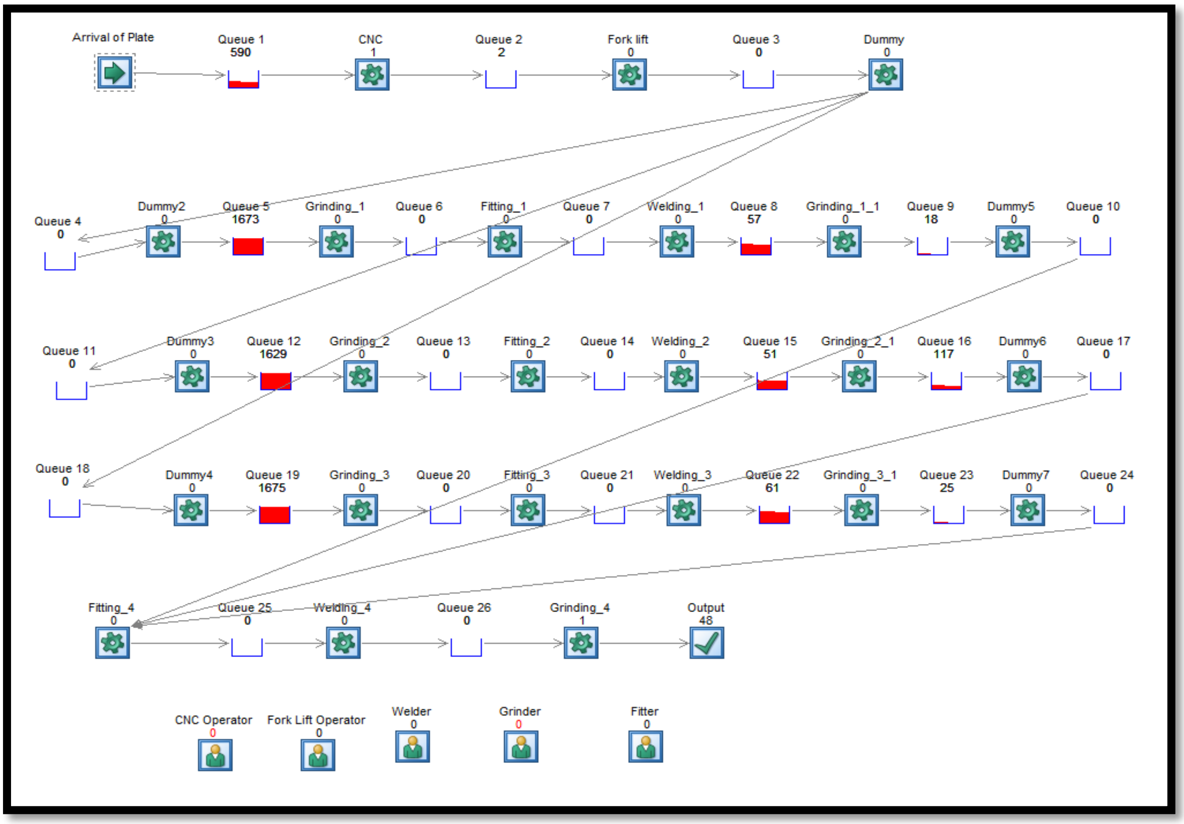

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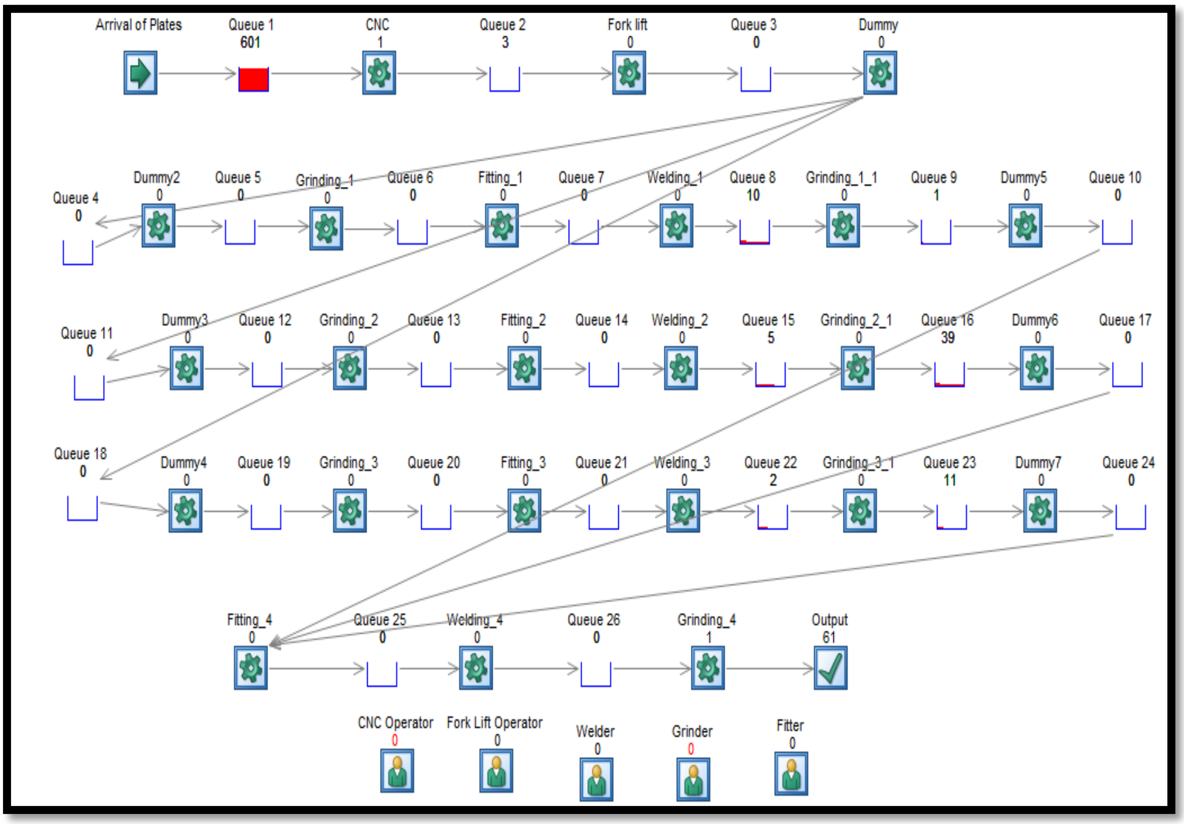

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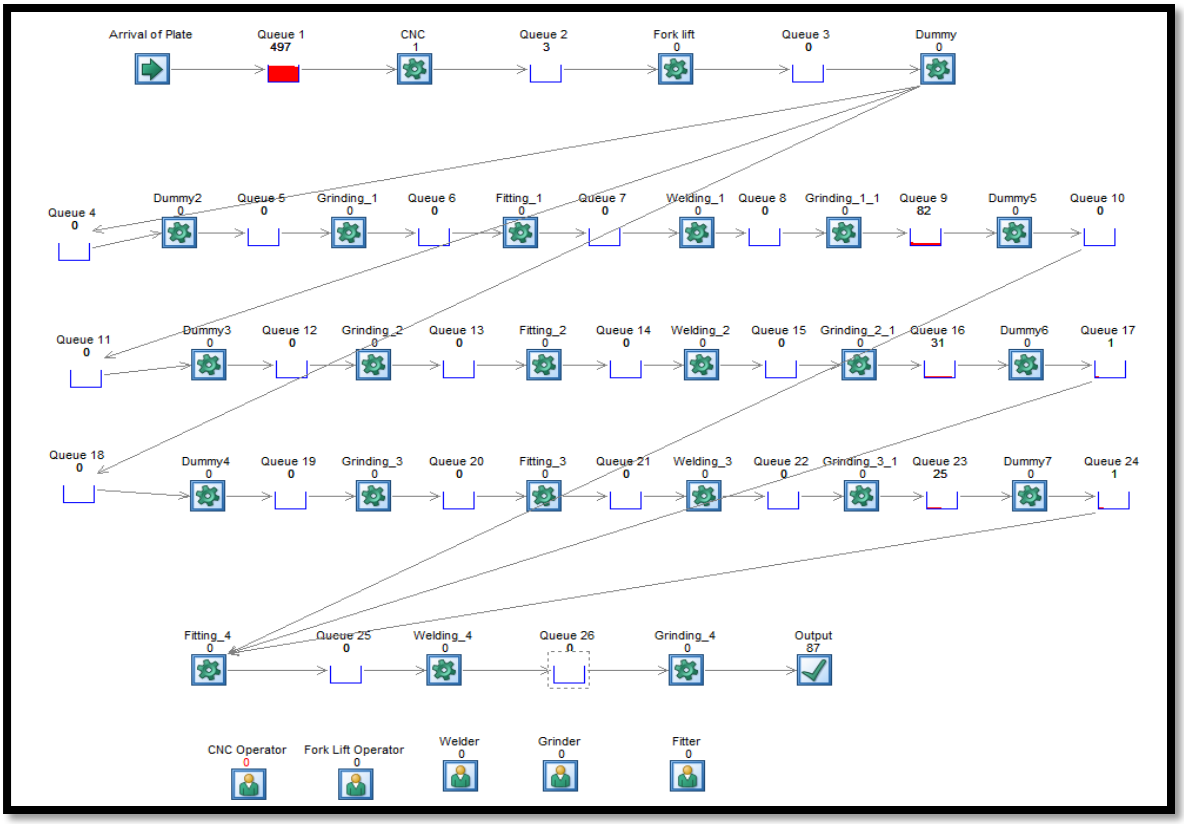

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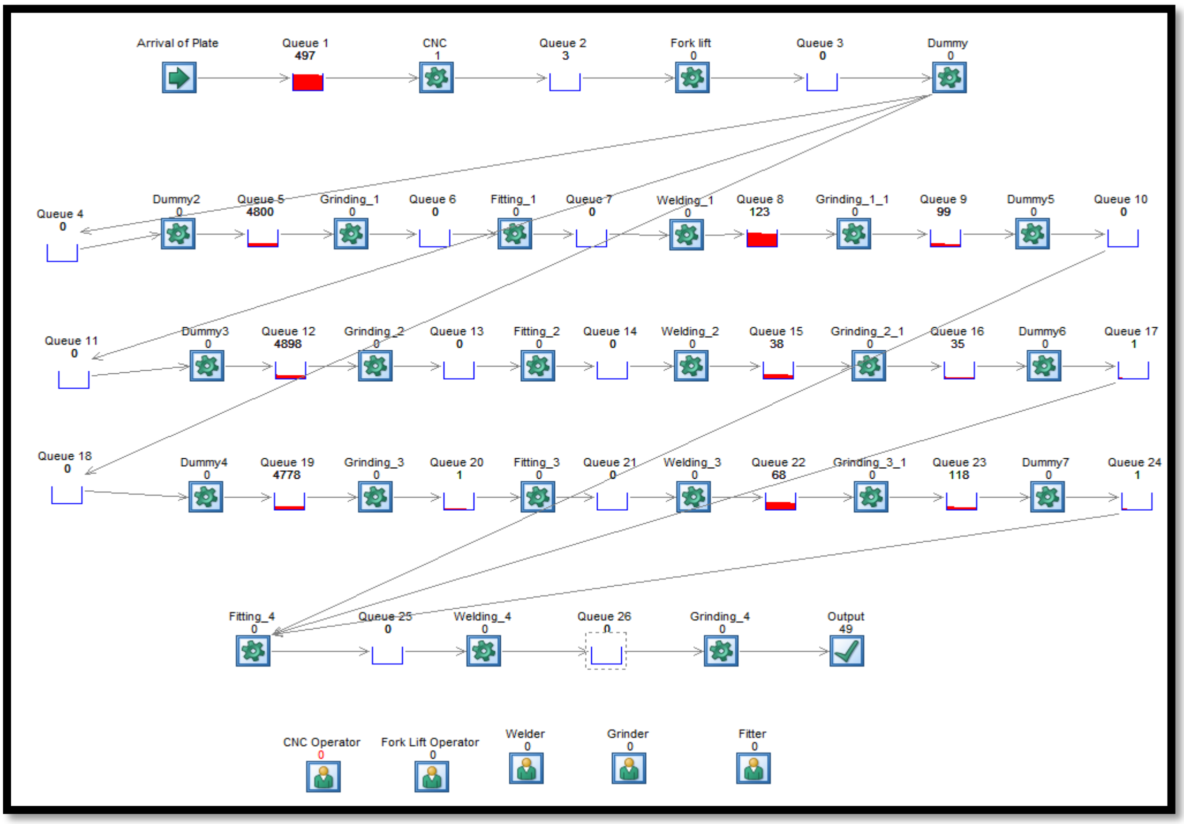

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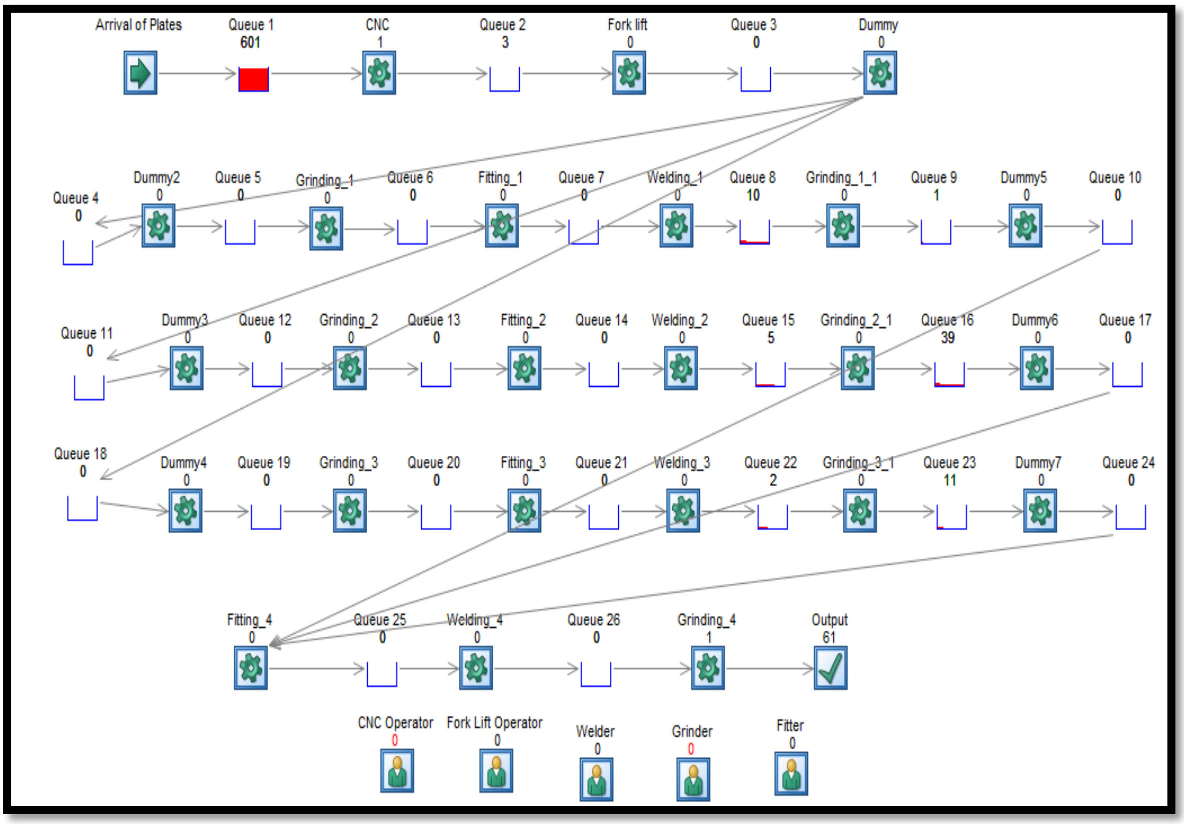

