THE DEVELOPMENT OF A NEW ROLLER TRACK GRAVITY GATE FOR SELF-UNLOADER BULK CARRIERS

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ABSTRACT

This study is fundamentally relevant to the development of a new enhanced Roller Track Gate (RTG) for the gravity type Self-unloading Bulk Carriers (SULS), called the Multi-functional Roller Track Gate (MRG). Self-unloading Bulk Carriers (SULS) are specialized types of dry bulk carrier vessels, principally because these ships discharge their cargoes without the assistance of external sources. In 1908, the first commercial vessel of these types started trading in the Great Lakes region of North America. Subsequent to the inception of SULS, the technology has developed mainly in the hull structure and onboard unloading systems. Due to the 1980s GL shipping recession, SULS migrated internationally and are now trading worldwide.

Eight gravity gates for SULS were investigated in detail prior to designing the MRG. These examinations of previous gates were primarily to address the inherent issues and develop a new gate that would correct the current problems, when discharging dry bulk cargo with the existing gravity gates.

The newly designed gate is accompanied with special control system that improves the discharging operations of these type vessels. This gate resulted in being heavier when compared to the existing RTG. However, this study also addresses and mitigates the associated improvements in this new type gate that increases the ship's lightweight with the possibility of increasing payload / deadweight. High tensile steel was introduced for the hull to compensate for the added gate weight. The steel weight reduction investigation resulted in greater weight than what was required for offsetting the gate weight. The additional weight savings allowed for greater cargo lift for the vessels examined.

The economic case study confirmed that by replacing the present Roller Track Gate with the Multi-functional Roller Track Gate, the shipowners' would benefit from improve discharging performance, less port turn around time and reduced manning cost.

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DEDICATION

TO MY FAMILY AND PARENTS (DECEASED)

***A MI FAMILIA Y MIS PADRES (*FALLECIDOS)**

PHILOMENA HELEN CHAMBERLAIN

AND

CAMILLE ELI-ANA WELCOME CHAMBERLAIN

FREDA T. BODDEN de WELCOME

AND

Dr. JOSEPH SIMPSON WELCOME GRANT

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$A_{b.}$	Trapezoid Area
$A_{s.}$	Circular Segment Area
A_t	Total Area
AFT	After (Computer Print-out)
ABS	American Bureau of Shipping
Acc	Accumulator
Accel	Acceleration
Ack	Acknowledge
ACF	Annual Cashflow
AH32	High Tensile Steel Grade A (315 Mpa)
ASME	American Society of Mechanical Engineers
AP	Aft Peak and Aft Perpendicular
Auto	Automatic
Avg	Average
BCRC	British Columbia Research Corporation
BDP	Bioenergy Development Program
BFG	Bulk Flow Gate
BG	Basket Gate
BHD	Bulkhead
BM	Bending Moment
BMH	BMH Marine AB
Bus	Bushel
B	Buzzer
C	Centigrade
$C	Canadian Dollar
cm	Centimetre
cm^2	Centimetre Square
cm^3	Centimetre Cubic
CCR	Cargo Control Room

CEMA	Conveyors Equipment Manufacturers Association
CFG	Control Feeder Gate
CCMH AB	Consilium CCMH AB
CMOU	Canadian Marine Officers Union
Corp.	Corporation
Co.	Company
CSL	Canada Steamship Lines
Cyl	Cylinder
$D	Million Dollar
Diff	Difference
Dr	Doctor
deg	Degree
DC	Discounted Cashflow
DO	Diesel Oil
DR	Discount Rate
DWT	Deadweight Tonnes
e.g.	For Example
EMTI	EMS Technology Inc
E-stop	Emergency Stop
E-Pull Cord	Emergency Pull Cord
EO	Egon Oldendorff
etc	etcetera
FEA	Finite Element Analysis
FFP	Fox Fluid Power
FO	Fuel Oil
FP	Fore Peak and Forward Perpendicular
FS, FSmom	Free Surface and Free Surface Moment
FWD	Forward (Computer Print-out)
ft, ft^2, ft^3	Feet, Square Feet & Cubic Feet
ft^3/h	Cubic Feet per Hour
ft/min, fpm	Feet per Minute

g/cm^3	Gram per Cubic Centimetres
CG	Centre of Gravity
g	Gram
GMA	Gravity with Mechanical Assist
GL	Great Lakes
GM	Metacentric Height
GMt	Modified Metacentric Height
GTL	Gypsum Centennial of Gypsum Transport Ltd.
GZ	Righting Arm Length
HASR	Harrow Assisted Screw Reclaimer
h	Hour, Height
H	Hogging and Horn
Hi	High
HFO	Heavy Fuel Oil
H m-MT	Hogging Metre-Metric Tonne (Computer Print-out)
HT	High Tensile Steel
Hyd	Hydraulic
IACS	International Association of Classification Society
i.e.	For Instance
IFO	Intermediate Fuel Oil
Int'l	International
IRR	Internal Rate of Return
IMO	International Maritime Organisation
in	Inch
Inc	Incorporated
Int	Interest
IP	International Paints
J	Joule
KTI	Kamengo Technology Inc.
kW	Kilogramme
kg/cm^2	Kilogramme per Centimetre Square

kg/m^3	Kilogramme per Cubic Metre
kg/min	Kilogramme per Minute
KMT	Transverse Metacentric Height from Keel
KN	Knots
kN	Kilonewton
kW	Kilowatt
Lbs	Pounds
lb/ft^3	Pound per Cubic Feet
L	Length
LCF	Longitudinal Centre of Flotation
LCG	Longitudinal Centre of Gravity
LCB	Longitudinal Centre of Buoyancy
Lo	Low
LO	Lube Oil
LR	Lloyds Registry of Shipping
LSBG	Long Slot Basket Gate
LSCBG	Long Slot Centre-split Basket Gate
LSGF	Long Slot Gate Feeder
Ltd.	Limited
LW	Lightweight
M	Metre, Million, Metacentric
m, m^2, m^3	Metre, Metre Square & Metre Cubic
mm, mm^2	Millimeter & Millimeter Square
m/s	Metre per Second
m/min	Metre per Minute
m^3/h	Cubic Metre per Hour
Man	Manual
M-AFT	Metre Aft
m-BL	Metre Above Baseline (Computer Print-out)
MDO	Marine Diesel Oil
MDWT	Million Deadweight Tonne

Mfg	Manufacturer
Misc	Miscellaneous
m-FWD	Metre Forward (Computer Print-out)
Mod	Modified
MRG	Multi-functional Roller Track Gate
Mpa	Megapascal
m-rad	Metre Radius (Computer Print-out)
m-MS	Metre From Midship (Computer Print-out)
MS	Midship and Mild Steel
m^3/MT	Cubic Metre per Metric Tonnes
MTons	Metric Tonnes (Computer Print-out)
m-MTons	Metre Metric Tonnes (Computer Print-out)
m-MT/cm	Metre Metric Tonnes/Centimetre (Computer Print-out)
M/V	Motor Vessel
N	Nitrogen
NA	North America
N/A	Not Applicable
NCF	None Consolidating Feeder
NM	Nautical Miles
NPV	Net Present Value
No.	Number
Nor	Normal
NIS	Norwegian International Registry
OPEC	Organization of the Petroleum Exporting Countries
Opr	Operating
Ori	Original
PB	Push Button
Press	Pressure
Pri	Primary
Prop	Propeller
psi	Pound per Square Inch

PW	Potable Water
Rem	Remote
RFR	Required Freight Rate
R&D	Research and Development
RTG	Roller Track Gate
RR	Rate of Return
S	Sagging, Siren and Strobe
s	Second
SA, SACAN	Stephens Adamson Manufacturing Company of Canada Limited
SBS	Seabulk Systems Inc.
Sec	Secondary
S m-MT	Sagging Metre-Metric Tonne
SF	Shearing Force
SI	System International (Metric)
SIU	Seamen International Union
SNAME	Society of Naval Architect and Marine Engineers
S/S	Steamship
SULS	Self-unloader Bulk Carriers
SUL/L	Self-unloader / Loaders
Ste, St.	Saint
ST	Sterntube
Stbd	Starboard
SW	Sea Water
TC	Time Charter
Tech	Technology
tph	Tonnage per Hour
t/h	Tonnes per Hour
t/m^3	Tonne per cubic metre
tonnes/h	Metric Tonnes per Hour
tons/hr	US Tons

tonnes/m^3	Metric Tonnes per Cubic Metre
T_A	Draft at the after perpendicular
T_F	Draft at the forward perpendicular
T_M	Trim for Naval Vessel
t_{ms}	Thickness of ordinary-strength steel
t_{hts}	Thickness of higher-strength material
Tun	Tunnel
UHMW	Ultra High Molecular Weight
UK	United Kingdom
USA	United States of America
USD	United States Dollar
US	United States
VCF	Voyage Cashflow
VCG	Vertical Centre of Gravity
WBT	Water Ballast Tank
WBDBT	Water Ballast Double Bottom Tank
WBST	Water Ballast Side Tank
WT	Water Tank
Yrs, Yr	Years and Year

GREEK and Other SYMBOLS

ρ_b	Bulk Density of Discharging Material (Kg/m^3)
k_β	Is Equal to $(\tan \beta)^{-0.35}$ for $\beta<45^\circ$ or Equal to Unity for $\beta>45^\circ$
β	Angle of Idler Roller, Degrees
α	Angle of Surcharge, Degrees
π	PI
σ_h or σ_1	Normal stress in the hoop directions, psi
σ_l or σ_2	Normal stress in the longitudinal directions, psi
μm	Micron

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Chapter 1

1. INTRODUCTION

1.1 Introduction

This study is relating to the "Development of a New Roller Track Gravity Gate for Self-unloader Bulk Carriers". The aims and objectives are now outlined:

Aims:

- To address and correct the hanging-up of dry bulk cargoes resulting from bridging due to arching and rat-holing; and
- To reduce the lightweight of Self-unloader Bulk Carriers by introducing high tensile steel as a replacement for mild steel, while ensuring that the vessel's strength and stability are not impaired.

Objectives:

- To develop a New Roller Track Gravity Gate for Self-unloader Bulk Carriers and address the cargo flow impediments experienced with current gravity gates;
- To mitigate any increase in the lightweight of Self-unloader Bulk Carriers due to the new gate design; and
- To retrofit the new gate in an existing SULS while ensuring that the conversion is economically feasible and benefits the shipowners.

Self-unloading Bulk Carriers (SULS) are unconventional dry bulk carrier vessels that discharge cargoes independently with shipboard conveyor machineries, when compared to the 'gearless types' bulk carriers' which require shore-side assistance for unloading and the 'geared types' bulk carriers' that are equipped with cranes for discharging their cargoes. In summary, SULS discharges their cargoes autonomously directly to the customers' facility ashore and are unaided by external equipment in the unloading ports.

The inception of SULS technology was primarily for transporting natural commodities (i.e. iron ore, coal and grain) from the remote mining and producing areas to the manufacturing and distribution centres on the Great Lakes (GL) of North America.
The invention of SULS technology was an economic advantage for dry bulk traders in the GL region, resulting from not having to develop and maintain costly ports infrastructure for discharging the ordinary gearless bulk carriers. This SULS technology also benefited shipowners in the GL region and particularly the smaller owners by allowing them to be competitive and survive during the Great Depression.

Commercial shipping by SULS started during the summer of 1908 and predominantly these vessels traded in the GL region. However, due to the 1980s' shipping recession in the GL region, the shipowners of these vessels developed international trades and currently SULS are trading both domestic (i.e. GL) and internationally.

While designing the new enhanced gravity 'Roller Track Gate' (RTG) for Self-unloader Bulk Carriers', eight gravity gates for SULS including the existing RTG types were investigated. This was primarily to determine the advantages and disadvantages posed with each gate design. These studies of previous gravity gates for SULS led the author into proposing a new design of gravity 'Roller Track Gate' for SULS, called 'Multi-functional Roller Track Gate' (MRG) with developments that would address previous issues encountered during discharging operations with the existing gravity gates for SULS. Included in this new design gate are: detail design of operating mechanism; control system for gate operations; control system for conveyor operations and design of resulting midship section structure to include the new gate in sufficient details. These aspects allow for subsequent commercial exploitation of the proposed concept.
Additionally, the RTG design improvements in this study focused on correcting some issues experienced by the author who has been employed in numerous sectors of the maritime industry for 43 years **(1967-2010)**, while studying Marine Engineering, Shipbuilding and Ship Management in both the theoretical and technical areas. During the past 43 years of service while studying and working, 17 years was spent involved with SULS at sea (i.e. Second Engineer and Chief Engineer) and ashore (i.e.

Superintendent New Construction, Technical Superintendent, Operations Manager and Newbuilding Project Manager). For the past 13 years, the researcher has been managing and supervising newbuilding projects in Asia (i.e. China, Japan and Korea). The remaining 13 years was spent servicing other sectors of the maritime industry.

The technological development of SULS are considered and used as basis for a new design of gate that subsequently demonstrated economic advantages. This study is based on real-life scenario with a case study comprising economic evaluations. Nevertheless, the economic figures originated from credible sources of the maritime industry.

In this study the technological advances of SULS are featured and not the commercial aspects. This resulted from limited literature published on the market and trade of SULS. By majority, SULS shipowners are private owned companies, forming a niche sector of the global dry bulk carriers' fleet and commercial information remains confidential, endogenous and not released to the public. However, the author was allowed access to real data for a number of SULS by shipowners. To preserve the confidential nature of this information these ships are subsequently referred to as Models 'A', 'B' and 'C'.

The objectives and thesis outline are herewith discussed with details and comprehensive overview of the study.

1.2 Objectives and Outline of the Approach

The objectives of this study encompass three separate elements pertinent to the improvements of Self-unloader Bulk Carrier technology. The above mentioned objectives were studied in detail to establish the potential benefits to shipowners and operators of Self-unloader Bulk Carriers. The approach that was adopted to progress these three themes, can be summarized as follows:

1.2.1 Development of a New Roller Track Gravity Gate for SULS

Eight existing cargo gates of different designs for gravity SULS were examined. These investigations were principally to determine both operational advantages and disadvantages, while discharging dry bulk cargoes with these gates. Upon examining the benefits and shortcomings linked to previous gravity types cargo gates, the primary objective is the development of an enhance Roller Track Gate (RTG), that addresses various issues encountered with earlier designed gate.

1.2.2 Implications to Cargo Deadweight by Mitigating Increase in Lightweight

While designing the MRG, it was evident that this gate accompanied the disadvantage of increased weight, when compared to the existing RTG. This led to examining the lightweight displacement of three existing SULS hulls (called Model 'A', 'B' and 'C'), to verify how the shipowners could benefit financially from reducing these hull weights:

- Model 'A': Self-unloader designed for trading only on the Great Lakes – weight reduction of 181 tonnes;
- Model 'B': Self-unloader designed for trading both on the Great Lakes and internationally – weight reduction of 208 tonnes; and
- Model 'C': Self-unloader designed for trading only internationally – weight reduction of 212 tonnes.

The investigation of utilizing high tensile steel (HT) for constructing certain sections of the hulls concluded that the ships lightweight could be reduced without adversely affecting stability and strength. The Model 'B' was selected for this investigation because this vessel has the ability to trade on the Great Lakes (GL) and internationally, whereas the other two models have limited trading regions (i.e. either GL or international). In the scenario of the Model 'B', the outcome from the steel reduction exercise resulted in savings of 208 tonnes or 2.02% of the original lightweight. This reduction in lightweight compensated for the added weight of the MRG and also enhanced the ship's cargo deadweight. Thereby, the owners would benefit from additional income, when the reduction in lightweight was explored using the Model 'B' type Self-unloader Bulk Carrier.

1.2.3 Retrofitting New Design Gate in Existing SULS

The Model 'B' SULS was selected for retrofitting the existing Roller Track Gate (RTG) with the Multifunctional Roller Track Gate (MRG), primarily because this vessel has the ability to trade on the Great Lakes and Internationally. As a result, the Model 'B' SULS can trade twelve months a year and annual profit from trade would be greater for this type of handymax SULS.

Upon replacing the existing RTG, the financial outcome was beneficial for the Owners and the conversion cost was paid-off in 1.4 years.

1.3 Thesis Outline

Except for the General Introduction, Conclusion and Future Studies (Chapters 1 and 9), the overviews of the remaining Chapters (i.e. 2 to 8) are introduced and summarised.

1.3.1 Chapter 2: The Development of the Great Lakes Dry Bulk Shipping Trade

Historically, trading on the Great Lakes started from the early 1600s' prior to arrival of the European pioneers. Chapter 2 discuss various factors which influenced the dry bulk trade in the Great Lakes region, from the inception of shipping in that area until the present day.

This Chapter also describes various facets of the Great Lakes shipping, such as: the routes from the nineteenth to the twenty first century; the commercial aspects of the dry bulk trade; the impact from improvements of the water transportation system; the USA dry bulk trade and SULS issues and the Canadian sector dry bulk trade and SULS issues. In addition, this Chapter also describes both the framework and growth of the ordinary and self-unloader bulk carriers' fleet, during the inception of shipping with these vessels on the Great Lakes of North America.

1.3.2 Chapter 3: Self-unloader Bulk Carriers

In terms of the global dry bulk carriers' fleet, Self-unloader Bulk Carriers' (SULS) comprise a niche sector of this global fleet. This Chapter explains the expansion of the global dry bulk carrier fleet, showing the percentage of Self-unloaders consisting of the worldwide fleet. Chapter 3 also provides: the definition of Self-unloader Bulk Carriers'; the origin of Self-unloader Bulk Carriers; the reasons for the evolution of Self-unloader Bulk Carriers; the comparison of Self-unloaders Bulk Carriers with Conventional Bulk Carriers and the design issues encountered during the development of these specialized types of dry bulk carriers.

There are various types of SULS designed for specific trade in the maritime dry bulk sector. Chapter 3 reviews, describes and explains the underlying operational principles of the different categories of discharging systems relevant to these particular bulk carriers'. The accompanying operational advantages as well as disadvantages are highlighted while trading these vessels. Nevertheless, SULS provides considerable benefits in the discharging of dry bulk cargoes, principally when trading in regions with limited or no unloading infrastructure.

1.3.3 Chapter 4: The Evolution of Midship Section Design for Self-unloader Bulk Carriers

In Chapter 4, the focus is primarily different designs of midship sections for SULS, starting from the first commercial vessel of these types to the present day.

The developments of midship sections are explained with their associated benefits and drawbacks. SULS midship structures are highlighted in terms of hopper angles for specific trades, space in the unloading tunnel for installing various types of discharging machineries and cargo hold volumetric capacity.

Due to the complex structure of SULS unloading tunnel, these vessels inherently have reduced cargo hold volume. However, this lost of cargo volume is occasionally compensated for by owners demanding higher freight rates. This is because SULS discharges their cargoes without the involvement of external sources.

Improvement to the midship sections of SULS by having greater slope hoppers lined with anti-friction liners to increase cargo flow is described. This design allowed the ships to achieve enhanced discharging rates and in turn greater financial benefits for the owners.

1.3.4 Chapter 5: The Development of Existing Cargo Gates Designed for Self-unloaders Gravity Discharging Systems

There are various types of cargo gate installations onboard SULS. Chapter 5 provides a detailed review of existing gravity cargo gates that are installed in SULS.

From the available literature, there are currently eight different types of gravity cargo gates installed onboard SULS. The origin and evolution of each cargo gates type are explained. The individual gates are examined, emphasizing the operational principles and advantages as well as disadvantages posed with these gates while discharging cargo. Individual cargo gates functionality is underlined, ascertaining the operational comparisons and inherent encumbrance with each gate.

Cargo flow can be restricted by a number of cargo related phenomena despite the cargo gates functioning correctly. Particularly, some dry bulk cargoes naturally hang-up from bridging, resulting from arching and rat-holing. These occurrences affecting the cargo discharging operations are explained, which clearly confirms the need for an alternative gate that would provide smother and constant flow such as, the Multi-functional Roller Track Gate.

1.3.5 Chapter 6: The Detail Design and Evaluation of the Proposed Multi-functional Roller Track Gate and Integrated Tunnel Conveyors

Chapter 6 focuses exclusively on the design processing, analysis and evaluation of the Multi-functional Roller Track Gate (MRG) and designing of the tunnel conveyors. This design of gate is the first known Roller Track Gate (RTG) that combines two independent gates in one roller track gate assembly. This adopts the moving-hole principle, which is ideal for discharging cohesive cargoes that otherwise may bridge, resulting from arching, rat-holing and impeding the outflow of cargo. Comparisons of the design relevant to the Multi-functional Roller Track Gate versus the existing Roller Track Gates are discussed, in order to establish benefits of the MRG. The advantages and disadvantages are examined in detail to clearly confirm the design limitations of the MRG.

This gate is specifically designed for marine applications and for installation in SULS of the Model ‘B’ type. The MRG design is somewhat complex, when compared to industrial gates for single hopper/silo/bin. For this reason, the MRG would be unsuitable and uneconomic for shore-based industrial applications.

Engineering aspects of the MRG are explained, featuring the integration of cargo holds and typical two tunnel / hold conveyors. These conveyors are designed with the capability of discharging 2220 tonnes of coal per hour from each belt. The cargo gates operating cylinders are designed with sufficient safety factors to ensure appropriate operations of the cargo gate.

Two gate models were manufactured to evaluate the proposed gate design comprising seven different discharging operations. One model is 1:10 scale representation for visualization of the gate design concept and the other simpler iconic model was used for experimental tests with various actual commodities transported by SULS. Experiments to measure flow rates were conducted while discharging cargoes with the gate in the primary, secondary and reciprocating modes. The experimental discharge flow rates determined in this way allowed verification of the design concept for the MRG. These experiments do not take into account any scaling of the particulate cargoes between model and full scale. Therefore, the experiments only provide a comparative measure of the gate performance relative to an existing gate and not the full scale discharging rate as a quantitative measure. Nevertheless, idealized theoretical discharging rates were calculated numerically for comparison while discharging various commodities with the iconic model gate.

Both strength and weakness of the MRG are highlighted. However, the shortcomings in the design were considered to be outweighed by the advantages.

The appendices of this Chapter examines the possibility of reducing the ships steel weight by introducing high tensile steel to offset the increase in weight of the proposed gate with the possibility; of further reduction in the lightweight displacement and increased payload deadweight.

Self-unloader Bulk Carriers' (SULS) have higher lightweight displacement, when compared to the ordinary bulk carriers'. The deadweight and cargo capacity of SULS could be increased by utilizing high tensile steel to benefit from weight reduction.
Three existing Models SULS hulls were examined for weight criterion, primarily to determine the benefits resulting from weight reduction, increase deadweight and cargo capacity. Subsequent to reducing the steel weight of these three models SULS by experimentally replacing mild steel with high tensile steel, the hulls were analysed for strength. After conducting the steel weight reduction exercise, the stability and strength for these vessels were in accordance with the American Bureau of Shipping (ABS) Rules. Therefore, since the common structure rules are the same for the International Association of Classification Societies (IACS) members, it was not necessary to further investigate the strength criterion through calculations of the other Classification Societies Rules.

Steel deterioration as a result of corrosion is addressed, explaining the importance and manner of protecting steel from corrosion by appropriate steel / surface preparation and coating. This steel pre-treatment is imperative, especially when the steel thickness was reduced by installing high tensile steel to benefit from lighter ships.

1.3.6. Chapter 7: The Control System Designed for the New Enhanced Gravity Roller Track Cargo Gate

This Chapter and accompanying appendices describe the control systems for the integrated conveyors and new enhanced roller track gravity gate design that has been named the Multi-functional Roller Track Gates (MRG). This gate control systems is a development of the existing Roller Track Gates (RTG). The sole purpose of this control system is primarily to improve the cargo discharging operations onboard gravity type Self-unloader Bulk Carriers' and having installed the MRG.

The MRG design comprises two gates, four separate discharging modes and three additional redundancies. These seven discharging options make this gate unique and flexible in terms of discharging cargoes onboard SULS, when compared to other Roller Track Gates that have a maximum of two discharging modes and in some cases one mode.

Accompanying operational models have been designed with guideline matrices for the discharging modes proposed, allowing for monitoring of the entire discharging operations (i.e. gates and conveyors) with safety precautions to protect both operators and equipment. Conveyor configurations of the one, two and three tunnel belts arrangement are demonstrated. However, the selected installation would depend on the shipowners' desire and trade demand.

This Chapter also provides some guidelines for the shipowners when choosing equipment for Self-unloader Bulk Carriers.

1.3.7 Chapter 8: Economic Evaluation of the Multi-functional Roller Track Gate

In this Chapter a case study is used to evaluate the relative economic merits of the proposed Multi-functional Roller Track Gate (MRG) design. The case study selected is based on the purchase of an existing SULS of the Model 'B' type and retrofitting of the MRG. This scenario assumes that the owner would wish to:

- Carry out extensive steelworks renewal for life extension of the vessel;
- Replace the existing Roller Track Gates (RTG) with the Multi-functional Roller Track Gates (MRG); and
- Sell or scrap the vessel upon completion of the 6 year project.

The data for this economic case study originated from credible sources. Nevertheless, some information is subject to logical assumptions resulting from: the author's experience; real life scenarios from the SULS sector of the maritime industry; and confidential data collected from SULS shipowners.

Prior to the owner purchasing the vessel, the assumption is that feasibility studies were carried out in numerous areas, such as: the trade; the charter party (i.e. Time Charter Contract); purchasing / investment plan; conversion cost; and financing of the project. Principally, these studies were necessary for the owner to verify possible employment of the vessel after purchasing and whether the project was financially viable. The estimated return from investment was 10% for the 6 year project. Annual and Discounted Cashflows were carried out to verify the estimated annual return and viability of the project. In addition, sensitivity analyses were conducted on steel cost, fuel price, conversion time and income from charter. The outcomes of these analyses were that the rate of return was greater than 10%.

1.4 Major Contribution of this Thesis

Roller Track Gates (RTG) designed for Self-unloader Bulk Carriers (SULS) is the original gate for these types of vessels. Starting from the twentieth century, designers have made numerous innovations and development relevant to the RTG. However, the Multi-functional Roller Track Gate (MRG) is the first roller track gate comprising two gates in one assembly capable of discharging cargoes in seven different ways, while addressing the moving-hole principle. These multiple discharging operations are considered the **major contributions of this study**. To achieve the additional discharging operations, this resulted in a heavier gate when compared to the original and existing RTG. Added gate weight was compensated for by using high tensile steel to reduce the vessel's lightweight and enhances cargo carrying capacity. This is considered the other significant contribution of this thesis. In the conclusion, the major contributions of this study are clearly identified.

1.5 Summary

This Chapter provides a synopsis of the background to Self-unloader Bulk Carriers technology, the aims and objectives of the study, and an outline of the methodical approach adopted. An outline of subsequent Chapters has been provided and what is considered to be the contribution of this thesis identified.

Chapter 2

2. THE DEVELOPMENT OF THE GREAT LAKES DRY BULK SHIPPING TRADE

2.1 Introduction

This Chapter discusses the historical framework and inception of early shipping on the Great Lakes (GL) of North America, commencing from the 1600s' which was prior to arrival of the European pioneers. Included in this Chapter are features of the dry bulk trade industrial revolution that enhanced shipping in the Great Lakes (GL) region. The commercial issues encountered by shipowners pertinent to the Great Lakes dry bulk trade are also explained. The market downturn during the development of the dry bulk trade in the GL region was primarily due to the Great Depression. This resulted in a reduction of the market freight rates which was a contributing factor to the development of Self-unloader Bulk Carriers (SULS). These ships had the ability to trade profitably in this depressed market and this was one reason for the survival of some the smaller shipowners in the GL region.

As the dry bulk trade increased so did the number and size of SULS as well as conventional bulk carriers'. This led to the development and expansion of ports infrastructure and the water transportation system. During the waterway improvements, charted shipping routes and channels were established to improved ports access in order to promote the sea borne trade. These seaway paths are clearly illustrated in chart form from the 19th to 21st centuries.

The origin and development of Canadian and USA Great Lakes bulk carriers' fleet are described, for both the Ordinary and Self-Unloader type vessels. Aspects related to the GL fleet growth of SULS and Ordinary Bulk Carriers are incorporated in this Chapter with further explanation as to why SULS migrated from the Great Lakes to international trade during the recession on the Great Lakes in the 1980s'.

Generally, this Chapter describes the background to the inception and evolution of GL Shipping on this great body of navigable waters called 'The Great Lakes of North America'.

2.2 Historical Background to the Shipping Trade on the Great Lakes

Fifty percent (50%) of the world's fresh water encompasses the Great Lakes (GL) of North America that is approximately 1,295,000 square kilometres (500,000 square miles) in area. From the 17th century these waters have greatly influenced the inception and development of the dry bulk shipping trade relevant to the GL water transportation sector of Canada and the United States of America (USA).

2.2.1 Early Shipping Trades on the Great Lakes

Navigation on the GL prior to the arrival of European pioneers was done by means of birch-bark canoes for transporting pelts i.e. hides and valuable furs. The larger of these craft averaged 9.75-10.67 metres in length, 1.52-1.83 metres in beam, capacity of 3 tonnes and with a crew of 6-8 natives. *'It has been noted that in the Great Lakes region, boats from different tribes could often be recognized similar to ships built by separate builders…'* Workman **(1945, p.363*)*.**

From around 1679, most bulk freight was transported in sailing ships. The largest of such vessels were in the order of 1800 tonnes in deadweight. During river passages between lakes, these vessels were towed in convoy i.e. by tugs. The remaining legs of these voyages to Great Lake ports, principally Chicago and Detroit, were done independently under sail.

'In 1679, the first ship known to trade the Great Lakes was constructed. This vessel was the 'Griffin', a sailing wooden hull built by La Salle on the Niagara River east bank…' Workman, **(1945, p.364).** The North American natives (i.e. Indians) opposed the idea of

building this vessel, perhaps because of trade competition; hence, construction was delayed, but eventually the ship was completed.

On the maiden commercial voyage to the Canadian landmark port of Detour, the vessel 'Griffin' was loaded with furs and set sail down-bound on Lake Huron. Unfortunately, she was lost on passage under mysterious circumstances. Figure 2.3 demonstrates the port of Detour. It wasn't until the 19th century that another sailing vessel was built for the GL operation. This vessel was built on Lake Superior and named the 'John Jacob Astor'. She was the first USA flagged ship on the GL.

In 1869, the S/S 'R. J. Hackett' was built. This vessel was the first GL wooden steam barge and was effectively the prototype bulk carrier of the 19th century. This vessel marked the transition from sail to steam as a means of motive power and marked the beginning of the GL bulk carrier fleet.

Wooden vessels were superseded with the building of the first iron hull bulk carrier steamer 'Onoko' that was built in 1882. She was the largest vessel on the GL in 1885. Workman, **(1945, p.366)** stated that *'During and subsequent to launching this innovative ship, spectators expected her to sink because of her weight and being constructed from iron…',* The steamer 'Onoko' traded on the GL while being manually loaded and discharged by 'ship loaders'. This pre-dates the introduction of any self-unloading capability.

2.2.2 Further Development of Shipping Trades on the Great Lakes

Bulk carriers during the 1800s' were loaded and unloaded by shore machines or rigs that were very much less sophisticated and effectives than present bulk cargo handling gear. It took the steamer 'R. J. Hackett' approximately 3 to 7 days on average to unload her 1000 tonnes of cargo. In the years following 1869, the technology for loading and unloading of bulk carrier vessels was slowly developed through various designs to meet the demands of the dry bulk industry.

According to Workman **(1945, pp.374,375),** **'***Alexander E. Brown in 1880 invented a shore based single-cable-wired rig for hoisting bulk cargo by buckets, from ships' cargo holds to the storage facilities ashore…'*. This was a transformation in the handling of bulk commodities compare to the original method of unloading, where buckets were hoisted on rigs by horses and discharged into wheelbarrows ashore. In 1882, an unloading plant consisting of five rigs was installed on a dock in Cleveland, Ohio. Cleveland, being a major discharging port for ore, profited from this innovation of Brown.

Between the years of 1882 and 1899, the Hoover and Mason Company of Chicago further revolutionised shore based loading and unloading arrangements by inventing a rig comprising of self-filling buckets, or clamshells, hoisted from a tower. At that time, this unloading equipment had advantageous features in that the capacity of each clam shell was 5 short tonnes (4.54 tonnes) with a span of 18 feet (5.49 metres) and was capable of handling all grades of ores in the region.

Workman **(1945, p.375)** stated that, **'**George H. Hulett in 1899 *optimised the system of shore base bulk handling, (i.e. load and unload rigs), by designing machines that were different in numerous aspects to those of Brown, Hoover and Mason in terms of the record unloading times that were achieved...'*. These machines were enormous gantry cranes on rails travelling parallel to the supporting docks with extendable and retractable carriages at right angles to the ships side. The carriages had vertical legs with rotating clamshell buckets on the end, which could be tilted for directing the cargo from conveyors when loading. While unloading, cargo was clammed, lifted and dumped onto conveyor belts that discharged it to a storage area. A version of the 'Hulett' ship loader is shown in Figures 2.1 and 2.2.

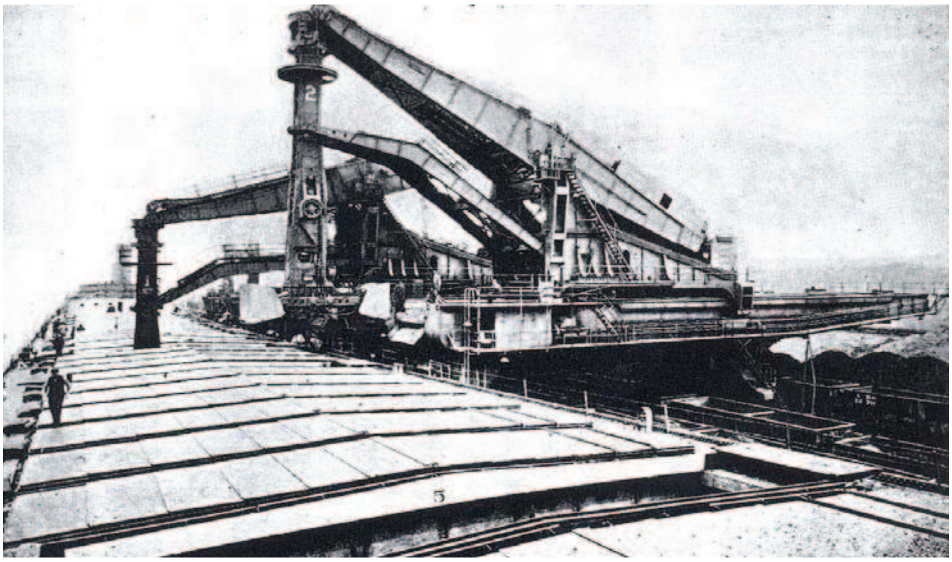


Figure 2.1 Two 17 Tonnes Electrically Operated Hulett Ore Unloaders (SNAME, 1945).

Figure 2.2 The Hulett Automatic Ore Unloader (SNAME, 1945).

Ship loaders of the George H. Hulett design type, continued to be the most widely used dry bulk handling equipment on the Great Lakes for bulk carrier vessels. Today, on the

Great Lakes in most the ports of Ohio State, similar loading and unloading rigs are still in operation.

2.3 The Great Lakes Shipping Routes From the Nineteenth to Twenty First Century

As the Great Lakes shipping trade developed, charted navigable routes were created to facilitate ships access to the various ports. This development in the Great Lakes water transportation system continued to enhance the Great Lakes dry bulk commerce for trading of larger size bulk carriers. From the 1800s' to the present day, Figures 2.3 and 2.4 demonstrate the major shipping routes and waterways for the North American Great Lakes region.

2.3.1 Great Lakes Shipping Routes During the Nineteenth to Twentieth Century

The importances of the shipping routes on the GL in the twentieth century are typified by considering that in 1945 *'one third of the USA population, around 47,248,395 people lived in states bordering the Great Lakes…'* The United States of America Census Bureau **(2004).** The inhabitants of the surrounding states have benefited immensely from the trade on this great body of navigable waters. The Great Lakes provide a bridge of water for shipping businesses between both the Great Lakes ports of USA and Canada as well as with the international maritime bulk trade. These routes are shown in Figures 2.3 and 2.4.

In Canada, the Great Lakes frontier provinces are Ontario and Quebec. During 1945 these prefectures had an estimated population of 4,000,000 and 3,560,000 respectively or 63% of the country total residents. Presently, the provinces of Ontario and Quebec remain being the largest populated regions in Canada, when compared to the other maritime districts of Canada.

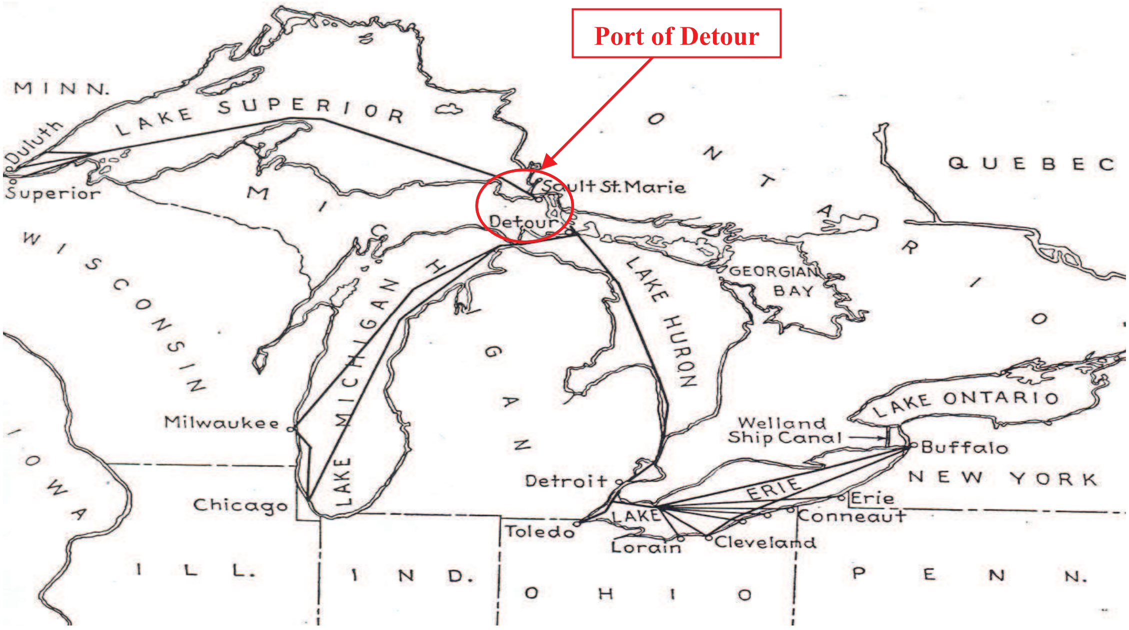


Figure 2.3 Great Lakes Principal Shipping Routes 1800-1900 (SNAME, 1945).