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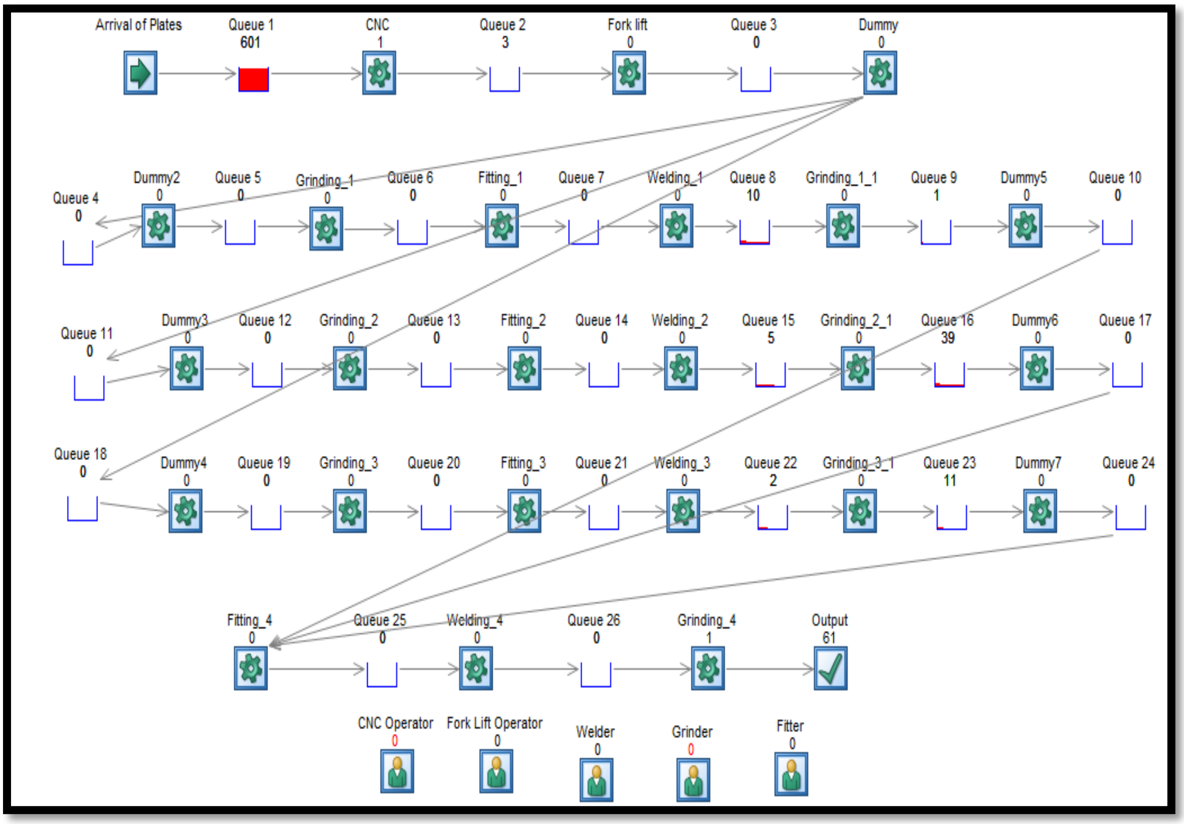

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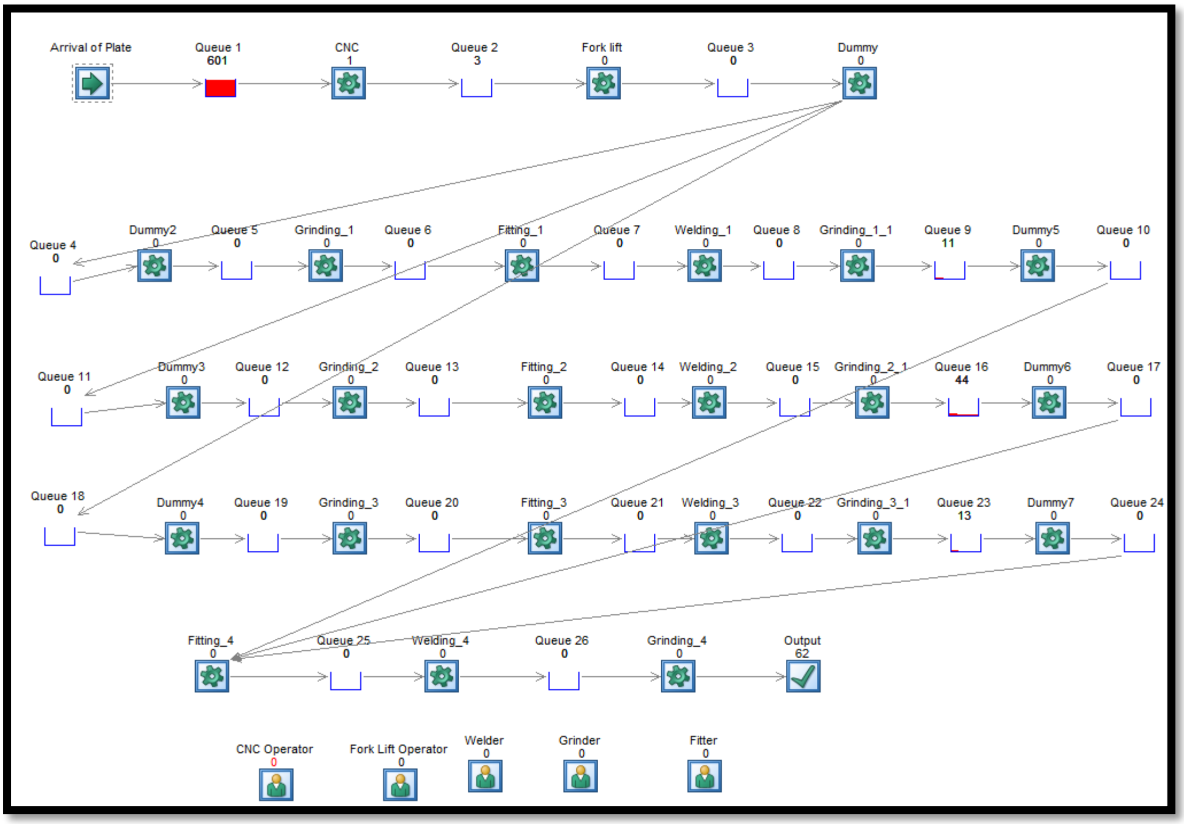

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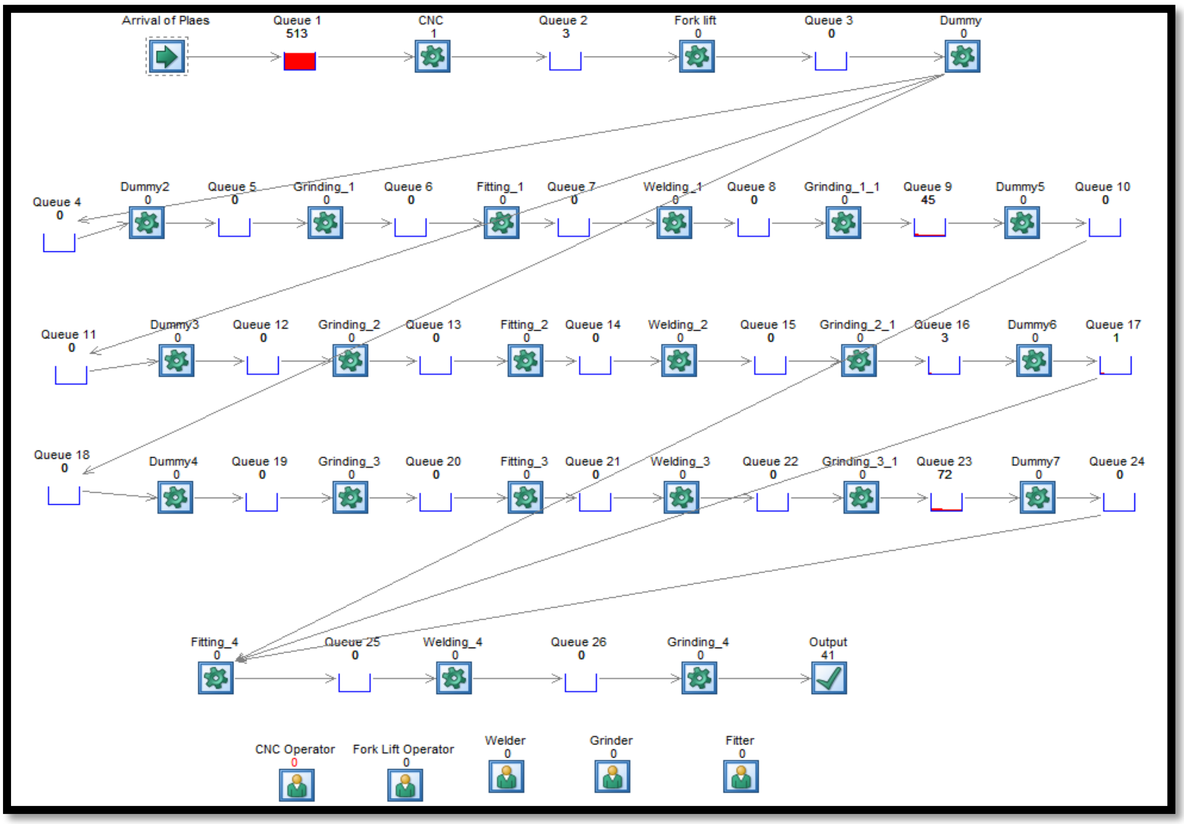

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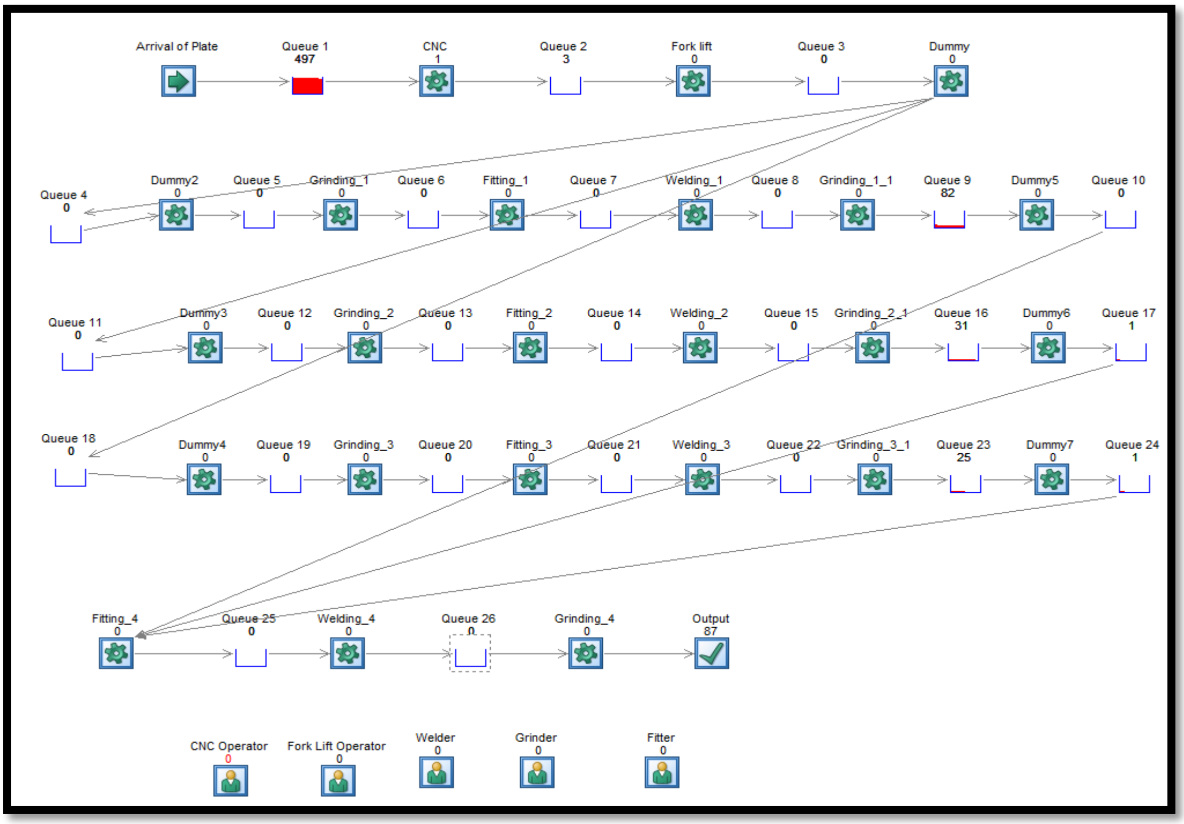

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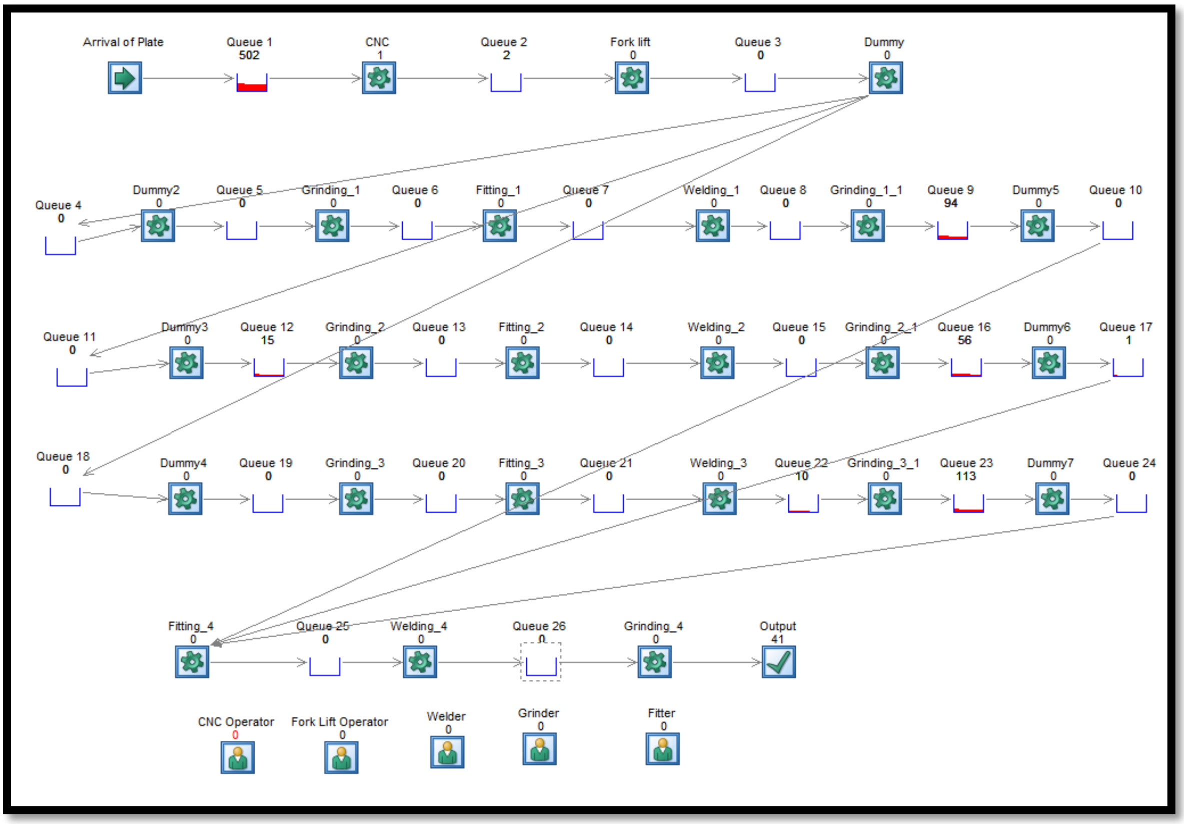