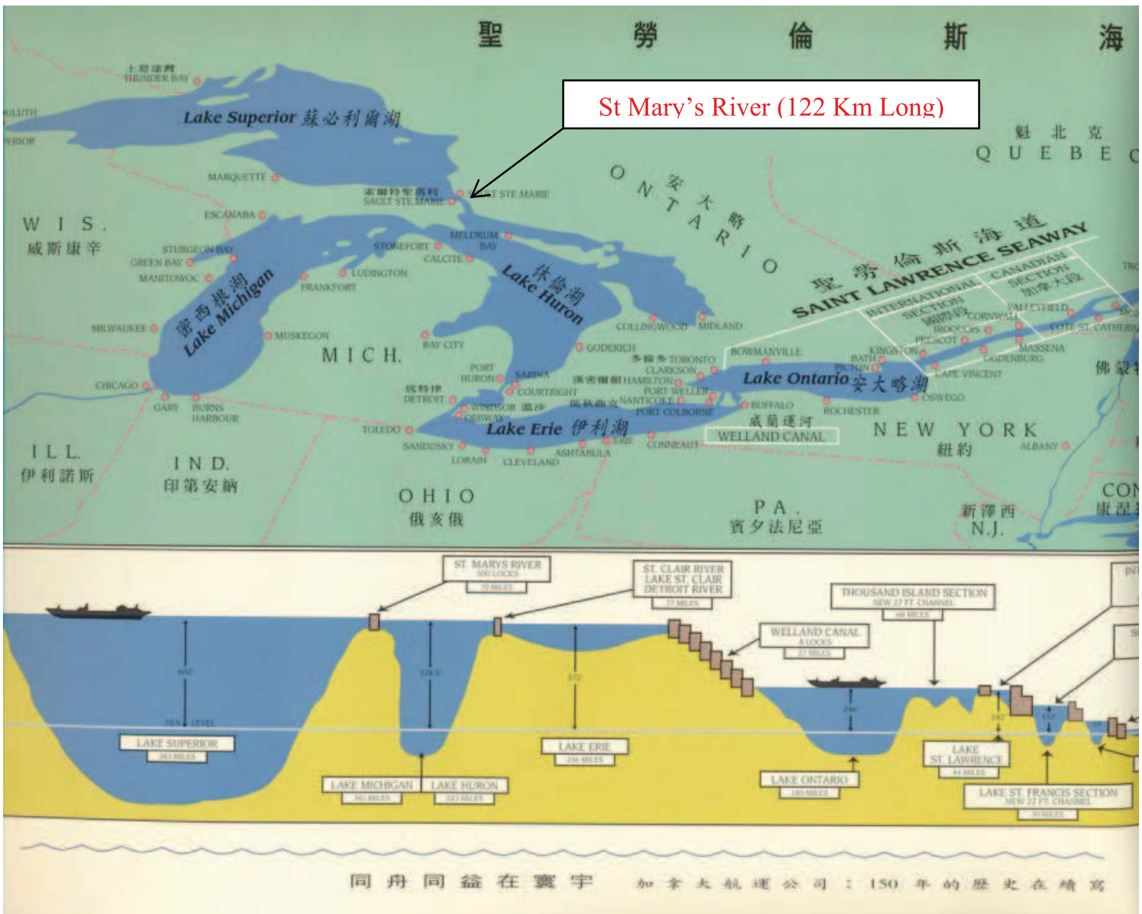


Figure 2.4 Great Lakes and St. Lawrence Seaway Shipping Routes 1900-2000 (CSL, 1995).

2.3.2 Great Lakes Shipping Routes During the Twentieth to Twenty First Century

Today, residents of the Great Lakes states are still profiting from water trades in the demographic areas of Minnesota, Wisconsin, Michigan, Illinois, Indiana, Ohio, Pennsylvania and New York. These states comprise 28.2% of the total USA population of 293,655,404, as of 2004.

Currently the regions of Ontario and Quebec, amounting to 19,935,500 or 62% of Canada's total population of 31,946,300 - Statistics Canada **(2005),** are still benefiting economically from the Great Lakes water bourne trades as shown in Figure 2.4.

2.4 Development of the Iron and Steel Industry in the Great Lakes Region

In 1844, iron ore deposits were discovered in the vicinity of Lake Superior. However, the mines commercial development did not come into effect until 1855, which was harmonized with the construction and opening of the first Sault Ste. Marie Lock by the Michigan State. This lock allowed for shipping trade between Lake Superior to Lake Huron via the St Mary's River.

Over the 122 kilometres long St Mary's River that connects Lake Superior to Lake Huron, there are a number of 18 feet (5.49 metres) drops in the river level that form a natural obstacle to its use as a navigable waterway. This impediment presented a transportation barrier for shipping iron ore by water to southern lakes port where the steel plants were located. The alternative shipping route was around the falls by rail. As a result, the opening of Sault Ste. Marie Lock between Lakes Superior and Huron played an important role in the development of Great Lakes shipping and marked the start of the evolution of commerce on the Great Lakes of North America. Figure 2.5 illustrate a pictorial view of the St Mary's River.

Figure 2.5 Saint Mary's River – Canada (Environment Canada www.ec.gc.ca, 2009).

Because the iron ore mines were located at the upper northerly lake and coalmines in the southern regions, the pioneers of the iron and steel revolution decided that both commodities, namely ore and coal, had to be brought to a common point in order to produce iron and steel. To achieve this ore was shipped to the Lake Erie ports, i.e. Cleveland, Erie, Conneaut and Ashtabula, and this became the centre of the steel industry in this region as, in terms of distance, these ports were easily accessible by rail to steel mills at the centre of Pittsburgh in the state of Pennsylvania, USA.

Limestone was the third most important commodity and was utilized as flux in smelting of ore for producing iron. In the years subsequent to 1855 considerable deposits of this product were discovered in the State of Michigan, hence large steel plants were established in this region. This was also facilitated by having coal deposits readily available in the adjacent State of Illinois and principally Michigan was an appropriate centre for steel distribution to consumers in the northwest of the USA.

Because of this rapid growth in production of iron and steel in the Great Lakes region after 1855, it was evident to the iron and steel majors that enhancing ship loading and unloading technologies was necessary if the industries increasing demand for coal and ore was to be met. The changes that were considered necessary to facilitate this increasing trade were primarily: hull construction; cargo capacity; motive power; construction of locks; deepening of channels and canals. As a result, to manage larger vessels and fulfil the demand for the commodities, the GL water transport system was improved by the completion of several new locks and channels from the mid nineteenth to mid twentieth century. These changes are clearly shown in Table 2.1.

Two improvements of particular note were the widening of The St. Mary's River, i.e. the Nebbish Channel, in 1908 and The Detroit River, i.e. the Livingston Channel, in 1925. These improvements made it possible to use larger vessels for transporting ore from Lake Superior to the southern lakes and instead of a northbound voyage in ballast; coal was occasionally shipped to Lake Superior from the southern lakes.

Table 2.1 Improvements of Great Lakes Lock and Channels (SNAME, 1945).

Locks	Channels	Completed	Dimensions	
			Imperial	**SI**
Sault Ste. Marie		1855	370Lx70Wx11.5D	595.5Lx21.3Wx3.5D
Weitzel		1881	515Lx80Wx17.0D	828.8Lx24.4Wx5.2D
Welland (Third)		1887	N/A	N/A
Canadian		1895	900Lx60Wx22.0D	1448.4Lx18.3Wx6.7D
Poe		1896	800Lx100Wx22.0D	1287.5Lx30.5Wx6.7D
Davis		1908	1350Lx80Wx24.5D	2172.6Lx24.4Wx7.5D
	Nebbish	1908	13.3x300Wx21.0D	21.4Lx91.4Wx6.4D
	Livingston	1912	6Lx300Wx22.0D	9.7Lx91.4Wx6.7D
Fourth		1919	1350Lx80Wx24.5D	2172.6Lx24.4Wx7.5D
	Livingston	1925	6Lx450Wx22.0D	9.7Lx137.2Wx6.7D
Welland (Fourth)		1932	800Lx80x30D	1287.5Lx24.4Wx9.1D
St. Lawrence Seaway		1958	14 ft. depth	4.3 m depth

Note: Dimensions in feet and metres except for lengths (L) that are in miles and kilometres.

2.5 Commercial Aspects of Great Lakes Dry Bulk Trade during the Nineteenth and Twentieth Century

The original dry bulk water-borne movement during the nineteenth century was primarily related to open barges, utilized as lighters in sheltered harbours, employed fundamentally in the stone trade and unloaded by shore equipment. These barges were rather basic in their designs and constructions. Additionally, statistics of cargo unloaded from such barges in this given period were not recorded, so it is not possible to economically compare technological advancement in the unloading of dry bulk cargoes. SNAME **(1945)** concluded that the Great Lakes original annual dry bulk trade by water and ship was relatively low in terms of tonnage transported (see figures in Table 2.2).

In the early 1800s', traffic of principal commodities, i.e. iron ore, coal, grain and stone, was only measured and recorded at the Sault Ste. Marie Locks; both Canada and the USA maintained complete statistics of the trade transiting the locks and canals. In 1855, subsequent to the opening of Sault Ste. Marie Lock, the Lake Superior trade was less than 15,000 short tons (13,608 tonnes) per year for the navigable season, namely about 240 days per year. By 1885, a total of 3,256,628 short tons (2,954,413 tonnes) of bulk freight passed through the Sault Ste Marie Locks. Forty years after traffic began, i.e. 1895, the growth of commerce had increased considerably, accounting for a volume in excess of 15 millions short tons (13,608,000 tonnes) per year just from the Lake Superior bulk business. Throughout the subsequent years, from the early 1900's onwards, the bulk trade for Lake Superior increased progressively from 36 million short tons (32,659,200 tonnes) in 1902 to more than 51 million short tons (46,267,200 tonnes) in 1913 and reached almost 80 million short tons (72,576,000 tonnes) by 1916. Table 2.2 shows the corresponding degree of increase in dry bulk traffic over a 10 years period in millions of tonnes of cargo per year for the Sault Ste. Marie Locks.

In 1923, the Great Lakes stone and coal trade accounted for almost 10 million short tons (9,072,000 tonnes) of stone and in excess of 33 million short tons (29,937,600 tonnes) of coal for the navigable season. However there is no record of what percentage was transported in SULS.

Table 2.2 Volume of Bulk Trades Traffic for Sault Ste. Marie Locks – 1885 to 1934 (SNAME, 1945).

Periods (Years)	short tons	tonnes	Remarks
1885-1894	80,343,218	72,887,367	
1895-1904	253,002,697	229,524,047	
1905-1914	576,962,068	523,419,988	
1915-1924	763,934,346	693,041,239	
1925-1934	651,071,593	590,652,149	(-102,389,090 tonnes to previous 10 years)

Note: 1 short ton = 0.9072 tonnes

From 1885 to 1924, the Lake Superior trade increased steadily each decade. Nevertheless, between 1925 and 1934, the total commerce decreased, resulting in 112,862,753 short tons (102,389.090 tonnes) of lost trade in a 10 year cycle. Table 2.2 demonstrates this decline in bulk trade primarily for the Lake Superior area.

By the end of 1935, records demonstrated that the total Great Lakes dry bulk trade for major commodities, i.e. ore, stone and grain, had been somewhat depressed for the previous 5 years and that there was a similar situation in 1938. The exception to this was grain commerce, where there was an increase of over 10 million short tons (9,072,000 tonnes) of trade, significantly higher than in the previous years. The tonnes of cargoes handled in the period 1920 to 1941 and the ranges of commodities are shown in Appendix II.

During the years identified, i.e. 1931 to 1935 and in 1938, shipowners suffered great losses in revenue not only from low freight rates but also from this reduction in demand for major commodities. This downturn in the market was highly influenced by the Great Depression of North America, which lasted from 1929 to, officially, the beginning of World War II in 1939. Appendix II also illustrates the lost revenues from poor trade during this period.

Nevertheless, after a year of recession in 1938 for the total bulk trade, from 1939 the overall GL dry bulk market started to increase and showed positive signs of recovery for most cargoes, with the exception of the coal, i.e. anthracite and bituminous. Again these trends are shown in Appendix II.

Despite the Great Depression and the accompanying low freight rates, the amount of dry bulk trade on the Great Lakes was still significant and the market demand motivated further development of the Great Lakes bulk fleet (Appendix II). This growth in the Great Lakes dry bulk fleet is evident from the numbers of ships solely employed for the iron ore trade during 1939 and 1940. However, of this fleet an unknown quantity of these vessels were Self-unloader Bulk Carriers (SULS). This expansion in the Great Lakes dry bulk fleet is clearly demonstrated in Appendix II.

2.6 Impact from Improvements of the GL Water Transportation System

As a result from the Great Lakes improvements illustrated in Table 2.1 with regard to construction of locks, the deepening and widening of channels and canals, etc. Larger vessels with higher power were built allowing, the faster turn-around of ships and the trips time were significantly reduced. Thereby, the expansion of the water transportation system resulted in an overall enhancement of the vessels cargo carrying capacities.

In addition to these water infrastructure changes, the installation of onboard SULS equipment and shore based loading and unloading facilities were the other factors that boosted the Great Lakes commerce still further. The positive impacts from the water transportation systems in terms of trade are clearly demonstrated in Appendix II. These quantities demonstrate the magnitude of the overall increase in the Great Lakes dry bulk shipping of major commodities over the period from 1920 to 1941, namely before during and after the depression years .

The innovations from 1885 to the mid 1900s' relevant to the Great Lakes water transportation systems, shore based loaders including the discharging systems accompanied by SULS made the Great Lakes region dry bulk trading by ships highly competitive when compared to the railroad system of transportation.

Competition pertinent to the two modes of shipping cargoes, (i.e. by sea or rail), was evident and commodity movement by sea was obviously the most economical and favourable method. SULS ships were the preferred carrier for the reason that in a given period, these specialized types of vessels were capable of moving considerable quantities of commodities at economical freight rates. Attaining the unloading of cargo to isolated areas with undeveloped ports or directly ashore into customer storage facilities without support from shore-side facilities.

By using SULS type vessels during these depressed times, both the shipowners and shippers benefited from the SULS method of transportation, where no shore based assistance was required for unloading cargoes. This economical incentive for operators of SULS remains true to this day.

2.7 USA Sector Dry Bulk Trade and SULS Issues on the Great Lakes

There are two particular important periods in the USA Great Lakes dry bulk commercial history:

- In 1923, the transport of bulk commodities was rose to 111,019,171 short tons (100,716,592 tonnes) per year, from 68,033,575 short tons (61,720,059 tonnes) in 1921 and 89,454,848 short tons (81,153,438 tonnes) in 1922; and
- During July and August of 1923, a total of 28,742,052 short tons (26,074,789 tonnes) of cargoes were recorded transiting the Sault Ste. Marie Lock in 62 days. This quantity exceeded the 1923 yearly tonnage passing through the Panama (21,916,015 short tons or 19,882,208 tonnes) or Suez Canals (23,545,128 short tons or 21,360,140 tonnes).

These changes in freight movement activity demonstrated by the cargo capacity transported in 1923, clearly illustrates the GL fleet flexibility at that time. This rapid expansion in the GL water transportation system sustained the agricultural and industrial growth of North America, both Canada and USA, from the second to fourth decade of the 20th century.

However, the introduction of the Self-unloaders Bulk Carriers' concept in the 20th century was another motive other than the Great Depression that caused a reduction in the Great Lakes freight rates. In 1943 the tariffs for carrying iron ore from Lake Superior to Lake Erie ports decreased from USD 2.11 to 80 cents per short ton (or 80 cents/0.9072 tonne) and rates during the same period reached a record low of 50 cents per short ton (or 50 cents/0.9072 tonne). Grain rates were subject to fluctuation based on supply and demand, but according to Workman **(1945)** the costs were as low as 2 cents per bushel (1 bushel = 27.22 kg), while coal was carried from Lake Erie to Lake Superior ports for 45 cents per short ton (or 45 cents/0.9072 tonne). At the time, Workman **(1945, p.365)** commented on the cost of transporting coal by ship as 'l*ess than a labourer would charge to shovel the same quantity of coal from the sidewalk to a person's cellar…'*

In spite of the Great Depression and low freight rates, to avoid insolvency some shipowners had to seek alternative commercial strategies for their survival in the market place. These owners were not complacent and did not simply rely on waiting for the economy to improve. The SULS concept was seen as a likely solution for their continued existence in the shipping market. As a result, *'some shipowners had the courage to invest approximately half-million dollars (USD 500,000.00) for converting each of their older bulk carriers to SULS…'* Arnott **(1939a, p.246)**

He also stated, *'it was gratifying to learn that the owner's' ventures were certainly enterprising and justified in the subsequent years…'* Arnott (1939b, p.246). The revenue from investment in ship conversions, based on freight rates at the time, is evident in Appendix II, where examples of shipowners' revenue from 1931 to 1941 are given. This period, including the Great Depression years, was the most volatile in terms of decline and demand for major commodities.

Because of this demand for dry bulk cargo in the undeveloped GL areas during the Great Depression years, a number of the older standard bulk carriers were converted to SULS. Table 2.3, illustrates a percentage of these vessels.

Table 2.3 Principal Characteristics of Some Lake Freighters Converted to SULS (SNAME, 1945).

Ship	Built	Converted	Dimensions	
			Imperial (ft)	SI (m)
S/S Thunder Bay Quarries	1910	1932	504Lx56Bx30.0D	153.6Lx17.1Bx9.4D
S/S Diamond Alkali	1912	1932	504Lx56Bx30.0D	153.6Lx17.1Bx9.4D
S/S Dow Chemical	1906	1932	504Lx54Bx30.0D	153.6Lx17.1Bx9.4D
S/S J. F. Schoelkopf, Jr.	1907	1933	532Lx56Bx31.0D	162.2Lx17.1Bx9.5D
S/S J. L Reiss	1910	1934	504Lx56Bx30.0D	153.6Lx17.1Bx9.4D
S/S Anchilles	1915	1935	514Lx65Bx39.5D	156.7Lx19.8Bx12.0D
S/S John J. Boland	1907	1936	504Lx54Bx30.0D	153.6Lx16.5Bx9.4D
S/S George Rand	1911	1936	532Lx58Bx31.0D	162.2Lx17.7Bx9.5D
S/S J. S. Ashley	N/A	1937	504Lx54Bx30.0D	153.6Lx16.5Bx9.4D

Despite the inconsistencies in freight rates and dry bulk cargo demand from 1888 to 1945, Workman **(1944)** notes that in 1944 traffic passing through only the Sault Ste. Marie Lock amounted to 91,379,658 short tons (82,899,625 tonnes) for principal commodities. This value demonstrates the recovery of the Great Lakes trade towards the end of World War II and was similar to 1916 when 91,888,219 short tons (83,360,992 tonnes) of cargoes transited the Sault Ste. Marie Locks; the greatest amounted recorded for a sole navigation season.

The steady up turn in bulk commerce in the early 1940s' can be quantified from the total amount of GL dry bulk freight handled during 1939 to 1941. These figures are shown in Appendix II.

Historically, throughout the progression of SULS technology, the dry bulk trade for these ships was most prominent in the USA, than in comparison to Canada. The Americans, as inventors of this specialised dry bulk handling technology, more readily embraced it adoption. However, following the SULS inception, the USA Self-unloader Bulk Carrier businesses have predominantly remained domestic. This can be confirmed from the numbers of SULS under USA flag that are trading on the GL and internationally (see Appendices III.1 to III.5). Today Canada is the leader in the international SULS sectors.

2.8 Canadian Sector Dry Bulk Trade and SULS Issues on the Great Lakes

Upon finalizing the St. Laurence Seaway and Third Welland Canal in 1887, shipping companies commenced building a fleet of bulk carrier primarily for transporting grain from the Canadian Prairies to markets in eastern Canada. Ports cargo handling infrastructure was put in place by the grain majors to facilitate loading and unloading in ports from Thunder Bay to Montreal. Therefore, in the early 1900s', it was evidently uneconomical to deploy SULS in the grain trade, after already investing in developing shore based loading and unloading systems to support the handling of grain cargoes for the standard gearless bulk carriers.

Nevertheless, steel mills, power plants and the construction industry required natural resources such as ore, coal, stone and sand. The demand for these commodities was the principal reason for acquiring Self-unloading vessels into the Canadian Great Lakes dry bulk trade, from the second decade of the 20th century. The employment of SULS for transporting bulk cargoes, other than grain in the Canadian sector was certainly commendable commercially as it avoided having to build additional costly shore based ship unloaders. It should be noted that the original generation of SULS also traded grain occasionally. Today, depending on demands during the grain harvest season, SULS still transport grain to St. Lawrence ports.

Between 1908 and 1932, the Welland canal draught was restricted to 14 feet (4.3 metres). This limited both the size of vessels transiting the canal and the water bourne trade of major commodities from the northern lake ports to Lake Ontario including the eastern seaboard. However, in 1932 the Welland Canal system was improved as a result of the completion of the Fourth Canal and increased size of locks.

Despite these enhancements in the Canadian water transportation system, the grain trade in Canada was suffering commercially from the impact of the Great Depression during the early 1930s'. The Canadian Encyclopaedia **(2004, p.1)** provide the following description. '*The 1920s' had been boom times in Canada. In 1928 Canadian farmers* *produced a huge wheat crop and 1929 began as the best year yet. Factories were busy and western Canadian farmers were getting high prices for their wheat crop. Suddenly there was an enormous glut of wheat on the world market. Wheat fell from $C1.61 a bushel in 1929 to 0.38 cents a bushel in 1932. Within nine (9) months of the stock market crash commencing from October 24th 1929, all of North America and the world were in grip of the Depression…*'.

From 1932 until 1958, the St. Lawrence Seaway was further developed and despite the ongoing stagnation of the dry bulk trade, the seaway changes allowed larger SULS for transporting coal and ore to and from both the Great Lakes and Canadian eastern seaboard. The St. Lawrence Seaway formally opened in 1958 and during late 1950s' the Canadian SULS fleet expanded dramatically to satisfy the demand of dry bulk trade in the Canadian Great Lakes water business sector. This remarkable demand for major commodities, such as ore, coal and grain created a rapid expansion of the SULS fleet from 1965 to 1982. As a result, there was an over-supply of Self-unloaders Bulk Carriers in the Canadian Great Lakes sector. The Great Lakes region was faced with a recession in the early 1980s'. Because of this dry bulk trade slump on the Great Lakes, Canadian SULS shipowners expanded their business horizons to the international markets for survival during this downturn. The principals Canadian SULS operators had not previously explored foreign markets to any great extent. However, with the continuing global inflation and concerns of labour cost and trade unions, the SULS became more attractive economically to customers trading in geographical areas other than the Great Lakes. This is evident from Elder and Detenbeck **(1988a, p1)** statement, who stated that *'With worldwide price increases and labour rates rising, these Self-unloaders vessels are becoming more cost effective on longer voyages that were not thought possible previously…'*

'The technology of SULS is a North American invention and surprisingly this expertise has not been copied to a great degree by other countries…' Elder and Detenbeck **(1988b, p1)**. Taking into consideration the development and size of the global dry bulk fleet that has been increasing annually, it would appear that the growth of SULS on a

worldwide scale would have also increase considerable. Nevertheless, the growth of SULS has not been significant, when compared to the international dry bulk fleet size. This perhaps stems from the fact that these vessels are specialized and remains a niche sector of the maritime dry bulk trade sector and the fleet growth is limited.

Canada to this day remains the leader in SULS technology in every respect, fundamentally because of their dominant or larger market share in SULS trade for both the international and domestic sectors.

2.9 Summary

In this Chapter the historical background of shipping trade on the Great Lakes (GL) of North America has been presented. This includes the shipping routes from the nineteenth to twenty first centuries; the development of the iron and steel industry; the commercial aspects of Great Lakes shipping during the mentioned period (i.e. 1800s' to 2000s'); the impact from improvements of the GL water transportation system and dry bulk trade issues involving SULS in both the Canadian and USA Great Lakes sector.

Subsequent to the inception of Great Lakes shipping (1600s') and during the 1800s' industrial revolution of North America (NA), large deposits of natural resources, principally ore, coal and stone were discovered in the Great Lakes region. North America required these products for the fabrication of iron, steel and for producing energy. Grain was another important commodity produced by North American farmers for feeding the worlds' population. These commodities, i.e. ore, coal, stone and grain, were located in secluded areas and needed to be brought and discharged to a common point for processing, fabrication and shipping. The manufacturing and distribution requirements for these raw materials were the foundation and development of both the Great Lakes Dry Bulk Trade and water transportation system, on the worlds' largest waterway of fresh water.

Fundamentally, the expansion of the Great Lakes dry bulk trade provided employment for citizens of Canada and the USA. The commercial growth of this dry bulk trade, also led to the development of the Ordinary Bulk Carriers, but primarily the Self-Unloader Bulk Carriers Vessels (SULS). This was because of these vessels uniqueness and ability to discharge their cargoes in remote ports without involvement from any external source. SULS have disadvantages when compared to ordinary bulk carriers, discussed in the subsequent Chapter 3, but they do provide an obvious benefit with regard to the discharging of their cargoes. SULS are partly responsible for the reduction of required freight rates in the Great Lakes region during the 2^{nd} and 3^{rd} decades of the 20^{th} century.

Because of the distinctive unloading nature of SULS, these vessels have been considered a selective ship group as a subset of the global dry bulk fleet. These ships remain an unprecedented asset in the marine dry bulk trade and are now trading globally, primarily because of their adaptability in discharging their cargoes in undeveloped ports with adverse or no unloading infrastructure.

Chapter 3

3. SELF-UNLOADER BULK CARRIERS

3.1 Introduction

This Chapter describes the growth of the global dry bulk carrier fleet and identifies what proportion of that segment is made up of Self-unloader Bulk Carriers (SULS).

The definition of a Self-unloader Bulk Carrier is provided and the reasons for the evolution of SULS are described. The design issues encountered during the development of these specialized types of dry bulk carriers are explained.

In this Chapter, a comparison of the ordinary bulk carriers' with SULS is also made. The fundamental operational principles of various categories of SULS systems are identified and explained, these include: Crane; Hybrid; Full Gravity Discharge; Digging; Gravity with Mechanical Assist; and Self-Unloader / Loader.

Finally, this Chapter seeks to summarise the general trading operational advantages and disadvantages of SULS.

3.2 Dry Bulk Carrier Fleet

During 2005, when this study was started, the global dry bulk carriers' fleet amounted to 338.0 million deadweight tonnes (MDWT). In the same year, the SULS segment totalled 6.4094 MDWT or 1.90% of the global dry bulk carriers' fleet.

The aggressive new building programme from 2005 to 2008, primarily in Korea, Japan and China, resulted in the global dry bulk carriers' fleet increasing from 338.0 to 416.7 MDWT i.e. an increase of 23.3%. This additional tonnage to the worldwide dry bulk carriers' fleet comprised of vessels ranging from 10,000 to 80,000 tonnes deadweight and above. R. S. Platou **(2004-2008)** reports, the universal bulk carriers' fleet increased by 6.7% from mid 2004 to mid 2005 and by 8.8% from mid 2007 to mid 2008. This growth in the global bulk carriers' fleet confirms recent development in the new-building sector of dry bulk carriers.

Self-unloader Bulk Carriers' remain a niche sector of the dry bulk carrier's fleet, accounting for 1.64% of the global fleet by mid 2008 (see Table 3.1a). However, Canada Steamship Lines Inc. and R. S. Platou **(2008)** stated that from 2005 to 2008 the percentage of SULS vessels increased by 2.5%**.** This added SULS tonnage was solely in the international fleet outside of North America. During this period, the USA and Canadian fleet have remains unchanged in terms of deadweight tonnes. According to Canada Steamship Lines Inc. and R. S. Platou **(2005-2008-2009),** Tables 3.1a, 3.1b, 3.4, as well as Appendices III.1 to III.5, illustrates these changes in both the ordinary and SULS dry bulk fleets.

Table 3.1a Dry Bulk Carriers' Fleet Development, 2008.

SULS Sector			Global Dry Bulk Carriers	
Region	**No. of Ships/Registries**	**MDWT**	**Ship Size (DWT)**	**MDWT**
Int'l (31 Nations)	118 (59.1%)	4.0442	10-59,999	164.7
USA	49 (25.2%)	1.7229	60-79,999	95.8
Canada	37 (15.7%)	1.0774	80+	149.5
Total	**204**	**6.8445**	Sub-total	410.0
Note: According to RS Platou - global dry bulk carriers fleet MDWT increased 8.8% in 12 months, from 2007 to 2008. SULS total is 1.64% of the Global dry bulk carriers' fleet.			Combine in Dry	6.7
			Total	**416.7**

Source: Canada Steamship Lines Inc and R. S. Platou July, 2008

Table 3.1b Dry Bulk Carriers' Fleet Development, 2009.

SULS Sector			Global Dry Bulk Carriers	
Region	**No. of Ships/Registries**	**MDWT**	**Ship Size (DWT)**	**MDWT**
Int'l (31 Nations)	119 (58.6%)	4.0924	10-59,999	167.7
USA	49 (23.6%)	1.6479	60-79,999	96.4
Canada	37 (17.8%)	1.2445	80+	171.3
Total	**205**	**6.9848**	Sub-total	435.4
Note: According to RS Platou: Global dry bulk carriers fleet MDWT increased 5.3% in 12 months, from 2008 to 2009. SULS total is 1.59% of the Global dry bulk carriers' fleet.			Combine in Dry	3.3
			Total	**438.7**

Source: Canada Steamship Lines Inc and R. S. Platou July, 2009

When comparing the worldwide dry bulk carriers', the proportions of SULS tonnages forming part of the global dry bulk fleet are 1.64% (2008) and 1.59% (2009). These values are trivial, however, significant when considering the fleet size.

3.3 Definition of Self-unloader Bulk Carriers

A Self-unloader Bulk Carrier is a type of vessel that unloads cargo autonomously by having shipboard discharging equipment and requires no assistance from any external source; namely, no shore based ship-loader or cranes are required for unloading the cargoes.

3.4 The Origin of Self-Unloader Bulk Carriers Technology

Historically, the origin or birthplace of Self-unloaders Bulk Carriers (SULS) technology was undoubtedly the Great Lakes of North America. Elder and Detenbeck **(1988, p.1)** stated that *'The first known 2 SULS were the S/S Hennepin* ***(1903)*** *and S/S Topeka* ***(1904)***. *Both vessels were USA wooden hulls converted by an anonymous and innovative company, whose name has not been recorded in the history books…'*. These vessels were used for the transport of crushed stone, coal and ore on the Great Lakes. During the same period, there were historical rumours that a wooden hulled vessel was also converted to a SULS on the Pacific Coast of North America. However no record of this ship's name, company or owner has been documented. Elder and Detenbeck. **(1988).**

In SNAME **(1924)**, it is noted by Penton and Sadler **(1924a, p.49)** that '*the records of the United States and foreign (principally British) patent offices disclose numerous attempts to facilitate the handling of bulk cargoes by various forms of*:

- *Hoppering;*
- *Elevating;*
- *Conveying equipment;*
- *Weighting; and*
- *Measuring devices'*.

Nevertheless, Penton and Sadler **(1924b, p.49)** also stated that these *'developments up to 1907, however, might be practically all dismissed as having little or no value so far as rapid and continuous handling of bulk cargo is concerned'*. Actually, it was not until 1908 when the first commercial development of Self-unloading Bulk Carrier technology started and this was in the Great Lakes (GL) region.

3.5 The Origin of USA Self-unloader Bulk Carriers

During the 20th century in the GL region, SULS technology was researched by Penton and Sadler **(1924c p.49)**, who state that *'In 1907, to meet the requirements of a concern on the Great Lakes using annually some hundreds of thousands of tonnes of limestone in chemical processes, one of the authors developed a design employing a conventional single-deck, bulk-freight type of hull and installing therein a self-unloading, continuous conveyor system which delivered the cargo over-side without the assistance and intervention of any form of auxiliary or shore equipment'*.

Figure 3.1 S/S Wyandotte - 1st Commercial SULS of Wyandotte Transport Co. 1908 (GL Photo 2005).

This vessel was the S/S Wyandotte (see Figure 3.1), designed and owned by the Wyandotte Transportation Company of the USA. This company is considered the pioneer of the Self-unloader Bulk Carriers and are also attributed with being owners of the first commercial steel hulled American Self-unloader Bulk Carrier to trade the GL. The S/S Wyandotte started operation during the summer of 1908. A second similar vessel 'S/S Alpena' was built for the same company in 1909, Figure 3.2 shows this vessel.

Figure 3.2 S/S Alpena - 2nd Commercial SULS of Wyandotte Transport Co. 1909 (GL Photo 2005).

The S/S Wyandotte was designed principally to trade limestone of 100 mm (or about 4 inches) in size, but it was evident that the SULS system would also be suitable for trading coal and subsequently the vessel was used for both the stone and coal trades. Palmer **(1924, p.56)** stated that *'The S/S Wyandotte construction ideology was the foundation for developing subsequent SULS, which was copied by other companies…'.* According to Elder and Detenbeck **(1988c, p.1),** *'This vessel traded on the Great Lakes for the Michigan Alkali Company from 1908 to 1963…'.*

The introduction of the S/S Wyandotte and subsequent SULS in the GL bulk trade gave great impetus to the stone trade development during the 20th century. As discussed in Chapter 2, stone was an important and essential commodity in the manufacture of iron and steel as well as other chemical processes. Both vessels, the S/S Wyandotte and S/S

Alpena traded on the GL, starting from the early 1900s until the scraping of these vessels.

3.6 The Origin of Canadian Self-unloader Bulk Carriers

In Canada, the earliest known SULS was the S/S Collier No.1. This 1924 built vessel was a hybrid designed SULS, which was constructed in Britain and owned by Canada Steamship Lines Inc. (CSL). The design of this ship was a tailor made version of the customary shore based grab-bucket and marine system, as shown in Appendix III.6.

The S/S Glenelg was the first Canadian SULS of the continuous conveyors type with gravity discharging system. This vessel was built in 1923 for the Great Lakes Transportation Company, primarily for transporting coal. In 1926, Canada Steamship Lines Inc. became the owner of this vessel, which was the pioneer of gravity discharging type SULS in Canada. In 1955 the S/S Glenelg was converted to a gearless bulk carrier and later reconverted to a SULS in 1958 for employment in the cement trade. The S/S Glenelg was scrapped in 1966. This vessel design was similar to the S/S Wyandotte. Table 3.2 provides the principal particulars of these two pioneering USA and Canadian SULS with continuous conveyors and gravity discharging systems.

Table 3.2 First USA and Canadian GL Pioneer SULS with Gravity Discharge (SA, 1969).

Ship				Dimensions	
Name	Built (Year)	Capacity (tonnes)	Discharge (tonnes/h)	Imperial (ft)	SI (m)
S/S Wyandotte	1908	1814.4	453.6	303L×45B×24.0D	91.4Lx13.7Bx7.3D
S/S Glenelg	1923	2358.7	392.8	259L×43B×46.5D	78.9Lx13.1Bx14.2D

Note: According to the literature, these ships capacity were 2000 and 2600 short tons.

3.7 The Evolution of Self-Unloader Bulk Carriers

The Great Depression was one reason for the invention of self-unloader Bulk Carriers and was described by Cross **(1938a, p.230)**, as *'a child of the depression'* that has greatly enhanced the Great Lakes (GL) dry bulk trade of the United States of America (USA) and Canada during the 20th century. The evolvement of SULS was due to various factors, such as:

- Dry bulk trading ports without proper unloading facilities;
- Undeveloped ports with improper mooring arrangements;
- The demand for major commodities in time of need; and
- In some cases, the demand for commodity in the Great Lakes region with limited navigational season of 225 to 240 days/year.

In summary, the primary objective of these ships during the inception stage was to transport cargoes rapidly to and from regional Great Lakes ports that generally had inappropriate or inadequate unloading infrastructure.

3.8 Design Concerns during the Development of Self-unloaders

While designing the original SULS during the Great Depression era of North America, Cross **(1938b, p.230)** stated that *'cost was the all-important factor throughout the design, even to a point at which some Engineers believed the work would not stand up. There were many more who believed the owner had more courage than good judgement to go ahead with such a venture'***.** This perception by Engineers during the preliminary designing of these vessels was fundamentally because of obvious and recognized engineering omissions. These omissions included deficient hull designs during the initial construction and conversion stages, that would render the system relatively unreliable when the vessels in service. The design deficiencies were principally caused by economic constraints, resulting from insufficient finance for equipment and proper construction. Despite these economic burdens for shipowners in developing SULS, the end results from their endeavours were financially rewarding. This avoided insolvency of many small and independent shipowners in the GL region.

3.9 Development of the Global Self-unloader Bulk Carriers Fleet

By 1924, Penton and Sadler **(1924, p.50)** stated that *'the Great Lakes SULS bulk carrier's fleet of the continuous conveyors type had grown to 11 ships of various sizes and capacities…'.* According to available historical data, Table 3.3 provides a summary of the percentage of the continuous conveyor types SULS that were operating on the GL by 1924.

It has been more than a century since the first commercial SULS started trading on the GL and subsequent to the introduction of SULS; the fleet size has developed considerably for both the GL and international sectors. However, this niche shipping segment still remains trivial, when compared to the worldwide geared and gearless bulk carrier fleet. From the beginning of SULS technology, the largest proportions of these ships pertinent to registry and deadweight tonnes have been from the United States of America (USA).

Table 3.3 Percentage of SULS of Continuous Conveyors on GL by 1924 (SNAME, 1939 & SA, 1969).

Ship	Built/Converted	Owners
S/S Hennepin (Converted)	1903	Unknown
S/S Topeka (Converted)	1904	Unknown
S/S Wyandotte (New)	1908	Wyandotte Transportation Co.
S/S Alpena (New)	1909	Wyandotte Transportation Co.
S/S Calcite (New)	1912	Bradley Transportation Co.
S/S W. F. White (New)	1915	Bradley Transportation Co.
S/S John G. Munson (New)	1917	Bradley Transportation Co.
S/S B. H. Taylor (New)	1923	Bradley Transportation Co.
S/S Glenelg (New)	1923	Great Lakes Transportation

Appendices III.1 to III.5 provide, in detail the numbers of SULS operating under different flags and Table 3.4 provides a summary of global registries and tonnage for SULS in 2005.

Table 3.4 Dry Bulk Carriers' Fleet Development, 2005.

SULS Sector			Global Dry Bulk Carriers	
Region	No. of Ships/Registries	MDWT (tonnes)	Ship Size (DWT) (tonnes)	MDWT (tonnes)
Int'l (31 Nations)	113 (56.8%)	3.6753	10-59,999	141.1
USA	49 (26.6%)	1.7229	60-79,999	82.9
Canada	37 (16.6%)	1.0774	80+	108.8
Total	**199**	**6.4756**	Sub-total	332.8
Note: According to RS Platou: Global dry bulk carriers fleet MDWT increased 6.7% in 12 months, from 2004 to 2005. SULS total is 1.92% of the Global dry bulk carriers' fleet.			Combine in Dry	5.2
			Total	**338.0**

Source: Canada Steamship Lines Inc and R. S. Platou July, 2005

When comparing the USA with other countries, this global dominant trend of SULS under USA registry remains true to this day. Table 3.4 shows the fleet magnitude for the SULS populations in three different regions, namely: international comprising 31 states (including the USA and Canada), the USA and Canada. In terms of the numbers of SULS registered and in million deadweight tonnes (MDWT), Table 3.4 also shows these figures, accounting internationally for 3.6753 MDWT (113 ships), USA 1.7229 MDWT (49 ships) and Canada 1.0774 MDWT (37 ships).

The universally SULS tonnage by mid 2005 was approximately 6.4756 MDWT. This figure according to R. S. Platou **(2005, p.6)**, '*was about 1.92% which is a minute fraction of the global dry bulk fleet accounting for 338 MDWT…'*. Table 3.4 also shows how this value as a sum of the SULS from three regions or groups.

On a worldwide scale, the SULS registries and tonnages in foreign trade belonging to the USA and Canadian regions are trivial, when weighed against the open registry nations.

For example, the Bahamas, Liberia, NIS and Vanuatu have the larger share of tonnage in the international SULS group. These values are shown in Table 3.5.

Table 3.5 also substantiates that a larger numbers of SULS (i.e. 119) are registered by countries other than Canadian and the USA, which totals 86 ships (see Appendices III.1 and III.2).

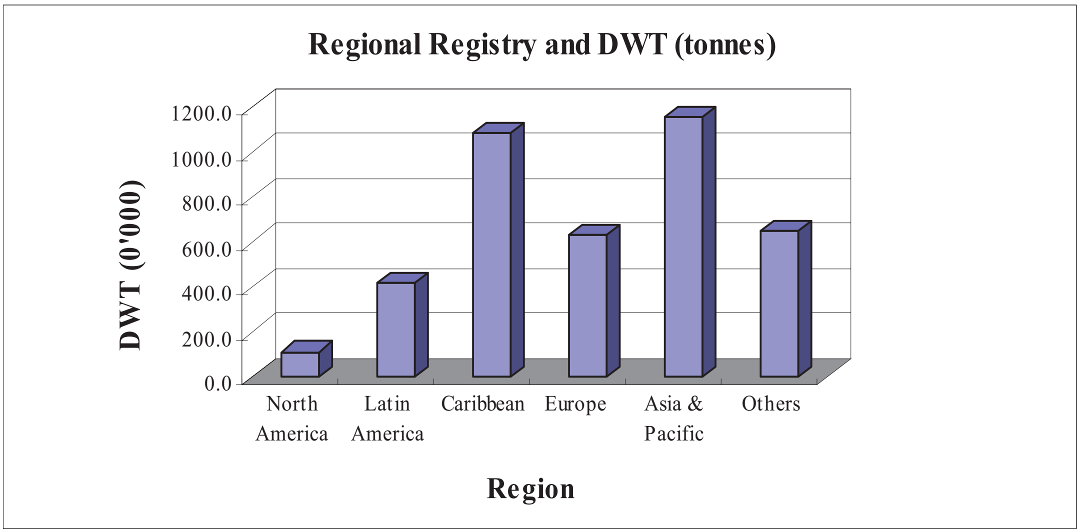
Today, the greater numbers of SULS are trading internationally or to regions other than the Great Lakes. Based on the number of registered vessels listed in Table 3.5, it is apparent that at least 119 SULS are engaged in trades or shipping businesses unrelated to the Great Lakes and are trading internationally

Table 3.5 Registries and DWT of SULS Trading Int'l (LR 2004 and CSL, 2009).

COUNTRY	No. OF SHIPS	DEADWEIGHT (tonnes)
Antigua	6	81851
Australia	3	93158
Bermuda	4	132911
Barbados	1	5050
Bahamas	14	912079
Bolivia	1	3180
Brazil	1	51501
Cyprus	5	156928
Canada	**2**	**77470**
Greece	1	3350
Hong Kong	1	61760
Indonesia	7	89722
India	2	134093
Iran	1	6412
Japan	5	45085
Korea	1	9571
Liberia	7	408197
Marshal Is.	3	112638
Netherlands	1	11545
NIS	13	388161
PR China	3	102590
Portugal	3	43854
Panama	8	187950
Singapore	3	135830
Sweden	3	26539
Taiwan	4	58695
Tonga	1	6666
UK	1	2210
USA	**1**	**33373**
Unknown Flag	**5**	**238685**
Vanuatu	6	297970
Venezuela	2	173407
Total	**119**	**4,092,431**

Note: Table updated in 2009 when the last recorded SULS was built in Brazil

In Figure 3.3, the SULS trading internationally have been categorized into six regions of operation and surprisingly the Asia Pacific sector accounts for approximately 1.154 MDWT. This figure represents the largest region in terms of registry and deadweight for SULS trading internationally. The Caribbean sector is the second largest region, primarily because of the deadweight and numbers of vessels registered under Bahamian flag, which forms part of the Caribbean group.



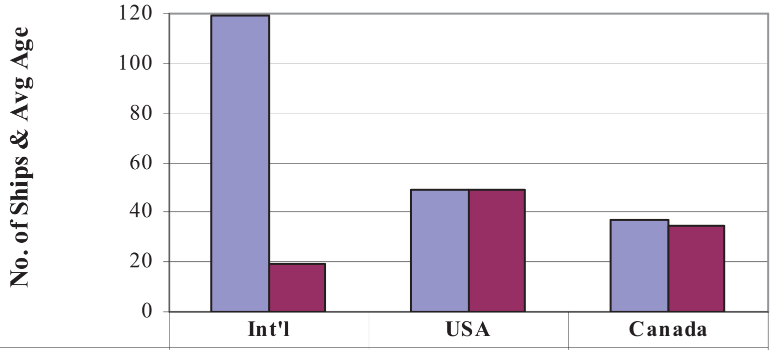
North America	Latin America	Caribbean	Europe	Asia & Pacific	Others
110,843	416,038	1,131,891	632,587	1,154,190	646,882

Figure 3.3 Regional Registries in DWT for SULS Trading Int'l (LR 2004 and CSL, 2009).

It is not surprising that the North American section (i.e. Canada and USA) has the least tonnages trading internationally as the larger percentage of Canadian and American registered SULS are handymax trading domestically on the Great Lakes and St. Lawrence Seaway.

As shown in Table 3.4 and Figure 3.4, the SULS population is small, when compared to the global dry bulk carriers' fleet and certainly much older. In 2009, it is apparent from this data that 42.0% of the SULS fleet was over 20 years old, which is the typical economical life for merchant ships. Figure 3.4 demonstrates this trend by showing the average age for SULS for three groups; Canadian, International and USA. The corresponding age ranges for these different categories are 21 to 62, 1 to 38 and 26 to 111 years respectively. These figures are provided in Appendices III.1, III.2 and III.3.

These older SULS are primarily those registered under USA and Canadian flags trading on the Great Lakes, where the commerce is rather stable from year to year.



	Int'l	USA	Canada
No. of Ships	119	49	37
Avg. Age (Years)	19	49	35

Figure 3.4 Global Self-unloader Bulk Carriers Average Age (LR 2004 and CSL, 2009).

The older SULS remain in an acceptable trading condition. This is primarily due to the GL trading season being limited to approximately 240-250 days per year, thereby allowing ample time for proper repairs and life extension of the vessels. Additionally, this aging fleet stems from various other factors, such as:

- The larger percentages of the shipowners are not ‘asset players’ and belonging to a group of original and traditional principals, who practice ongoing preventive maintenance for their ships. For example, Canada Steamship Inc **(2005, p.1)** *‘has allotted a yearly expenditure of 16 million Canadian Dollars for the maintenance of their vessels…*’;
- The shipowners good relationship with customers who are not prepared to invest large sum of money to establish their own port unloading infrastructures, in order to charter and unload the standard bulk carriers. This customer view creates a market for SULS and render a reason for life extension of these vessels;
- Long-term time charter or contract of afreightment for individual ships; and
- For those ships trading on the GL, there is less deterioration of the hulls by trading in a freshwater environment.

Because of these reasons, annual investment for new SULS tonnage is uncommon. This is unlike the standard ocean going bulk carriers, where from 2004 to 2005 the global standard dry bulk carriers' fleet increased by 6.7% and by about 5.2% from 2008 to 2009. See Tables 3.1a, 3.1b and 3.4.

Table 3.6 New SULS Tonnage of the 21st Century (CSL, 2005).

Vessel	Flag	SUL Type	Built (Year)	Age (Year)	DWT (tonnes)
Sophie Oldendorff	Liberian	Gravity	2000	5	70,034
Shin Hsing No.2	Taiwan	Gravity	2000	5	13,601
Gem of Enore	India	Hybrid	2000	5	75,458
Alice Oldendorff	Liberian	Hybrid	2000	5	50,259
CSL Spirit	Bahamas	Gravity	2001	4	70,018
Gypsum Centennial	Bermuda	Gravity	2001	4	47,761
Stones	Antigua	Gravity	2001	4	28,115
Barkald	NIS	Hybrid	2002	3	49,463
Balder	NIS	Hybrid	2002	3	48,184
Harmen Oldendorff	Liberian	Gravity	2005	1	66,188
Total (DWT)					**519,081**

From 2000 to 2005, the SULS international fleet increased only by 10 ships totalling 519,081 new deadweight tonnes or 16.4% averaging 3.3% annually for 5 years, when compared to the total SULS tonnage at the beginning of 2000. This value is small when compared to the global standard dry bulk fleet that increased by 6.7% or approximately 22.7 MDWT in 1 year from 2004 to 2005. Tables 3.6 and 3.7 shows the SULS deadweight tonnage increased from 2000 to 2009.

Table 3.7 New SULS Tonnage of the 21st Century (CSL, 2009).

Vessel	Flag	SUL Type	Built (Year)	Age (Year)	DWT (tonnes)
Baldock	Unknown	Gravity	2006	3	75,569
CSL Acadian	Bahamas	Gravity	2006	3	74,517
CSL Argosy	Bahamas	Gravity	2006	3	74,423
CSL Metis	Bahamas	Gravity	2007	2	69,305
Hon Henry Jackman	Bahamas	Gravity	2007	2	75,597
Gypsum Integrity	Bermuda	Gravity	2009	1	47,761
Total					**417,172**

During the period from 2005 to 2009, the international SULS fleet has increase by 6 vessels amounting to 417,172 deadweight tonnes (see Table 3.7). This corresponds to 11.4% increase in this 4 years period. This figure averaged 2.9% annually or 0.4% less, when compared to the preceding years (2000 to 2005).

Perhaps prior to the recent recession (2008), the lucrative market, i.e. very high freight rates, for dry bulk is responsible for this added global SULS tonnage. Table 3.7 illustrates the new tonnage from 2005 to 2009.

In the GL area, there has not been any added tonnage to the SULS fleet. Instead, Canadian Owners such as Canada Steamship Lines Inc **(2005, p.1)** has *'Invested in excess of 200 million Canadian Dollars to modernize its fleet by renewing the entire fore-body section of certain vessels, which were constructed in the 1970s'* and today; *the company owns and operates the youngest, most technologically and environmentally advanced fleet of self-unloaders plying the waters of the Great Lakes and St. Lawrence Seaway…'*. An example of this is illustrated by Figure 3.5, which shows a section of a Great Lakes SULS fore-body under construction. This exemplifies the SULS tonnage renewal programme for the Canadian GL shipping sector.

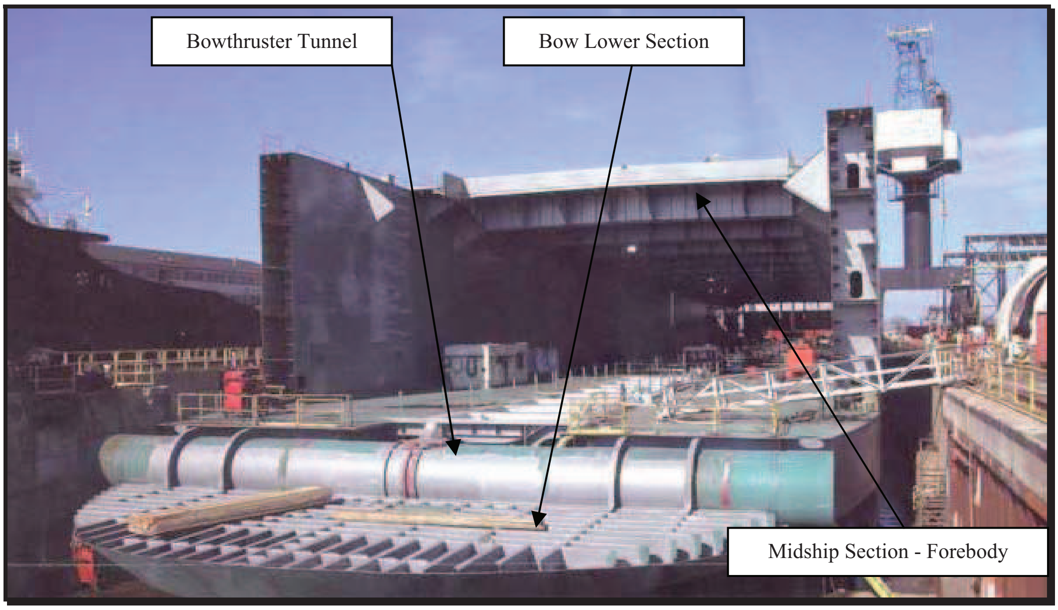


Figure 3.5 Forebody Renewal for Great Lakes SULS (CSL, 2005).

It worth mentioning that, throughout the second decade of the 20th century, Canada followed the USA in this technology and became second in terms of SULS ships registries and deadweight tonnage in the North American region. The Americans invented the SULS technology, but when compared to Canada, this expertise in SULS technology has been allowed to stagnate in the USA and without any great advances. Progress in new and versatile Self-unloading vessels has come from countries other than the USA. Based on SULS ship registries, those nations with recent developments are listed in Table 3.5. However, Canada presently maintains a lead in the research and development of this specialised way of handling marine dry bulk cargoes. Also, in terms of ship management for Self-unloader Bulk Carriers', Canadian shipowners are the largest global operators for this type of vessels. For example, Canada Steamship Lines and CSL International **(2005, p.1)** are. *'Managers of the largest fleet of self-unloading vessels in the world and handle annually bulk cargo movements totalling over 30 million tonnes. Both companies operate a fleet comprising 38 panamax and handymax SUL vessels of various types…',*

In Appendices III.1 to III.5, the complete details of the SULS populations are shown pertinent to registries for the USA, Canada and international sector. The SULS illustrated in these Appendices are relevant to both the gravity and other types of Self-unloader Bulk Carriers.

3.10 The Comparison of Self-Unloaders with Conventional Bulk Carriers

Self-unloaders or Self-discharging Bulk Carriers (SULS) are a distinct type of dry bulk carrier vessel and very different in how they discharge their cargoes, when compared to the ordinary geared and gearless types of bulk carrier ships. The difference between the discharging concept for SULS and standard geared and gearless types of bulk carrier vessels is very apparent by comparing Figures 3.6 and 3.7 with Figures 3.8 and 3.9.

Figure 3.6 M/V CSL Spirit -70800 Deadweight Self-Unloader Bulk Carrier (CSSC, 2005).

Figure 3.6 shows an SULS vessel with the unloading boom on the upper deck. The unloading boom has a conveyor that is used for carrying materials from the ship to shore facilities. Prior to discharging ashore, the cargoes are first transferred to the boom by various transfer conveyors below the upper deck. This is shown in Figure 3.7.

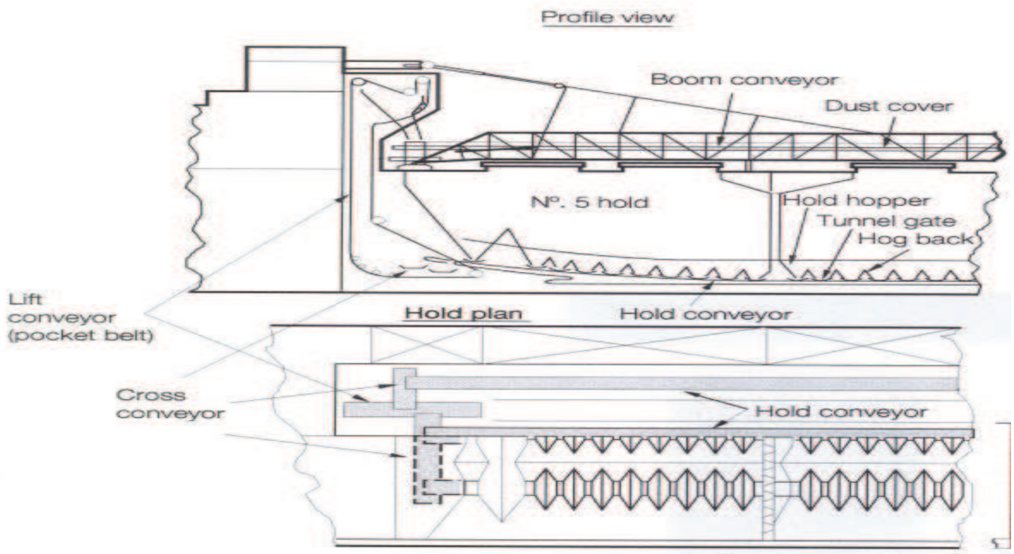


Figure 3.7 Transfer Conveyors below Upper Deck (Lloyd's Register, 1992).

Figure 3.8 shows a typical geared type bulk carrier that is equipped with cranes on the upper deck for loading and unloading her cargoes in comparison to the gearless bulk carrier shown in Figure 3.9, which has no discharging gear (i.e. cranes or conveyors) and is solely dependent on shore-based loaders for both loading and discharging its cargo.

Figure 3.8 M/V Ekavi - 52800 Deadweight Handymax Geared Bulk Carrier (ABS 2004).

Figure 3.9 M/V Tai Progress – 77000 Deadweight Panamax Gearless Bulk Carrier (ABS, 2004).

In comparing ordinary bulk carriers with SULS, **Penton** and **Sadler (1924, p,49)** stated *'The present-day bulk freighters of the Great Lakes represent one of the most interesting developments in ship design. They typify the extreme case where the* *equipment for handling cargo is entirely absent so far as the ship is concerned, the appliances for both loading and unloading being situated ashore. Of recent years, however, another type has been developed, also for handling bulk cargoes, and which may be considered as at the other extreme, namely a vessel which carries onboard complete mechanical equipment for unloading entirely independent of any and all shore plant. These vessels have come to be known as "Self-unloaders" bulk carriers'*. **Penton** has been portrayed as the father of SULS and **Sadler** as an influential council member of SNAME at that time.

Figure 3.10 illustrates an automatic ship-loader that was used for loading bulk carriers in ports of the Great Lakes during the development of SULS. Today in many ports of the Great Lakes, similar ship-loaders are still in existence and being used for loading bulk carriers of all types.

Figure 3.10 The Hulett Automatic Ore Unloader (Cleveland State University Library, 1998).

3.11 Operational Principles of Self-Unloader Bulk Carriers

With respect to the family of SULS bulk carrier vessels there are numerous types of systems, these are: Crane Systems; Hybrid Systems; Full Gravity Discharging Systems; Digging Systems; Gravity Systems with Mechanical Assist; and Self-unloader/Loader Systems. Appendix III.6 and sub-section 3.11.1 illustrate the various types of Self-unloading systems installed in SULS.

3.11.1 Full Gravity Discharge Systems

By and large, the 'full gravity' self-unloading method to this day is the most common system employed onboard SULS vessels and has been in existence since the early 20^{th} century. The first known installation, was onboard the wooden hulled bulk carrier S/S Hennepin that was converted to a SULS in 1903.

Full gravity type of self-unloading system is based on the following operating principles. Cargo is loaded into the ships' cargo holds by shore-based loaders. The product is then gravitated through manual or hydraulic operated cargo gates and onto the hold conveyors belts, which are located in a tunnel beneath the cargo holds. Depending on the ship type, conveyor belts in the tunnel could either be of the single, double or triple installation. These belts unload the cargo by taking the material through various transfer points to the incline/elevator systems which lifts the commodity to the upper deck. The cargo is then transferred onto the boom belt and finally discharges ashore into the customers' facility.

With a full gravity SULS installation, there is a decrease in the cargo holds cubic capacity. This is due to additional cargo hold hoppers when compared to the crane, hybrid and digging systems, where the cargo holds bottom structure or tank top is flat. However, the gravity unloading method has economical advantages for both shipowners and shippers relevant to reducing overall discharging and port turn-around times.

To clearly understand the concept of cargo flow for SULS ships with full gravity system, Figure 3.11 shows a typical example where cargo is flowing by gravity from a cargo hold through the gates and onto the longitudinal hold conveyor belts.

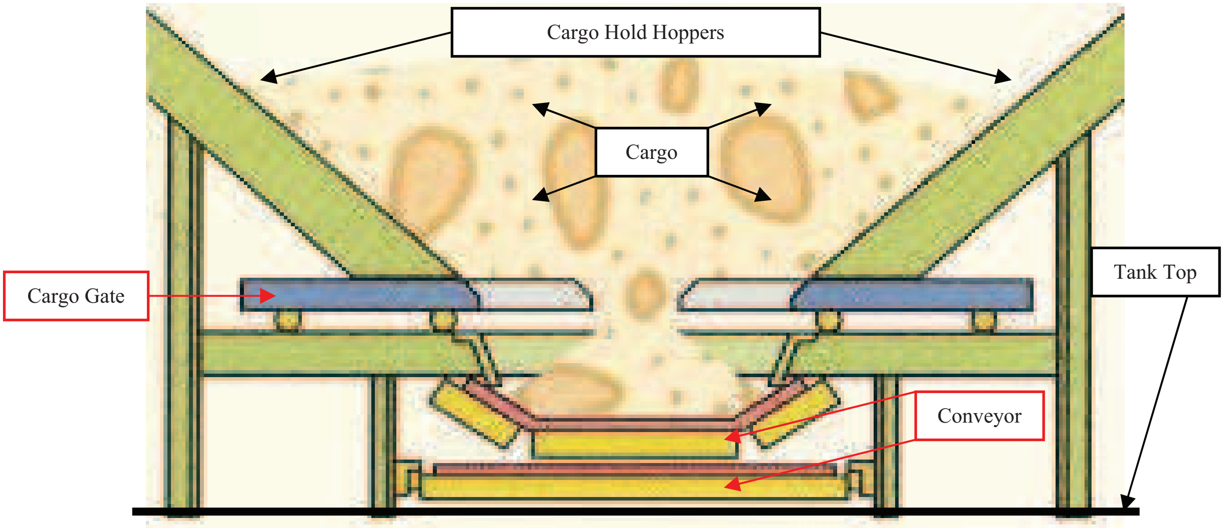


Figure 3.11 Cargo Flow from a Typical SULS Full Gravity System (CSL 1995).

3.12 Merits and Disadvantages of Self-unloading Bulk Carriers

With respect to the unloading systems described previously, the Self-unloader Bulk Carriers (SULS) of the continuous conveyor types are generally more flexible in discharging any dry bulk cargo that will flow by gravity. The success of these ships has been primarily because of their adaptability to trade in geographical areas with inappropriate unloading infrastructure. Also because of the flexibility of SULS in unloading dry bulk cargo, the volume of business handled by these ships has fundamentally been for all intensive purpose self-created.

When comparing the Great Lakes (GL) and international bulk trades, the SULS category of bulk carriers trading on the USA and Canadian GL have demonstrated the greatest earning power; taking into consideration the number of voyages and cargo capacity discharged on an annual / seasonal basis. Without a doubt, this class of vessel are regarded as the most arduous working vessels in water transport of dry bulk commodities. Nevertheless, SULS are better on short trips trade, when compared to gearless bulk carriers.

During the 20th century when SULS was first developed, some ships recorded as many as 110 trips in a GL navigational season of approximately 240 days/year transporting stone in one direction, coal in another and occasionally three cargoes for a round trip. In the late 20th and early 21st centuries, this record relative to number of yearly trips, i.e. 100-110, has been maintained by some SULS owners trading coal on Lake Erie from the state of Ohio, USA to the province of Ontario, Canada. For reasons of commercial confidentiality the shipowners name cannot be disclosed. This statement relevant to the annual trading days by SULS is further supported by the author who has previously been operating these types of vessels for 17 years **(1984-2001)** and carrying out research of SULS technology for 5 years **(2005-2010)**.

In recent years, various newbuildings and some existing SULS ships have migrated from the GL to ocean trades with generally longer hauls, averaging two to three loaded voyages in a month. SULS are normally best suited for short trades where the sea leg is short relative to port time so that they can benefit from having a quick turn-around time. SULS are obviously most desirable for trading ports having both poor unloading and mooring facilities. Despite the attractive economical benefits for owners and shippers trading SULS, there are certain disadvantages accompanying these types of vessels as well as some inherent advantages.

3.12.1 Merits of Self-unloading Bulk Carriers

The merits of SULS can be summarised as:

- Total independence from any form of shore base unloading plant, also the ability to discharge on shore or offshore with minimal capital investment at the receiving facility;
- Relatively independent from shore labour unions and longshoremen working conditions. Occasionally, in some US ports, trade unions demand payment for a small number of their staff;
- Ability to deliver cargo anywhere the ship can be moored. In some cases, modern SULS that are equipped with a bowthruster and bridge wing engine controls can discharge their cargoes without being made fast to the dock side. This manner of

discharging cargo is highly competitive in comparison to any other type of dry bulk carriers;

- Reduced port or turn-around time, resulting from high discharging rates with the onboard self-unloading machineries. Obviously, this increases the number of round trips per annum;
- Ability to demand a freight rate that is higher than the published market rates. This is because the vessels require no external source for unloading the cargo and the charter party benefit from not having to pay stevedoring costs. These costs are not published and remain confidential.
- No fixed cargo discharging hours while in port. Twenty four hours a day operation is possible;
- On a short term basis, SULS are economical for chartering in comparison to the high capital cost for installing extensive / expensive shore based unloading infrastructure such as docks and cranes with the associated expenditures for maintenance, operation and stevedoring of cargo. The cargo can be discharged ashore in stockpile or into shore based hopper and conveyor system that conveys the commodity directly to the customers facilities or processing plants;
- Variable discharging capacity catering to the customer requirements with a range of unloading rates up to 5000-6000 tonnes/h for existing vessels;
- Customers benefit by offering lower overall cost to receivers;
- The SULS provide environmental benefits by discharging with an enclosed boom, dust collection systems, water sprays and dust suppressants; and
- Elimination of cargo waste and degradation with the full gravity discharging system. When using methods of unloading other than the gravity system, the cargo remaining in the holds after the initial discharging is gathered by bulldozers for the secondary discharging operation. This bulldozing action of the remaining cargo causes both waste and degradation of the commodity.

These merits offered by the SULS in the discharging of their cargoes, are highly unlikely to be matched by the standard dry bulk carriers. Fundamentally, this is because the standard or ordinary bulk carriers are reliant on external source for discharging their cargoes. Nevertheless, there are certain inherent disadvantages with SULS that are explained in the following sub-section. These disadvantages of SULS are obviously the advantages of the ordinary bulk carriers, when comparing with these types of vessels (i.e. SULS).

3.12.2 Disadvantages and Weaknesses of Self-unloader Bulk Carriers

The disadvantages of SULS can be summarised as:

- The lost of cargo hold volume, increased lightweight and total displacement capacities, when compared to the standard geared and gearless bulk carriers;
- The reduction of cargo capacity in terms of both volume and deadweight, resulting from having longitudinal conveyors and unloading machineries fitted above the tank top in a tunnel beneath the cargo holds; and unloading equipment also fitted on the upper deck. These installations also add to the ships' lightweight;
- When the incline conveyor is installed inside the cargo holds, this installation causes an additional loss of the cargo hold volume. Figure 3.7 and Appendix III.6 demonstrate this deficiency in capacity, resulting from placing the unloading machinery and incline conveyor in-way-of cargo holds.
- When loaded, the cargo is above the tunnel. Thereby, the ships have a higher vertical centre of gravity in the loaded condition. This situation could possibly cause instability of the vessels and has to be considered to ensure SULS maintain adequate stability;
- Increased manning with relatively higher paid crew, specially trained for both unloading cargo and maintenance of discharging equipment, when compared to standard bulk carriers;
- Higher capital cost for construction, but again the cost is offset by higher chartering freight rates for the ships' economical life; and
- Less suitability for range of material.

3.13 Summary

This Chapter starts by discussing the magnitude of the global dry bulk carrier fleet and reveals the percentages of SULS comprising the dry bulk fleet. During 2005, the worldwide dry bulk carriers accounted for 338 millions deadweight tonnes (MDWT), by 2008 the fleet increased to approximately 416.7 MDWT and in 2009 the fleet size grew to 438.7 MDWT. Throughout these periods (i.e. 2005, 2008 and 2009), SULS amounted respectively for 1.92%, 1.64% and 1.59% of the global dry bulk carrier fleet.

Chapter 3 also gives a definition of Self-Unloader Bulk Carriers. An introduction to the inception and evolution of both SULS technology and the vessels are presented for Canada and USA, where this expertise was developed. During the initial development of SULS, the designing Engineers expressed their concern due to omissions in the hull design. These deficiencies resulted from shipowners not having sufficient finance to improve the ships design. Nevertheless, in the twentieth century SULS were constructed / converted and the development of this technology allowed some small shipowners in the Great Lakes region to remain solvent.

The expansion of the Self-unloader Bulk Carriers fleet is addressed, showing the deadweight tonnage registered under various nations in three regions (i.e. international, USA and Canada). Despite the fact that SULS is a North American invention, the international group has the majority of registered ships and followed by the USA and then Canada. In 2009, the average age of SULS in the international group accounted for 19 years, when compared to the USA and Canada, having respectively 49 and 35 years.
Self-unloader Bulk Carriers discharging concept is explained in detail, highlighting the comparison with the conventional bulk carriers and SULS. The development of SULS technology has led to numerous shipboard discharging systems, for instance: crane; hybrid; full gravity; digging; gravity with mechanical assist and self-unloader/loader. The operational principles of these different types of discharging techniques are described in detail and each system is remarkable in the unloading of dry bulk commodities. However, the full gravity discharging class vessels continue to have

improved flexibility and to be more versatile, when unloading their cargoes independently.

The inherent trading / operational advantages and disadvantages of SULS are presented. Nevertheless, the merits of SULS outweigh the weakness, when unloading dry bulk cargoes with SULS versus the ordinary bulk carriers. The obvious benefits relevant to discharging dry bulk cargoes with these types of vessels, are the unloading adaptability that requires no assistance from any shore-based installation. This was the original design concept, which remains true to this day.

Some of the primary disadvantages with SULS are loss of cargo capacity; increased lightweight and total displacement; high vertical centre of gravity; increased manning and higher capital cost. However, in spite of these shortcomings, these classes of vessels are categorically regarded as the hardest working vessels in water transport of the dry bulk sector.
Based on the number of voyages (i.e. 100-110) and cargo capacity discharged annually by SULS when involved with short trades, Self-unloading Bulk Carriers Vessels of the Great Lakes have demonstrated the greatest earning power in marine transportation of the dry bulk sector.

Undoubtedly, Self-unloading Bulk Carriers Vessels (SULS) have played an important role in the dry bulk water transportation system of the Great Lakes of North America. These types of bulk carrier vessels have evolved to provide exceptional cargo unloading capabilities that unquestionably differ, from other breeds of dry bulk carriers. SULS vessels have served the purpose for which they were designed to achieve, primarily to discharge dry bulk cargoes rapidly to undeveloped ports.

Chapter 4

4. THE EVOLUTION OF MIDSHIP SECTION DESIGN FOR SELF-UNLOADER BULK CARRIERS

4.1 Introduction

This Chapter describes the overview of midship sections designed for SULS. This Chapter also addresses the original midship sections and the improvements in cargo holds structure throughout the developments of SULS, starting with the first commercial vessel of these types early in the 20^{th} century until 2007 and 2009, when the last two recorded SULS was converted and built.

Unprecedented designs of SULS capable of discharging extremely high rates are illustrated, with reasons for these developments. Midship section improvements are highlighted showing design measures that could increase cargo holds volumetric capacities, deadweight, cargo flow rate and larger space in the unloading tunnel for maintaining the machinery.

The original midship sections for trading low and high density dry bulk cargoes are described. This includes the cargo holds hopper slopes ranging from 35 to 48 degrees. Hopper surfaces lined with Dyna-flo Polymer Liners (UHMW) are explained, demonstrating the potential benefits, by having installed UHMW on the surfaces of hoppers in cargo holds to enhance cargo flow. Comparisons of the original midship sections are discussed to determine the loss in cargo holds volume, when the pan and belt conveyors are installed.

In this study, the structures of three Model SULS i.e. ‘A’, ‘B’ and ‘C’ were examined for weight reduction by replacing certain sectors of mild steel plates with high tensile steel. Subsequent to the weight reduction exercise, the hulls were assessed for strength (see Appendix VI.8). To emphasize the potential benefits resulting from altering the cargo hold hopper angles to enhance cargo capacities, the cargo holds of the Model 'B' SULS was used for calculating the differences in cargo hold volumes and ship's deadweight. The comparison of lightweight is investigated for the Model 'C' and recent built SULS. This is primarily to demonstrate the reduction in ship's weight, when comparing the Model 'C' with current new panamax SULS.

Midship section developments are addressed demonstrating the evolution of cargo hold structures during conversions of the earlier ordinary bulk carriers to SULS. With these initial conversions, the lost volume in the cargo holds are underlined illustrating the disadvantage in cargo carrying capacity after converting the ordinary bulk carriers to SULS.

Further developments of midship sections are examined, focusing on the economic aspects of cargo hold structures design to incorporate the multi conveyor belts unloading system and improving ballast capacity for appropriate propeller immersion. Different designs of cargo elevating techniques are exhibited, primarily to establish the volumetric benefits in terms of cargo capacity, which is accompanied with each of the elevator designs.

Chapter 2 of this study explains the inception of dry bulk trade in the Great Lakes region and Chapter 3 discusses the origin and evolution of Self-unloader Bulk Carriers (SULS). This Chapter focuses on further development of SULS technology and principally describes the design benefits of midship sections, resulting from altering the cargo hold hopper angles to enhance volumetric capacity, deadweight and cargo flow.

4.2 Overview of Midship Section Designs for SULS

When it is expected to transport commodities of both high and low densities with Self-unloader Bulk Carriers, the designers since the introduction of these vessels, have endeavoured to develop midship section designs which are commercially viable for achieving the shipowner objectives. Studies conducted by Penton and Saddler **(1924)**, concluded that the optimum hopper angle for trading stones is 35 degrees from the horizontal axis.

Hopper angles of 35 degrees are the norm for SULS and have also been used when trading low-density commodities. When compared to larger angles (i.e. 37 to 40 degrees), the 35 degrees hopper offers greater clearance below the hoppers (i.e. lower edges to tank top) and for installing narrower conveyor belts. Therefore, the 35 degrees hopper allows for better access to maintain the conveyors and for installing the existing size of cargo gates. Appendices IV.1, IV.2, IV.3, Figure 4.1 and Table 4.1 show the clearance around the hoppers and width of gate openings with various hopper angles.

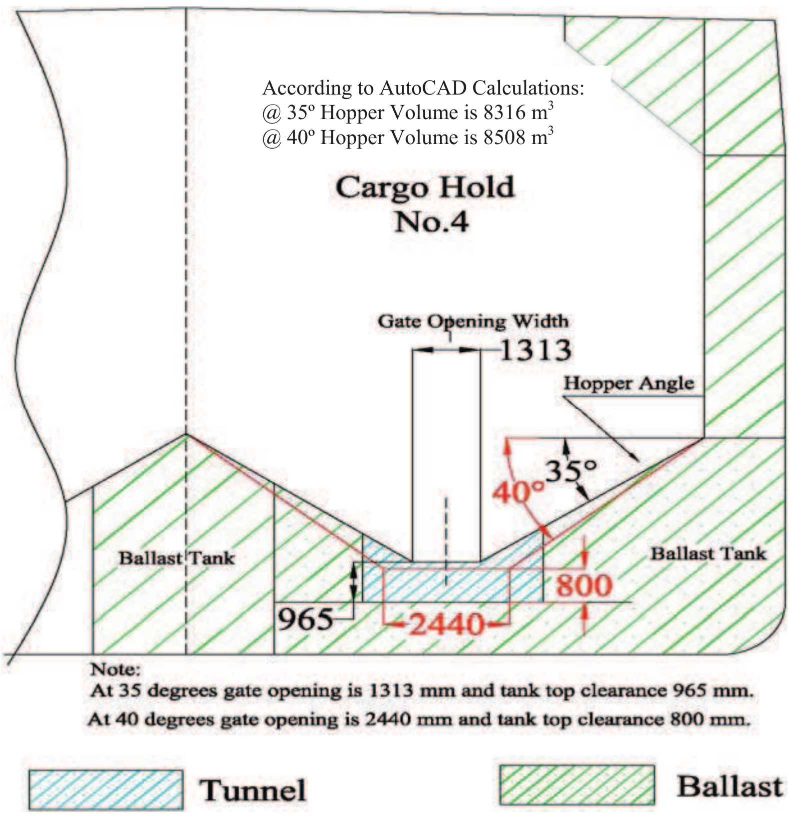


Figure 4.1 Midship Section of 'B' Type SULS Showing Dimensions of Gate Opening & Below Hopper.

For specialized SULS trades, primarily when transporting high density cargoes, the hopper angles and midship sections design have varied considerably from the initial designing stage of SULS to present day. Midship sections with hopper slopes ranging from 40 to 48 degrees are generally designed for high-density cargoes and these hopper angles have been employed with conveyor belt arrangements of the single and multiple types. With these larger hopper angles, friction between the cargo and steel plate is less. Thereby, the cargo flow rate would be enhanced and capital cost is reduced by not having to install anti-friction liners on the hopper surface. However, the original hopper angles of 35 degrees remain the norm and are widely used globally for most SULS installations.

Nevertheless, in spite of the numerous hoppers angle designs for midship sections, principally for improving cargo flow and cubic capacities, novel designs of cargo gate openings have not been increased to any great extent throughout the various gate designs. This clearly indicates that, despite developments relating to hopper angles and midship sections, the cargo flow in most scenarios has remained limited, fundamentally due to the gate opening size and, obviously, the conveyor's size and speed. Except for a few recorded cases, unloading rates for SULS have reached a plateau averaging 5000-6000 tonnes per hour. Historically, there are two unprecedented vessels which were designed with record elevator discharging rates; the 'M/V Stewart J. Court' and the 'Tug-Barge Presque Isle'. According to Elder and Detenbeck **(1988)** ***'****the wheel elevator conceived in 1964 was to provide the operator with a high capacity elevating unit while consuming less cargo space than alternative available at that time. These vessels achieved discharge rates of 20,000 long tons per hour in 1972 and 10,000 long tons per hour in 1973 respectively...'* Apparently, designs with these high discharging rates have not been repeated. This statement is based on current available SULS information. Figure 4.2 shows the typical wheel elevator which was installed in these two vessels.

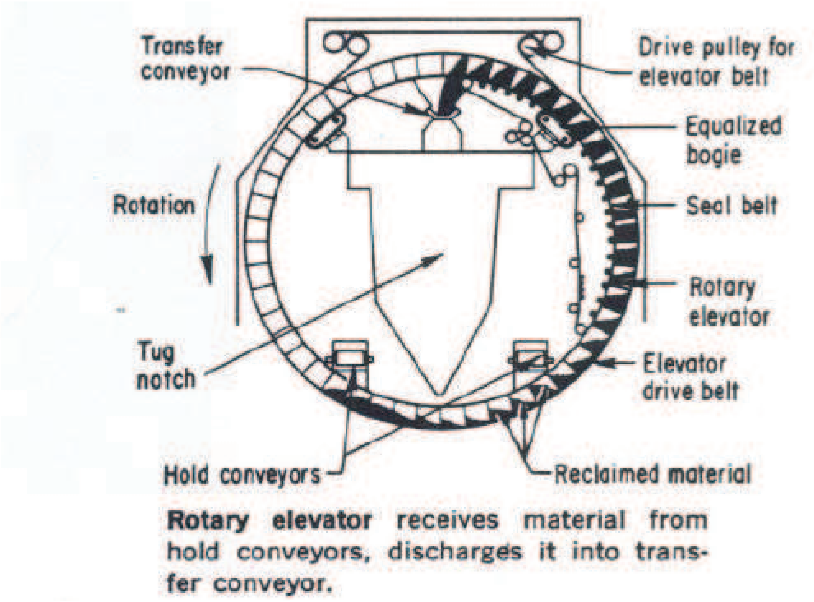


Figure 4.2 Wheel Elevator Installed in M/V Stewart J. Court and Tug-Barge Presque Isle, 1964.

Source: Elder, J. and Detenbeck, M (1988).

4.3 The Original Midship Section for SULS

This study of SULS technology has revealed that, by altering the original SULS cargo hold lower hoppers to a larger angle (i.e. 35º to 40º) with respect to the horizontal axis, the volumetric capacity can be enhanced. Figure 4.1, Table 4.1, Appendices IV.1, IV.2 and IV.3 confirmed that the volume for the No.4 cargo hold (i.e. Model "B") increased by 190 m^3, when the hopper angle was changed from 35 to 40 degrees. Obviously, these changes in the hopper angles would result in an improvement of cargo gravitation. Studies conducted by Saddler and Penton **(1924, p.50)** regarding cargo hold hopper design concluded that '*The flattest slopes at which stone would flow without some kind of agitation or disturbance was found experimentally to be 35 degrees from the horizontal. The lost of cubic due to this construction is not important with stone, which, in the sizes commonly handled, averages about 23 cubic feet per short ton, but with coal, at about 38 cubic feet per short ton, the loss is substantial'.*

As a result of vessel construction with hoppers of 35 degrees gradient from the horizontal axis, Saddler and Penton **(1924)** stated that the original SULS average volumetric loss with stone cargo was approximately 23 cubic feet/short ton and 38 cubic feet/short tons with coal. Clearly, this indicates that the original SULS encountered two major operational and trading concerns:

- Draft restrictions when transporting high density cargoes; and
- Reduced volume of cargo holds when transporting low density cargoes.

These views of Sadler and Penton **(1924)** regarding draft restrictions and volume of cargo holds remain true to this day with the operations of modern SULS.

As the Great Lakes trade developed, other low-density commodities became available and marketable such as coal and grain. With these cargoes, Saddler and Penton **(1924)** stated that the impact from loss of volume increased significantly with cargo hold hopper slopes of 35 degrees, averaging 38 cubic feet/short ton or an increase of 15 cubic feet/short ton when compared to stone.

In scenarios where low-density cargoes were transported, the ships never attained their full loaded draft. Therefore, volumetric capacities of the cargo holds were imperative, in order for the shipowners to increase their revenue and profit by loading larger volume of cargoes.

Nevertheless, because large size pan conveyors for the tunnel were originally preferred for installation by shipowners, the lowering of cargo hold hoppers and increasing angles above 35 degrees were not practical ways of benefiting from increased cargo hold volume, refer to Figure 4.3. These constraints respectively limited the sizes of both the cargo hold volumetric capacities and gate aperture dimensions. Additionally, an increase in size and width of conveyors to accommodate larger gate apertures would have resulted in supplementary lightweight and so compromise the deadweight. Alternatively, with wider conveyors and the appropriate prime movers, the unloading would have certainly been improved in terms of greater discharging rates.
To accommodate the pan tunnel conveyors, there were considerable losses in cargo volume beneath the cargo holds. This loss in cubic was not uniform throughout the

tunnel and was obviously exacerbated due to interference from two additional standpoints:

- Where the unloading machinery is installed; and
- Secondly from changes in the hull form, principally forward in-way-of No.1 cargo hold towards the collision bulkhead.