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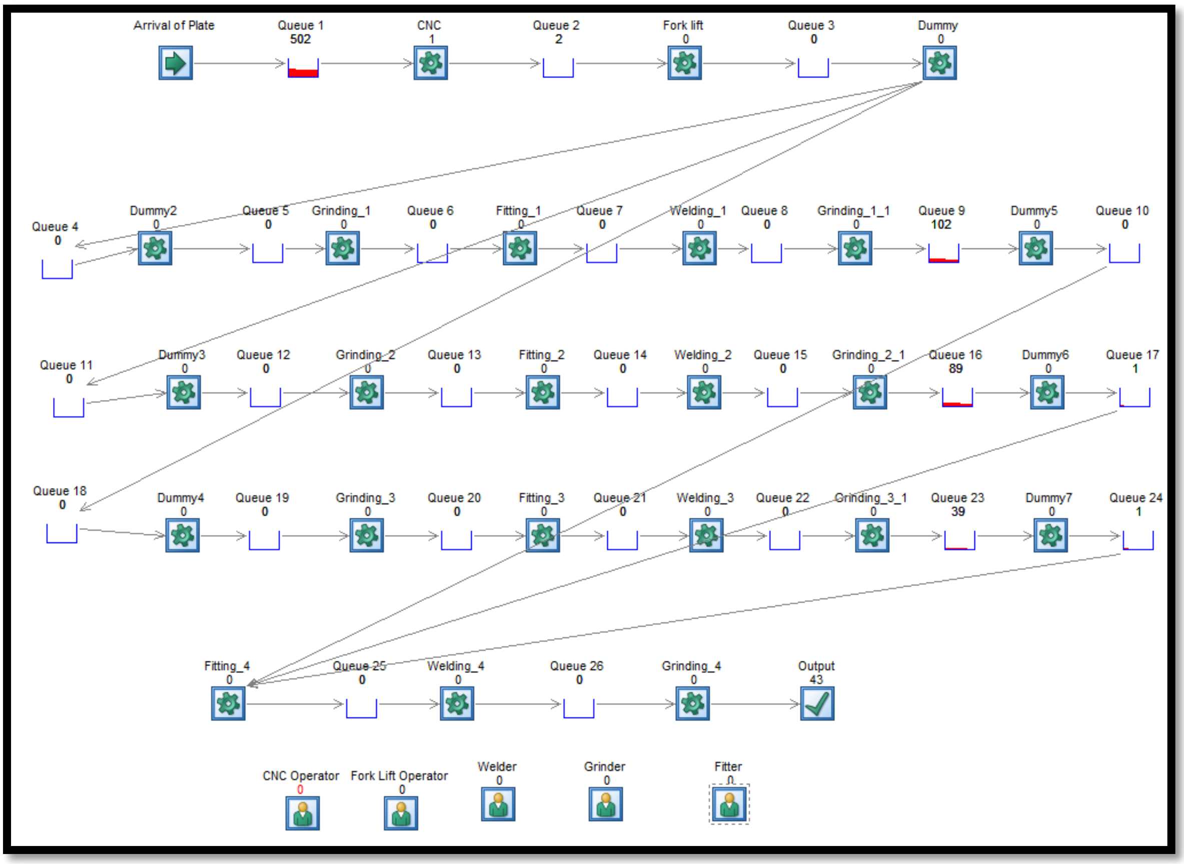

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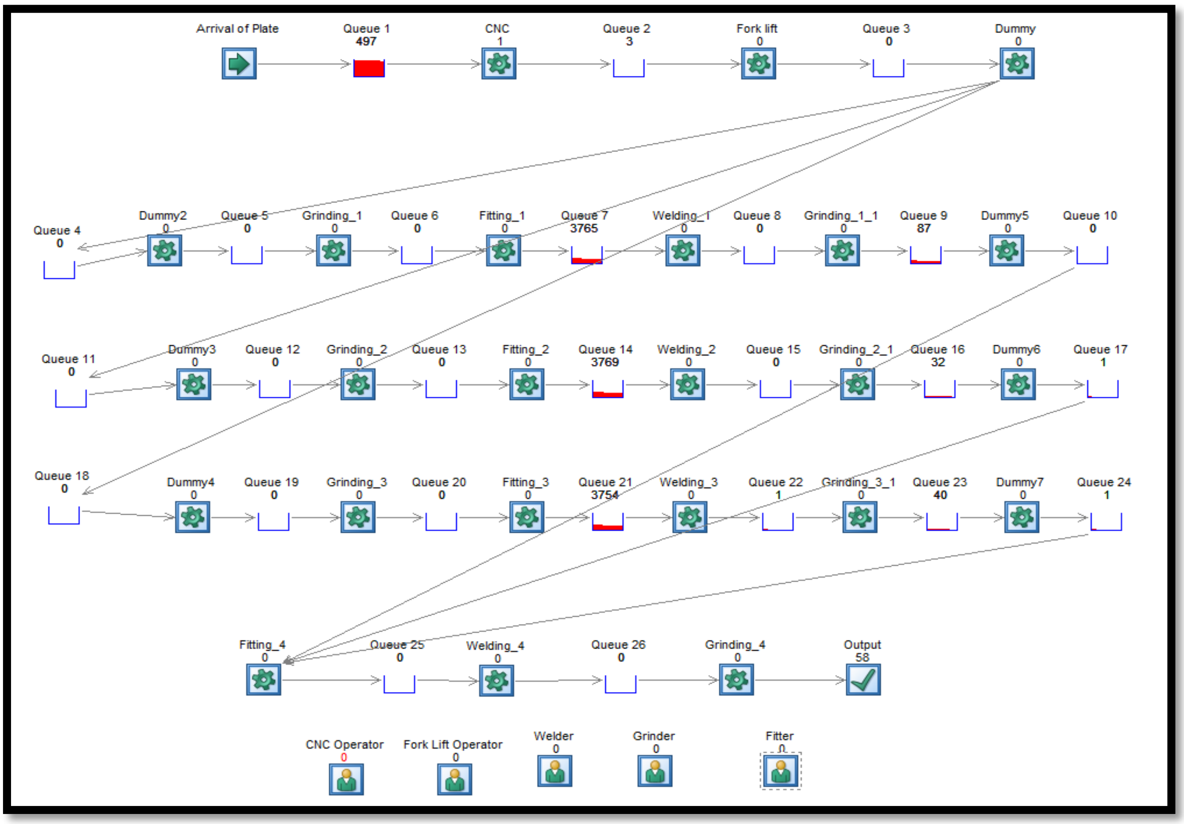

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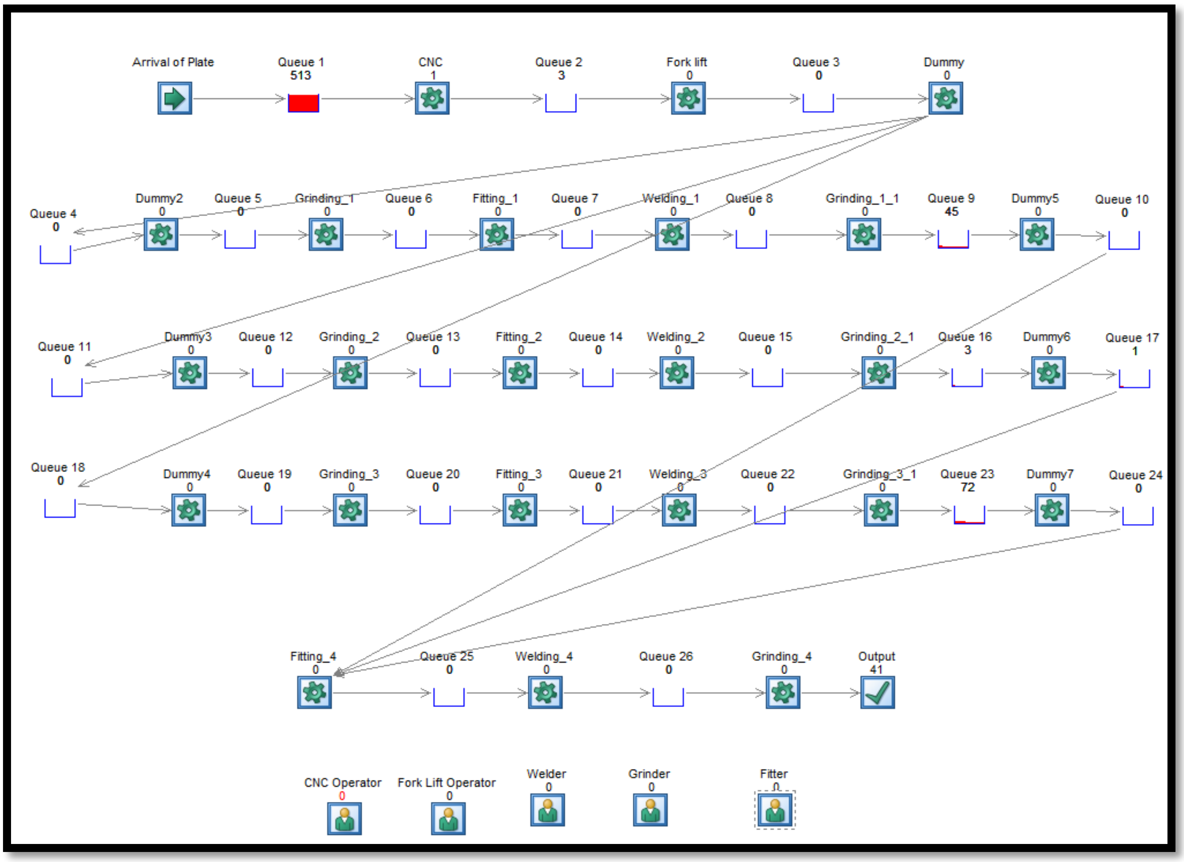

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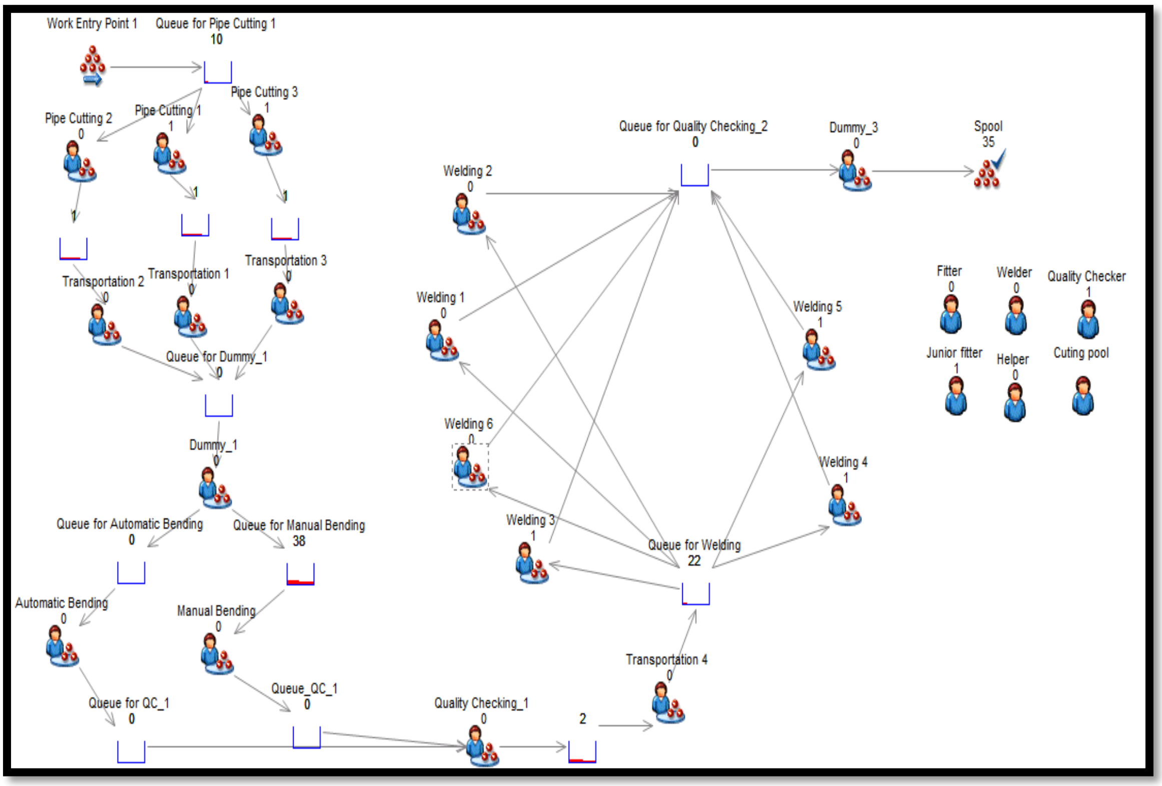
Appendix C



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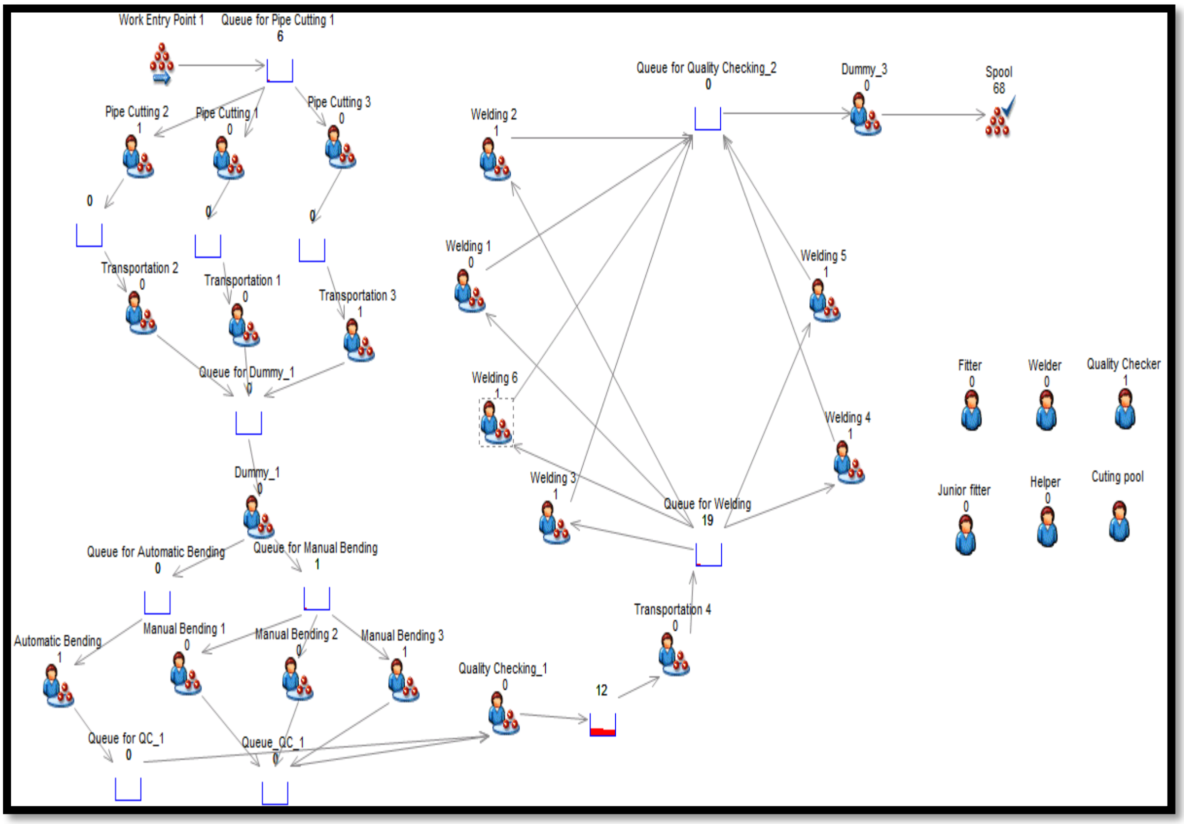

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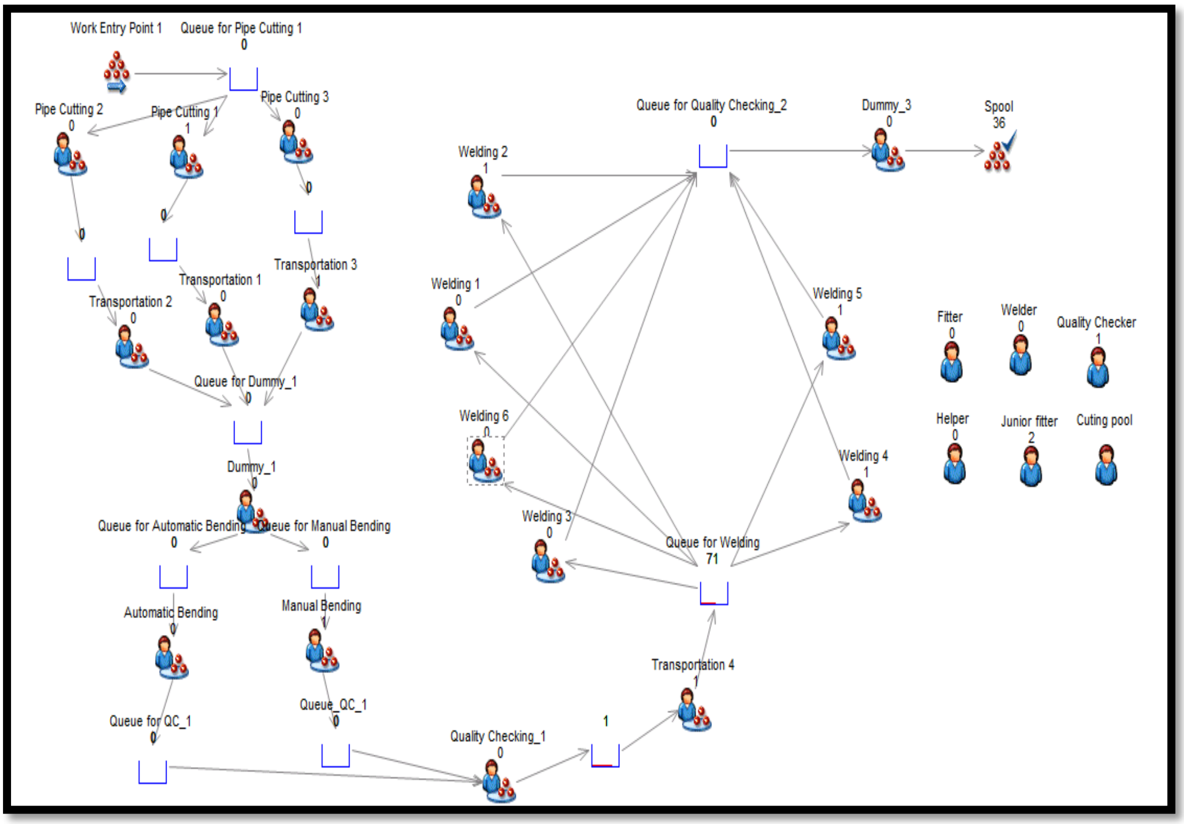

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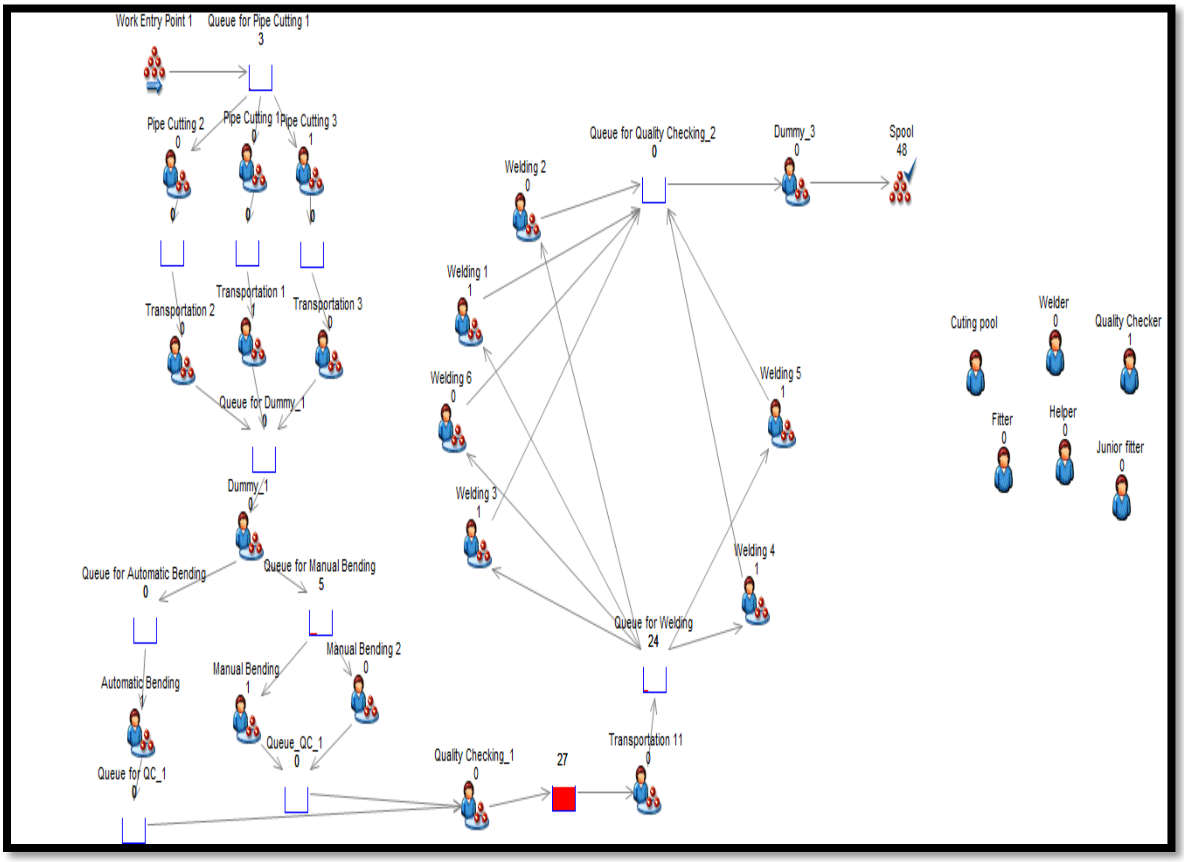

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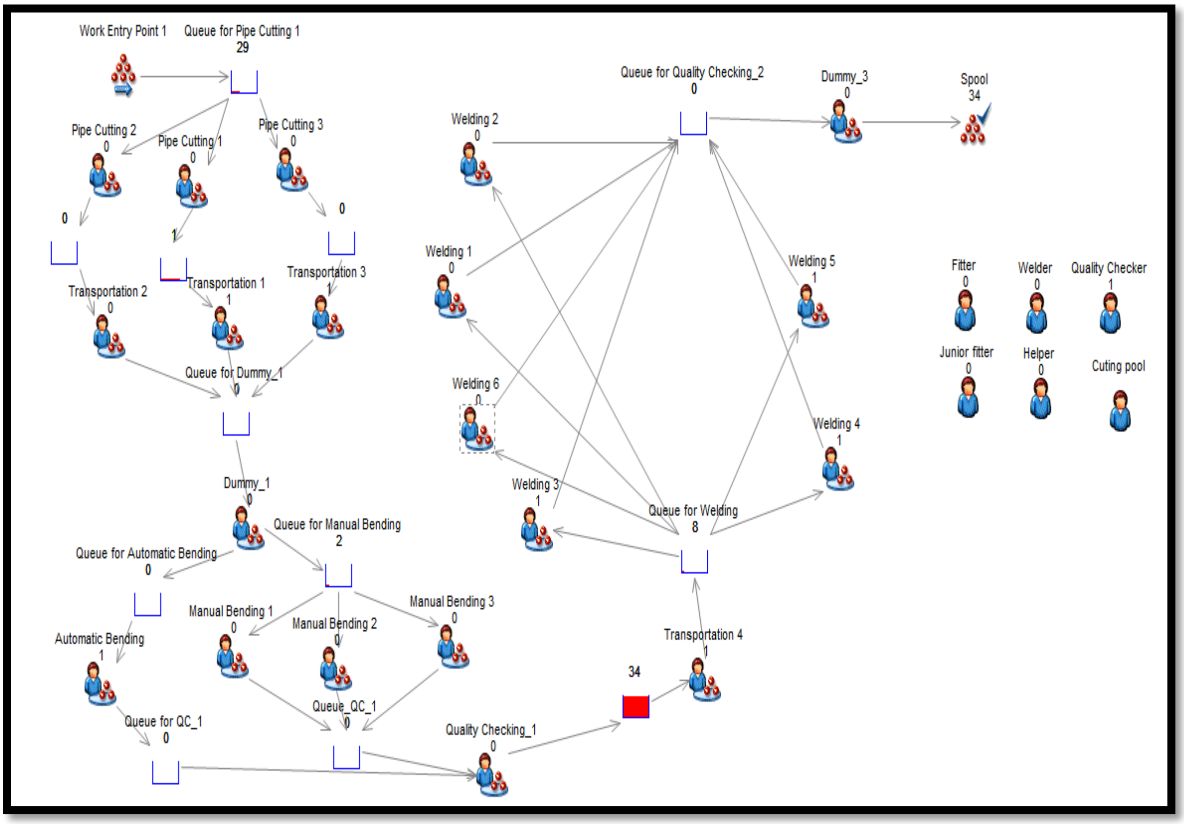

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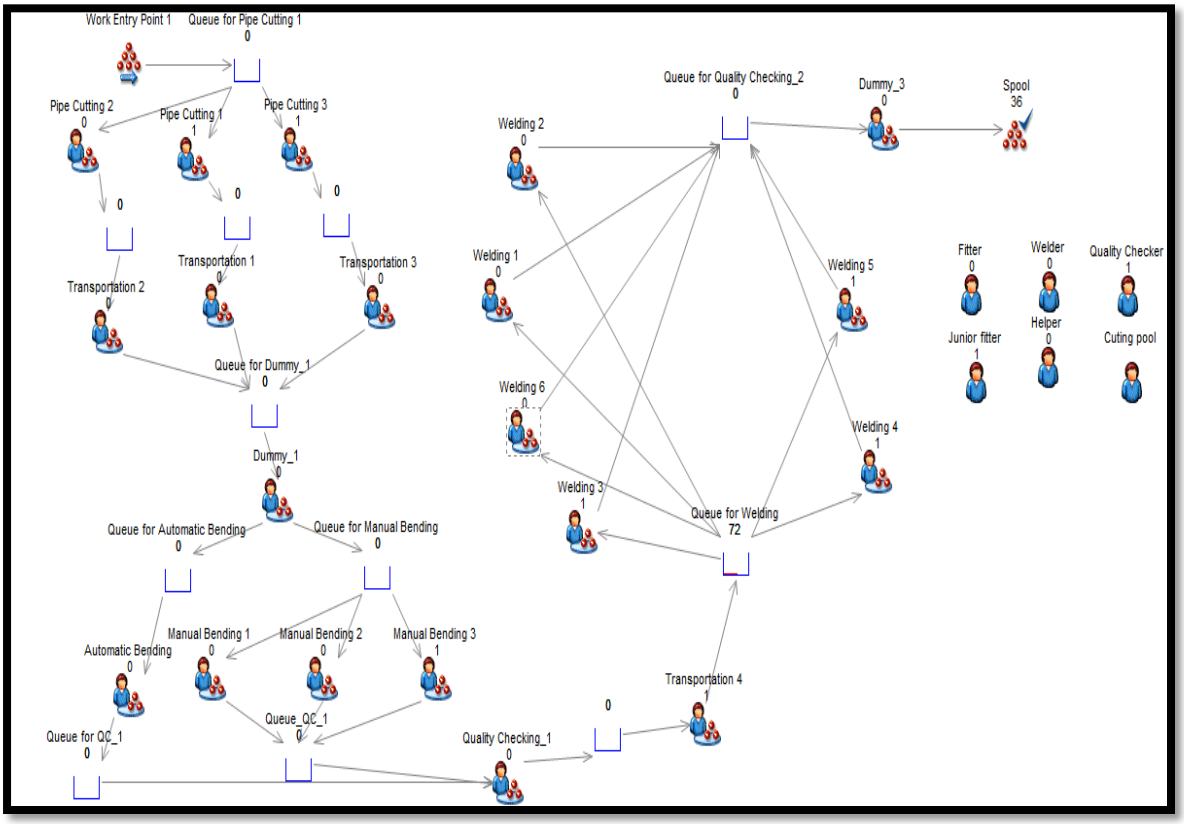