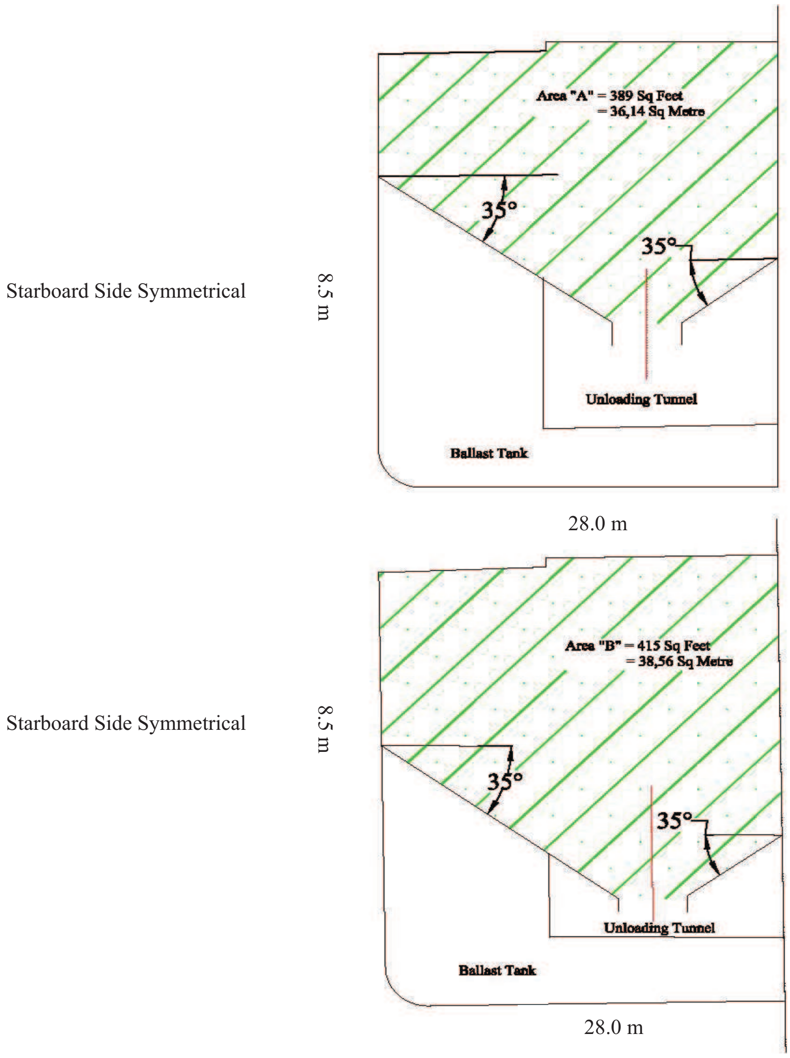


Figure 4.3 Comparative Diagrammatic of Original SULS Midship Sections (SNAME, 1924).

Depending on vessel type, equipment for discharging cargo was placed either adjacent to the engine room or collision bulkheads. Figure 4.3 demonstrates the volumetric comparative difference of the first commercial SULS midship section design. Elevation 'A' with greater cargo hold loss volume, illustrates the area (36.14 m^2) forward of this vessel unloading tunnel for accommodating the unloading machineries and elevation 'B' (38.56 m^2) the remaining tunnel sectors, Penton and Sadler **(1924).**

Ideally, if the midship section configuration relevant to the hoppers were identical throughout the tunnel sectors, then the loss in cubic would be reduced. However, this was not possible because of the hull form forward and unloading machineries fitted.

When carefully assessing the midship sections for the first series of SULS exhibited in Figures 4.3 and 4.4, it is clear that there was substantial loss volume in the cargo holds with these designs. This loss cargo volume was primarily due to occupied space used for installation of equipment and structures of the vessel's relating to the discharging system, namely:

- Machinery;
- Tunnel / pan conveyors (beneath the cargo holds);
- Cross / transfer conveyors (adjacent to either the engine room or collision bulkheads); and
- Incline conveyor / incline gallery in the forward cargo holds.

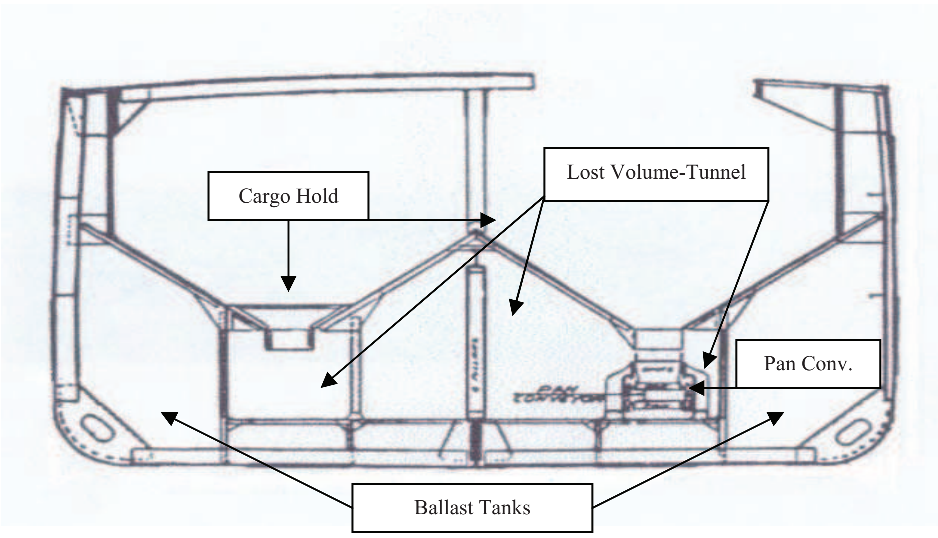


Figure 4.4 Midship Section of S/S Wyandotte – Except No.1 Cargo Hold (SACAN. 1969).

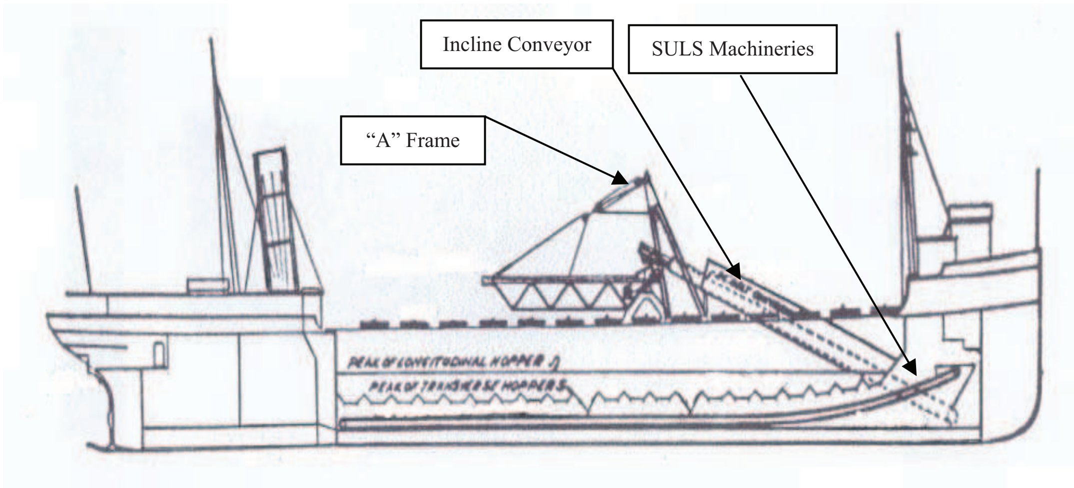


Figure 4.5 Side Elevation of S/S Wyandotte – 1908-1963 (SACAN, 1969).

The reduced cargo spaces certainly suggest that the quantity of low-density cargoes (i.e. coal, grain, etc) to be transported would be less. Figure 4.3 further demonstrates the loss area of 2.4 square metres, when comparing the area of No.1 cargo hold with the remaining holds. This reduction in the No.1 cargo hold area resulted from the hopper design to accommodate the installation of SULS machineries.

However, in respect of this loss volume when pan conveyors were employed for the holds instead of belt conveyors, Palmer **(1924, p.56)** concluded that *'There have been very little data heretofore published on the self-unloading vessels, and Mr. Penton and Professor Sadler are to be congratulated on the masterly way in which they have covered the subject. However, the Wyandotte Transportation Company can rightly claim to be the pioneers of the self-unloading bulk cargo ship, owning and operating four self-unloader cargo vessels with an aggregate carrying capacity of 25,444 tons of stone or 18,200 tons of coal. The pan conveyor is satisfactory, as it allows for maximum cubic. Considering the case of the Wyandotte Transportation Company's steamer Huron, which has a maximum cubic for 8,000 tons? If this vessel were fitted with belt conveyors, the maximum cubic would be 7,600 tons or 5 percent less, a loss in earning capacity of this vessel of over 13 percen*t…'**.** This loss cubic / cargo capacity with belt conveyor is due to the longer elevated slope at the discharge point into the cross conveyor, Saddler and Penton **(1924)**. The pan conveyor has a shorter slope at the cargo delivery end. Therefore, the volume of the tunnel compartment would be reduced allowing for greater cargo hold capacity.

Saddler and Penton **(1924)** concurred with the views of Palmer **(1924)**, in that there would be no loss in cubic when pan conveyors are selected for the tunnel instead of belt conveyors. Saddler and Penton **(1924, p.51)** stated that *'The hold conveyors are in general of two types – the pan or bucket type and the belt. Both have proven very satisfactory, and the choice is largely one of preference. The former, because of its link or chain-belt construction, can be guided in straight lines fairly close up to the delivery end and the length of slope restricted, while the latter necessarily assumes a catenary's with a much longer slope. For stone cargoes only this is unimportant, but aggravates somewhat the lost of cubic for coal'.*

Young **(1969, p.10)** looked at the development of SULS and pointed to the waste of cargo holds volume in the early model SULS, such as the S/S Wyandotte, indicating that the consumed or loss cargo space volume was primarily because *'This ship and others of the same design had unloading machineries comprised two steel pan conveyors located in the tunnel beneath the cargo holds with a forwarding / incline conveyor running through the cargo space to the boom, which was located approximately at the centre of the ship…'.*

Palmer **(1924)** views was contrary to that of Young **(1969)**, who stated that there was no loss of cargo holds volume when installing the pan conveyors, in comparison to the belt conveyors. The author, shipowners, operators and designers of today's SULS would be inclined to agree with the conclusion of Young **(1969)** that, categorically, cargo hold volume is less with pan tunnel conveyors installed rather than belts. The author's assumption is based on pictorial views (i.e. Figure 4.4), where apparently the pan conveyor installation is somewhat elevated above the tank top in the tunnel.

4.4 Improving Midship Sections for SULS

Deciding on the appropriate design midship sections for Self-unloader Bulk Carriers during the design stage has always been a concern for shipowners, shipyards and designers of Self-unloading systems. The SULS shipowner's view is always to:

- Maximize the ship's deadweight;
- Maximize volumetric capacities of the cargo holds;
- Improve cargo flow; and
- Maintain high unloading rates.

These considerations are linked to the ship's displacement, scantling draft and block coefficient as well as being influenced by cargo hold design with respect to volumetric capacity and appropriate hopper angles. These criteria are primarily to enhance cargo carrying capacity and also cargo flow to achieve improved discharging rates for the intended purpose or trade with the selected unloading machineries.

As SULS vessel trading patterns are mostly to ports with draft restrictions, higher lightweight is a predicament that conflicts with the need to maximise deadweight, principally when transporting high-density cargoes such as iron ore, stone, gypsum, etc. However, less lightweight could be accomplished by introducing additional higher tensile steel (HT) in the construction. The possibility of mitigating lightship weight through the adoption of higher tensile steel is considered in Appendix VI.

Regarding the improvement of cargo hold volume, this aspect can certainly be achieved by both lowering the bottom hoppers and increasing the angles relevant to the horizontal axis, in-way-of the ship's centreline and side longitudinal bulkheads or shell. Appendices IV.1, IV.2 and IV.3 confirmed that an increase of hopper angle from the horizontal axis, results in greater cargo hold volume. Obviously, when the hopper slopes are modified to improve cargo hold volume, shipowners benefit from enhanced revenues. This is primarily due to greater cargo lift when transporting low-density cargoes and the cargo holds volume are consumed or full before attaining the maximum deadweight draught. However, a larger cargo hold volume resulting from greater hopper angle is associated with the disadvantage of reduced ballast capacity. This reduction in ballast water capacity could have problematic consequences during the ballast voyage by increasing freeboard, reducing draught, trim and propeller immersion. Thereby increasing cavitations and ultimately have a negative influence on the speed of the vessel.

Varying the lower hopper angle to larger angles would improve cargo flow due to reduced friction between the commodity and hoppers. Consequently, the unloading rates would be enhanced. However, the increase of discharging rate would also depend on the conveyors design for transporting cargoes from the vessel to the customers' facility ashore. In this study the engineering details for the conveyor discharging rate are mentioned in Chapter 6.

By promoting greater cargo flow with increased hopper angles, the cargo gate aperture needs to become larger. Thereby, allowing additional quantity of cargo to gravitate through the gates and onto the conveyor belts. This alteration of the hopper angle would result in the conveyors being larger, heavier and more expensive to install. The clearance between the hopper and tank top would also be reduced. Therefore, based on the author's experience onboard SULS, the space necessary for maintaining the conveyors would be limited.

Table 4.1 summarises the potential benefits gained when the original hopper structures for the Model 'B' are modified. The existing volumetric capacity for No.4 cargo hold is 8,316 m^3 for a hopper slope of 35 degrees. Using an Auto-CAD model to investigate the influence of hopper angles, for an angle of 37 degrees from the horizontal axis, the volumetric capacity was increased by approximately 110 m^3 or 95 tonnes (totalling 8,426 m^3) for the No.4 cargo hold.

This alteration of the Model 'B' No.4 cargo hold would evidently increase the deadweight and benefit the shipowners with additional revenue, when transporting low density commodities that are volume related such as coal, grain, etc. However, the drawback from added cargo volume is a reduction in ballast volume. In this case it is estimated to be 110 m^3 or 95 tonnes (see Table 4.1) which could have the disadvantages previously identified.

Table 4.1 Volume/Tonnes Comparison of Model 'B' No.4 Cargo Hold (Welcome, H. 2007).

Hopper Angles (Deg)	Gate Opening (mm)	Distances (mm) Gate To In BHD	Distances (mm) Gate To Out BHD	Tank Top To Hopper (mm)	No.4 Cargo Hold Dimensions Area (m^2)	No.4 Cargo Hold Dimensions Length (m)	Hold Vol (m^3)	Difference (+ Cargo & - Ballast) m^3 or tonne
35°	1313.00	941.00	1222.00	965	227.21	36.6	8,316.00	**110 or 95**
37°	**1489.00**	**874.00**	**1137.00**	800	230.21	36.6	8,426.00	
35°	1313.00	941.00	1222.00	965	227.21	36.6	8,316.00	124 or 107
38°	1791.35	722.45	986.20	800	230.60	36.6	8,439.87	
35°	1313.00	941.00	1222.00	965	227.21	36.6	8,316.00	158 or 137
39°	2080.83	577.65	841.97	800	231.52	36.6	8,473.70	
35°	1313.00	941.00	1222.00	965	227.21	36.6	8,316.00	192 or 165
40°	2361.00	438.00	700.00	800	232.46	36.6	8,508.04	

The other noted advantage from increasing the hopper angle from 35 to 37 degrees was the cargo gate apertures increased in size by 176 mm (i.e. 1313 mm to 1489 mm). There was also a reduction of 165 mm clearance between the tank top and the hoppers lower edges. This reduced distance of 165 mm is considerably for SULS installations. However, the available space under the hopper should allow for sufficient clearance to install the conveyor belts and troughing rollers, see Appendices IV.1 and IV.2.

An adjustment of the hopper angles to improve cargo carrying capacity and discharging rate is a practical structure modification, which is possible to pursued onboard SULS. Nevertheless, by implementing these changes, the entire structure design under the hoppers and inner bottom (i.e. cargo holds' tank top) would have to be re-assessed for strength. This could be verified by performing appropriate structural evaluation of the relevant sections under the hoppers using standard analytical and numerical approaches, such as 'Finite Element Analysis'. The examination of under-hoppers strength is considered beyond the scope of this study.

Appendices IV.1, IV.2, IV.3, IV.4 and Table 4.1, show the results of a simple parametric study with respect to cargo capacity for the No.4 cargo hold of the Model 'B', when modifying the hopper angles from 35 to 40 degrees and then reducing to 26 degrees. These modified angles for the Model 'B' were considered to be undesirable for various reasons:

- Insufficient space between the hopper's lower edges and longitudinal ballast tank bulkheads (i.e. inboard and outboard);
- Inadequate clearance from hopper lower edges to tank top, in order to accommodate troughing rollers and conveyors belts;
- Insufficient vertical clearance due to inadequate head room (i.e. 1188 mm) for personnel to maintain the unloading equipment (see Appendix IV.4); and
- Excessive gate apertures resulting in oversize conveyor belts.

The principal focus of this study is the design of a new improved cargo gate suitable for installation in the midship section of the Model 'B' type SULS. The hopper angles of 35 degrees were selected for the final design. Fundamentally, because this hopper slope appears to be the best compromise of angle with other associated dimensions for this type of vessel.

4.5 The Development of Midship Sections for SULS

As the Great Lakes trade and fleet developed subsequent to 1908, when the first commercial SULS was put into service, numerous ordinary bulk carriers were converted to SULS. However, despite the improvements of SULS technology, the majority of cargo holds hopper angles for SULS remained at 35 degrees from the horizontal axis. This angle was considered the norm, principally because a hopper slope of this configuration that is lined with UHMW allowed for both acceptable flow of different materials and satisfactory cargo hold volume. Thereby, shipowners continued to build and convert SULS ships with cargo hold hoppers of 35 degrees angle, for trading all type commodities that are transported by these vessels.

According to Workman **(1945)**, Figure 4.6 exhibits the classic midship section, for ordinary bulk carriers vessel built and commissioned in the Great Lakes region during the 1930s' and 1940s'. Bulk carriers of this design were converted to SULS, having midship sections similar to the 1911 built vessel illustrated in Figure 4.7.

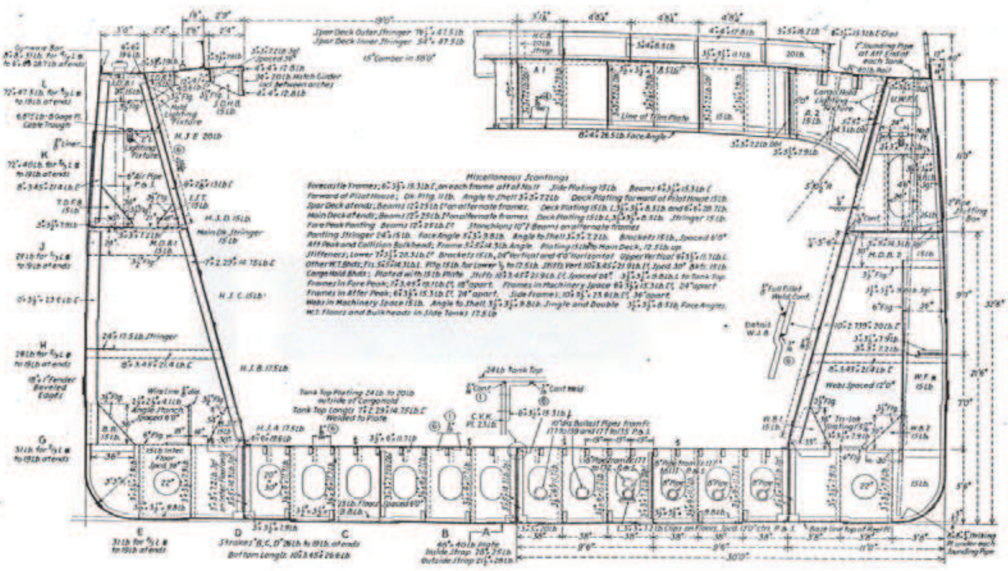


Figure 4.6 Midship Section of Great Lakes Ore Carriers S/S William A. Ervin & S/S Governor Miller (SNAME, 1893-1943 – Published 1945).

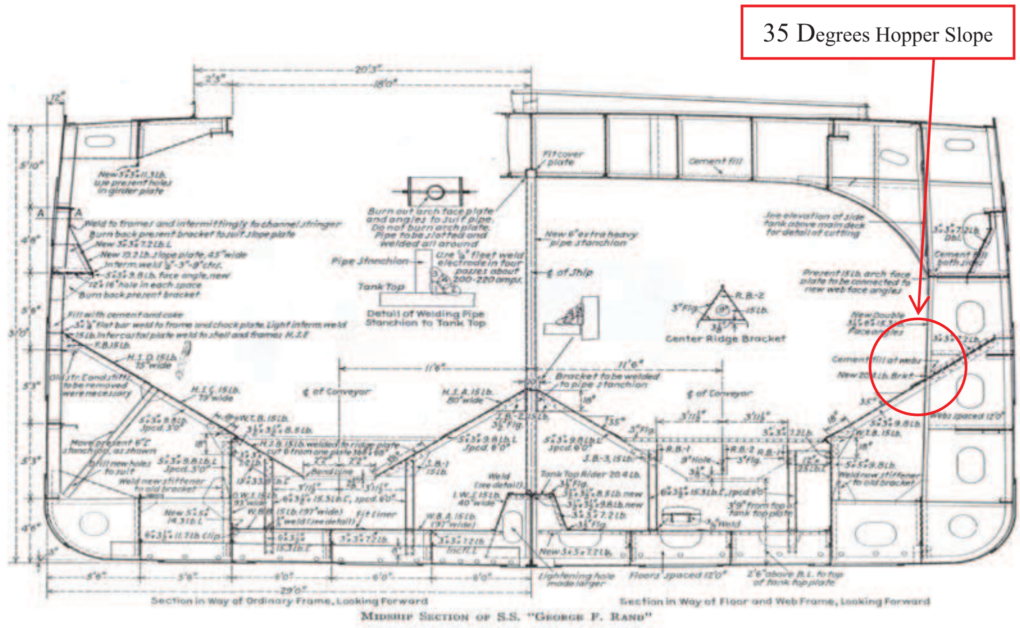


Figure 4.7 Midship Section of S/S George F. Rand After Conversion (SNAME, 1938 – Published 1939).

This 1936 SULS conversion (Figure 4.7) illustrates an early evolution of midship sections, when compared to the first SULS that was put into operations commencing from 1908.

Historically, on the Great Lakes ship conversions from ordinary bulk carriers to SULS first started in 1923 with hopper slope of 35 degrees.

Obviously, by converting the original standard bulk carriers to SULS, the cargo hold volume and deadweight tonnage was reduced with an increase in lightship displacement. However, Cross **(1938, p.239)** stated that *'Before conversion, the George F. Rand had a total capacity in the cargo holds of 455,000 cubic feet, self-trimmed, at 35 degrees. After conversion, the capacity was reduced to 406,100 cubic feet, or a total loss of 48,900 cubic feet. The sectional area curve of the cargo space, reproduced* in Figure 4.8*, shows the effect of the conversion. This lost of 48,900 cubic represents 10.75 percent of the original volume. While this is, of course, an appreciable loss, it nevertheless is very small considering the fact that the entire cargo is self-discharged through the gates below. As a matter of fact it is not always possible to obtain the draft necessary for a full cargo, so that even this percentage is reduced in practice…'.*

The above quote of Cross **(1938)**, is fundamentally applicable to SULS that are trading high density cargoes in areas where there are ports with draft restrictions, simply because the loaded draft is attained before the cargo hold volumetric capacity is exhausted. With regard to volume loss due to conversion of the early ordinary bulk carriers to SULS, Cross **(1938)** concluded that the reduction in volume was approximately 11%. Figure 4.8 demonstrates an analysis of the S/S George F. Rand cargo holds self-trimming volume that was originally 455,000 cubic feet (12,884 cubic metres). After the vessel was converted to SULS, the volumetric capacity was reduced to 406,100 cubic feet (11,500 cubic metres).

When comparing the Model ‘C’ (1999) that has lightweight of 17,547 tonnes (i.e. see Chapter 1 – sub-section 1.2.2) with the present converted panamax to SULS **(2006 and 2007)**, today shipowners are experiencing a reduction of lightweight averaging 1,000 to 1,200 tonnes less than the Model “C”. This is following the conversion of panamax single hull tankers to SULS.

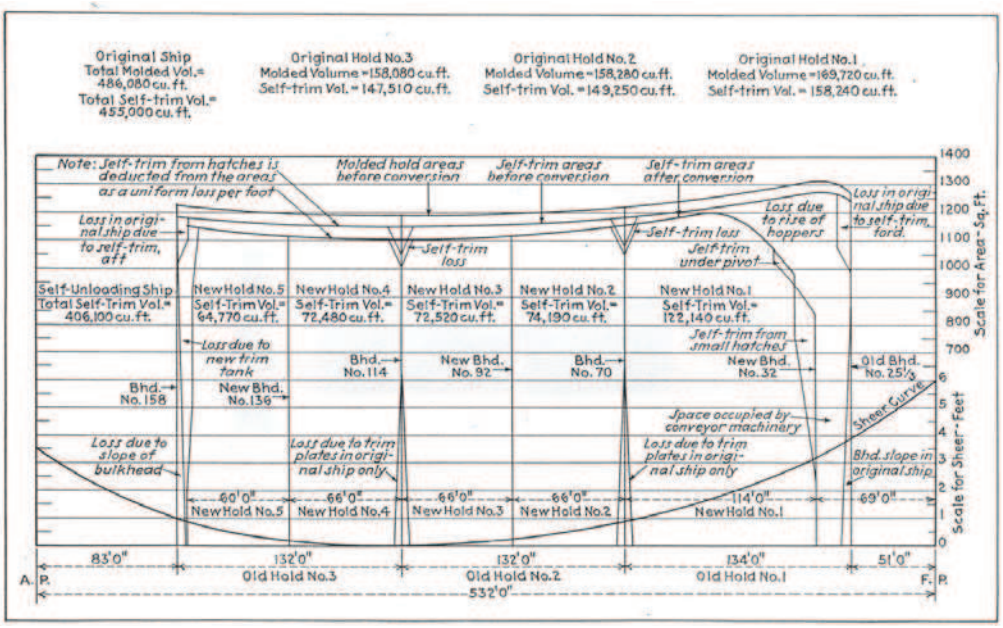


Figure 4.8 Cargo Capacity of S/S George F. Rand – Before and After Conversion (SNAME, 1939).

This reduced weight resulted from using lighter unloading equipment and a greater percentage of high tensile steel for constructing the hull, when compared to SULS similar to the Model 'C'. However, panamax SULS with lightweight around 16,000 deadweight (DWT) tonnes range is still high, considering that the ordinary panamax bulk carriers have a lightweight around 12,000 tonnes.

When considering the trade-off and other accompanying aspects of SULS (i.e. ballast capacity, propeller immersion, gate opening, maintenance access, weight of conveyors, etc), hoppers with 35 degree slopes have evolved as being both the most practical and economical for the shipowner. This trade-off with different hopper angles is clearly identified in Table 4.1. Nevertheless, some shipowners have opted for larger angles ranging from 45 to 48 degrees. These increased hopper angles are primarily incorporated in SULS designed specifically for trading high density cargoes such as iron ore and stones. In circumstances when trading heavier cargoes, the vessel's maximum draft is reached prior to achieving full cargo hold volume. Thereby, cargo hold volume is less significant as this situation is deadweight limited one. A steeper hopper angle also improves cargo flow and the shipowners benefit from cost savings by not having to install hopper liners to assist the flow of cargo, such as 'Dyna-flo Liners' or 'Ultra High Molecular Weight (UHMW) Polyethylene Liners', see Figure 4.9.

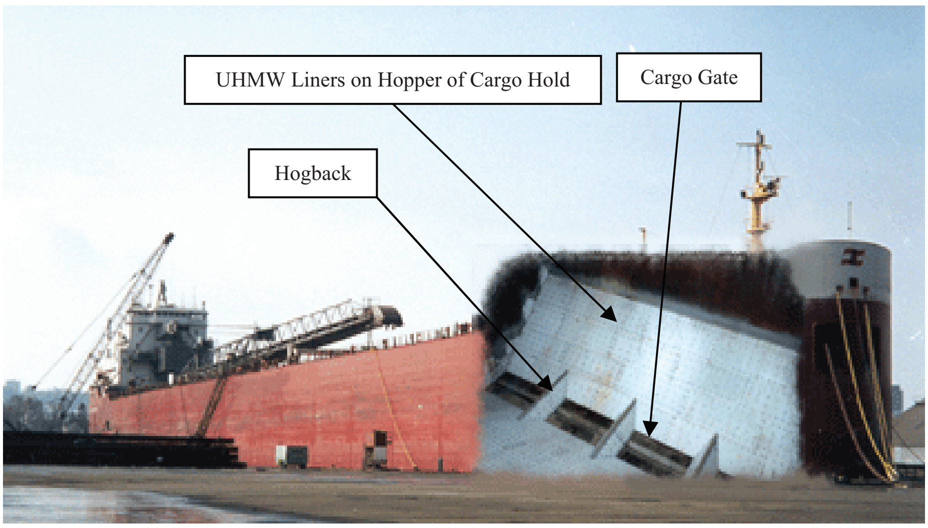


Figure 4.9 UHMW Liners Installed in Cargo Holds of SULS (Mentor Dynamic Ltd, 2005).

These UHMW are normally attached to the hopper surfaces of 35 degrees angle to aid cargo flow. Therefore, shipowners benefit from less material hang-up, resulting in faster discharging and less turn-around times in port. Figure 4.9, shows a typical UHMW installed in the cargo hold of a handymax SULS.

According to Mentor Dynamic Ltd. **(2006)**, Dyna-flo Polymer Liners (UHMW), as demonstrated in Figure 4.9, *'Are used extensively in self-unloading vessels and barges where material flow is essential to maintaining high productivity'.* This quote of Mentor Dynamics Ltd. is credible for the reason that the author has worked onboard SULS with and without UHMW installed in the cargo holds. Unquestionably, UHMW enhances cargo flow onboard SULS and shipowners have improved ships discharging performance, when unloading problematic cargoes (such as moist coal and gypsum) and having Dyna-flo Polymer Liners installed in the cargo holds. Based on Mentor Dynamics Ltd. **(2006)**, these are some of the cargo discharging benefits when UHMW liners are fitted in the cargo holds of SULS:

- *'Freezing: Dyna-Flo polymer liners release frozen materials better than ordinary painted cargo hold steel and performance is better with lower temperature;*
- *Impact Strength: The energy absorbing qualities of high performance polymer liners are matchless by other similar thermoplastic product and at low temperatures, the impact resistance improves;*
- *Abrasion Resistance: High performance polymer has high abrasion resistance, when compared with other commercially available plastic. It will outwear steel in most applications, also hardox steel liners in some instances* – this would perhaps depend of the type of cargo;
- *Chemical Resistance: Unaffected in most chemical environment. High performance polymer is suitable for the food processing industry because it is inert to fungus. However, strong oxidizing acids will attack the surface; and*
- *Noise Abatement: The sound deadening effects of high performance polymer is approximately 20% greater than other materials used in the construction of bulk handling equipment'.*

With regard to the utilization of polymer liners for cargo hold hoppers to reduce friction between the cargo and hoppers, improve the discharging rates, reduce turn-around time in port and increase volume of cargo hold, Wright **(1990, p.78)** supported the utilization of UHMW for cargo hold liners and concluded that *'The introduction of high density plastic linings has enable hopper angles to be reduced with significant cubic benefits'*.

4.6 Further Developments of Midship Sections for SULS

As has been already discussed, throughout the evolution of Self-unloader Bulk Carriers, the midship sections of these ships have been designed in various shapes and forms. The different types of midship section designs were fundamentally focussed on economic aspects for the purpose of enhancing cargo flow; greater ballast capacity for appropriate propeller immersion; improving discharging rate; space for fitting machineries; design for specific trades and larger volumetric capacities of cargo holds.

Numerous manners of midship section configurations can be effective for improving the cubic of cargo holds. One classic example is to retain the cargo hold shape similar to ordinary bulk carriers and use discharging combinations by first gravity unloading through conveyor belts and finally with the ship's gantry crane, feeding the conveyors. Figure 4.10, demonstrates the principles of this type of midship section design for SULS.

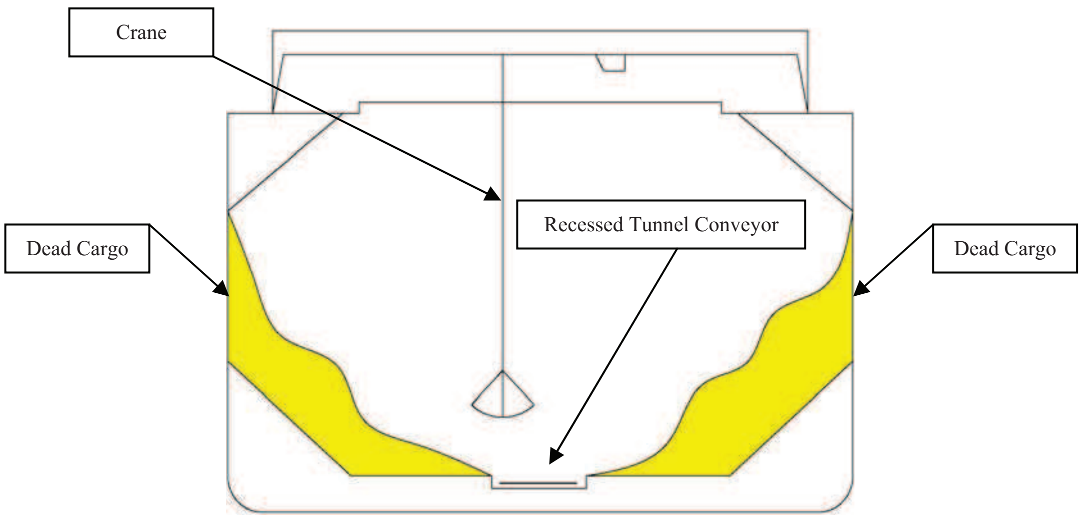


Figure 4.10 Midship Section for SULS Using Deck Cranes (Jones, Wright and Smith, 1972).

Regarding the structure described in Figure 4.10, until the angle of repose for the commodity is attained during gravity discharging, material will flow freely from the cargo holds and onto the centreline tunnel conveyor. Subsequently, cargo is transferred to the various downstream belts onboard the vessel and ultimately to the customers' facility ashore. Dead cargo remaining in the cargo holds after the free flowing gravity discharging process, is then unloaded by the shipboard gantry crane, transferring material directly to the centreline tunnel belt.

This design is somewhat of a hybrid. However, it has considerable benefits for the shipowners as no external shore-based assistance is required for cargo discharging operations and the vessel cargo hold volume is greater. This is because the vessel has the midship section of an ordinary bulk carrier with less accompanying unloading machinery when compared to a full gravity SULS system. The tunnel conveyor is single belt and of the recessed type, which allows for additional cargo hold volumetric capacity. Nevertheless, there is one major impediment with this system. Traditionally, some of these vessels had single skin hulls with exposed cargo hold frames that invariably results in impeding the flow of cargo, due to material hang-up. Figure 4.11 shows a typical occurrence of poor cargo flow, caused by having such opened frames in the cargo holds.

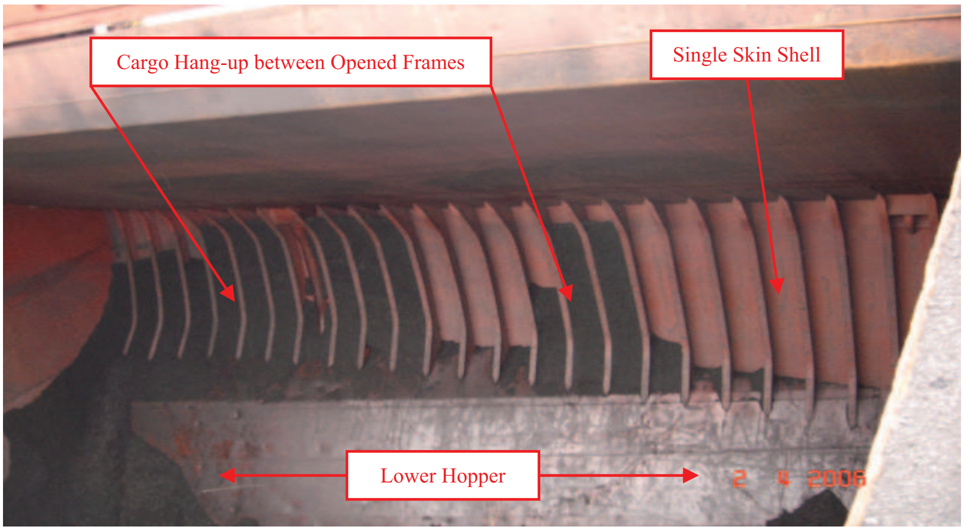


Figure 4.11 Cargo Hang-up with Opened Cargo Hold Frames – M/V Fourth Earth (Welcome, H. 2006).

Throughout the continuing development of midship sections, designers focused on accomplishing enhanced cargo discharge rates. As a result, SULS of the dual tunnel conveyor belts was employed with certain supplementary characteristics when weighed against earlier design vessels, namely:

- The hopper slopes were increased to angles ranging from 40 to 48 degrees for the purpose of improving both cargo flow and discharge rates; and
- A double skin in-way-of cargo hold side shells was implemented, primarily to avoid cargo hang-up between opened frames. Also, double skin structure warranted an increase of ballast capacity that is vital for appropriate propeller submersion.

These innovations in the twin belt midship section design with greater hopper angles were beneficial for vessel performance, especially material flow when unloading problematic cargoes, as well for increasing ballast capacity to prevent propeller cavitations during ballast voyages. To some extent, however, these deviations from the original design of single skin and hopper angles of 35 degrees have compromised cargo hold volume. With respect to cargo hold capacity for the two tunnel belt system. **Wright (1990, p.77)** attests that *'for 2 identical SULS midship cross sections with the 2 belts installation, the cargo holds cubic is 7% higher for those vessels with 35 degrees hopper slopes, when compared to SULS ships with 45-48 degrees hopper slopes…'*

Figure 4.12 demonstrates the midship section of a panamax SULS with double skin configuration in the cargo hold and a hopper angle of 40 degrees.

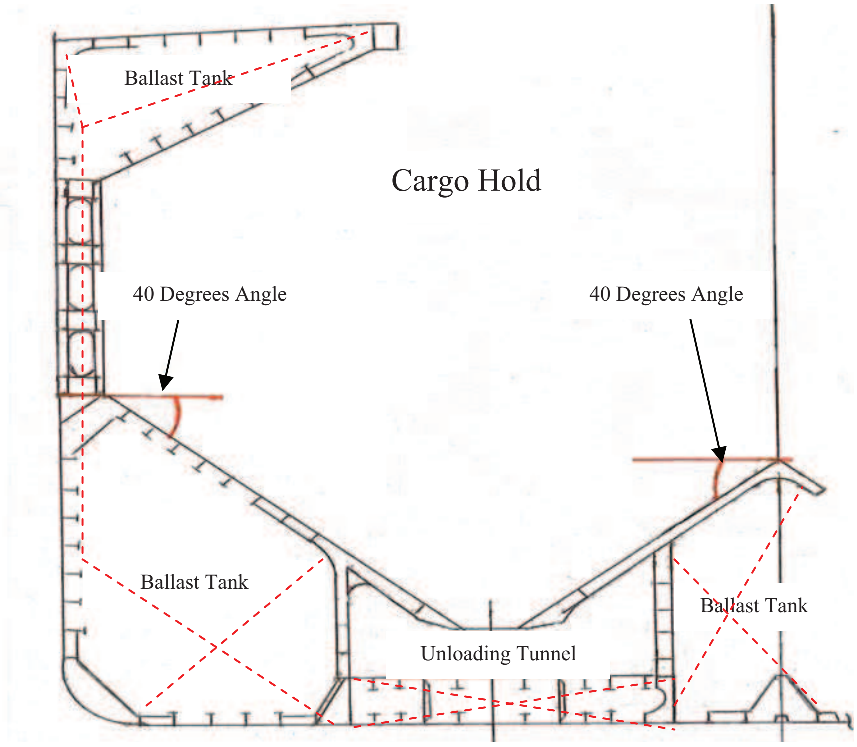


Figure 4.12 Midship Section of Double Skin Shell SULS (Model 'C', 1999).

Undoubtedly, in addition to the cargo gate aperture size, optimising the discharge rate of SULS is greatly influenced by the conveyor belt size and speed, in conjunction with the prime mover's design criteria. The numbers of tunnel belts installed also determines both the unloading rate and cargo hold volume. Jones, Smith and Wright **(1972, p.242)** stated that midship sections of the three belt SULS design came into effect essentially, given that *'It is particularly suited for moderate to heavy density cargoes where maximum cubic is not required. The all-belt system is tailored to suit a specific type of free-running cargo such as: ore pellets, stone, small-lump coal, sand, phosphate rock and certain grains'.*

Despite the versatility of multi-belt SULS systems, Jones, Smith and Wright **(1972, p.242)** identified that there was an accompanying cost which must not be ignored when choosing the option to add conveyor belts, simply because *'Self-unloader type of multi-belt installations are generally expected to cost 10% to 20% of the vessels' capital cost* *for two-belt systems; a third belt adds cost of 10% to the self-unloading equipment. However, the cargo cubic increases by approximately 10%...'.*

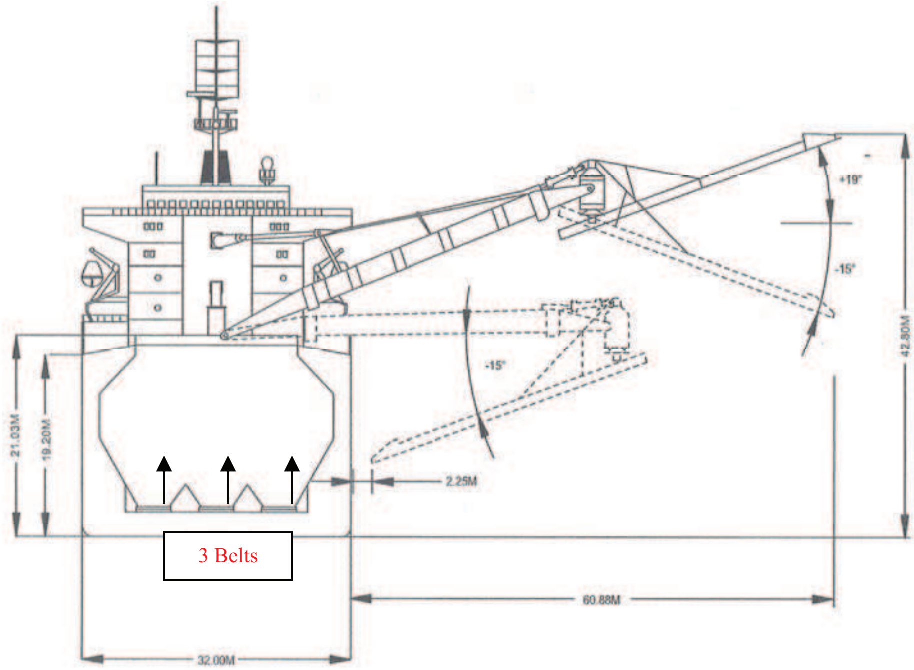


Figure 4.13 Midship Elevation of Three Belts SULS System (www.cslint.com/fleet.html, 2006).

Notwithstanding the escalated cost for a three belt SULS system (see Figure 4.13), these vessels are adaptable for trading numerous major dry bulk cargoes with supplementary cargo hold cubic and improved discharging rates. As a consequence, the shipowners' income and profit is enhanced. Figure 4.13, illustrates the principles of a midship elevation section with three belts.

To benefit from larger cargo hold volume, owners of gravity SULS have also focussed on designing midship sections for installing specific unloading equipment for elevating commodity from the tunnel to upper deck (see Figure 4.14). Research conducted by Wright **(1990, pp77.78)** substantiated that *'The main areas of technical development has been in the method of elevating cargo from the tank top to the main deck, and the cargo gates which release cargo from the hold onto the belt'.*

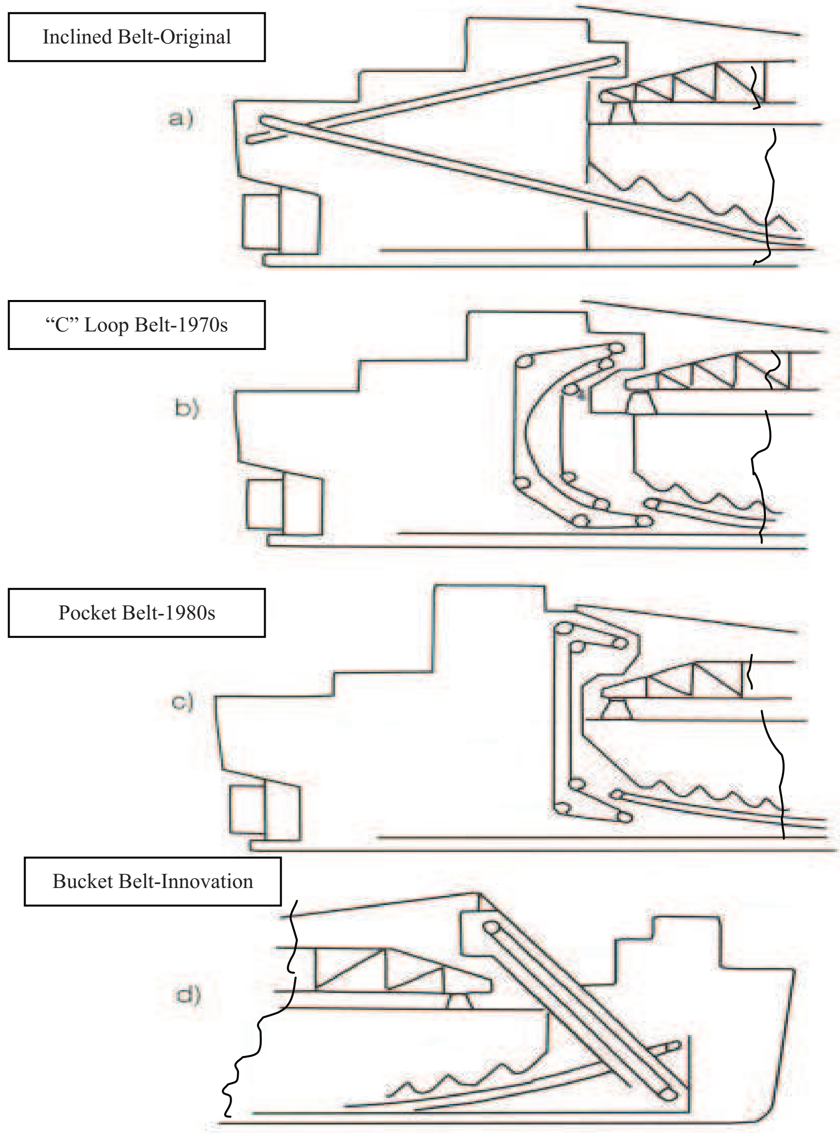


Figure 4.14 Principal Cargo Elevation Techniques for SULS (Wright, C. 1990).

These elevating systems for cargo, from the tank top to the upper deck are illustrated in Figure 4.14. With the exception of the No.1 and aftermost cargo holds, the midship sections for gravity SULS are relatively similar in most respects. However, depending on the type of cargo elevating system, the location of the unloading equipment could be adjacent to either the collision or the forward engine room bulkheads. Therefore, having an appropriately designed midship section to accommodate the discharging equipment is imperative in any installation arrangement, if the design is to benefit from increased cargo hold volume.

Figures 4.14 (a, b, **c** and d) exhibit the four basic designs of cargo elevating systems employed onboard SULS. The inclined belt could either be installed forward in No.1 to No.3 cargo holds or aft as illustrated in Figures 4.5 and 4.14 (a) to 4.14 (d).

The selection of elevating systems has always been driven primarily by capital cost, maintenance, designed for intended purpose, resourcefulness and inevitably volume requirements of cargo hold. Historically, the trends for cargo elevating techniques on SULS have principally been:

- The incline belt (original);
- The bucket elevator (early innovation);
- The ‘C’ loop (1970s); and
- The pocket belts (1980s).

These various cargo elevating systems as described in Figure 4.14**,** clearly endorses the versatility in design of SULS midship sections, predominantly in-way-of the collision and forward engine room bulkheads. Nevertheless, the choice of midship sections remained a contentious issue with different views between shipowners. According to Wright **(1990)**, some SULS owners preferred the inclined belt arrangement, due to the relative low cubic penalty, when compared to the ‘C’ loop belts. The inclined belt design also offers operational practicality with moderate maintenance cost.

In terms of enhancing cargo hold cubic when inclined elevating belts are fitted, the potential savings in volumetric capacity varies from one installation to another depending on ship design. When installation of unloading machinery is such that the inclined tunnel conveyor penetrates the engine room bulkhead as shown in Figure 4.14 (a), this design apparently results in greater cargo hold cubic if compared to the ‘A’ frame configuration demonstrated in Figures 4.5 and 4.15, which evidently occupies considerable volumetric capacity of the cargo holds.

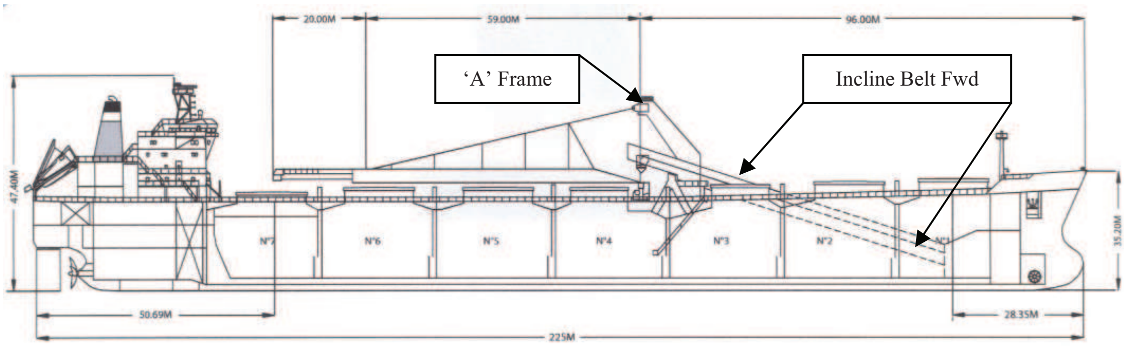


Figure 4.15 M/V Sheila Ann Demonstrating Incline Belt Forward (www.cslint.com/fleet.html, 2006).

As the Great Lakes trade expanded subsequent to the introduction of SULS, volumetric capacity of cargo holds became a pre-requisite for shipowners to benefit financially from trading low density cargoes. This trade pre-condition led to development of the bucket elevator, simply because this installation required less cubic in comparison to the inclined belt. Incidentally, the first commercial SULS (S/S Wyandotte-1908) was designed and constructed with an incline elevating belt. However, according to Wright **(1990, p.77)** *‘In 1910, this vessel was lengthened and the inclined belt was replaced with a bucket elevator, primarily to improve cargo capacity…’.*

As demonstrated in Figure 4.14 (d), numerous early designs of SULS, until the 1960s, had their accommodation forward. Thereby, the compact bucket elevator was fitted partially within and beneath the forward superstructure of these vessels. Obviously, the bucket installation was most advantageous for conserving cargo hold volume with these types of vessels. Principally, because the hull space under the accommodation occupied by the cargo elevators, could not be utilized for stowing and transporting cargo. The second benefit was reduced steel weight, due to not having an ‘A’ frame, as the boom was fixed directly to the forward superstructure. According to Elder and Detenbeck **(1988, p.6)** *‘Bucket elevators can be operated at any incline from 30 degrees to vertical. However, for best loading conditions and volume of the bucket assembly, installations ranging from 30 to 70 degrees are recommended…’.* Figure 4.16 demonstrates two different types of bucket elevators. The left Figure ‘A’ shows a bucket type shiploader in operation, during the unloading of an ordinary panamax bulk carrier at the port of

Taichung, Taiwan (photo by H. Welcome). For comparison, Figure 'B' shows the arrangement of an original bucket elevator design used onboard SULS that operated on the Great Lakes.

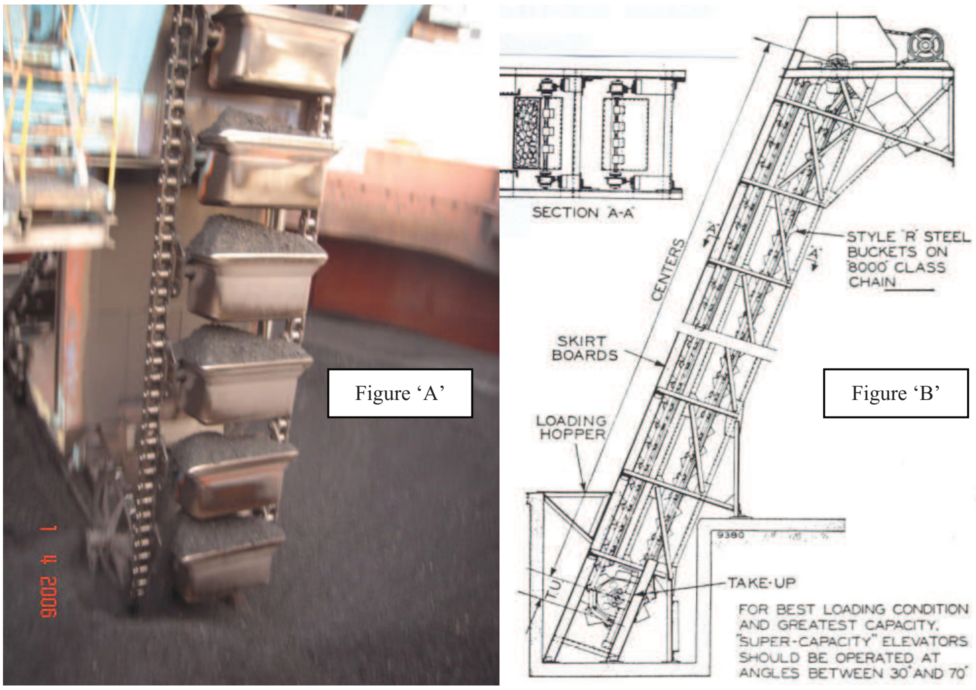


Figure 4.16 Ship Loader and Bucket Elevators (Port Taichung 2006, Elder, J and Detenbeck, M. 1988).

These bucket elevators are somewhat robust with cumbersome dynamic mechanisms. Hence, as demand for higher unloading rates grew, so did the operational noise levels and maintenance costs. These features were of some concern, leading to the development of the so-called 'C' loop belts during the 1970s'. However, the greatest benefit with the 'C' loop belts innovation was primarily higher unloading rates with moderately lower maintenance cost in comparison with the bucket elevating system.

Despite certain beneficial trade-offs with the 'C' loop belts installation, the main advantages were cost savings from both higher discharge rates and lower maintenance costs. This system is typically installed partially within the after superstructure, having the accompanying disadvantages of occupying greater cargo hold volume and relatively high noise level in the living quarters while unloading. However, the level of noise during discharging with the 'C' loop is less, when compared to the pocket belt and bucket elevator unloading systems. The 'A' frames do not form part of the 'C' loop installation. In most scenarios, the boom luffing attachment is connected directly to the superstructure. Figure 4.17 illustrates the side elevation of an SULS showing the 'C' loop location, which certainly substantiates a midship section with reduced cargo hold volume in the aftermost cargo hold. Figures 4.18 ('A') and ('B') further emphasizes the decrease in cargo cubic in the aftermost cargo hold when 'C' loop belts are fitted.

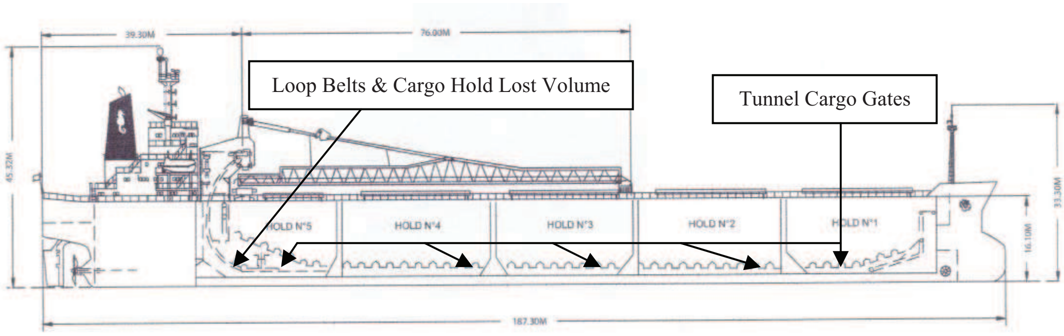


Figure 4.17 M/V Bahama Spirit Demonstrating 'C' Loop Location (www.cslint.com/fleet.html, 2006).

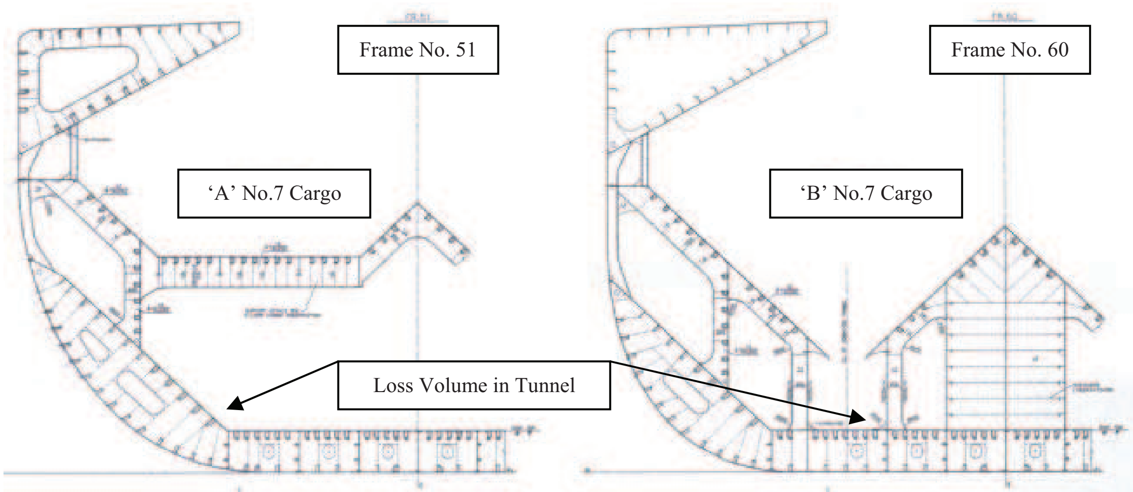


Figure 4.18 Midship Section of a Converted Panamax Vessel to SULS (Seabulk Systems Inc., 2006).

During the 1970s', cargo elevating system was further developed to address the high maintenance cost experienced with the original bucket elevator illustrated in Figure 4.16 'B'. Elder and Detenbeck **(1988, p.10)** stated that an alternative elevating system appeared on self-unloaders which '*Was introduced on the Great Lakes as a replacement to the ageing high maintenance bucket elevator system onboard the "Agawa Canyon"*.

The pocket belt, Figure 4.19*, which heavily resembles the bucket elevator, was refined and further developed in 1975 by a firm (Trellex) in Hamburg, West German, to include belt sidewall heights of 16 inches. This would enable the pocket belt to match capacities provided by a bucket elevator arranged in similar position; as illustrated in* Figure 4.16 'B'… '.

In many respects, the pocket elevator can endure onerous loading conditions similar to the original bucket system, except that this elevator is made from rubber instead of steel. Therefore, the design features operational flexibility and distortion without bond failure or fracture, which is likely to occur with the steel buckets. The pocket belt invention was a major design achievement for SULS technology, primarily by addressing less cubic loss relevant to the cargo hold capacities. Nevertheless, accompanying the positive characteristics of the pocket belt innovation, there are operational impediments in maintaining proper alignment to prevent damaging the belt. This resulted from flexibility of the belt assembly when in operation. This view is based on the author's experience as Chief Engineer onboard SULS with pocket belt installed.

Figure 4.14 (c) illustrates a side elevation of the pocket belt when fitted adjacent to the engine room bulkhead. The bucket elevator installation in Figure 4.14 (d) has a similarity to the pocket elevator assembly, if mounted forward next to the collision bulkhead. Both illustrations (c) and (d) of Figure 4.14, underlines a midship section employing enhanced cargo hold volume vis-à-vis the 'C' loop belts installation noted in Figure 4.14 (b). Figure 4.19 demonstrates an actual detailed view of the rubber pocket belt.

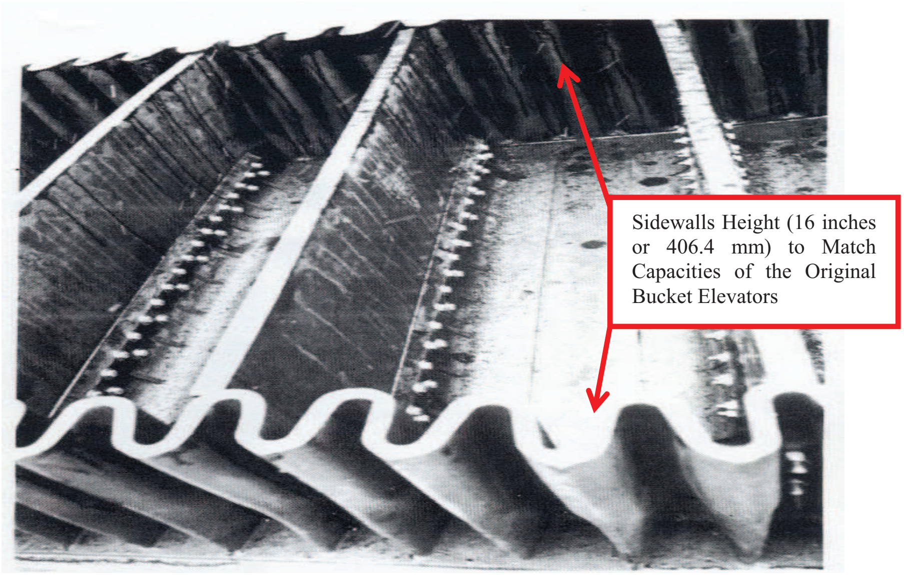


Figure 4.19 Pocket Elevator Details (Elder, J. and Detenbeck, M., 1988).

Occasionally, there are unprecedented designs of midship sections for SULS specifically for trading high density material. In this scenario the cargo hold volume becomes insignificant. The reason why cargo hold volumetric capacities are unimportant when designing a midship section explicitly for trading high density commodities, is simply because the vessel's fully loaded draft limit is attained prior to maximizing the cargo hold volumetric capacity. Fundamentally, this unique design of midship section is related to SULS intended solely for the carriage of high density commodities, such as iron ore, gypsum, and stones of various grades. Figures 4.20 and 4.21 illustrate the midship sections for two specialized SULS, one vessel for trading stones and the other dedicated to the iron ore trade.

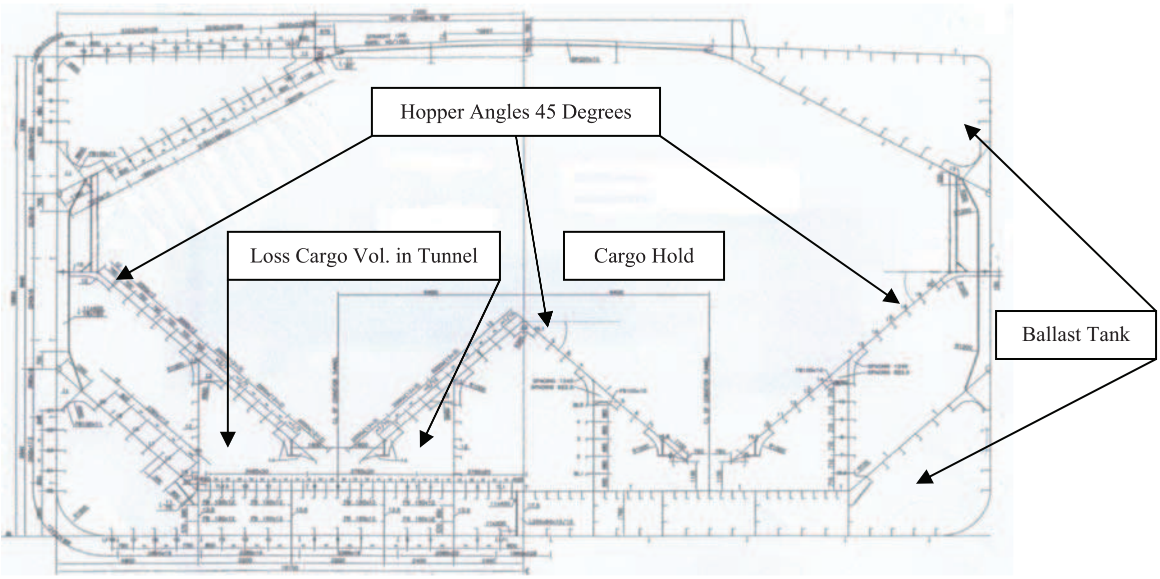


Figure 4.20 Twin Belt Midship Section Designed for Trading Stone (Seabulk Systems Inc. 2006).

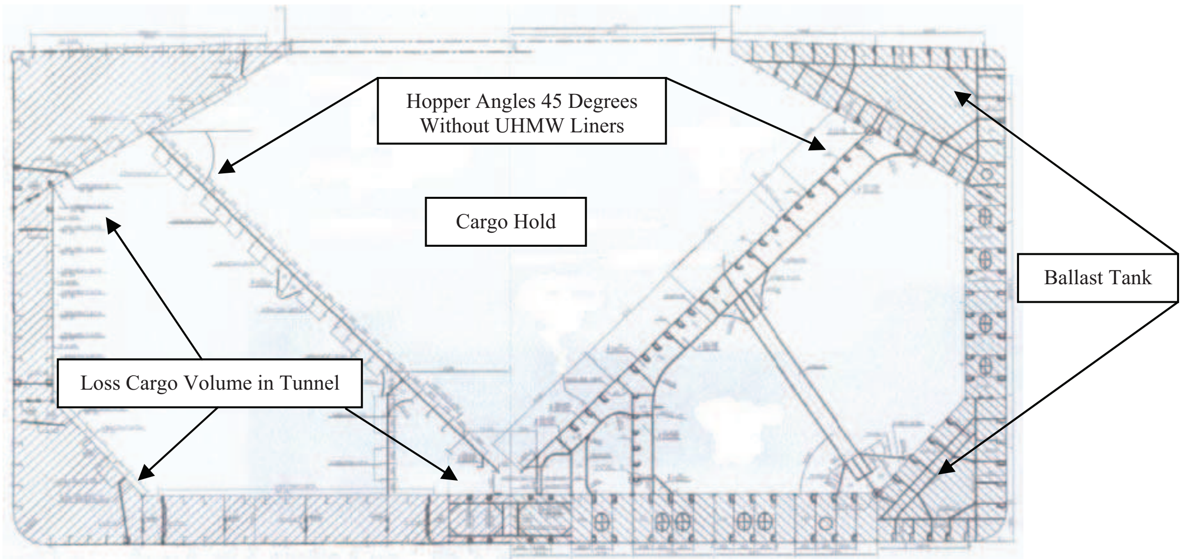


Figure 4.21 Single Belt Midship Section Designed for Trading Ores (Seabulk Systems Inc. 2005).

Normally, when trading dense cargoes only, the cargo hold hopper angles relevant to the horizontal axis average 45 to 48 degrees. Obviously, hoppers with greater sloping angles enhance material flow through the cargo gates and, in turn, improve the discharging rates, primarily when transporting lower grade cargoes that are highly cohesive. For instance, when trading inferior grade of iron ores concentrate with both excessive moisture and clay contents and having reduced percentages of iron (i.e. low ferrous value).

Secondly, SULS shipowners could exercise the option of not installing UHMW liners in cargo holds, when hopper angles are 45 to 48 degrees. Therefore, capital cost is reduced during the building stage, as well as ongoing cargo hold liner maintenance and renewal for the vessel's lifecycle.

4.7 Summary

This Chapter presented various designs of midship sections for SULS, starting with the original design of SULS in the early 20th century to the most modern types of these vessels, which were converted and built during 2007 and 2009. Unprecedented designs of SULS capable of discharging extremely high rates i.e. 10,000 long tons (10,160 tonnes) and 20,000 long tons (20,320 tonnes) per hour are demonstrated, while consuming less cargo space than alternative available systems during the 1970s'.

This Chapter also highlights the fact that cargo holds hopper angles vary from 35 to 48 degrees depending on the trade. However, the hopper angles of 35 degrees became the norm for global SULS that are trading both low and high density dry bulk cargoes. The hopper angles of 35 degrees reduce capital cost due to the economic benefits resulting from not having to install wider tunnel conveyor. This hopper angle (i.e. 35 degrees hopper) also allows for appropriate ballast capacity, while having sufficient space in the tunnel for maintenance. Despite the potential advantages offered by the hopper angles arrangement of 35 degrees, with some of these installations, the cargo flow has been improved by fitting Dyna-flo Polymer Liners (UHMW) on the hoppers. Nevertheless, the configuration of having UHMW attached to the hopper is accompanied with the disadvantage of increasing capital cost.

Regardless of the capital and operating costs for installing cargo hold liners when hopper angles are 35 degrees, the shipowners by majority have opted for this hopper slope. There are exceptions to this rule when trading high-density cargoes, such as iron ore and stone. The original hopper angles of 35 degrees remain the norm and are widely used globally for most SULS installations.

The hopper angles ranging from 40 to 48 degrees were discussed and are mainly used for SULS designed to transport high-density cargoes. Primarily because these hoppers slope (i.e. 40 to 48 degrees) enhance the cargo flow and the cargo holds volume is unimportant as draft and deadweight takes precedence. Additionally, with these larger hopper angles, the shipowner benefits from reduced capital, operating and maintenance costs. This is due to not requiring Dyna-flo Polymer Liners (UHMW) on the hoppers surface.

Improving the midship section by altering the hopper angles, resulted in changes to the cargo holds volume, deadweight and gate opening size. The modification of the gate apertures along with the hopper angles determined the space in the tunnel for maintaining the conveyors. This adjustment in hopper angles also altered the ballast capacity, which would possibly vary the vessel's trim and propeller immersion. This reduction in the vessel's draught could result in cavitations of the propeller while in ballast condition.

Fundamentally, the development of midship sections was driven by the following underlying considerations, namely:

- To comply with the elevation of cargo from the unloading tunnel to upper deck;
- To accommodate the installation of various types of cargo gates design;
- To accommodate conveyors of the multi-belt system;
- To comply with the trade requirements, primarily because the commodity (i.e. high or low density) governs the hopper angles to benefit from cargo lift, cargo flow and in some cases to reduce capital cost by not installing cargo hold anti-friction liners.

When comparing midship sections of dry bulk carriers, SULS construction inherently results in having less volume in the cargo holds. However, recent newbuilding SULS have reduced lightweight, when compared to SULS built during the early 2000s'. Essentially, the reduced cargo space with SULS is the sacrifice made for constructing the unloading tunnel, which is a pre-requisite for accommodating the discharging machineries and the cargo gates discussed in the subsequent Chapter.

Chapter 5

5. THE DEVELOPMENT OF EXISTING CARGO GATES DESIGNED FOR SELF-UNLOADERS GRAVITY DISCHARGING SYSTEMS

5.1 Introduction

Having discussed in previous Chapters the historical framework and development of Self-unloader Bulk Carriers' (SULS) and midship section designs for these vessels, this Chapter provides a comprehensive systematic review of the various cargo gate installations onboard gravity type SULS. The intention is to provide an understanding of the gates origin, describe their evolution, the arrangements and operations, and also address the issues shipowners encountered with gravity gates for SULS.

Investigations by the author confirmed that there are eight types of gravity gates, which have been installed onboard SULS. The cargo gates description, operations and years when these gates were put into service are described in chronological order. These cargo gates can be categorised as:

- **Roller Track Gate (original – 1908):** This gate operates on longitudinal tracks and the functionality is by using manual operating wheels in the tunnel (see Figure 5.2);
- **Roller Track Gate (1st development – no recorded date):** This gate is similar to that of the original Roller Track Gate (RTG). However, the gate function is carried out by two hydraulic cylinders (see Figures 5.3 and 5.4);
- **Roller Track Gate (2nd development - no recorded date):** The operations of this gate is similar to the 1st development of this style gate, except that the entire gates assembly is suspended from the hopper underside instead of supported by the tank top (see Figure 5.5);

- **Bulk Flow Gate (1974):** This style of gate operates transversally on tracks by four hydraulic cylinders and is supported onto the tank top (see Figures 5.7 and 5.8);
- **Basket Gate (original 1986):** Gates of this design are operated by a single hydraulic cylinder that opens the gate longitudinally and downward towards the belt, while being supported by two hinged pins (see Figures 5.10 and 5.11);
- **Long Slot Basket Gate (1989):** The functionality of this gate is by two hydraulic cylinders, operating linkages and gears that opens the gate halves transversally downward towards the belt (see Figure s 5.13 and 5.14);
- **Non Consolidating Feeder (1995):** This gate operates on longitudinal tracks by four hydraulic cylinders. The discharging is based on the 'moving hole' and 'open hole' principles, which is ideal for discharging cohesive materials (see Figures 5.15 and 5.16).
- **Long Slot Centre-split Basket Gate (1996):** This type of gate is operated by either one or two hydraulic cylinders. The gate halves open transversally downward towards the belt that is similar to the Long Slot Basket Gate (see Figures 5.18 and 5.19).
- **Controlled Feeder Gate (1999):** This gate operates on longitudinal tracks by two hydraulic cylinders. The discharging operations is based on the 'moving hole' and 'open hole' principles, However, the construction is different than the NC feeder (see Figures 21 and 22).
- **The Long Slot Gate Feeder (2002):** The discharging operations of this feeder is by two hydraulic cylinders that open the gate halves transversally downward towards the belt, which is similar to the Long Slot Basket Gate and Long Slot Centre-split Basket Gate (see Figures 5.28 and 5.29).

Operational principles for gravity SULS gates are revealed and discussed in detail, demonstrating the accompanying intrinsic hindrances. The operating comparisons of the gates are explained, primarily to establish the benefits as well as disadvantages with each of these gates.

When trading dry bulk cargoes, the 'bridging' of materials are natural occurrences resulting from 'arching' and 'rat-holing'. These issues are explained, primarily to clearly understand the phenomena of cargo hanging-up and the reasons why it occurs.

Hoppers and 'hogback' are longitudinal and transversal structures surrounding the gate opening. 'Bridging' and 'arching' are solid masses of cargo formed over the gates. An explanation is presented, as to how the cargo gate is influence from 'longitudinal bridging' and 'arching' with cohesive materials that causes restriction of cargo flow through the gate. 'Rat-holing', is addressed showing how this centre opening in the cargo over the gate called 'rat-hole' is formed from cohesive material.

In summary, this Chapter provides an understanding of the development and operations of existing cargo gates for gravity discharging SULS.

5.2 Cargo Gates Design for Gravity Discharge SULS

Current investigation of the original and existing cargo gates onboard the gravity discharging type Self-unloader Bulk Carriers (SULS), revealed that there are eight different types of gates installed onboard these vessels. These cargo discharging gates are located beneath the ship's cargo holds in a tunnel, which extends from the forward engine room bulkhead and terminates at the collision bulkhead. Figure 5.1 illustrates the position of the gates under the cargo holds in the tunnel.

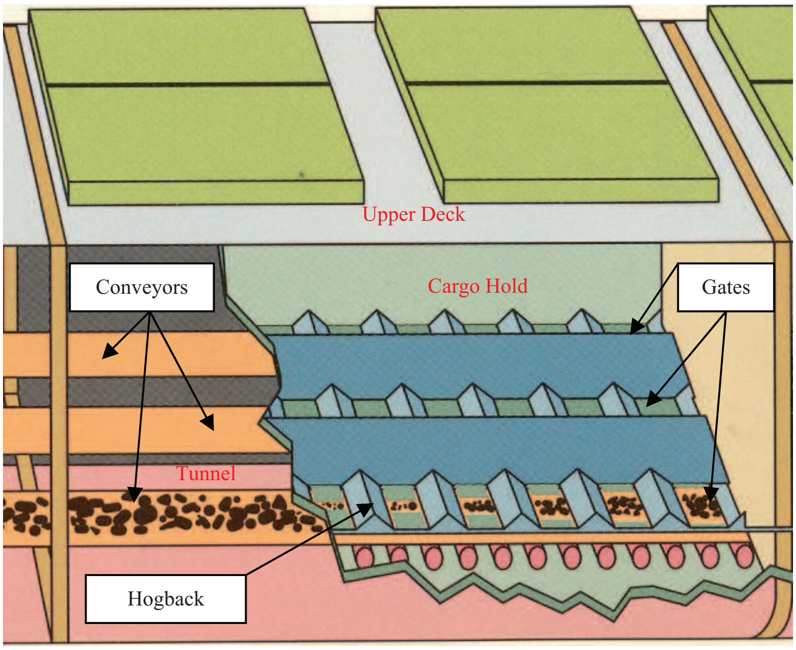


Figure 5.1 Cross Section of SULS Cargo Hold and Tunnel (CSL, 1995).

The basic operation of gravity discharging system is succinctly summarised by Canada Steamship Lines Inc. **(2005)** owner and operators of the largest SULS fleet globally, as *'Self-unloaders bulk carriers operate with a mix of high-tech and nature's invisible force-gravity. Basically, the cargo falls by gravity onto conveyor belts beneath the cargo holds. The flow of cargo is controlled by hydraulic gates, which allows cargo to flow through the gates and onto the cargo holds conveyor belts that brings the cargo to the downstream conveyors and discharges the product ashore into the customers' facility…'*.

SULS gravity gates of the various types are designed differently and have unique functionalities, but the underlying concept of how the cargo is discharged, is fundamentally similar in all cases. The commodity is allowed to free-flow due to gravity from the cargo holds down through the cargo gates and onto the tunnel / hold conveyor belts.

5.3 The History, Development, Arrangement and Operations of Gravity Cargo Gates for SULS

The origin, development, layout, operations, advantages and disadvantages of gravity gates installed onboard SULS from the inception of these vessels until today is now outlined.

5.3.1 Roller Track Gates

Based on Cross (**1938**) historical development of SULS technology relevant to gravity cargo gates, it appears that a version of the Roller Track Gates (RTG) has been in existence from the inception of these types of vessels in 1908, when the first commercial SULS (i.e. S/S Wyandotte) was put into service. Therefore, the RTG could conceivably be considered as the pioneer gravity discharge type gates for SULS. Subsequent to the original RTG, there have been two other developments of this style gate. However, there is no recorded date when these two gates were developed.

5.3.1.1 Arrangement and Operations of the Roller Track Gates

Cross **(1938, p.232**) described the arrangement of the original roller track gate as '*a combination slide and drop-lip type, about 2/3 of the gate opening is closed by the sliding part of the gate and the remainder is hinged and drops away as the gate is drawn back. This arrangement permits closer spacing of the gates with added hold capacity. The hinged section also serves as an apron, causing the material to move in the direction of belt travel. The gates are supported on tracks which extend the length of the hold. They are operated by hand by means of large hand wheels, geared to chain drums* (see Figure 5.2). *It is customary to operate the gates in pairs, one on each side'.*

According to Cross (1938), with the early designed RTG, the operators became very skilful in their work and learn to control the discharging flow rate by manually operating hand wheels in order to obtain maximum capacity without overloading the belts.