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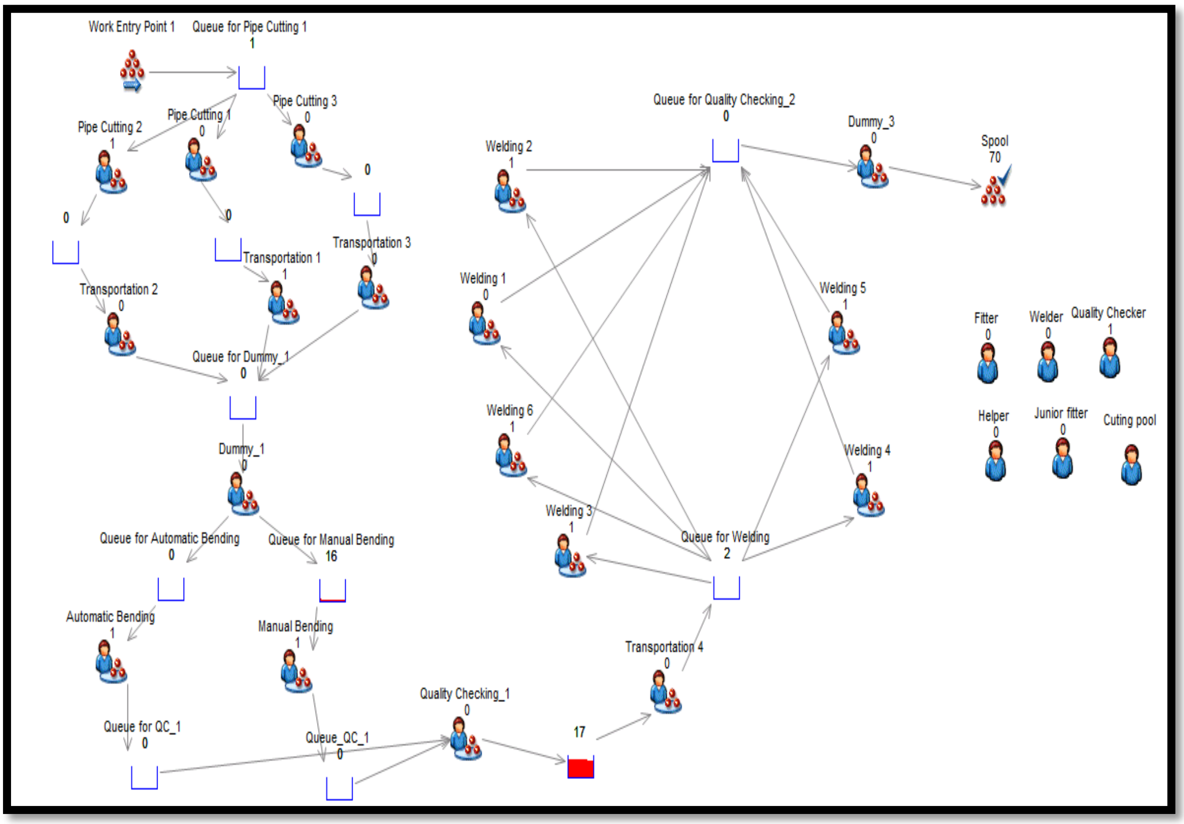

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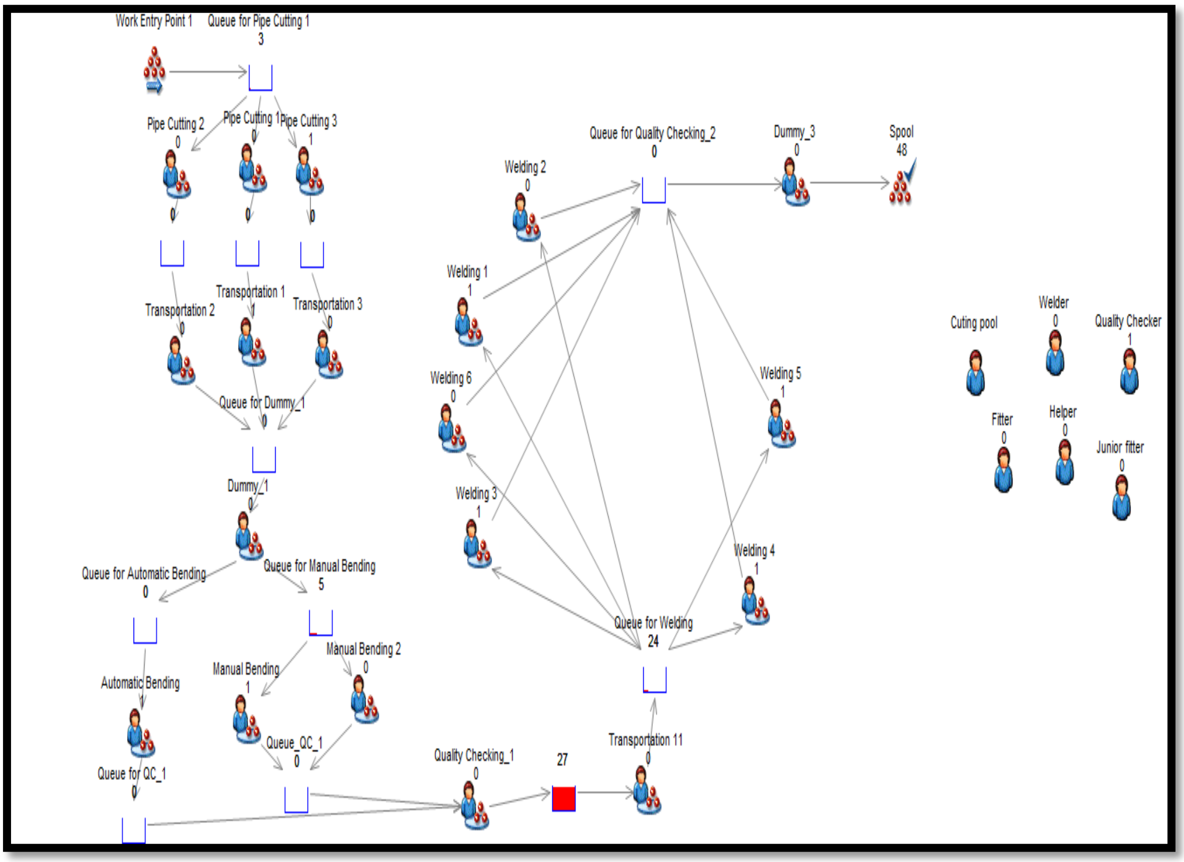

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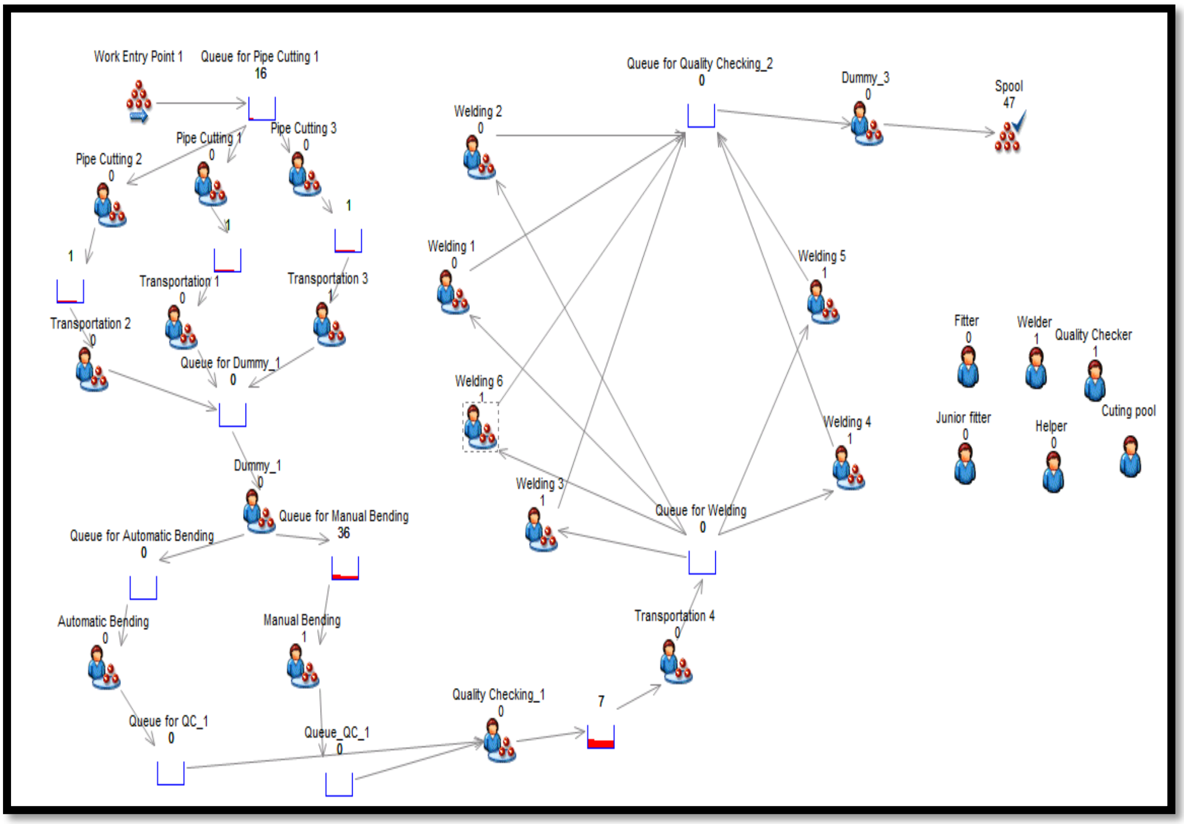
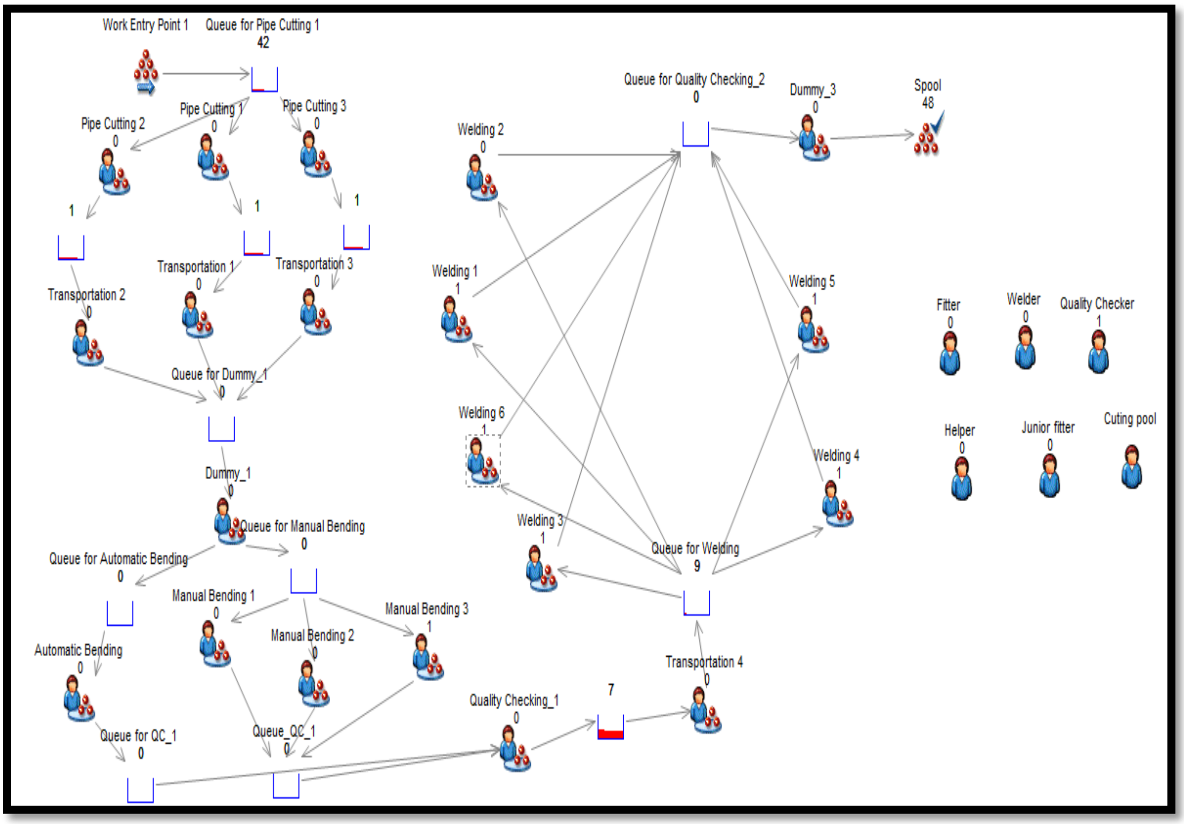
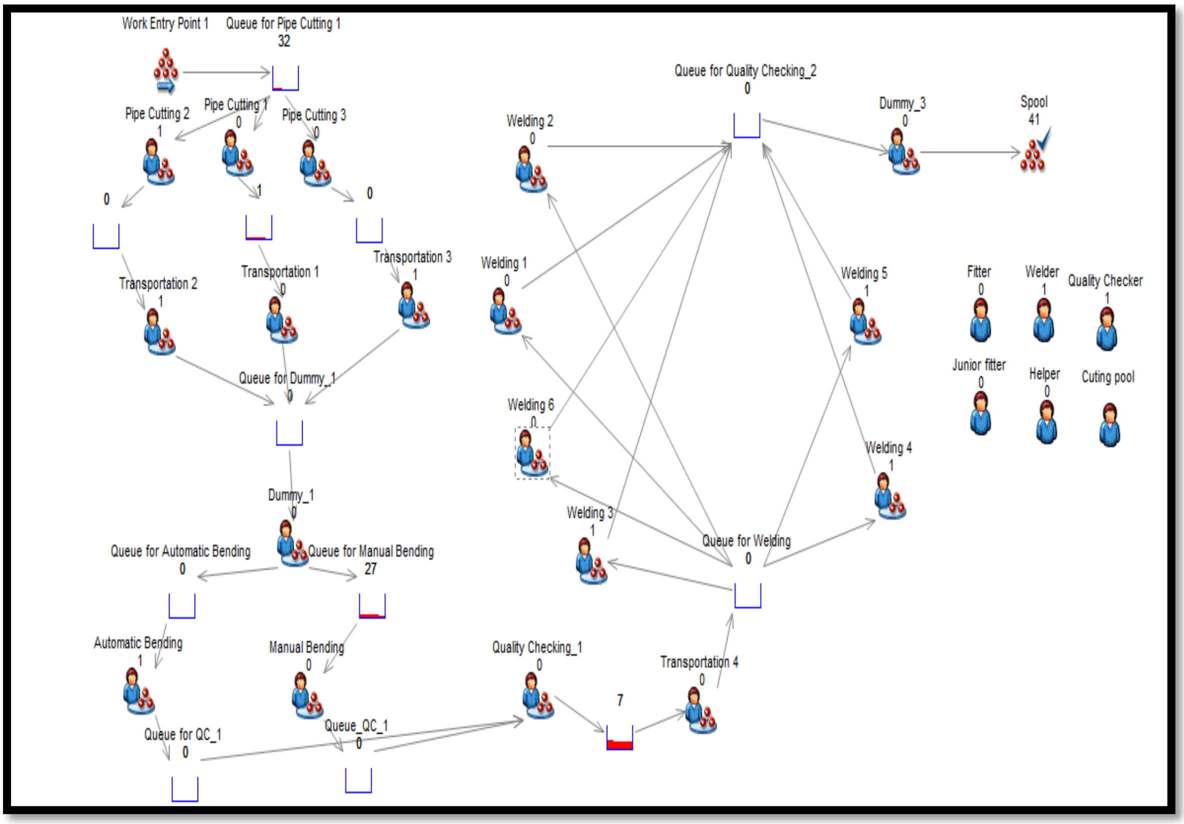