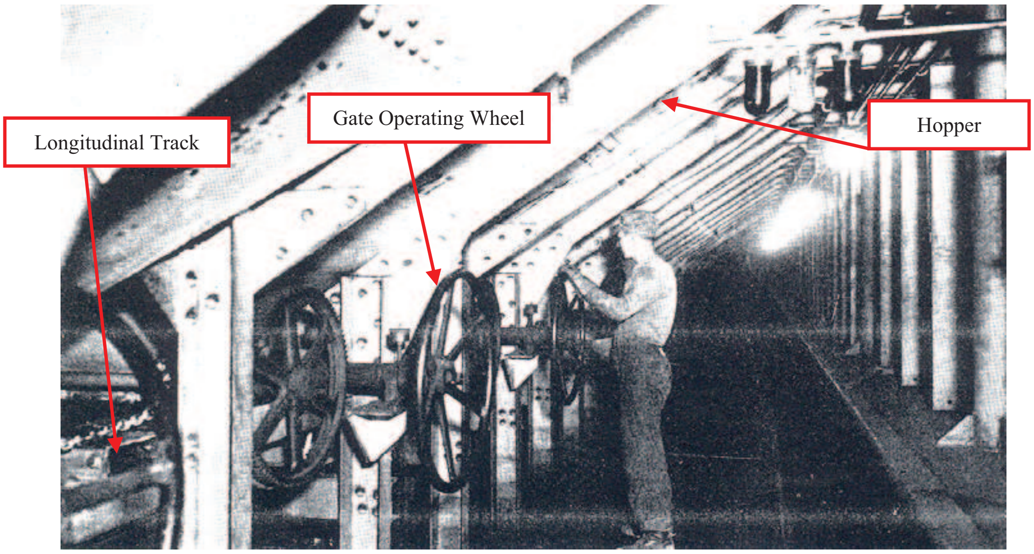


Figure 5.2 Features of SULS Tunnel Onboard S/S George F. Rand (SNAME, 1939).

Figure 5.2 reveal some characteristics of the original gate structural details and elevation of the unloading tunnel onboard the S/S George F. Rand. This ordinary bulk carrier vessel was built in 1911 and converted to SULS during 1936.

Figure 5.3 is a pictorial view illustrating the current design of RTG in both the closed and opened positions. This design is a development of the original RTG.

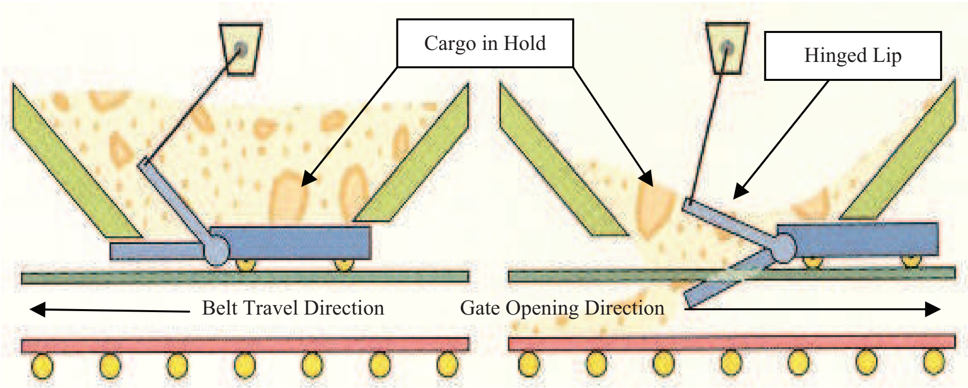


Figure 5.3 Roller Track Gates – Closed & Opened (SA & CSL, 1995).

From a functional standpoint, a version of the existing designs RTG is also installed parallel on longitudinal tracks and supported onto the tank top similar to the original RTG. (refer to Figure 5.4). With this gate installation, the opening and closing are achieved by means of hydraulic cylinders connected to both sides of the gates. Operations of these contemporary RTG are such that, controlling the opening and closing can either be accomplished from both a local and remote locations, namely the unloading tunnel or cargo control room (CCR).

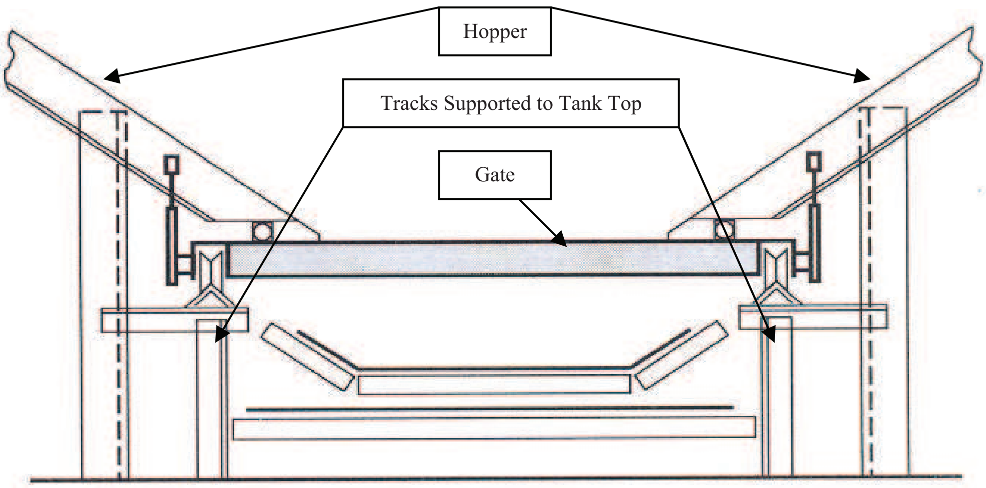


Figure 5.4 First Development of Roller Track Gate – Section Elevation (LR, 1992).

During discharging it is important that the cargo flow smoothly to avoid spillage. This is achieved by having a hinged lip attached to the gate and ensuring that the gate opens in opposite direction to the belt travel. This arrangement is shown in Figure 5.3.

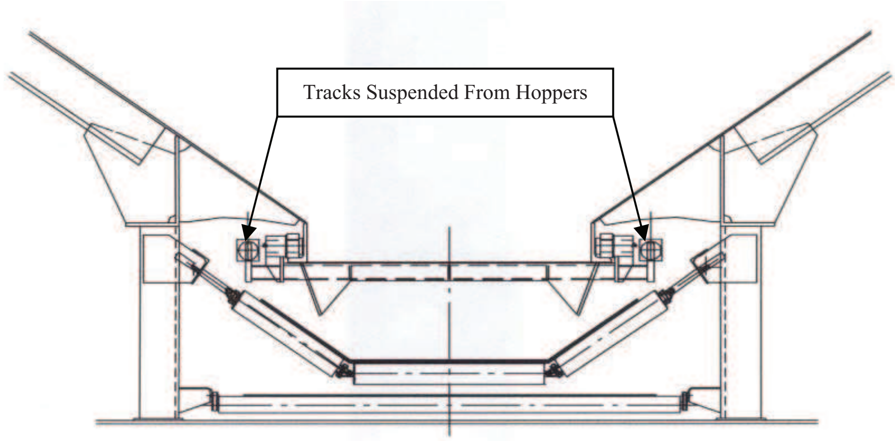


Figure 5.5 Second Development of Roller Track Gate – Section Elevation (EMS-Tech Inc, 2001).

The operation of the modern RTG opening functions are similar to the pioneer RTG and is self-explanatory if reference is made to Figure 5.3. Figure 5.5 demonstrates the most recent design of the RTG, which is suspended from the hoppers instead of being supported by the tank like the original RTG. When comparing the previous RTG with the suspended type gate, the advantages are smoother operation due to no longitudinal deflection of the tank top and reduction in the ships lightweight.

The RTG has an added advantage in comparison to the original Basket Gates (BG) of BMH Marine AB, described in Figure 5.6. This is due to the fact, that more than one RTG can be opened simultaneously without obstructing the flow of material. Therefore, for an identical capacity of conveyor the discharging rate would be higher for the RTG, when compared to the BG. This is providing one BG is insufficient to achieve the discharging rate. When more than one BG is opened on the same conveyor, the cargo flow will be obstructed and this condition causes an overflow of commodity into the unloading tunnel. Figure 5.6, exemplifies this blockage of cargo when two of the original BG are opened at the same time.

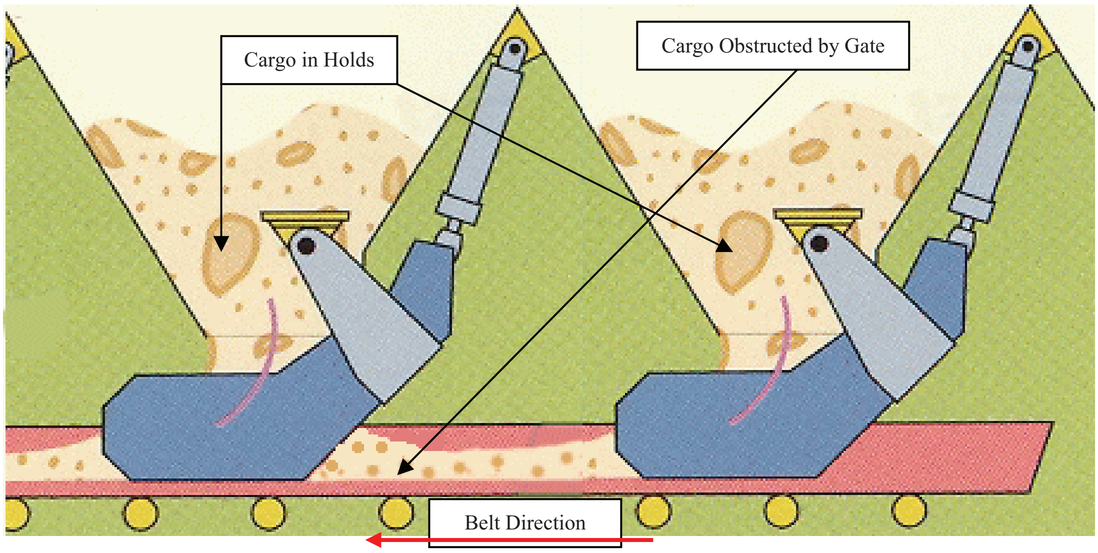


Figure 5.6 Basket Gates – Two Units Opened (BMH Marine AB and CSL, 1995).

5.3.2 Bulk Flow Gate

In 1974 this gate was developed and installed onboard Great Lakes SULS. The Bulk Flow Gate (BFG) was designed by Stephens-Adamson Mfg. Co. of Canada Ltd. (SACAN). Figures 5.7 and 5.8 illustrate this gate.

Fundamentally, this gate was introduced to address discharging flow issues encountered with the original and existing RTG, when discharging large mass bulk cargoes of cohesive nature that was poorly flowing. At that time, the problematic bulk cargo was primarily the western Canadian coal with high moisture contents and also the gypsum rocks.

5.3.2.1 Arrangement and Operations of the Bulk Flow Gate

There is a significant inherent structural disadvantage associated with the BFG, which occurs subsequent to loading the vessels. The gates supporting transversal beams or tracks shown in Figures 5.7 and 5.8, often deforms after loading the vessels. The structure deformation resulting from the "filled load" with this style of gate was greater, when compared to other gravity gates installed in SULS. This deformation of the gates supporting beam prevents the hydraulic cylinders from opening the gates. Therefore, resulting in delays or increasing the turn-around time in the discharging ports.

Nevertheless, the (BFG) after being installed onboard numerous SULS has certainly served the purpose for what it was intended, which was to discharge cohesive commodities of large mass that was difficult to discharge with the original and existing RTG.

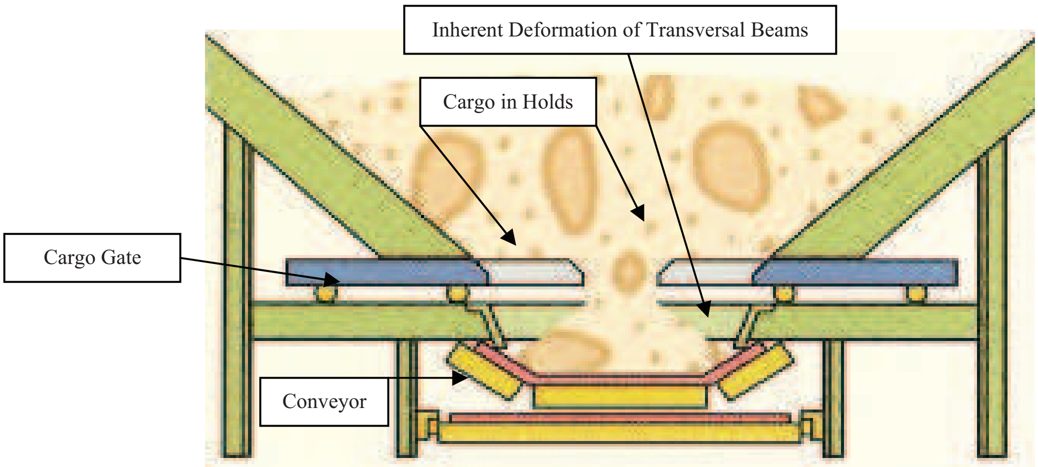


Figure 5.7 Bulk Flow Gates – Opened Position (SA and CSL, 1995).

Because of the BFG large opening size, the operators have to develop special skills to operate the gates reliably and avoid overloading the conveyors. Especially when there are mixtures of big and small objects incorporated with the cargo, such as gypsum.

Other than gypsum rock cargo, shipowners of SULS have occasionally encountered huge segregated masses or solids integrated with the shipment of various dry bulk commodities, such as crystallized salt, cement exposed to humidity, frozen iron ore, frozen coal, etc. The large gate opening BFG, with experienced operators, has proven to enhance the unloading rates, when discharging cargoes that are mixed with large solid and fine materials. Additionally, more than one gate can be opened simultaneously, which further improves the discharging rate. Figure 5.7 illustrate the BFG in the opened position. From the pictorial view in Figure 5.7, it clearly demonstrates the size of gate opening for allowing and conveying large mass of cargo from the cargo holds and onto the hold conveyor belts.

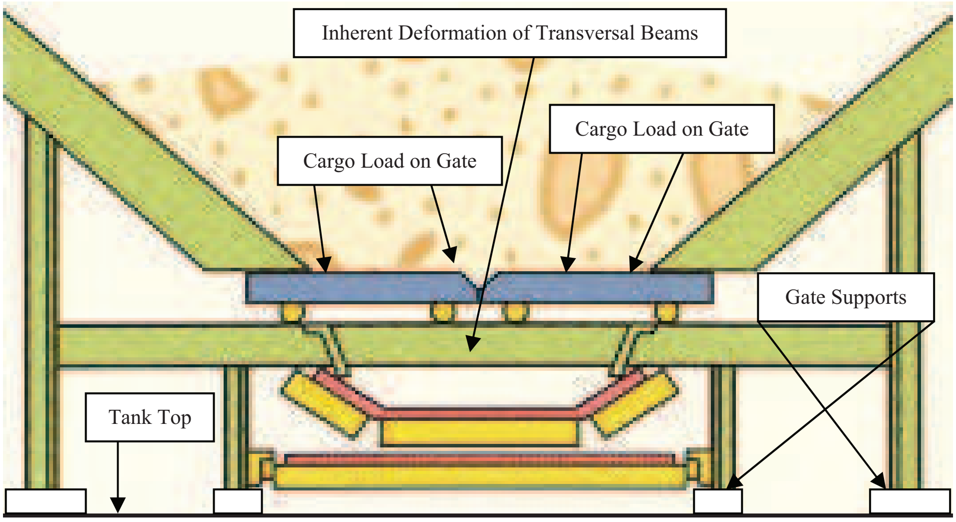


Figure 5.8 Bulk Flow Gates – Closed Position (SA and CSL, 1995).

Occasionally, in addition to the forces applied by the hydraulic cylinders to open the gates, supplementary and separate means, such as, chain-falls or portable hydraulic jacks, have to be utilized to overcome the force, resulting from the mass of cargo acting downward on the gates. This gravity force from cargo on the gates, in SULS trade is normally referred to as the 'filled load', which is exacerbated by cargo compaction on top of the gates due to the vessel's motions at sea. Studies conducted by Ding, S. and Enstad, G. G. (2003) confirmed that *'the vertical stresses (i.e. filled load) in granular material at the outlet of hopper were greater for 'layer-by-layer' filling than for 'switch-on' filling. Layer-by-layer filling is accomplished by introducing or filling material into a hopper in different layers; where as, 'Switch-on-filling is a process of consolidation with no initial stresses in the material rather than a filling process…'*. Clearly, the 'layer-by-layer' filling is similar to the loading process onboard SULS and for this reason the gates are occasionally difficult to open due to stresses developed at the hopper opening or on top the gates (i.e. filled load).

Once the gates are opened and the cargo is flowing, the gates are operating under what is referred to as the "flow load" condition. In some instances, when the supporting beams are relieved of this cargo force they never return to their un-deflected shape, namely the elasticity limit of the steel has been exceeded.

The second significant hindrance shipowners have experienced with the BFG; is with the operating cylinders. Sometimes the four operating cylinders have unequal hydraulic oil flow or pressure and this situation causes the gates to skew, twist or jam when opening and closing. Invariably, the outcome of this is flooding of the conveyors with cargo, especially when the gates are seized in the opened position and the belts are not stopped in time.

In 2003, new developments were tested in an attempt to resolve the operational issues associated with the BFG. This was relevant to deformation of the supporting transversal beams, which prevented the operating cylinders from opening the gates squarely. Figure 5.9 illustrates these modifications carried out for rectifying the supporting beams and cargo gates hydraulic issues.

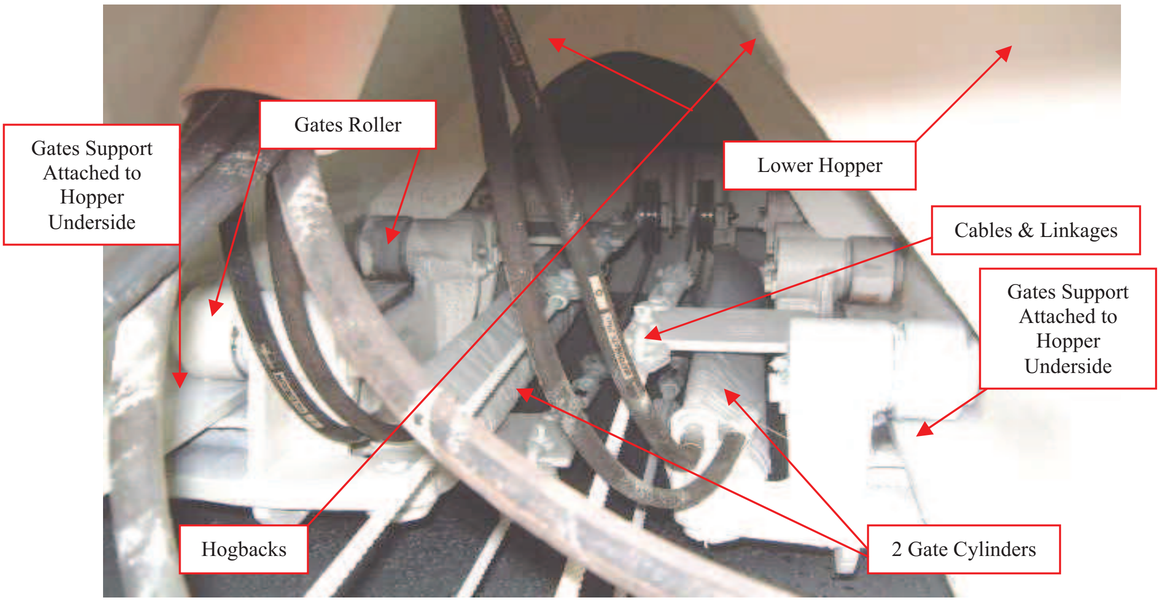


Figure 5.9 Bulk Flow Gate Modifications (EMS-Tech. 2003).

Figure 5.9 clearly demonstrates the forward and after side elevation of two gates, viewed from the unloading tunnel inboard. When comparing Figure 5.8 with Figure 5.9, it clearly shows in the modification that supports for the gates (in Figure 5.9) is suspended from the hopper underside instead of the original design, where the gate supports were erected onto the tank top (see Figure 5.8). The second modification is having only two operating hydraulic cylinders instead of the earlier design, which comprised four cylinders.

The third and final changes concerned the re-arrangement of the hydraulic system and cylinders. The hydraulic flow dividers for allowing the gates to open and close uniformly were removed and instead linkages with wire cables were installed to achieve smoother operation and even opening and closing of gates. As a consequence, this avoided the gates skewing while discharging. Some of the components used in the modification are shown in Figure 5.9.

According to some SULS operators, these modifications to the BFG improved the cargo discharging operations for those vessels having this type of gate installed.

5.3.3 Original Basket Gate

The records of BMH Marine AB (BMH) stated that the original Basket Gate (BG) for Self-unloader Bulk Carrier vessels was developed in 1986, which was subsequent to the Roller Track (i.e. pioneer and existing) and Bulk Flow Gates.

BMH Marine AB **(2005)** is a renowned marine dry bulk designing company, promoting the BG into the maritime industry, accounting for the installations of *'32 Self-unloading systems of gravity types that have been or are being supplied for ships ranging in size from 3,500 to 96,000 DWT…',*. According to BMH **(2005)**, their designs of self-unloaders have the following characteristics:

- *'The discharge capacities vary between 1000 to 6000 t/h and can be higher if required;*
- *Materials conveyed are free flowing bulk materials such as iron ore, coal, aggregates, etc;*
- *Conveyor system designed and manufactured to suit each vessel and the intended cargo in order to reach maximum performance and efficiency; and*

- *The conveyor system can be designed either for newbuildings or for converted vessels…'.*

In 2009 a new gravity discharging type SULS was delivered in Brazil for Gypsum Transport Ltd. with a discharging system designed by BMH Marine AB and Kamengo Technology Inc. Other than the commercial benefits for BMH Marine AB, there are no specific reasons recorded as to why the original BG was developed.

5.3.3.1 Arrangement and Operations of the Original Basket Gate

From a design and operational perspective, this type BG has an apron/lip with enclosed sides or wings. This arrangement allows for the cargo to be conveyed smoothly onto the belts, which prevents cargo spillage / overloading during discharging. This design feature is an advantage with the original BG in comparison to the RTG and BFG, primarily when unloading commodities of large mass such as gypsum rocks. This is providing that the cargo is free flowing. The side wings allow for stopping the tunnel conveyor belts while the gates are fully opened and causing no overload condition, due to the feed rate being regulated by the speed of the hold conveyors. This advantage with the BG is similar to that of the Long Slots Gate Feeder, but unlike the other gravity gates.

The following are some of the benefits emphasized by BMH Marine AB **(2005)** pertinent to the original design BG '*During operation the gate is guiding material into the belt trough at an initial speed and with minimum dust spillage. Due to the design, no overflow of the belts will occur in an event that the conveyor stops accidentally while the gate is opened. The side wings of the gates prevent overflow of the conveyor even if the belt stops and a gate is fully opened (i.e. when black out condition occurs).The Basket gate is wider compared to other gates giving a larger volume in the ship's cargo holds. Each gate is suspended to the ships' structure by only two hinged brackets with pins providing an easy installation and adjustment. Only one hydraulic cylinder, two hoses and one operating valve are required for each gate, which is less installation and maintenance costs…'.*

Some of the above quoted characteristics of the BG construction are clearly evident in the Figures 5.10 and 5.11.

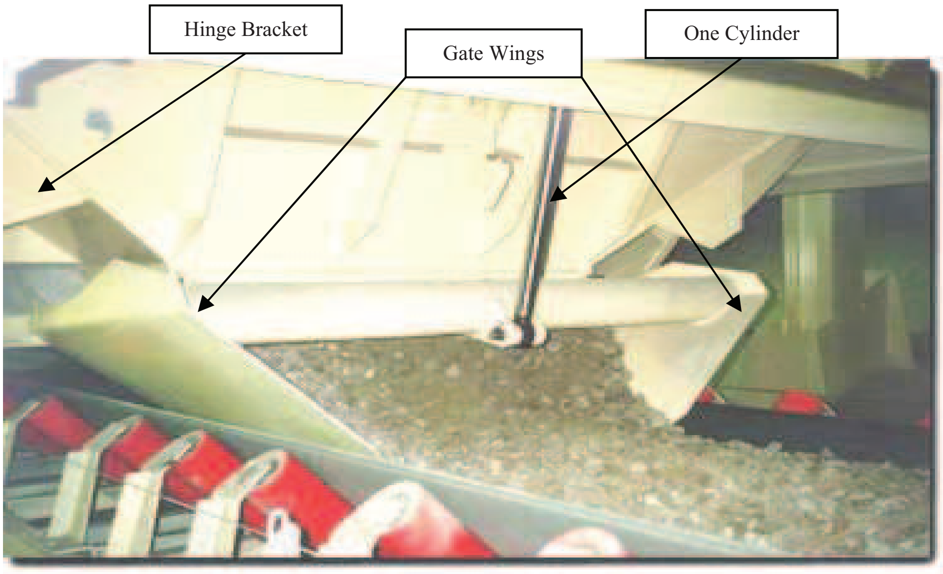


Figure 5.10 Basket Gate in Opened Position During Unloading (BMH Marine AB, 2005).

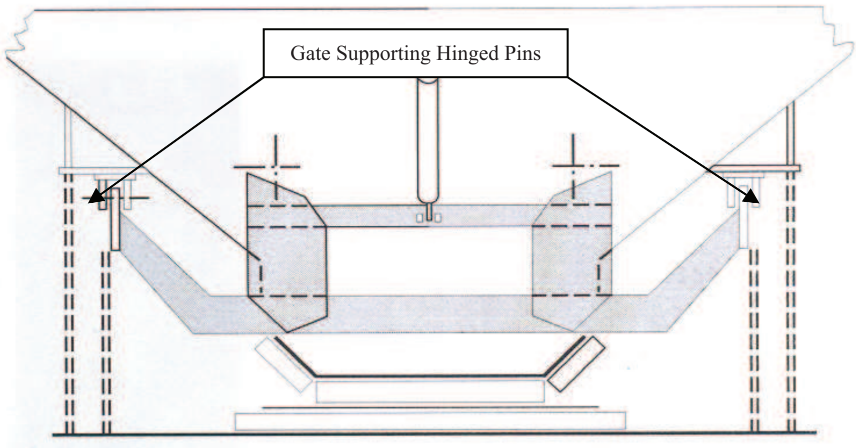


Figure 5.11 Basket Gate Section – BMH Marine AB Design (LR, 1992).

As stated previously in section 5.3.1.1 and Figure 5.6, there is one fundamental obstacle with the BG design, which is that two gates on the same conveyor cannot be opened concurrently. For the reason, that this situation causes an obstruction of the material resulting in overflow or spillage of cargo into the unloading tunnel. This is one of the disadvantages with the BG, when comparing with the RTG and BFG that permits simultaneous discharging with two or more gates.

Figure 5.12 illustrates one BG in the opened position while the other gate is closed. This condition is the normal discharging operation for this type of gate and allows cargo to flow freely along the conveyor.

The operating mechanisms of BMH Marine AB Basket Gate (BG), are somewhat simpler and have less components in comparison to the both the Roller Track and Bulk Flow Gates. Nevertheless, in actual practice the BG supporting arrangement is always known to have seized pins and hinge assemblies. This creates tremendous force on the operating cylinders, when opening and closing the gates. These hinged pins are displayed in Figure 5.12.

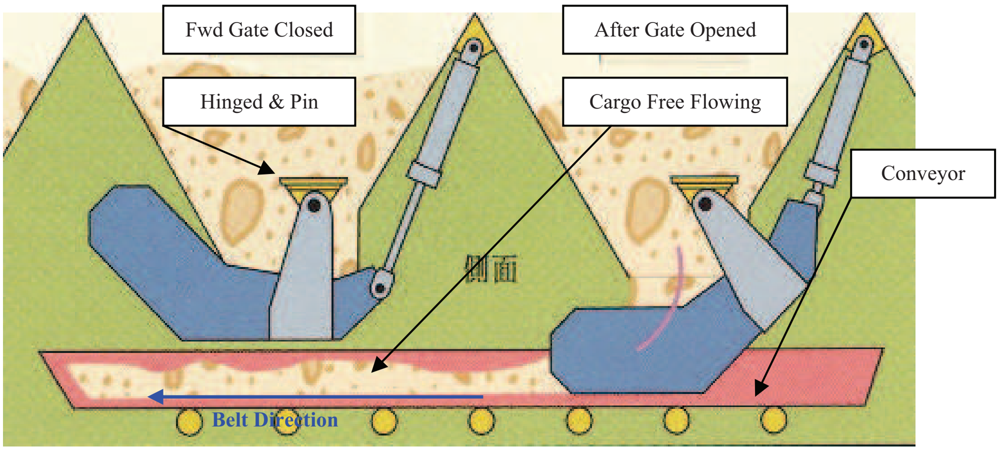


Figure 5.12 Basket Gates – Opened and Closed Positions (BMH Marine AB and CSL, 1995).

5.3.4 Long Slot Basket Gate

Prior to 1989, Basket Gate (BG) technology was limited to the feeder type BG of BMH Marine AB (BMH) designed in 1986. Following this BG invention, Stephens-Adamson MFG. Co. (SACAN) became involved in seeking solutions to improve the unloading of SULS, when using Basket Gates. In 1989, SACAN developed the Long Slot Basket Gate (LSBG) to address operational issues encountered with the company's previous gate designs and primarily for correcting existing discharging impediments associated with the Bulk Flow Gate of 1974.

According to EMS-Tech Inc. **(2005, p.3)**, the birth of the LSBG by SACAN was principally because the company recognized that *'The Bulk Flow Gate proved to be troublesome and unreliable. There were ongoing problems associated with synchronizing the opening and closing of the two gate halves; for this reason, the alternative Long Slot Basket Gate (LSBG) was introduced in 1989. Nevertheless, this gate (LSBG) is excellent, but it relies on the operator to adjust the gate opening size to regulate the flow of material onto the hold conveyor belts. The LSBG is good for high material flow rates; however, not good for low flow rates requirement…*'.

This gate was fitted in selected marine installations on the Great Lakes. However, the expansion of this particular gate was limited onboard SULS without further improvements by SACAN.

5.3.4.1 Arrangement and Operations of the Long Slot Basket Gate

This Long Slot Basket Gate (LSBG) has two operating cylinders, which apparently is an improvement, when compared to the original Bulk Flow Gate (BFG) that has four cylinders.

When comparing the BFG with LSBG, the operational enhancement is not just by employing less mechanisms or operating cylinders. The design improvement of the LSBG is relating to exchanging two cylinders assembly for two sets of 'involutes tooth gear segments' and linkages. These devices were primarily for improving the operations of the gate halves, in order to achieve better synchronization of the gate during opening and closing. This design addresses the typical operational issue of uneven gate opening / closing (i.e. skewing and twisting) during discharging operation with the BFG.

Figures 5.13 and 5.14 demonstrate the end and side elevations of this pioneer LSBG in the closed position with the accompanying gears, linkages, cylinders and hogback.

The Long Slot Centre-split Basket Gate of EMTI has some resemblance to the original Long Slot Basket Gate of SACAN. However, the two gates designs are not identical. This is evident by carefully comparing Figures 5.13 and 5.18.

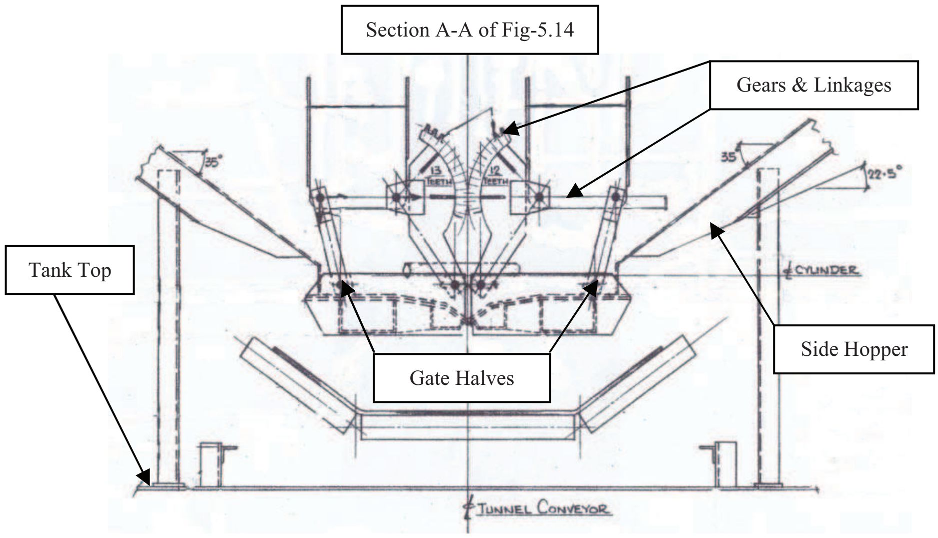


Figure 5.13 Long Slot Basket Gate End Section Elevation – Closed (SACAN, 1989).

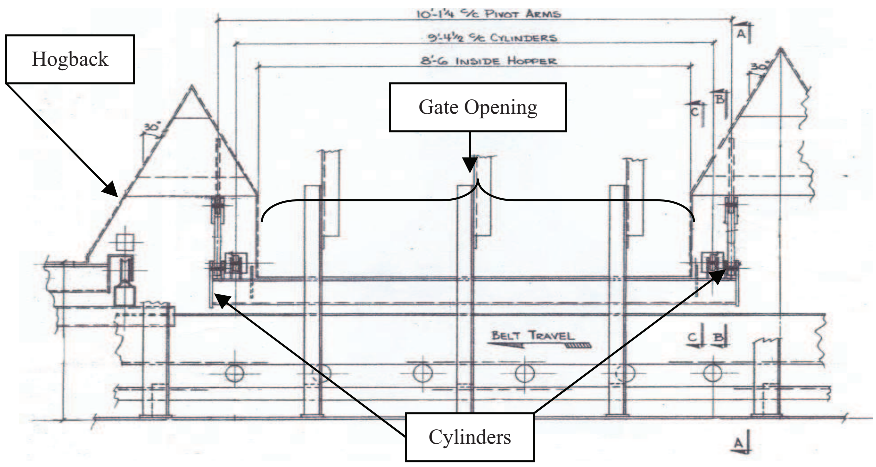


Figure 5.14 Long Slot Basket Gate Side Elevation (SACAN, 1989).

In summary, trading-off two cylinders for gears and linkages with the LSBG were fundamentally for improvement of the gate performance instead of reduction in components. Additionally, this gate has a long centre slot in the longitudinal direction with a large opening, which is an advantage that reduces the possibility of material arching and rat-holing.

5.3.5 Non Consolidating Feeder

In 1979 the British Columbia Research Corporation (BCRC) of Vancouver, Canada was established. This organisational group was focused on research and development in material handling, preparation and conditioning systems with emphasis on biomass products. As a result, in the 1980s' the Non Consolidating Feeder (NCF) was developed. In 1986, the earliest machine of this type was installed in a grain elevator at Vancouver for handling grain dust. Figure 5.15 demonstrates a NCF unit.

This machine was specifically invented, to overcome flow impediments linked with wood waste generally known as 'hog fuel' used as an energy source in the Canadian pulp and paper industry. Hog Fuel is categorized as low bulk density with high compact-ability that bridges or 'hang-up' easily over large area. According to Kamengo Technology Inc. **(2001)**, one feature with the Non Consolidating Feeder *'Is the ability to avoid compaction of the stored material and to provide 'effective' discharge without stagnation, even from very long storage hoppers? The latter feature makes it suitable for reclaiming from long hoppers such as: under stockpiles, storage domes and ships'*.

In 1995, the first marine installation of this machine was placed onboard an SULS. The author was the Superintendent Engineer responsible for co-ordinating the installation of this prototype gate. Subsequent KTI confirmed that in 2001 a second marine unloading system of the NCF was installed onboard the M/V Gypsum Centennial of Gypsum Transport Ltd. (GTL).

KTI and SULS operators stated that, there are three vessels to date in existence which has the NCF installed. The name of the other two vessels that have the NCF installed cannot be disclosed as it is commercial in confidence.

5.3.5.1 Arrangement and Operations of the Non Consolidating Feeder

The NCF comprises a number of shifting slots on the top surface or deck and stationary belts that are in direct contact with the cargo. The friction between the static belts and material is reduced considerably, preventing compaction of the commodity. These belts are shown clearly in Figures 5.15 and 5.16. The material flow into the NCF is dependant on gravity only. This is unlike the other SULS gates described in this study, where the cargo is discharged by gravity, but the material is also subject to shear force by the gates. With this feeder the slot / hole moves so the buttresses of arches are undermined and shear forces are lower.

Kamengo Technology Inc. attested that the foremost significant feature of the Non Consolidating Feeder (NCF) is its ability to prevent material from compacting, when discharging dry bulk cargoes. Based on the ‘open-hole’ and ‘moving-hole’ theories with this gate design, not only should consolidation of commodity be avoided, but also in general ‘bridging’ resulting from ‘arching’ and ‘rat-holing’ ought to be eliminated.

Cargo is allowed to gravitate or flow freely from the opened bottom cargo holds, via feeder deck slots, ladder, and tray and onto the conveyor belts that are located beneath the feeders (see Figure 5.16). The feeders are attached directly to the bottom of the cargo holds. During the discharging process, the feeder assembly goes through the following processes:

- The dynamic deck with a numbers of slots are being moved longitudinally back and forth by four hydraulic cylinders providing a continuous and uniform flow of material due to gravity from the entire cargo holds length to the hold conveyors.
- When the feeder moves in one direction, the material flows from the cargo holds through the slots and is stored in section ‘A’ of the tray. At the same time, the material in the opposite section ‘B’ of the tray that has previously being stored is now discharged onto the belts. This process is repeated throughout the discharging, as the deck moves back and forth. Figure 5.16 illustrates this unloading concept of the NCF.

- Volumetric metering of material is carried out at the same time by both 'ladder and tray' arrangements under the slots, and the hydraulic cylinders displacement that is readily controlled from local or remote locations. The volume of material discharged is directly proportional to the hydraulic cylinders speed. These functions of the feeder relevant to the ladder, tray and hydraulic cylinders are imperative to control metering of the product and avoid flooding the conveyor belts.
- With respect to the ladder, this stationary component is located between the deck and tray that are dynamic members of the feeder. The ladder serves two main purposes: firstly the attached 'rubber rungs' are used to scrape and feed material onto the conveyor belts as both the deck and tray moves longitudinally back and forth; and secondly, to act as a seal preventing flooding of material from the cargo holds. Figure 5.17 exhibit a pictorial view of side elevation showing the operational principles of the NCF from the longitudinal standpoint.

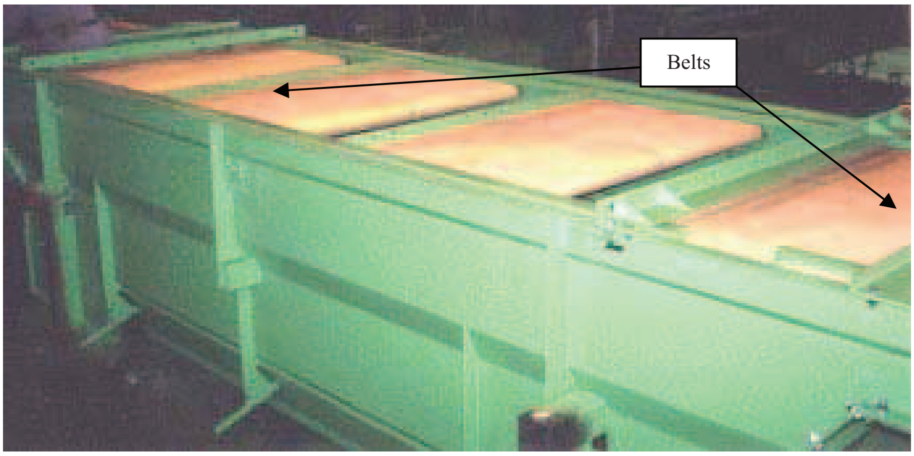


Figure 5.15 Non Consolidating Feeder Assembly (Kamengo Technology, 2005).

The NCF design is such that, 'hogbacks' are excluded from the ship construction, thus reducing the possibility of longitudinal bridging of material. This alteration in shipboard structure benefits the shipowners immensely, primarily in decreasing the ship's lightweight and enhancing cargo lift relevant to both deadweight tonnage and volumetric capacity of the cargo holds. Except for the Non Consolidating Feeder and Control Feeder Gate (CFG), hogbacks are structural components installed in the cargo holds of all other SULS with gravity discharge systems (see hogbacks in Figure 5.14).

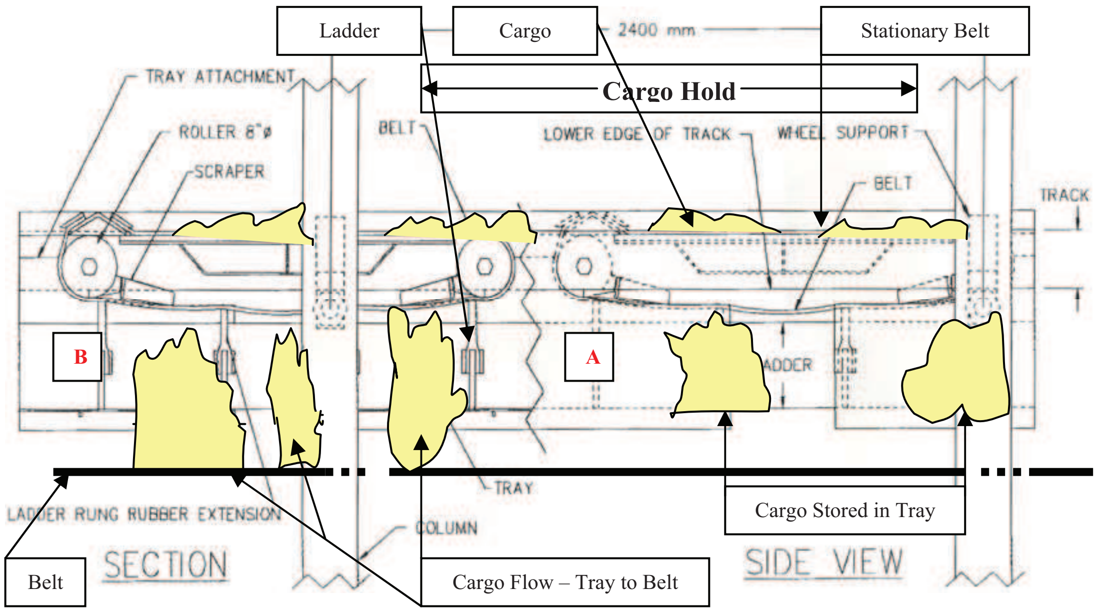


Figure 5.16 Concepts of None Consolidating Feeder Discharging Operations (Welcome and KTI, 1995).

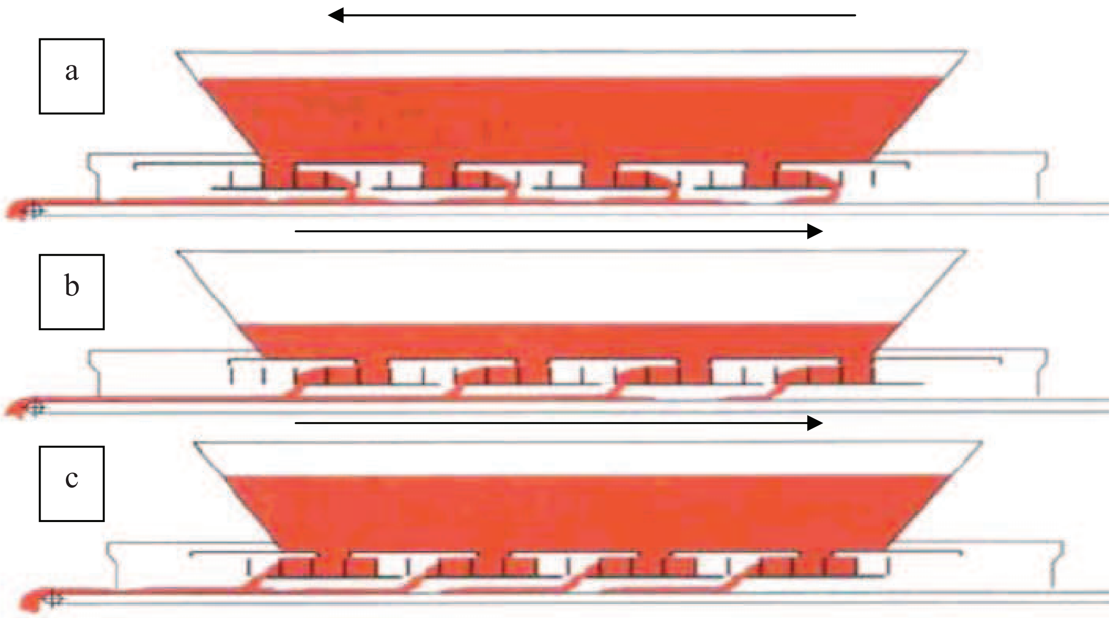


Figure 5.17 Concepts of None Consolidating Feeder Discharging Operations (KTI, 2005).

Fundamentally, hogbacks (in current and perhaps future designs) are necessary structures utilized for separating the gates and in doing so, the ‘hogback’ also provide supporting points for the commodities, which could result in material ‘bridging’, ‘arching’ and ‘rat-holing’. The ‘bridging’ ‘arching’ and ‘rat-holing’ of material occurs especially with those problematic flowing cargoes, such as gypsum, coal, salt, iron ore concentrate, etc.

Kamengo Technology Inc. **(2001)** indicated that in a 1994 report, an engineer from Canada Steamship Lines Inc. evaluated the Non Consolidating Feeder by stating that *'The feeder system is full of potential and must be rated the best innovation in self-unloading techniques since the development of the loop belt'* and went on by saying *'The Moving Hole Feeder enables efficient unloading of bulk cargo ships in less time, without the delays associated with cargo hang-ups; The feeder makes it possible to discharge difficult flowing cargoes such as synthetic gypsum, currently not handled by self-unloader ships because of the inability to achieve gravity flow with conventional gates system; A fully automated system free-up crewmembers for other tasks; and Safety concerns associated with clearing up hang-ups are eliminated…'*.

5.3.5.2 Inherent Issues Linked with the NCF Design

As mentioned by a CSL Engineer, the NCF is a great innovation. However, with most designs there are accompanying natural encumbrances, which the operators encounter throughout the life of the equipment. In this respect, the NCF is no different than any other machine.

The NCF is a construction that is overly robust in comparison to other SULS gravity discharging systems. In spite of this sturdy structure, the ladder components are fragile which frequently resulted in sheared bolts during unloading. Additionally, the NCF installation is best suited onboard SULS that transport dedicated cargo for the following reason. The shipboard staffs encounters difficulty in cleaning the feeder, in order to avoid contamination of commodity when there is a change in cargo to be transported. Apparently, this was the major concern with the prototype feeder in marine installation.

Despite these inherent impediments associated with the feeder, KTI concluded that, both shipowners are satisfied with the outcome from this ingenious new gate design for discharging marine dry bulk cargoes onboard SULS.

5.3.6 Long Slot Centre-split Basket Gate

By the late nineties (1996), EMS Tech Inc. (EMTI) enhanced SACAN's concept of the original Long Slot Basket Gate and revolutionized the Basket Gate design by launching a new 'single cylinder' Long Slot Centre-split Basket Gate (LSCBG). This basket gate design is illustrated in Figure 5.18.

Subsequent to the single cylinder basket gate design, EMTI introduced a similar gate using two operating cylinders. This gate was an enhancement to the company's earlier one cylinder invention (see Figures 5.19 and 5.20). However, the design was somewhat comparable to the original SACAN Basket Gate of 1989 - but not identical.

Fundamentally, the intention of these new gates development by EMTI was to resolve issues linked to both SACAN's Bulk Flow Gate (1974) and Long Slot Basket Gate (1989), and the original Basket Gate of BMH (1986). EMS Tech Inc. **(2005, p.3)** stated that *'The CSL/Consilium Basket Gate introduced in 1986, is a feeder style gate with interesting features. This gate largely relies upon belt speed to regulate the flow of material onto the conveyor belts. This particular gate while good for free flowing cargoes has proven to be inadequate for poor flowing dry bulk materials. The problem stems from the size of the hopper openings and the frequency and size of the hogbacks (i.e. the peaks that separate the hopper openings). Common belt feeder is costly and requires headroom to be fitted, which is an issue with marine installations and unlike industrial applications where only one feeder is required and headroom is not an issue'.*

The development of this 1996 single cylinder LSCBG shown in Figure 5.18 was jointly with EMS Tech Inc. and Algoma Central Marine from St. Catharine's, Ontario. Canada. The invention of this exceptional gate was principally due to John Elder of EMTI. By 2002, the single cylinder gate was installed in 5 ships.

5.3.6.1 Arrangement and Operations of the Long Slot Centre-split Basket Gate

Both the one and two cylinders Basket Gates have merits. Nevertheless, to some extent the single cylinder unit improves the installation in terms of less operational mechanism, maintenance and cost, when compared to the SACAN's Bulk Flow Gate (BFG) design.

Figures 5.10 and 5.18 illustrate pictorial views for comparison of BMH AB Marine Basket Gate and EMS-Tech. Inc. unprecedented Long Slot Centre-split Basket Gate. According to EMTI **(2005)**, the study pertinent to these new LSCBG resulted in the following:

- *'Proven high capacity;*
- *Exceptional flow performance with nominal operating mechanism;*
- *Synchronized;*
- *Centre split type Basket Gate;*
- *Utilizing single or double operating cylinders; and*
- *Designed for discharging dry bulk material onboard gravity type self-unloading bulk carrier ships…'.*

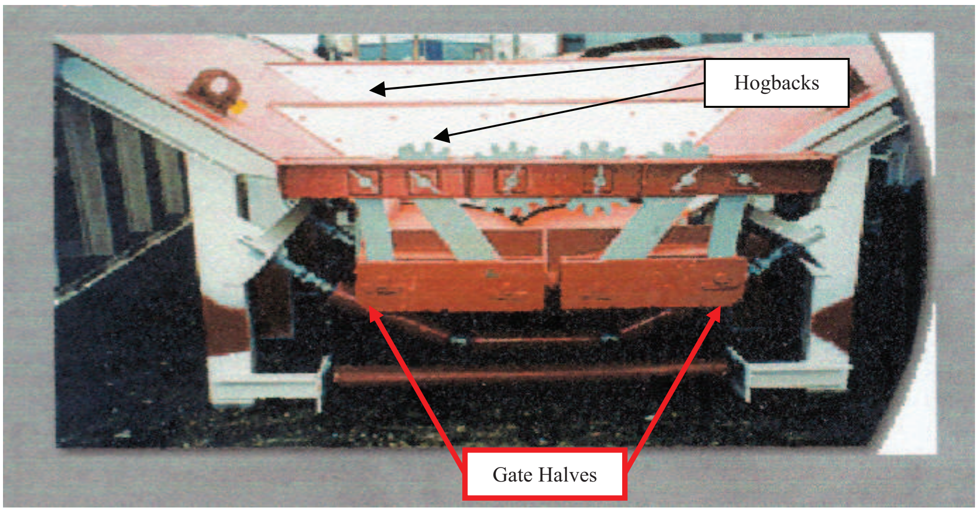


Figure 5.18 Long Slot Centre-split Basket Gate - Single Cylinder (EMS-Tech Inc., 2005).

Despite having additional components on the double cylinders gate, the operation of this gate has proven effective in discharging dry bulk cargoes. EMTI **(2002, p.3)** stated that *'in 1997, the introduction of their patented linkage for synchronizing the opening and* *closing actions of the two gate halves; have improved the functionality of the Long Slot Centre-split Basket Gate. This ingenious innovation is simple, but it replaces the more complex systems which were utilized in earlier designs…'.*

These gates also address and eradicate the skewing issue that is typical with the BFG. However, in order not to overload the hold conveyors when discharging, the operator has to give undivided attention to the gate operations. This is primarily when unloading bulk cargoes such as gypsum, where large masses (i.e. 200-300 mm rocks) and fine materials are incorporated with the cargo.

The LSCBG has an advantage over the BG of BMH, in that the long slot minimizes the possibility of arch formation over the gates and the 'filled load' on top of the gate halves assists in opening the gates (i.e. less filling stress).

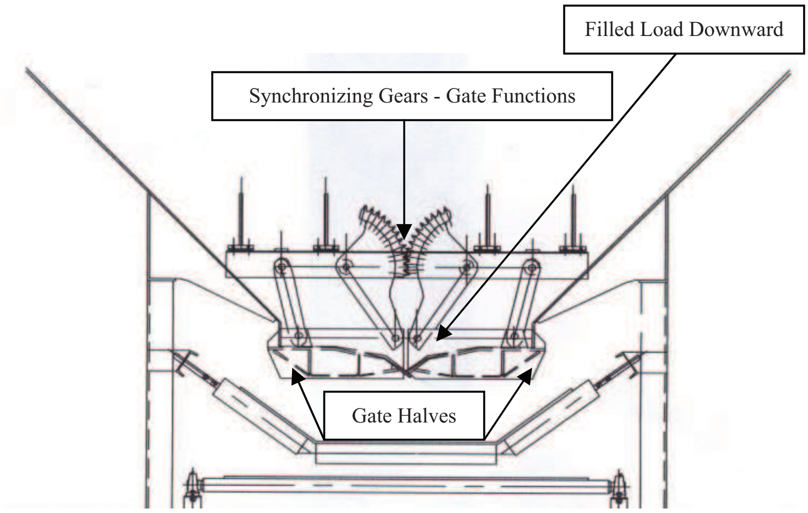


Figure 5.19 Long Slot Centre-split Basket Gate - Double Cylinder (EMS-Tech Inc, 2002).

In Figures 5.19 and 5.20, the end and side elevation views are demonstrated for the double cylinder LSCBG. These drawings, Figures 5.19 and 5.20, also illustrate the principal operating components of this type of gate, namely cylinders, linkages, gears, etc.

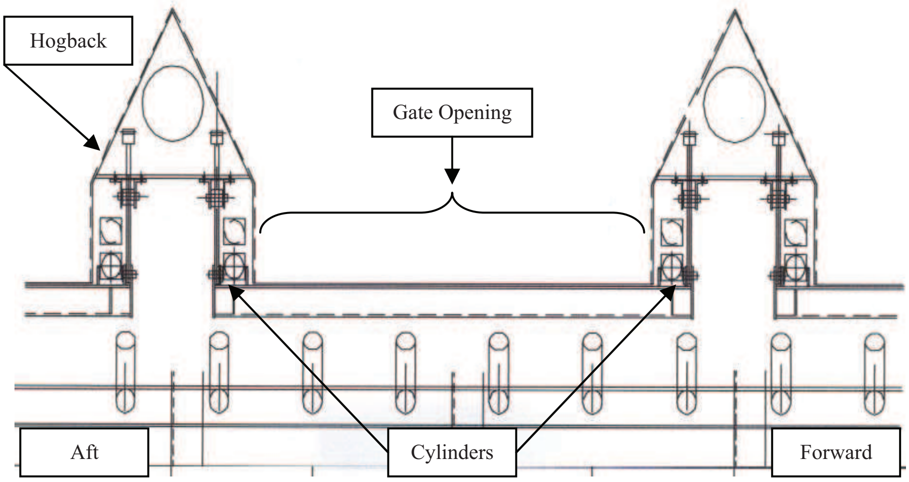


Figure 5.20 Long Slot Centre-split Basket Gate - Double Cylinder (EMS-Tech Inc, 2002).

Elder from EMTI stated **(2002)** that, the LSCBG is looked upon by many individuals within the maritime industry as the best gravity discharge gate on Self-unloader Bulk Carriers' vessel. The LSCBG is regarded by shipowners as an exceptional gravity gate. This is due to the reduction in mechanical components, reliability and discharging capability.

5.3.7 Controlled Feeder Gate

Seabulk Systems Inc. (SBS) designed the Controlled Feeder Gates (CFG). The first and only marine systems of the CFG were built in The Peoples Republic of China and installed in three panamax SULS. This project was managed by the author of this study. Figures 5.21 and 5.22 exhibit the end and side elevations of this revolutionary CFG design which was put into marine service during 1999 for the first time.

According to Gleaves **(1998a)**, *'when Canada Steamship Lines Inc. (CSL) was shopping for a new generation of Self-unloader Bulk Carriers vessel, the company had four basic requirements':*

- *'Reduce up-front cost;*
- *Reduce maintenance cost;*
- *Improve flexibility in cargo handling; and*

- *Environmental protection'.*

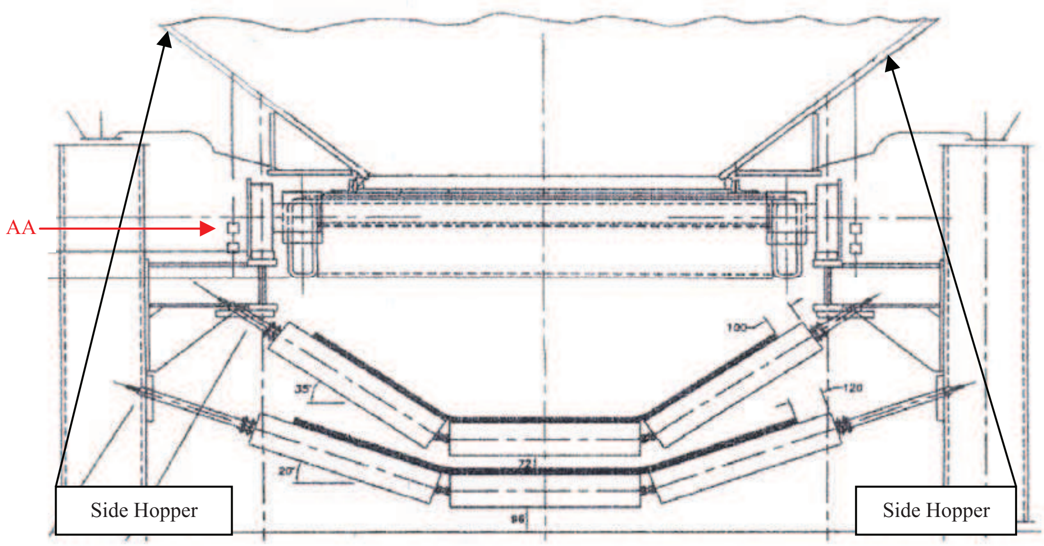


Figure 5.21 End Elevation Sectional View of CFG (SBS, 1999).

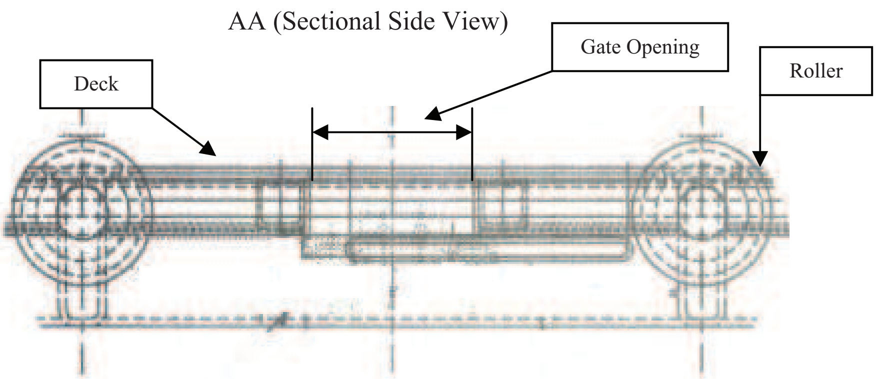


Figure 5.22 Side Sectional View of CFG (SBS, 1999).

Gleaves **(1998b)**, also stated that *'according to CSL International and Seabulk Systems, the company requirements were satisfied with the discovery of an innovative new design...* called the Controlled Feeder Gate (CFG). Without a doubt, the CFG is an exceptional invention in the history of SULS technology and this design has never been installed in any previous gravity type SULS

Based on Gleaves **(1998c)**, '*Seabulk's radical design approach reportedly solves many of the problems plaguing the industry with completely redesigned holds and delivery* *system'*. Gleaves **(1998d)** said that Seabulk Systems confirmed that the development of the CFG was to fundamentally resolve the continual inherent issues with the discharge of numerous dry bulk commodities onboard SULS, such as:

- *'Uneven belt loading;*
- *Clogging of product in hoppers;*
- *Spillage of cargo;*
- *Product loss;*
- *Downtime due to mismatch of ship and shore-based capability; and*
- *Environmental impediments from dust and noise'.*

The principal objective of the CFG invention was to promote and enhance SULS system with minimum downtime and low operating costs.

5.3.7.1 Arrangement and Operations of the Controlled Feeder Gate

Onboard SULS where the complete unloading gate system is equipped with the CFG's, every cargo hold has two units (Port & Starboard) extending throughout the entire length of the cargo holds. In some cases, each unit is 24.4 metres in length. The cargo holds hopper bottom sections are fully opened, allowing cargo to rest on top of the CFG's deck and their gates.

Each CFG has eight slots with controlled gates or closure plates that allow cargo to flow onto the hold conveyor belts when opened. The operator regulates the flow of cargo by adjusting the closure plates opening to achieve the correct discharging rate. This gate controlling function is accomplished from either local or remote locations, through hydraulic cylinders connected to operating linkages.

Depending on flow of the commodity, the desired unloading rate is accomplished by simply opening one or more gates to the required amount, in order to attain the desired rate of discharge, which is principally dependent on the customer receiver facilities or capability.

When the gates are opened and should the cargo flow be interrupted due to hang-up, the CFG has a second feature that can be employed to enhance gravitation of the cargo. This alternative unloading method to improve the discharging of difficult flowing cargoes is done by reciprocating the feeder, approximately two metres. The reciprocation of the feeder is primarily to eliminate cargo 'bridging' while discharging from the closure plates.

Based on research conducted by SBS with respect to cargo flow, if a 'slot' is stationary there is a likelihood of commodity 'arching' and 'rat-holing'. Therefore, this situation causes a no-flow situation. SBS **(1998)** suggest that *'Arching relates to bulk material in the way that the cohesiveness of adjacent particles is sufficient to form an arch; thereby, causing the flow of material to stop. Rat-holing is another related problem but the difference is that the cohesiveness of particles holds the material together to the sides of the slot, allowing only material from above the slot to be discharged from the open slot…'.*

When 'arching' and 'rat-holing' are encountered with dry bulk material, the commodity will cease to flow due to hang-up and freeing the hang-up could possibly be overcome by applying external forces to the hoppers structure, such as the installation of mechanical vibrators (operated electrically, hydraulically or pneumatically) or by sledge hammering the hoppers manually which is an arduous and dangerous task.

Both 'arching' and 'rat-holing' are fundamentally caused by the cargo slots size being too small and could be corrected by increasing the gate opening, which could potentially overload the conveyors. Therefore, flooding or plugging the system and resulting in cargo spillage into the unloading tunnel.

In practice, 'arching' and 'rat-holing' are limited to some extent by experienced operators onboard SULS with the RTG and BFG. This arduous task is accomplished by continuously and rapidly moving the gates to the open and close positions. Thereby, increasing the slot size and breaking the arch while exercising great care not to overload the conveyor belts. According to Hossfeld, R. J., Barnum, R. A. and Jenike and

Johanson Inc. **(2007)** *'two of the most common flow problems with dry bulk material experienced in bunker, silo or bin are no-flow and erratic flow, due to either arching or rat-holing…'.* These phenomena are also known facts that are applicable to the gravity discharging type SULS, where cargo hang-up in cargo hold results from 'arching' and 'rat-holing'. Figure 5.23 demonstrates the concept of 'arching' and 'rat-holing' in dry bulk material.

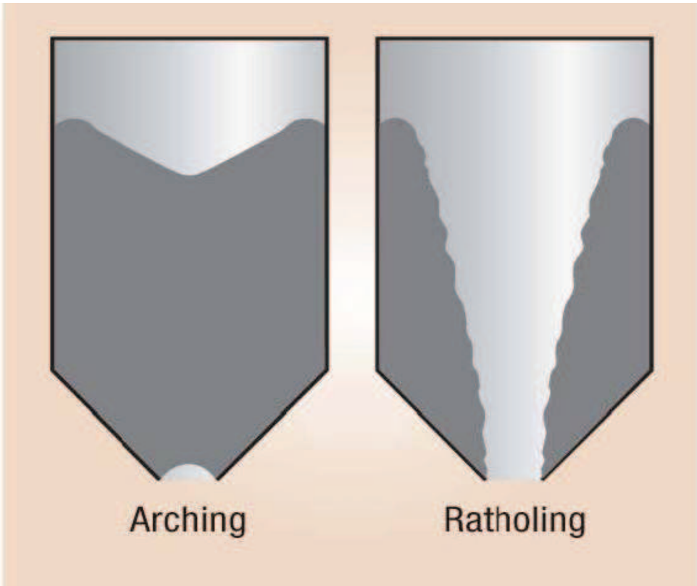


Figure 5.23 Arching and Rat-holing Concept for Dry Bulk Material (Jenike & Johanson Inc 2007).

With regard to the CFG design, the deck comprising a numbers of adjustable slots that reciprocates horizontally and longitudinally back and forth under the cargo. This action obviously creates an increase of slot size, which causes instability of the arches. As a result, conceptually the arches should collapse and this is the basis for continuous flowing of the cargo. Figure 5.24 (a, b and c) shows the process of arch formation with dry bulk materials and how the cargo hang-up is resolved and flow of material resumed.

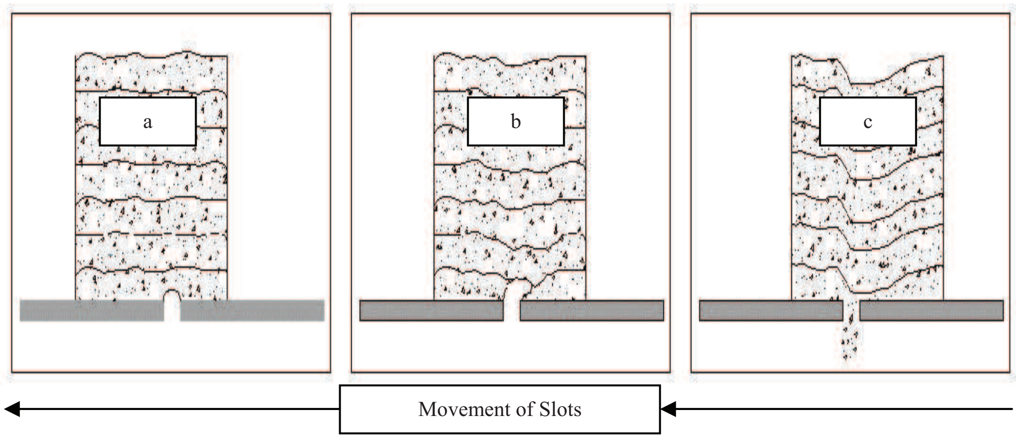


Figure 5.24 Arching Concept for Dry Bulk Material (SBS, 1996).

Figure 5.24a shows:

- An arch is formed over the slot with a right and left leg on the slot edges.

Figure 5.24b shows:

- The slot moves 'one slot width' to the left. This results in an arch on the right side of the opening;
- The original left leg has buckled and some material flows through the slot, making a bigger arch of two slot widths; and
- New legs are formed at the edges of the slot.

Figure 5.24c shows:

- As the slot continues moving to left, the arch cannot support itself and collapses. Thereby, causing material to flow. This arching sequence occurs numerous times while discharging cargo.

Another positive important feature with the CFG design is the absence of 'hogbacks' that undoubtedly assist the undesirable longitudinal bridging of cargo.

5.3.7.2 Inherent Disadvantages of the CFG Design

Despite the CFG is an exceptional innovation relevant to Self-unloading Bulk Carriers' technology and the fact that numerous concerns in previous designs have been addressed and successfully corrected. However there are still issues with the operation of the CFG that need addressing and that should be considered in the design of any future self-unloading system. These inherent disadvantages of the CFG design are:

- There is one fundamental obstacle experienced with the CFG during the first and subsequent marine installations. The entire construction for most cargo holds are approximately 24.4 metres long (i.e. rectangular box-shape structure), which resulted in deformation primarily because of its length. After assembling the CFG onboard the vessels, the distortion was clearly visible and certain traction rollers were not resting on the parallel tracks that are used as a base for reciprocating the CFG.
- Due to the deformed CFGs' structure, only after loading the vessels (i.e. placing cargo in the cargo holds) does the complete set of traction rollers come into contact with the longitudinal parallel tracks.
- After arriving at the unloading ports with a loaded vessel, occasionally it was noticed that the CFG could not reciprocate, because of insufficient hydraulic power exerted by the operating cylinders. Stroking of the feeders longitudinally is one of the main design features, to resolve arching by moving the slots. As a consequence, the gates had to be opened occasionally by manual assist (i.e. chain blocks) to discharge some cargo. This unloading method was necessary, in order to relieve the cargo "fill load" on top of the feeders, caused from material that was compacted while the vessel was at sea. Once the "fill load" was reduced, sometimes the hydraulic reciprocating cylinders were able to move the CFG.
- In other cases when a particular CFG assembly could not be moved longitudinally, the cargo load on top of the two adjacent cargo hold CFG had to be alleviated, by opening the gates and discharging a percentage of cargo. For example, if stroking of No.3 cargo hold CFG could not be achieved, some cargo would be discharged from the No.2 and No.4 holds. Subsequently, the cylinders from the No.2 and No.4 holds were linked together in series with No.3 by utilizing wire cables, in order to achieve the required hydraulic power necessary for reciprocating movement of No.3 CFG. Clearly, the exercise of connecting 3 CFG together to amplify the hydraulic power, demonstrated that occasionally the intended design characteristics of the CFG

could not effectively be accomplished, while discharging cargo and reciprocating the deck with closure plates opened.

- During the final discharging stage onboard previous SULS. It was common practice while the conveyors are in motion for shipboard staff to enter the cargo holds and shovel the remaining cargo onto the belts (i.e. known as clean-up). For safety reasons, this 'cargo clean-up' practice has created serious concern within the organisations of SULS shipowners. Therefore, one original intention of the CFG invention was to ensure that the cargo is discharged in full. Thereby, requiring no shipboard staff to enter the cargo holds while unloading. The issue of personnel entering the cargo compartments to manually assist with the final discharging of cargo was not fully addressed in the CFG design. After all possible cargo is discharged by the CFG, there is still material that invariably remains on top of the decks between the slots. This commodity has to be removed physically by the ship's crew entering the cargo holds. Figures 5.25 and 5.26 illustrate a typical example of surplus cargo remaining on top of the CFG after discharging all possible cargo with the unloading equipment.
- The issue of additional cargo remaining on top the CFG surfaces between the slots opening was discovered during the construction stage, when the first cargo test was performed. The designers did not address this evident issue of residual cargo on top the CFG decks after the main discharge. However, to improve the situation of left-over cargo on top the CFG decks, the owners added steel scrapers which were directly bolted to the cargo holds side hoppers above the CFG surfaces. The intention was that the stationary scrapers would scrape the surplus cargo into the slots and onto the conveyors, by simply moving the CFG's longitudinally. Figure 5.27 exhibits an example of this modification introduced by the on-site newbuilding representatives of the shipowners.

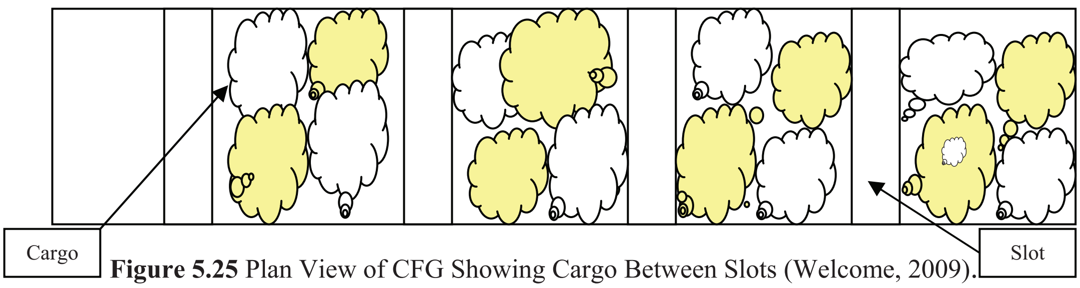


Figure 5.25 Plan View of CFG Showing Cargo Between Slots (Welcome, 2009).

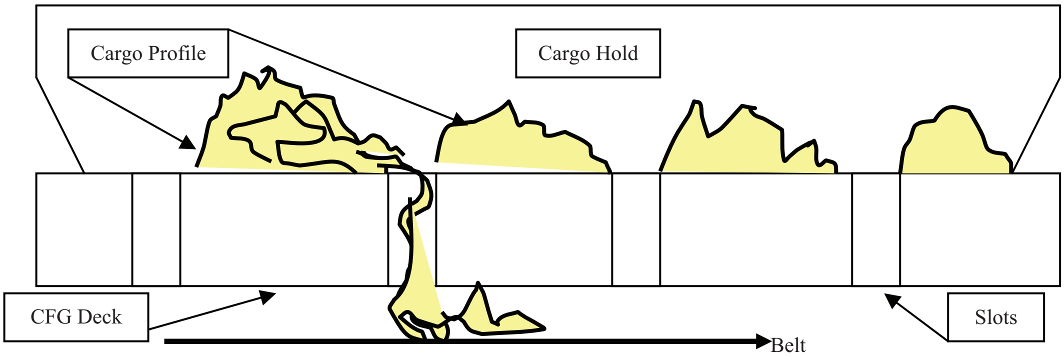


Figure 5.26 Side Elevation of CFG Showing Cargo between Slots (Welcome, 2009).

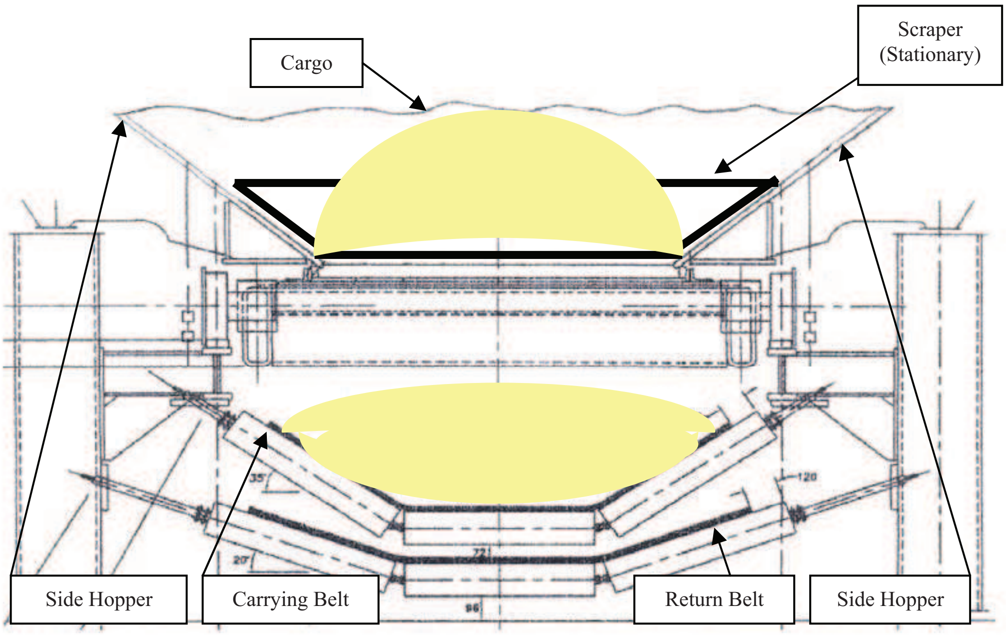


Figure 5.27 Demonstration of Steel Scraper on CFG – Section View (Welcome and SBS, 1999).

Having scrapers bolted to the side hopper plates, was a constructive notion of the shipowners, primarily for prevent personnel from entering the cargo holds and secondly for removing excess cargo from top of the CFG's. Unfortunately, according to the designer, scrapers attached to side hoppers on top the CFG would interfere with the cargo flow regime.

After the ships were in service, it was confirmed by the shipboard operators that, once the CFG reciprocated, some scrapers became detached due to the dynamic force exerted by the moving feeder and compacted cargo. Finally, the scrapers were removed to avoid damaging the conveyor belts in the event that broken steel pieces became trapped in the system.

SBS **(2005)** stated that, to date there are only three marine installations with the CFG, which were installed onboard panamax Self-unloader Bulk Carriers built in The Peoples Republic of China. This newbuilding project was managed by the author.

5.3.8 Long Slot Gate Feeder

The most recent development of basket gate was the Long Slot Gate Feeder (LSGF) in 2002 by EMTI. This gate was an extension or development of the company's Long Slot Centre-split Basket Gate design **(1996).** According to EMTI **(2005)**, the expansion of the LSGF stems from various perspectives and the principal one being the company's internal policy that '*encourages their people to think differently and allowing the liberty of looking at a problem from a new perspective and cost-effective way…'*

Figures 5.28 and 5.29, shows this innovative LSGF that opens transversally instead of longitudinally like the originally designed BG of BMH Marine AB.

In 2004, the first SULS was equipped with the LSGF and by 2006 according to EMTI; this feeder was installed in nine vessels. Currently, the LSGF dominates the market for both newbuildings and conversions. Nevertheless, EMTI **(2002)** stated that the modified or suspended Roller Track Gate remains highly favourable and competitive for some shipowners.

5.3.8.1 Arrangement and Operations of the Long Slot Gate Feeder

From Figures 5.28 and 5.29, it certainly appears that during the designing stage of this recent LSGF, an effort was made to address the cargo spillage issues experienced with the Bulk Flow Gate (BFG). Both halves of this gate are slanted downward towards the belt. Thereby, promoting a smoother flow of cargo onto the conveyors with minimum spillage and dust pollution, when compared to the Bulk Flow Gate that slides horizontally flat (see Figures 5.7 and 5.8) and is some distance above the belt.

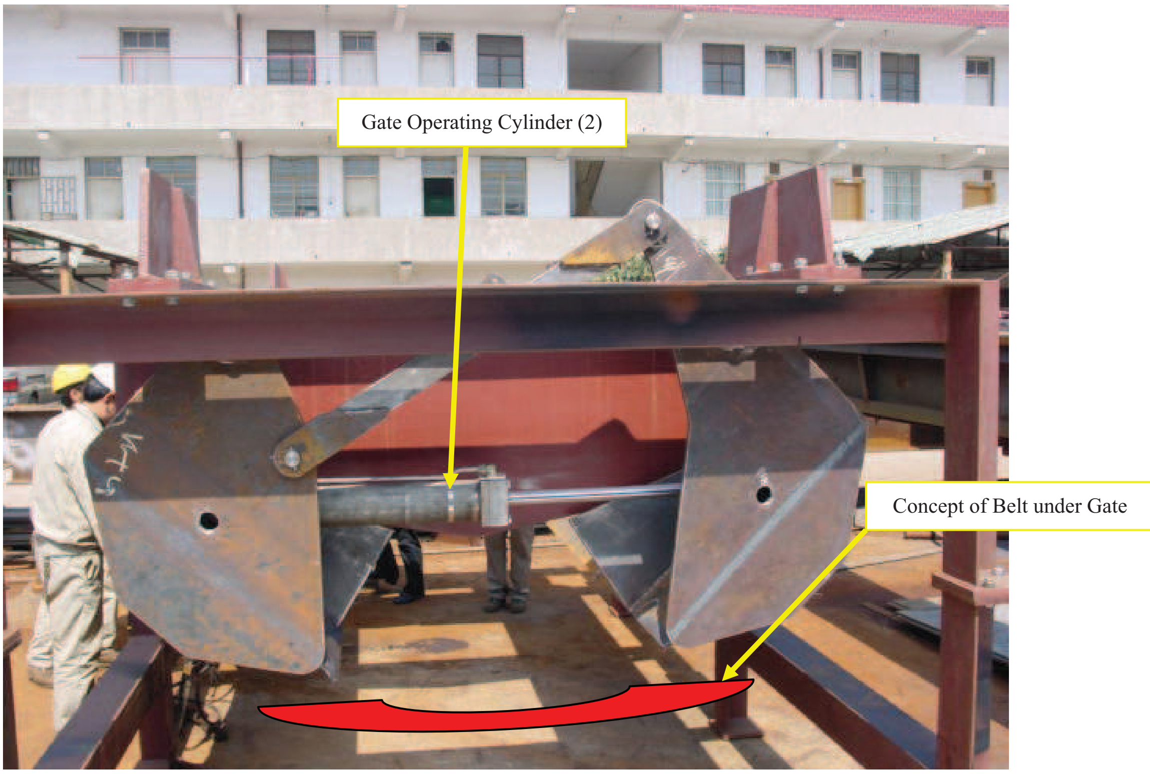


Figure 5.28 Gate Feeder Opened Position – Elevation (EMS Tech. Inc, 2005).