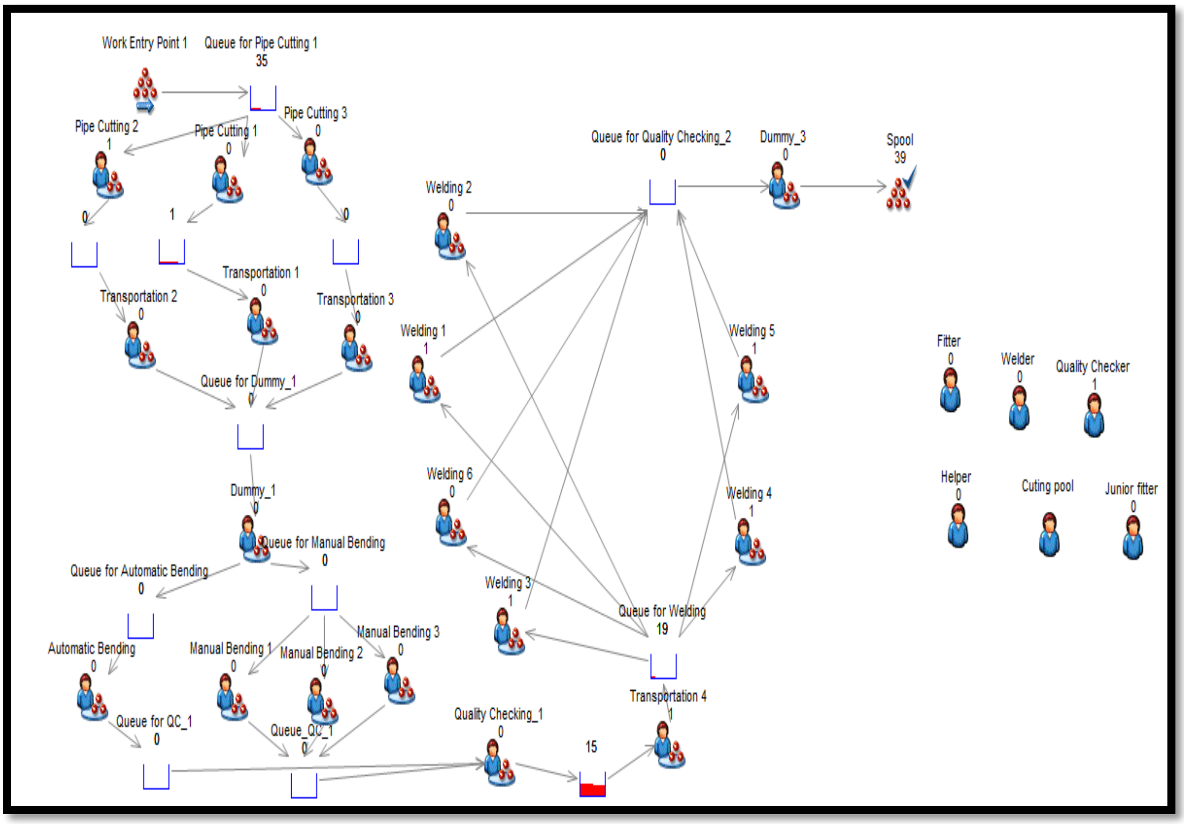
2^3 full factorial design run order 9



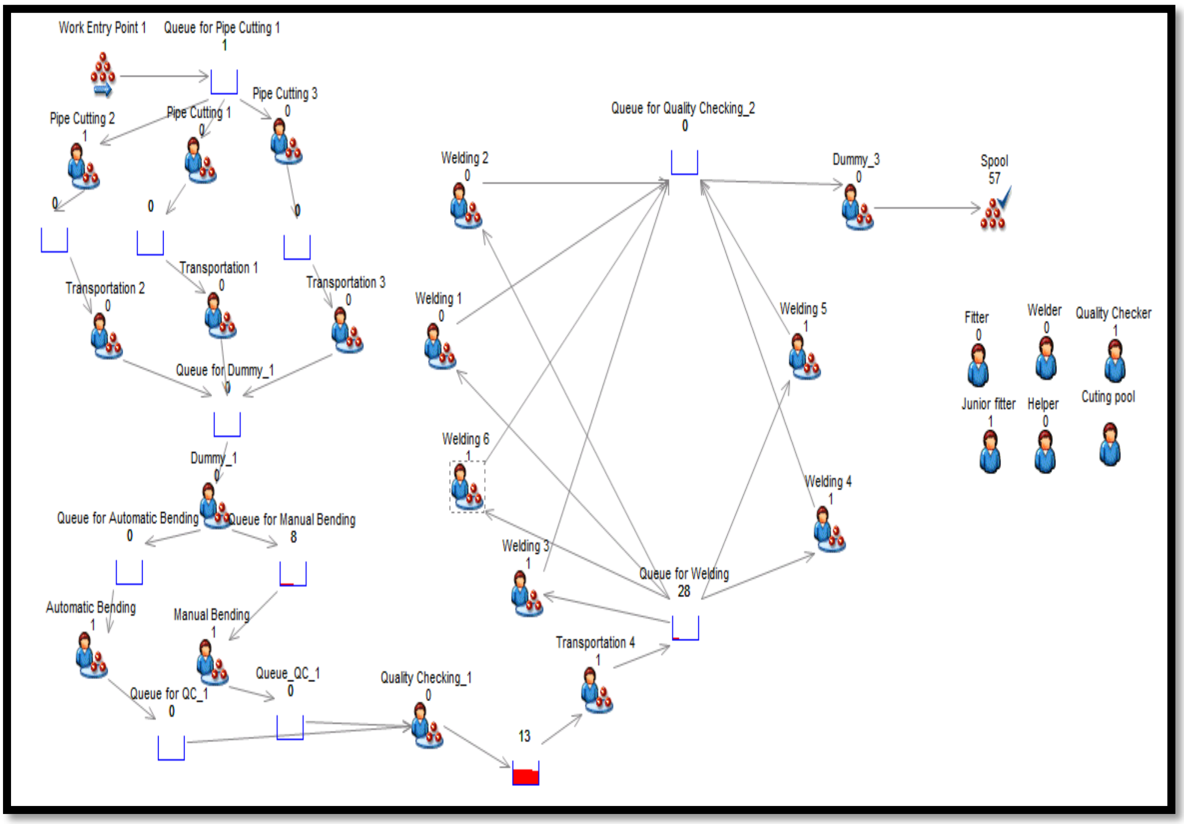
2^3 full factorial design run order 10



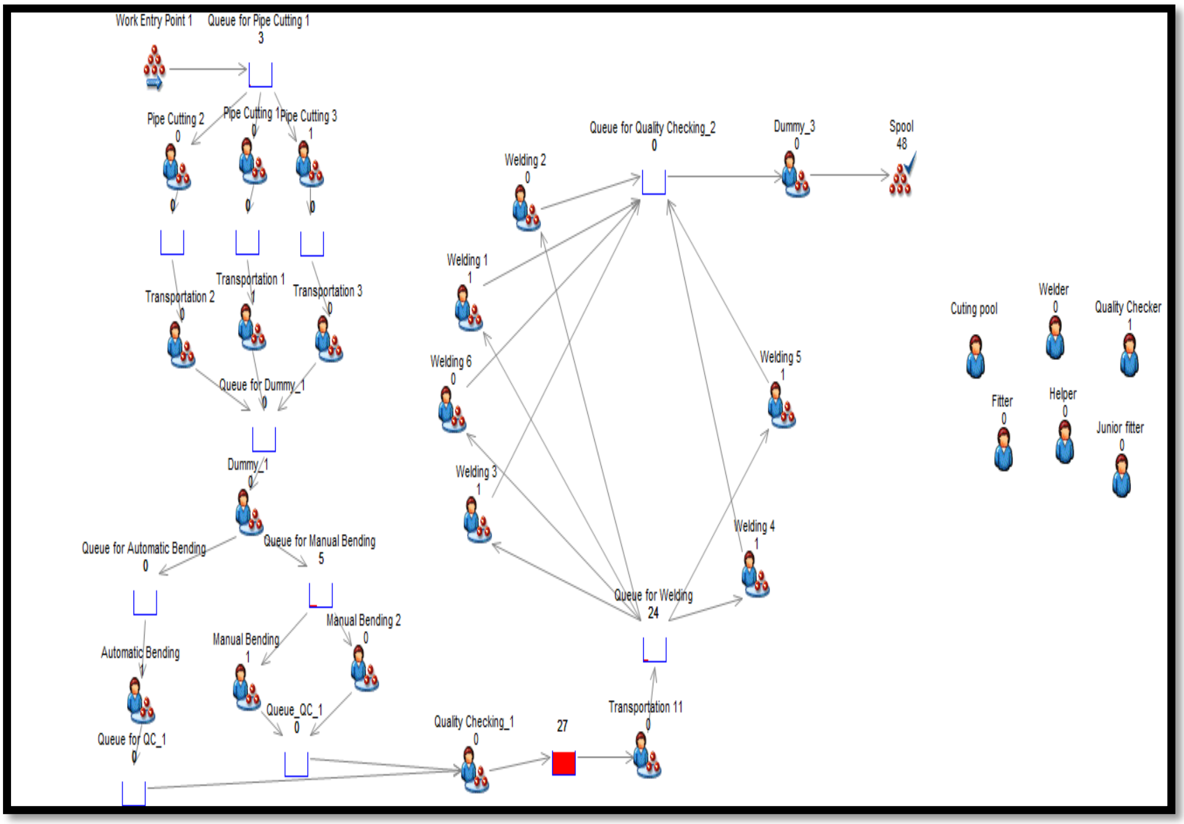
Box-behnken design run order 1



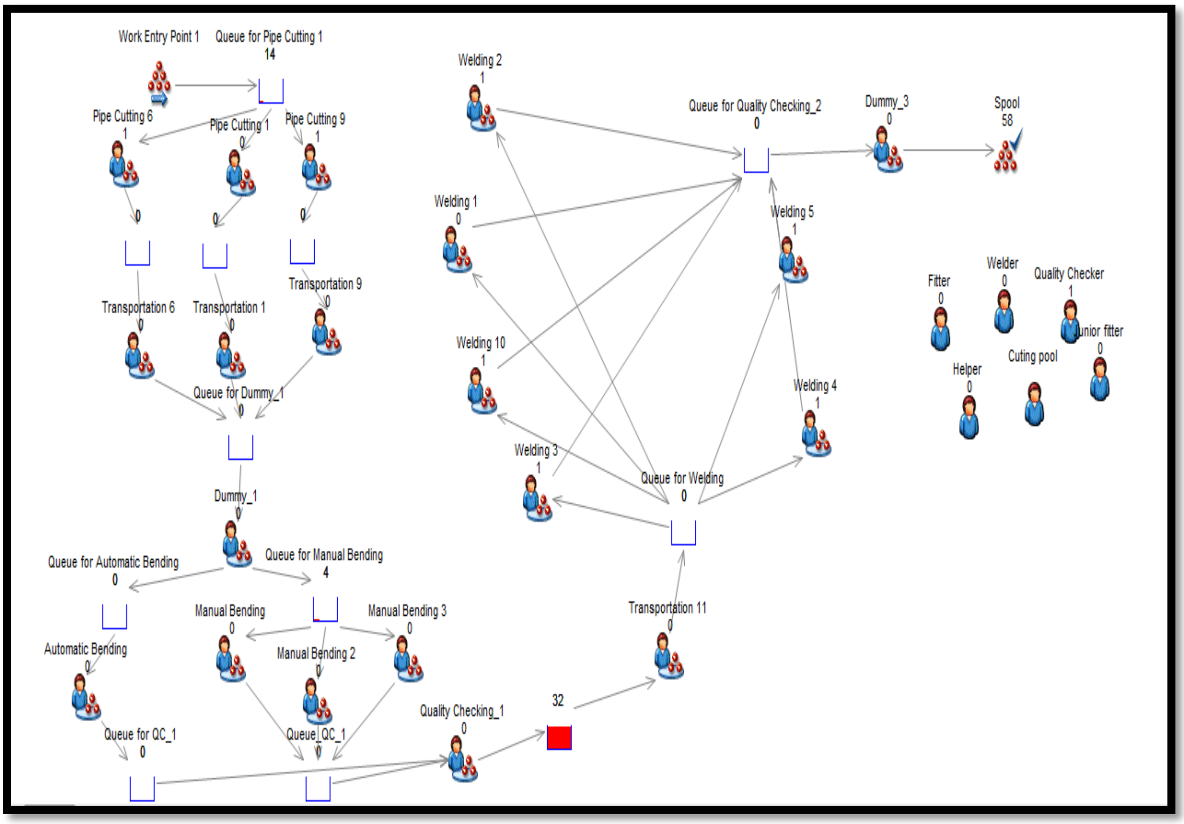
Box-behnken design run order 2



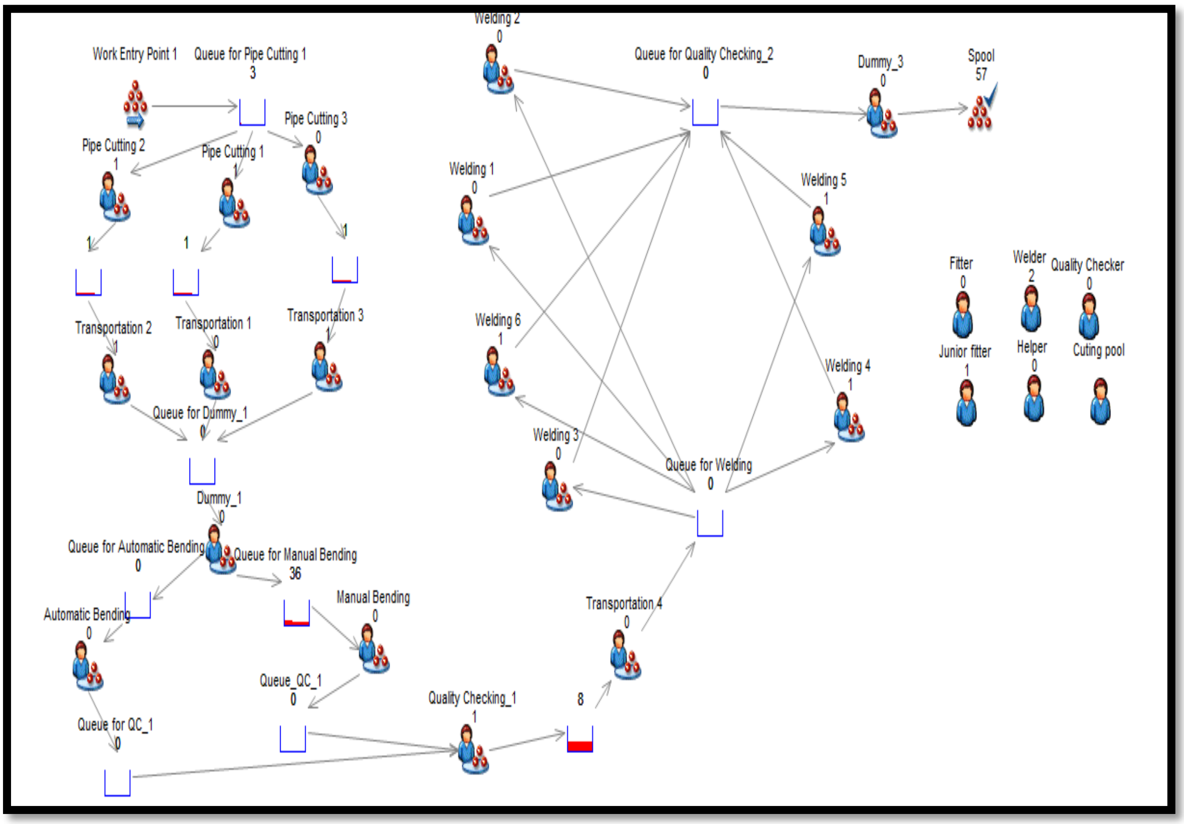
Box-behnken design run order 3



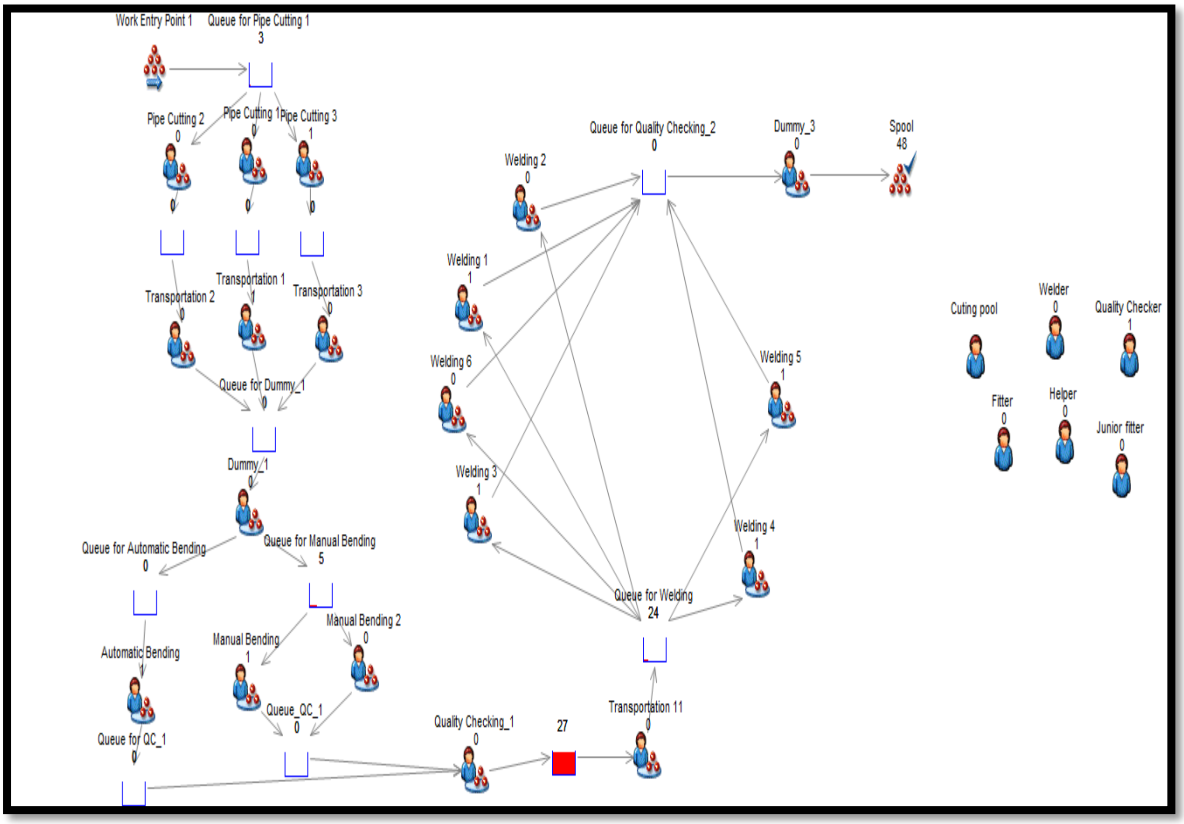
Box-behnken design run order 4



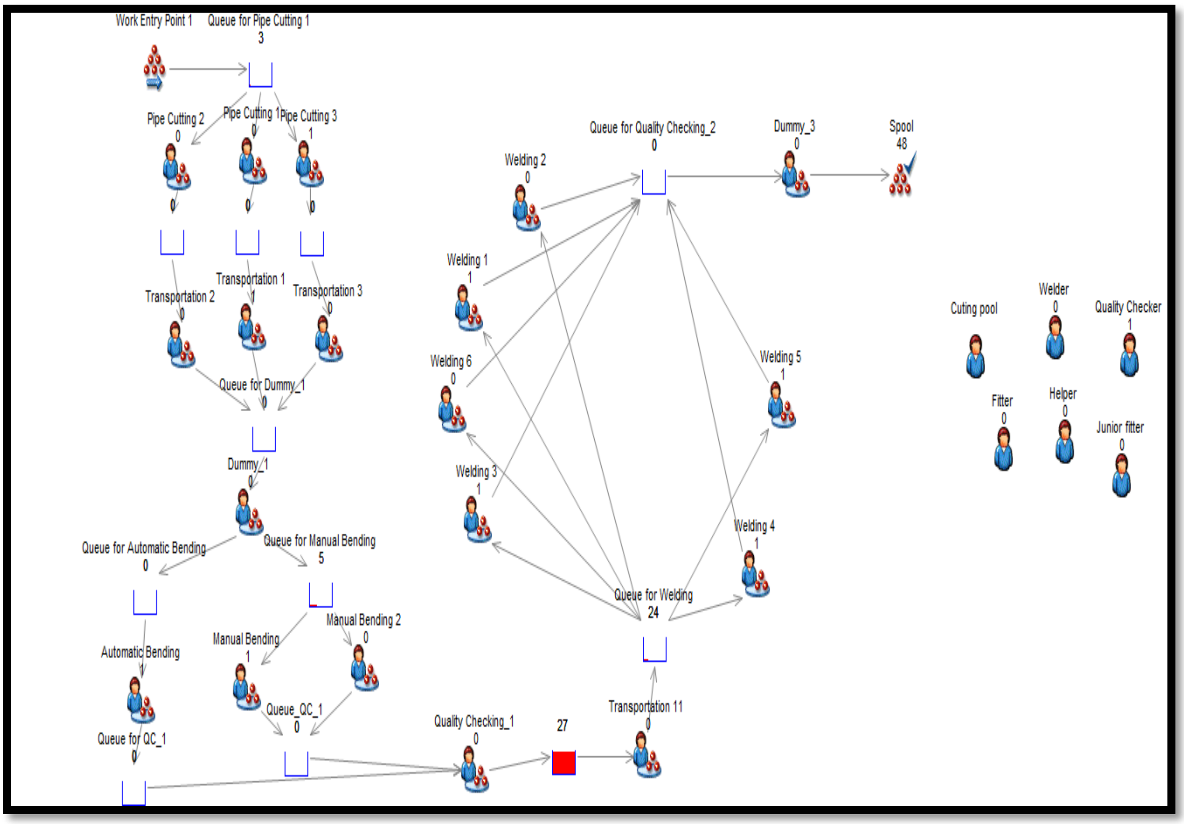
Box-behnken design run order 5



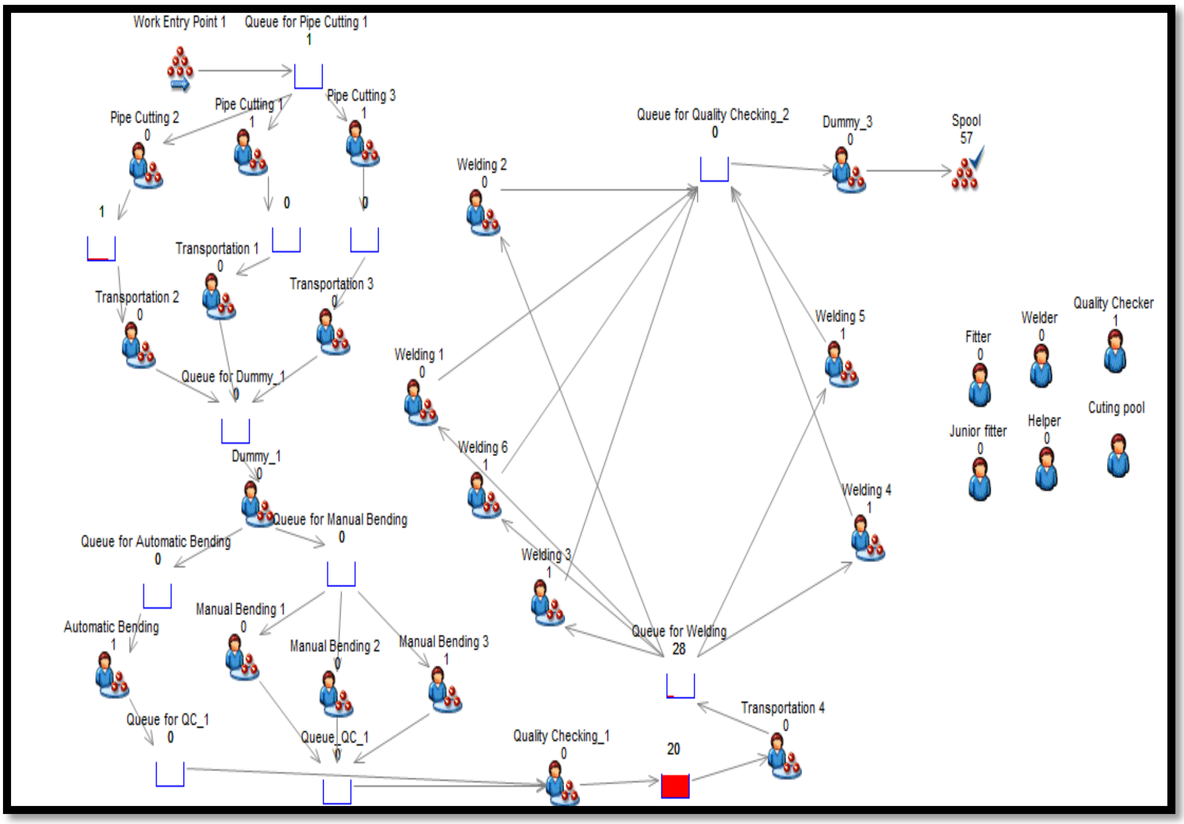
Box-behnken design run order 6



Box-behnken design run order 7



Box-behnken design run order 8



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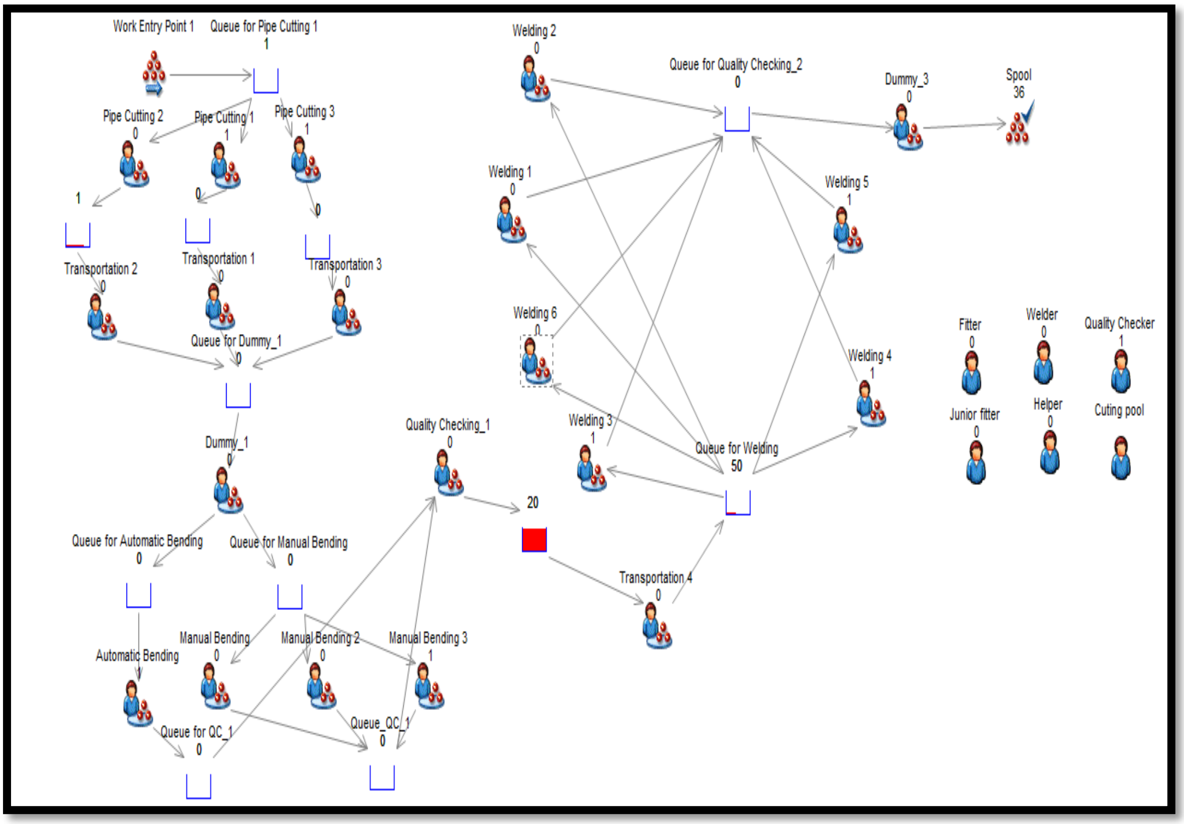

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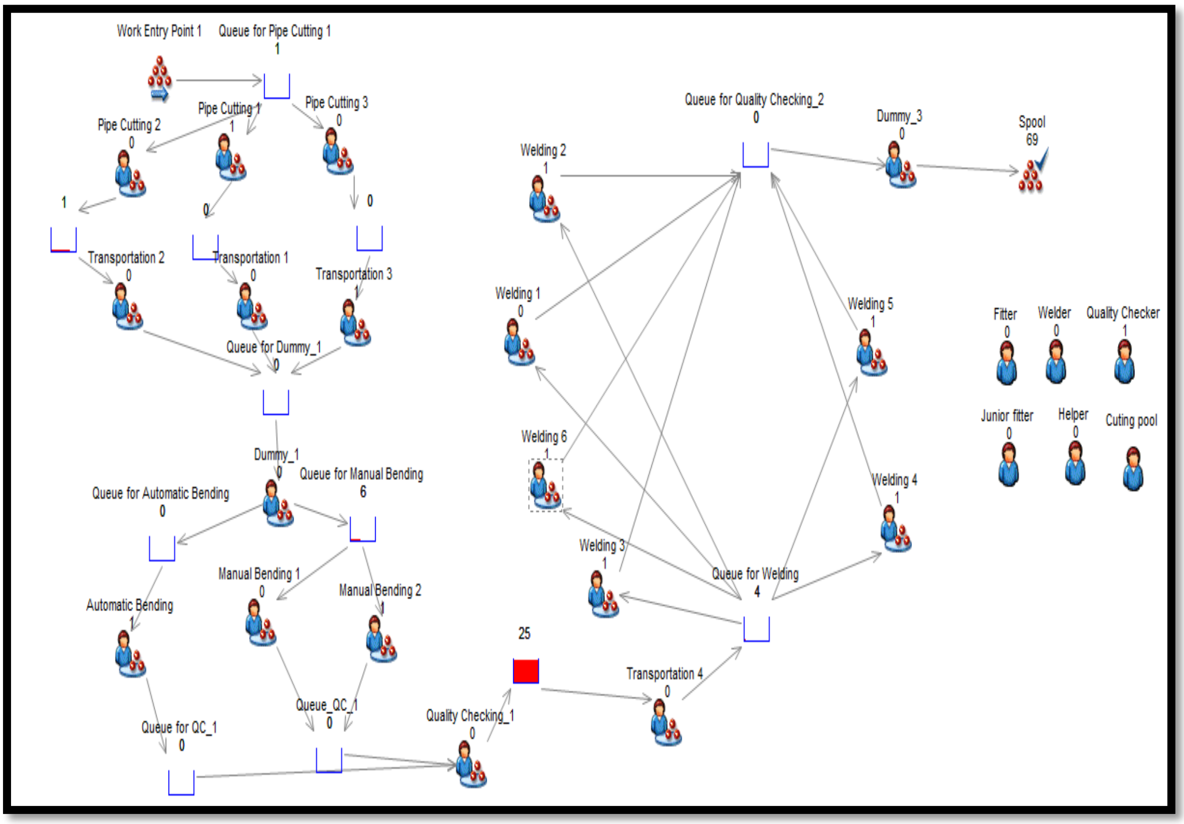

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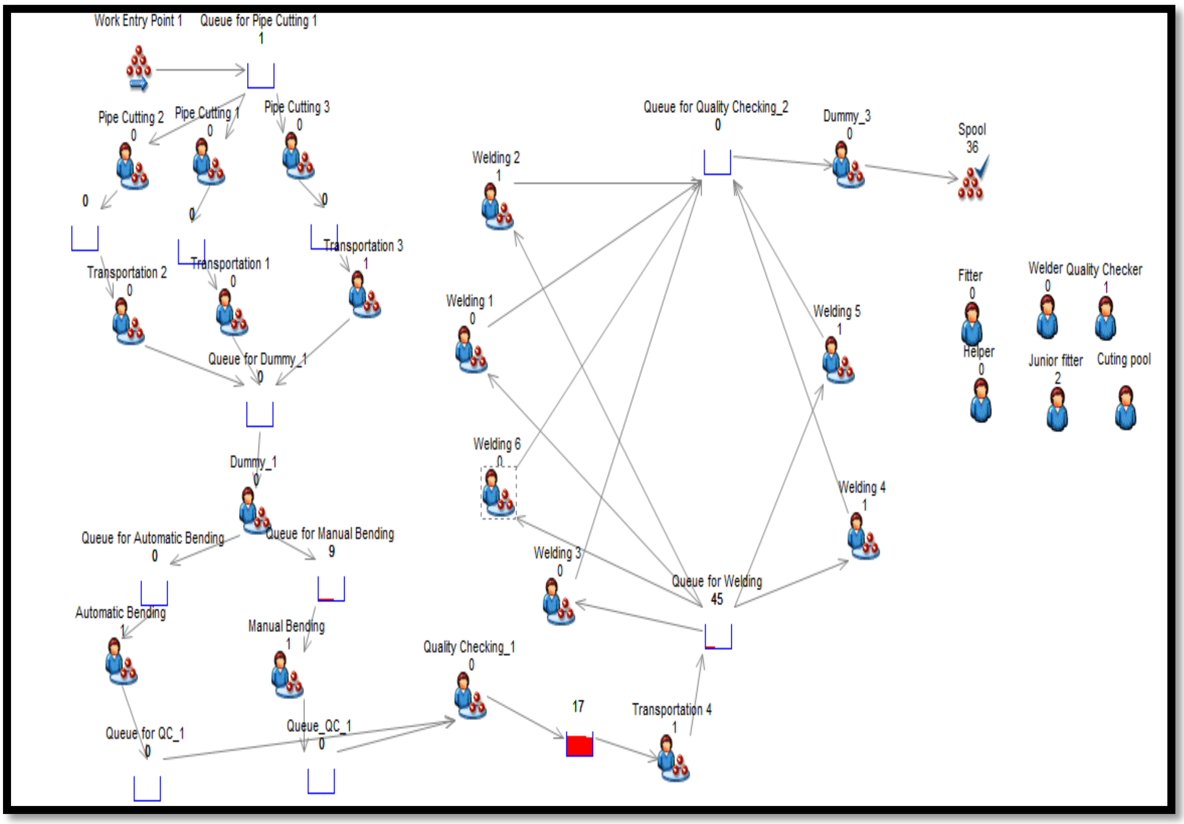

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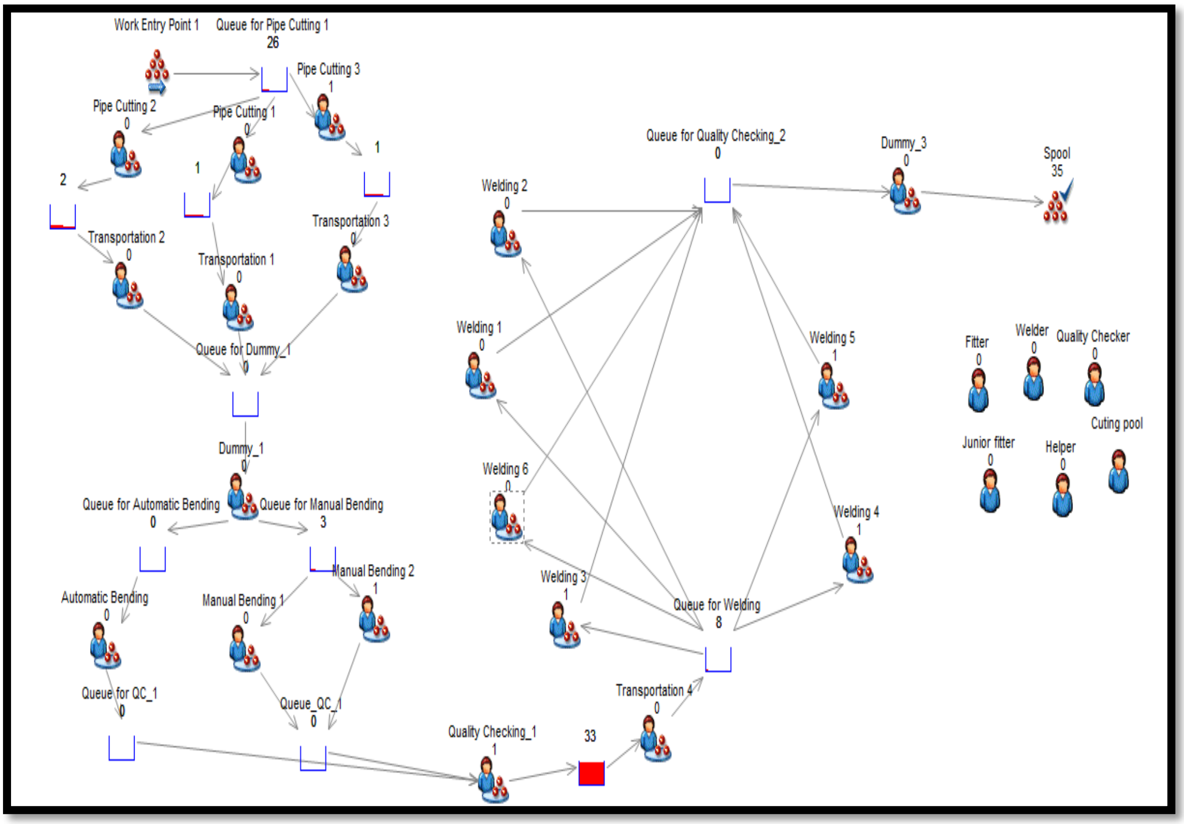

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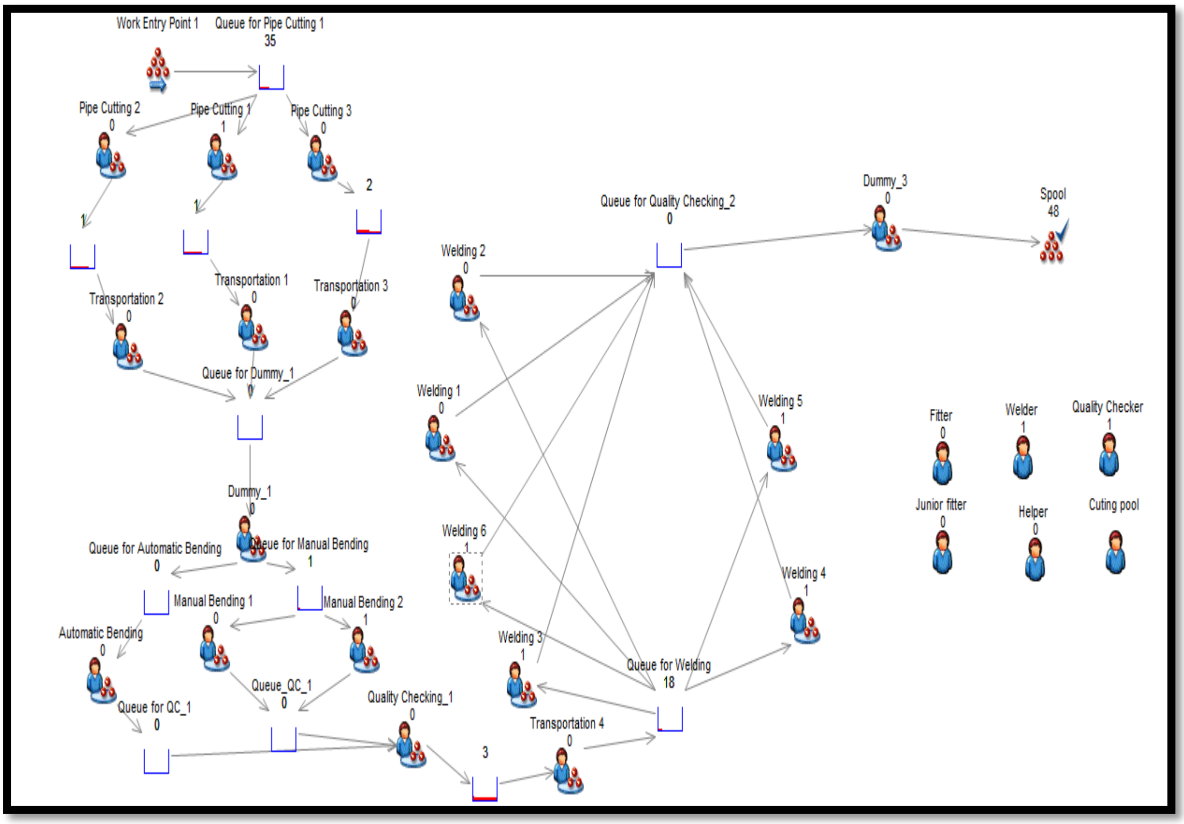

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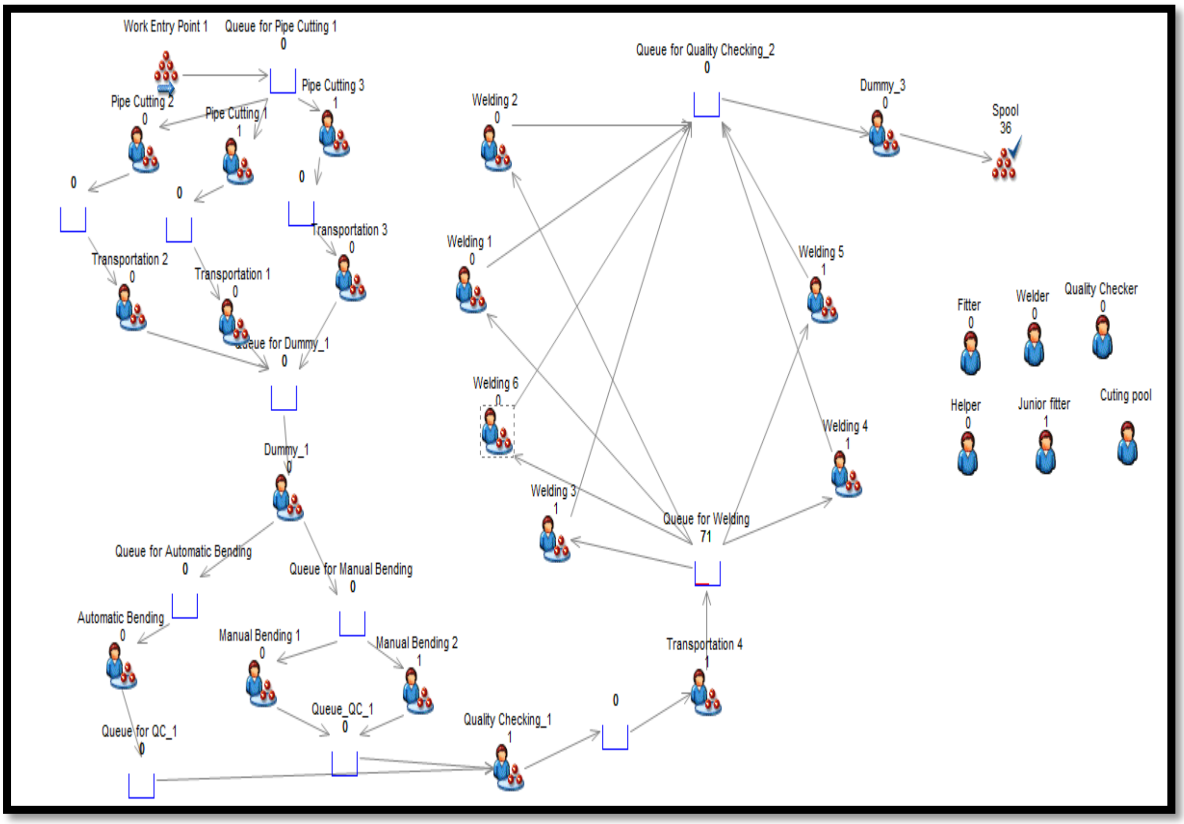

Box-behnken design run order 15

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