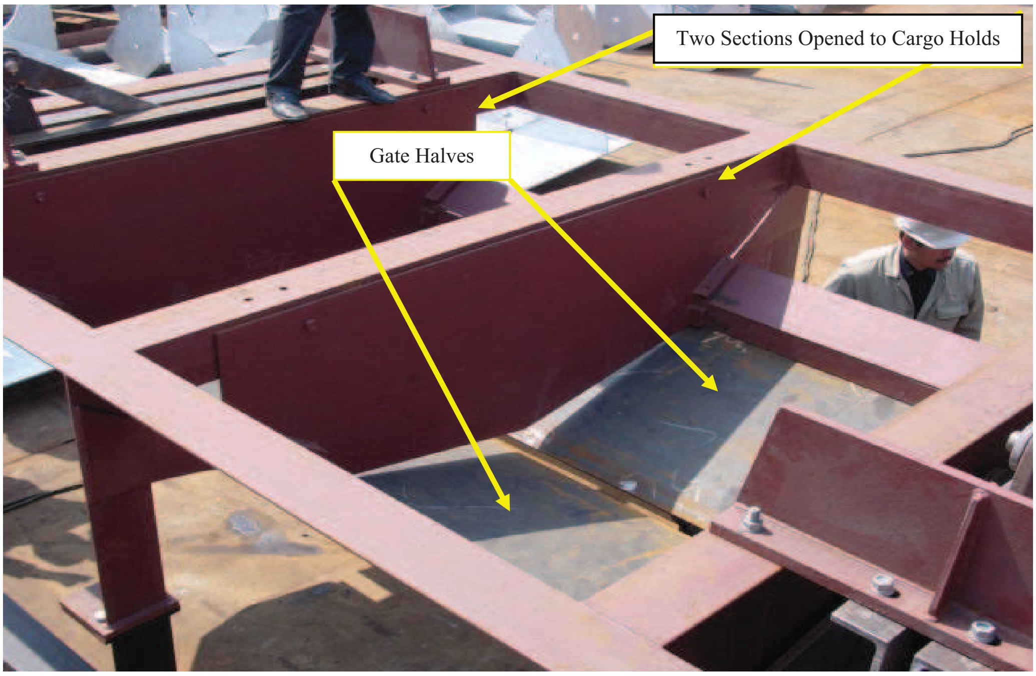


Figure 5.29 New Developments in Basket Gate–Closed Position (EMS Tech. Inc, 2005).

When analysing this Long Slot Gate Feeder (LSGF) versus both the Bulk Flow Gate (BFG) of SACAN and original Basket Gate (BG) of BMH, there are certain advantages with the LSGF to be considered, namely:

- The LSGF only requires two operating cylinders for its functionality that are easily accessible for maintenance from the unloading tunnel, whereas the original BFG's have four operating cylinders. Figure 5.28 illustrate this gate in the opened position.
- The LSGF aperture dimension varies in size from the full closed (i.e. 0 mm) to full opened (i.e. 430 mm) positions. This opening is suitable for discharging mass cargo flow similar to the BFG. These combinations relevant to the gate opening size is optimum for unloading commodities, which have incorporated small and large masses exceeding 200 mm in size, but less than 430 mm. This situation of mixed size material is commonly encountered when discharging cargo such as gypsum.
- With the LSGF installation, more than one gate can be opened simultaneously for improving the cargo discharge rates. This condition is comparable to the BFG. However, different from the original BG where for effective discharge rate, only one gate/conveyor can be opened at a time.
- The LSGF can be fabricated in modules, assembled remotely in a workshop and later lifted onboard for installation as a unit. This construction technique is similar to the BG, but unlike the BFG.
- The LSGF relies on belt speed to regulate the flow rate of material from the cargo holds to the conveyor belts. With the gate in the normal operating open position, the belt can be stopped and restarted if and when desired, at anytime. This condition is similar to the first design BG, but unlike the BFG.
- According to EMTI **(2006)**, reports from the vessel owners having installed the LSGF concluded that the discharging performance is remarkable in avoiding bridging and arching of material, which is primarily due to the taper interface of the longitudinal slot (see Figure 5.30).

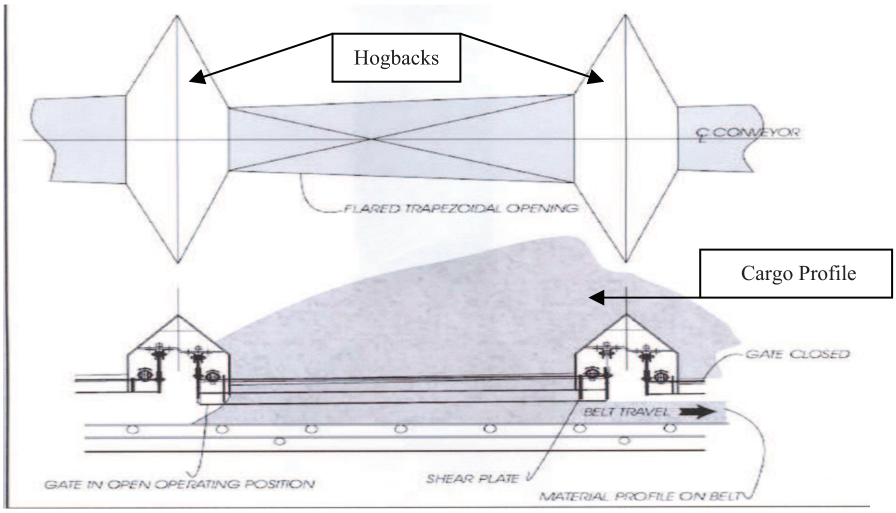


Figure 5.30 Gate Feeder Characteristic (EMS-Tech. Inc, 2005).

The construction arrangement of this exceptional gate is gradually elevated from aft to forward and likewise the opening size increases in width from the rear to front. These attributes are defined in Figure 5.30. According to EMS Tech Inc. **(2005, p.6)** the designers *'This gate configuration is both purposeful and desirable and follows the general design principles of the common belt feeder; while at the same time works within the standard parameters of ships and simple hoppers construction. This feature enhances material flow by ensuring some material feed along the entire length of the gate …'*.

EMS Tech Inc. concept of designing the LSGF with taper interface for improving discharging performance is further supported by Hossfeld, R. J., Barnum, R. A. and Jenike and Johanson Inc. **(2007)** who stated that *'an essential aspect of using a slotted outlet is to ensure the feeder capacity increases in the direction of flow. When using a belt feeder, this increase in capacity is achieved by using a tapered interface. The increasing capacity along the length is achieved by the increase in height and width of the interface above the belt'*. Figure 5.31 illustrates the concept of a mass flow belt feeder interface.

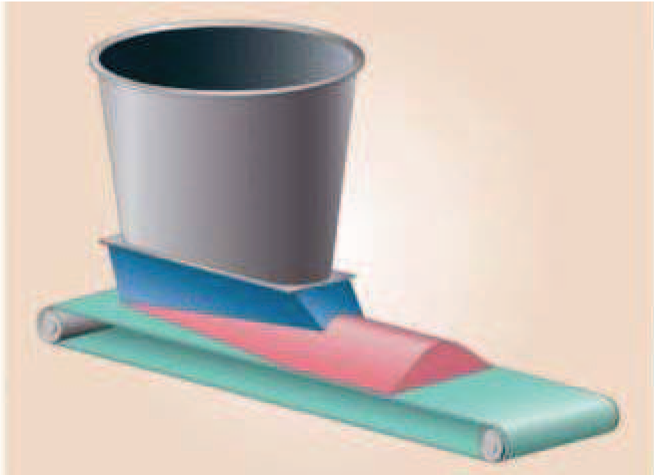


Figure 5.31 Mass Flow Belt Feeder Interface (Jenike and Johanson Inc. 2007)

Regarding the gate function, the operating cylinders are designed with dual opposed rods that perform the following tasks:

- For normal discharging, one cylinder rod is extended and the second unit / rod are utilized during clean-up (i.e. full opened gate upon completion of unloading). This unconventional gate opening is achieved by installing cylinders and linkages of different stroke and size, at the after and forward ends of the gates; and
- There are after and forward shear plates that drop downward, when the gate opens to its normal operating position. These plates are for controlling the cross section or top profile of the cargo. This condition also minimises flooding of the belts, despite the fact that the feeder gates can be opened fully and causing no spillage of material – the belt speed adjusts the unloading rate.

In summary, based on the above noted descriptions, the Long Slot Gate Feeder is an enhanced gate with a variety of additional positive operating characteristics, when compared to other type of gates currently employed onboard gravity discharging SULS. This design of gate also has some constructive features from both the Bulk Flow Gate and original Basket Gate.

5.4 Summary

In this Chapter, eight cargo gates of the gravity discharging types for Self-unloader Bulk Carriers' (SULS) have been investigated and discussed in detailed. Each gate has operational advantages as well as inherent disadvantages. However, the gates are all unique in design and their performances in discharging marine dry bulk cargoes have been remarkable.

Following the inception of SULS technology, the operational issues encountered with cargo gates have been primarily due to mechanical reasons and poorly flowing cargo, resulting from 'bridging', 'arching and 'rat-holing'. These terms relevant to material behaviour on SULS are explained. Endeavours to correct hang-up by developing different gate designs have been addressed. However, cargo flow remains a concern onboard SULS and frequently the need of manual intervention (i.e. use of mechanical vibrators and hammering of hopper) is necessary due to intermittent flow of materials with existing gates.

Problematic flowing cargoes with the pioneer Roller Track Gate led to the developments of various gates, namely: two designs of Roller Track, Bulk Flow; Basket, two versions of Long Slots; Non Consolidating Feeder and Controlled Feeder Gates. The inventions of these gates starting from 1908 until 1999 were primarily to address ongoing issues with both material flow and functionality of the gates while discharging. Recently **(2002)**, the Long Slot Gate Feeder (LSGF) was introduced principally to correct the shortfalls with previously designed gates, relative to both cargo hang-up and uneven gate opening. Reports from the industry concluded, that the LSGF performance is outstanding and that this feeder is the most desirable gravity gate by SULS shipowners. However, the Roller Track Gate still remains a popular contender.

The author was the Project Manager for installing the first marine prototypes NCF and CFG. Due to this experience, many operational impediments with gravity gates for SULS have been revealed while examining the gates in this Chapter. Additionally, the author's working knowledge with seven of the eight gates presented in this Chapter allowed for further scrutiny into the operations of gravity gates for SULS. This led the author into designing a new enhanced gravity cargo gate for SULS with the intention of correcting issues encountered with the operations of current gates. The design, control system and operations of this new gate are addressed in Chapters 6 and 7.

In summary, this Chapter fundamentally, describes the histories, arrangements, operations and discharging problems with gravity cargo gates installed onboard Self-unloader Bulk Carriers.

Chapter 6

6. THE DETAILED DESIGN AND EVALUATION OF THE PROPOSED MULTI-FUNCTIONAL ROLLER TRACK GATE AND THE INTEGRATED TUNNEL CONVEYORS

6.1 Introduction

In the previous Chapter the fundamental problems still experienced in the operations of gravity gates onboard Self-discharging vessels (SULS) have been identified, in order to provide the insight necessary to propose a new enhanced roller track gate. The new gate is designed to provide operational advantages that mitigate the issues previously described for existing gates. This entirely original gate design has been designated the 'Multi-functional Roller Track Cargo Gate' or MRG. This Chapter describes the methodology; rationale behind the design; the operating principles and functionality of the MRG.

This Chapter also outlines the design of a new Multi-functional Roller Track Gate and provides comparison of the perceived benefits of the design with existing Roller Track Gates (RTG). The advantages and disadvantages are described to establish the MRG limitations in terms of its design and operating principles. The application of the MRG is discussed in Appendix VI.1 and comparisons are highlighted when using this gate for shipboard and fixed industrial installations. Numerical, graphical and pictorial models of the MRG discharging operations are also presented in Appendix VI.1, primarily to establish the theoretical mass flow rate from each gate at various opening positions.

The MRG is exclusively designed for installation in SULS of the Model ‘B’ type. However, by adjusting the dimensions, this gate can be used for larger vessels (i.e. panamax, aframax and capsize). In this application each tunnel/hold conveyor is designed for discharging 2,220 tonnes of coal per hour (tonnes/h), which is a two belt arrangement, similar to the Model ‘B’ defined previously and provides a total output of 4,440 tonnes/h. The design of the cargo gates operating cylinders is also considered and they are designed with sufficient reserve force to ensure opening of the gates in difficult loading conditions (see Appendix VI.8).

In addition to the physical conceptual model gate constructed, another tenth scale iconic test model was manufactured for conducting experiments on the effectiveness of the gate with respect to the design concept and cargo flow. This experimental model was used to investigate different gate operational modes whilst discharging four typical commodities. The commodities selected were coal, oats, soya and corn, which reflect cargoes that are currently being transported by SULS. These experiments were to establish the integrity of the MRG design concept and not as a means of formally measuring the discharging rate. The MRG has strengths and some potential weakness; these design risks are underlined and explained.

The MRG design proposed is the first known RTG with two gates and this system employs the moving-hole principle, which is ideal for discharging cohesive cargoes. Consistent with current industry practice, prior to installing the MRG in SULS, it would be advisable to manufacture a full-scale prototype gate to fully confirm the design functionalities. The experimental model described in this Chapter can be considered as an initial step in this full experimental verification and validation of the proposed gate. It is hoped that the new design will be adopted commercially, which would provide the investment required to build a full-scale prototype gate that could possibly lead to installation of a complete unloading system of this type gate in SULS.

6.2 The Design Process Steps of the MRG

The author of this study has considerable experience in managing SULS from the shipboard and shore-based standpoints. Nevertheless, the design methodology of the Multi-functional Roller Track Gate (MRG) was affected in systematic steps consistent with good engineering design practice. This was to ensure that all tasks of the design process were carried out in a methodical manner, while carefully considering the technical and economic viability of the project. The design processes that led to developing the MRG were fundamentally based on actual unloading / hands-on experience by the author **(1984 to 1995)** while discharging SULS with the existing Roller Track and Bulk Flow Gates. *'With these gates, to enhance cargo flow while having hanging-up cargoes such as, coal, iron ore concentrate, gypsum and salt; it was imperative to continuously open and close the gate manually to demolish the arch formations. This gate function clearly substantiated that the notion of 'moving-hole' would promote and maintain constant flow of cargo and this would reduce the possibility of material bridging from 'arching' and 'rat-holing'*. This was my inspiration for developing a roller track gate called the Multi-functional Roller Track Gate and incorporating two gates in one assembly with multiple discharging operations. The MRG was designed solely by the author. However, during the designing stage, some approaches of Pahl and Beitz **(1988)** were adopted that are relevant to standard engineering design. According to Pahl and Beitz **(1988, p.40)**, these are *'the flow of work during the design process and the main phases involved'*:

- *'Clarification of the task;*
- *Conceptual design;*
- *Embodiment design; and*
- *Detail design'*

The flowchart in Figure 6.1 illustrates the steps of the designing process implemented for developing the MRG.

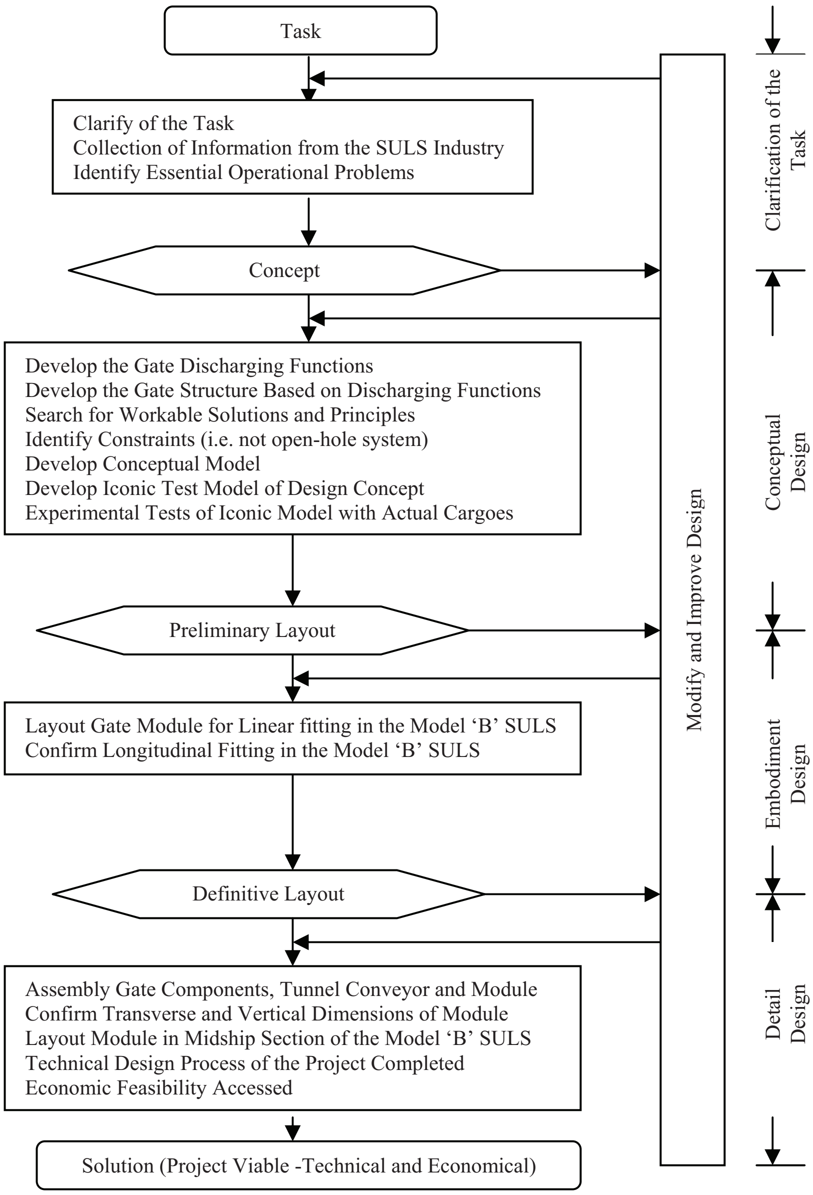


Figure 6.1 Steps of the Design Process for the MRG. Welcome, H. (2008) Reference: Pahl and Beitz (1988).

6.2.1 Clarification of the Task

The clarification phase of the Multi-functional Roller Track Gate (MRG) design is relevant to the collection of operational information experienced by shipowners and the author, while managing SULS with the gravity type cargo gates. The collection of data also revealed both the operational advantages as well as disadvantages, when discharging with the current gravity gates onboard SULS. Some major problems indentified with previous gravity gates, resulted in the requirements to be embodied in the MRG design. Chapter 5 of this study describes the shortcomings with existing gravity gates for SULS. Therefore, Chapter 5 is considered the 'clarification of the task', the issues that require correcting with existing gates and incorporating into the MRG design.

6.2.2 Conceptual Design

With this phase, the foremost criterion is of a technical nature. However, occasionally the economic criterion plays a vital role during this phase and based on evaluation, the best solution concept can be selected. The conceptual design of the MRG was based on having seven different ways to discharge cargo, which resulted in four operational modes with an additional three redundancies.

During this theoretical stage, a conceptual model was designed, primarily for verification of the discharging modes and redundancies. In addition to the conceptual model, an iconic test model of the design was also developed. Fundamentally, this iconic test model was developed to carry out experimental discharging operations with actual commodities transported by SULS. During these tests, the capacity of material discharged was recorded. However, the discharged capacities were primarily to establish the reliability of the design concept and not the actual quantity of commodity discharged by the gate.

The open-hole' discharging system is not incorporated with the MRG design. This resulted in an operational constraint with this type of gate. Nevertheless, the 'moving-hole' principle is included with the MRG design to prevent the possibility of material bridging from arch formation. The conceptual design for discharging with the MRG primary, secondary, both gates and automatic modes are shown in Appendices VI.2a, VI.2b, VI.2c, VI.3a, VI.3b and VI.3c. The control systems for discharging in these modes are illustrated in Figures 7.1 and Appendix VII.1.

6.2.3 Embodiment Design

Upon completion of the conceptual designs and addressing the seven discharging operations mentioned in section 6.2.2, the 'embodiment design' was carried out focusing on developing a module comprising two gates assembly (see Appendix VI.4). This design concept was primarily to ensure simultaneous discharging with two gates in the automatic mode; while one gate is retracting and at the same time the other gate is extending.

This arrangement of the gates was necessary due to limitation of space on the module and also to avoid mechanical interference of the two cylinders for the secondary gates. The layout of the gate module was crucial to guarantee that the two gates would occupy a longitudinal dimension of not more than 6300 mm. Therefore, allowing for the installation of fifty-six modules (28 ports and 28 starboards) in the model 'B' type SULS. Appendix VI.4 demonstrates the design principle of the gate module in plan and elevation views.

6.2.4 Detail Design

The 'embodiment design' confirmed the 'longitudinal dimensions' of the MRG. The 'detail design' stage of the MRG was relevant to assembling all components of the gate and tunnel conveyor, in order to verify the dimensions of the gate module in both transverse and vertical directions. This was primarily to ensure installation of this gate in a midship section similar to the Model 'B' type SULS. The flowchart in Figure 6.1 illustrates the steps of the designing process implemented for developing the MRG.

Appendix VI.4c shows the entire MRG and tunnel conveyor in the transverse direction. Figure 6.10 illustrate the MRG installed in a midship section of the Model 'B' type SULS. At this stage of the designing process, the technical aspects of the MRG were finalized and a detailed examination of the design i.e. drawings and models substantiated that the MRG project was technically viable. The completion of the detailed design phase would incorporate all production information for the fabrication of the full size gate and associated systems. However, the project required further analyzing for verification of economic feasibility.

The economic evaluation of the Multi-functional Roller Track Gate (MRG) design was examined in Chapter 8. The economic case study in Chapter 8 confirmed that shipowners would benefit economically from reduced operating costs and port turnaround time; when converting the existing Roller Track Gate to the Multi-functional Roller Track Gate onboard SULS of the Model ‘B’ types.

6.3 The Design Rationale of the MRG

The existing designs of Roller Track Gate (RTG) are constructed with one gate having both remote and or local unloading operations. These previous designs of RTG discharged cargoes effectively. However, there are limitations with the existing RTG when discharging cohesive dry bulk material; this is due to these gates not having incorporated the moving-hole principle. This operational limitation with the existing RTG, issues described in Chapter 5 with other gravity gates and the author’s 17 years experience with SULS; were the basis for developing this new gravity gate called the Multi-functional Roller Track Gate (MRG). The intention of the MRG is to automatically discharge dry bulk material by principally addressing the ongoing concerns of material ‘bridging’ from ‘arching’ and ‘rat-holing’, when discharging cohesive dry bulk cargoes. This new roller track gate has two gates and allows for seven discharging ways, comprising four modes and three redundancies.

Table 6.1 Modes and Redundancies for Discharging Operations with the MRG.

Discharging Modes and Redundancies	Gate Operations
Modes (4):	
Primary Gate Remote Manual Unloading Mode;	Remote Electro-hydraulic Controls - CCR
Secondary Gate Remote Manual Unloading Mode	Remote Electro-hydraulic Controls - CCR
Local Manual Unloading and Maintenance Mode	Manual Hydraulic Controls - Tunnel
Automatic Combination Unloading Mode – Principal Discharging Operation	Auto Electro-hydraulic Function of Primary Gate and Reciprocation of Gate Assembly - CCR
Redundancies (3):	
Primary Gate Local Manual Unloading	Manual Electro-hydraulic Push Button - Tunnel
Secondary Gate Local Manual Unloading	Manual Electro-hydraulic Push Button - Tunnel
Simultaneous Discharging with Primary & Secondary Gates	Manual Electro-hydraulic Push Button - Tunnel & CCR

Table 6.1 illustrates the discharging modes and redundancies of the MRG. These discharging modes of the MRG design offer advantages which are unlikely to be seen with the existing RTG, when unloading with the 'Primary Gate or Secondary Remote Modes'. These discharging functions allow for standalone operations with either the primary or the secondary gate, while discharging remotely from the cargo control room. For better understanding of this concept, Appendices VI.2a and VI.2b illustrate the primary and secondary gates discharging cargo independently. Figure 7.1 and Appendix VII.1, shows the control systems for discharging operations with the primary and secondary gate in the standalone condition.

The 'Local Manual Unloading and Maintenance Mode' is use primarily when it becomes necessary to maintain the cargo gates. However, this mode can also be utilized for discharging in an event of the remote controls failure. Appendix VII.1 demonstrates the control system for the local manual unloading and maintenance mode.

The 'Automatic Combination Unloading Mode' is the principal discharging operations of the MRG. Fundamentally, this mode addresses the 'moving-hole' principle that enhances the discharging of the MRG, when compared to the RTG. Appendix VI.3 illustrates the concept of discharging in the automatic mode and Figure 7.1 shows the control system for unloading in this mode.

With regard to the 'Primary and Secondary Gate Redundancies', the discharging operation is accomplished by manually energizing push button solenoids that directs hydraulic oil to the cylinders, which operates the gates. These redundancies are used primarily when there is a failure with the hydraulic controls. Appendix VII.1 shows the control system with solenoids for manual operations of the gates in emergency.

A third redundancy called 'Simultaneous Discharging with the Primary and Secondary Gates' is applicable to the MRG cargo unloading operations. This redundancy allows for discharging at the same time with both the primary and secondary gates from either the remote or local positions. This discharging operation is exhibited in Appendix VI.2c. Figures 6.2, 6.3 and 6.4 show the MRG in the plan and elevation views.

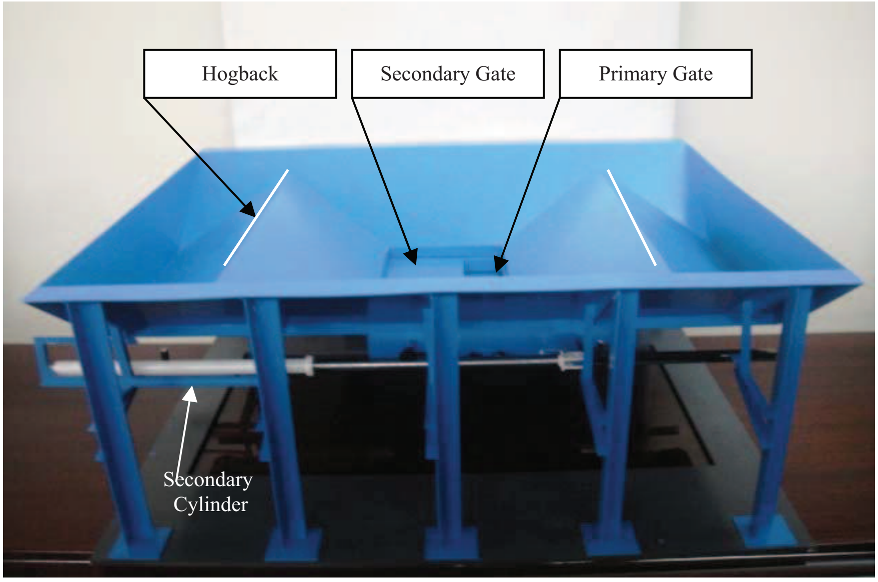


Figure 6.2 Pictorial View of the MRG – Side Elevation.

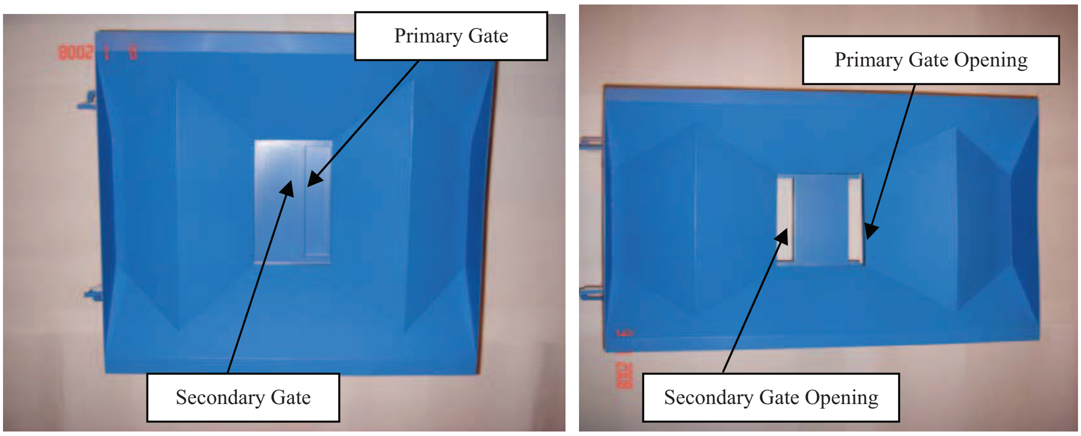


Figure 6.3 View of Primary and Secondary Gates in Opened and Closed Positions.

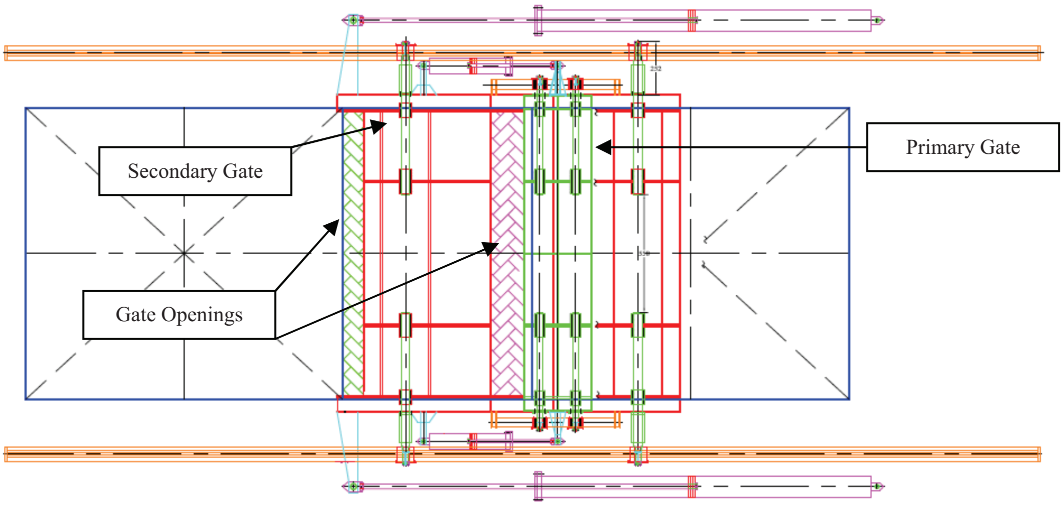


Figure 6.4 Drawing Showing the Primary and Secondary Gates in the Opened Positions.

Because of the four operational modes with two gates as shown in Figures 6.2, 6.3 and 6.4, the MRG is considered an original and unique design of the roller track gate category for gravity SULS, when compared to previous RTG design illustrated in Figures 6.5 and 6.6. This is due to the existing RTG having limited discharging operations, resulting in one gate and in some case two discharging modes:

- Local Manual Unloading and Maintenance Mode; and or
- Remote Manual Unloading Mode (i.e. only some existing gates).

Investigations by the author confirmed that there is no available published technical information on gate controls for public use. Nevertheless, **Elder (2002, p.3)** said '*that remote control systems have been around since the 1960s. It is only recently that they have become sufficiently reliable to warrant applause and further demands into the future. This can largely be attributed to the fact that control systems respond immediately and there is no waiting while the tunnelman shifts from cargo hold to cargo hold'*. This is one reason why the control system in this study was developed to improve the discharging with the MRG and secondly to both reduce the size of crews and increase efficiency onboard SULS. In Chapter 8 of this study, the economic evaluation confirmed that operational costs would be less by reducing the size of crew on SULS. **Elder (2002, p.4)**, also stated that to reduce the size of crew *'one of the recognized ways of accomplishing this objective is to provide remote control operation for the gate system'*.

The design methodology of the MRG is based on the author's working experience and the intention to address ongoing problems identified with current gravity gates onboard SULS. With this view, both conceptual and iconic test models were developed to emphasize the concept of the MRG, when carrying out discharging experiments with various cargoes transported by SULS.
Both the conceptual and iconic test models were designed by the author. The author also built the iconic test model and supervised the building of the conceptual model.

In previous gravity gate designs, full-scale prototype models have been tested prior to installation onboard SULS. These prototype gates were tested satisfactorily for mechanical functionality and verification of the control system. However, modelling these gates for discharging cargoes was primarily to confirm the functionality to the shipowners and not for determining the discharging capacity of the gate. The next stage of the MRG, if commercially exploited, would be full-scale prototyping for modelling the discharging capacity in accordance with the design of the gate and conveyors.

6.4 The Design Comparison and Operational Benefits Relevant to the Multi-functional Roller Track Gate versus Existing Roller Track Gates

This design of cargo gate for Self-unloading Bulk Carriers (SULS), called the Multi-functional Roller Track Gate (MRG), has some operational features that are similar to the original and existing versions of Roller Track Gates (RTG). The comparable features are that both types of gates operate on track and discharges cargo by gravity. These are the common characteristics of RTG designs installed onboard SULS. However, the MRG design has been proposed to provide enhanced operational features, when compared to existing RTG. The improvements of the MRG are primarily relevant to the gate functionality.

Chapter 5 provided a review of the various gravity gates currently installed onboard SULS. It also outlined the accompanying operational advantages as well as disadvantages, which have been associated with the previous SULS gravity gates operating on tracks, namely:

- Roller Track Gate – originally dating from the early 1900s' and developed during the 1970s' through to the 1990s';
- Bulk Flow Gate - dating from 1974;
- Non Consolidating Feeder – dating from 1995; and
- Control Feeder Gate – proposed in 1999.

Fundamentally, these four gates are those operating on parallel longitudinal and horizontal tracks. However, the Bulk Flow Gate, Non Consolidating Feeder and Control Feeder Gate are not necessarily classed as Roller Track Gate in terms of type or category.

Obviously, when comparing the operational features and design characteristics of the latter three cargo gates listed above, the functionalities in many respects are significantly different to those of the RTG and MRG. Nevertheless, the above-mentioned gates have one common fundamental feature; the cargo is discharged by gravity.

6.4.1 The Design Comparison of the RTGs' versus MRG

Subsequent to the original manually operated RTG of the early 1900's illustrated in Figure 5.9, there have been numerous developments in this style of gate. Figure 6.5 shows one design of the RTG development that has the total weight of gate supported by the double bottom tank top of the vessel.

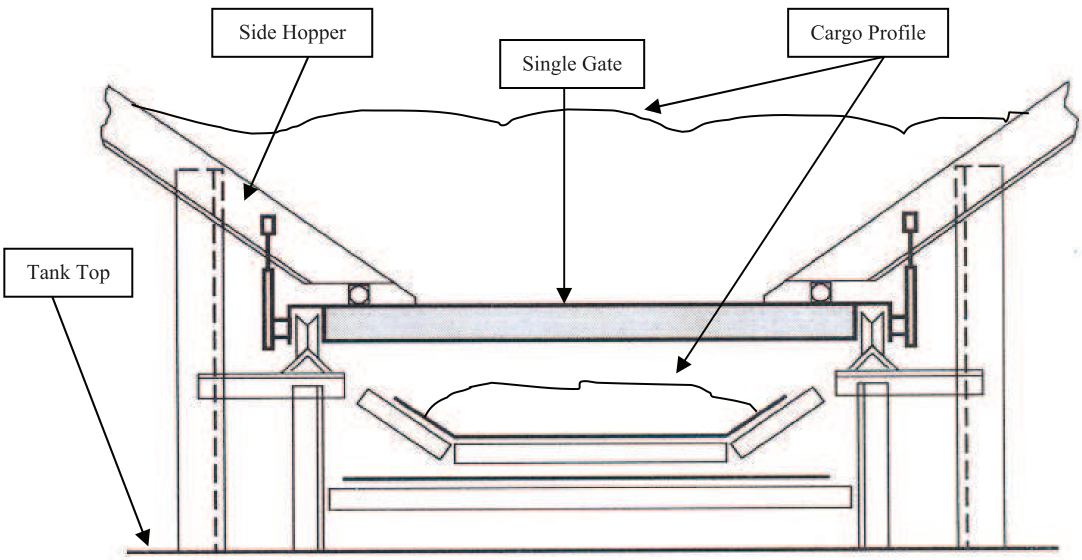


Figure 6.5 A Version of Existing Roller Track Gate Design – Section Elevation, (LR, 1992).

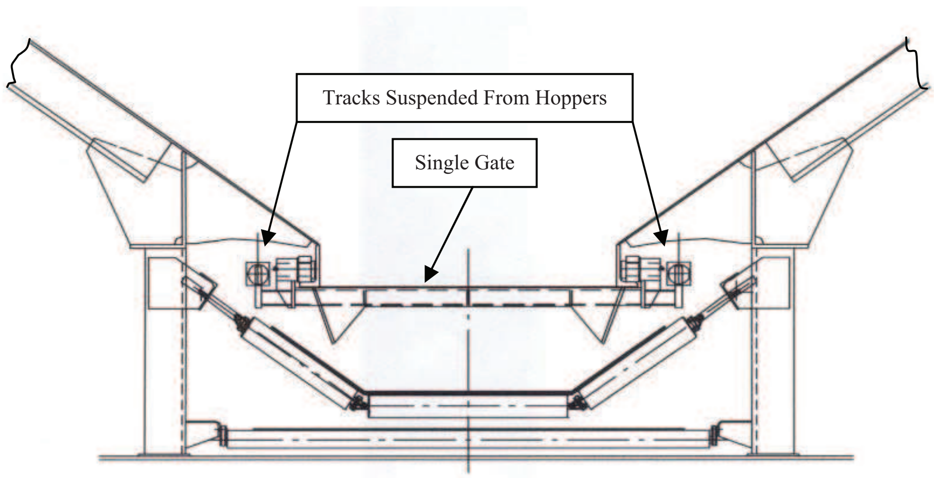


Figure 6.6 Roller Track Gate (Most Recent Design) – Section Elevation (EMS-Tech Inc, 2001).

Figure 6.6 represent the most recent version of the RTG design, which is suspended from the hopper. According to Elder **(2002)**, the suspended type of RTG is a development that superseded innovations of the RTG over the 1970s', 1980s' and early 1990s'. Also, Elder **(2002, p.2a)** stated that *'the concept of suspending the gate from the hopper has became an industry standard. Unlike the original roller track gate and systems of the 1970s', 1980s' and early 1990s; these new gate systems are reliable and allow for accurate and consistent remote control operation'*.

Historically, the Roller Track Gate (RTG) has been the most favourable gate amongst SULS shipowners and still remains popular to this day. Elder **(2002, p.2b)** stated that *'while the long slot gates tend to dominate the market for gravity self-unloaders, the fore and aft roller track-style gate remains a strong contender…'* The construction of the existing RTG illustrated in Figures 6.5 and 6.6 are such, that according to Yamashita, Endo and Fijiwara **(1991-1992, p.10)** these designs have a single gate that opens and closes *'in a longitudinally direction on tracks and supported by struts fitted on the inner bottom...'*. For these gates, there are two operational modes and cargo discharging operations can be affected from both remote and local positions, using two hydraulic cylinders to function the single gate. For the older design gates of this style, the cargo discharging operations could only be conducted locally from the unloading tunnel.

The Multi-functional Roller Gate (MRG) proposed here provides a further development to the family of RTG. The MRG is an enhanced gate design for gravity SULS having some constructional similarities, when compared to the existing RTG. However the functionality and arrangement of the proposed MRG are considerably different, when compared to both the original and existing RTG. These unique features are intended to provide the enhanced operational performance.

The MRG discharging operations can be accomplished from both remote and local positions, which are similar to the recent versions of RTG. Nevertheless, the MRG utilizes four hydraulic cylinders to achieve the previously mentioned seven cargo discharging operations, comprising four modes and three redundancies that are combinations of automatic and manual operations. These operational modes will further be explained in this Chapter as well as being described from the control systems perspective in the next Chapter.

The innovative developments of the roller track gates proposed in the MFG design are primarily to maximise the unloading of dry bulk cargo. This is also facilitated by having improved control and the moving-hole principle incorporated into the design, which allows for better metering of cargo. Thereby, while discharging reducing the possibility of spillage, cargo hanging-up and downtime. This enhanced cargo discharging operations are accomplished by adding to the MRG design a primary gate, amongst other developments and attributes to the original and existing RTG designs.

The additional primary gate in the MRG design allows for the moving-hole principle and also allows for discharging cargo simultaneously with two gates (i.e. primary and secondary). Clearly, the features of the two gates system makes the MRG an improved version of roller track gate, when compared to the original and existing RTG. These unique features result in the innovative MRG described and evaluated here. Figures 6.5, 6.6 and 6.7 demonstrate these differences in the design and structure of both gates (i.e. RTG and MRG), where the principal variations in the designs are shown. Figures 6.16 to 6.20 illustrate pictorial views of the MRG conceptual model.

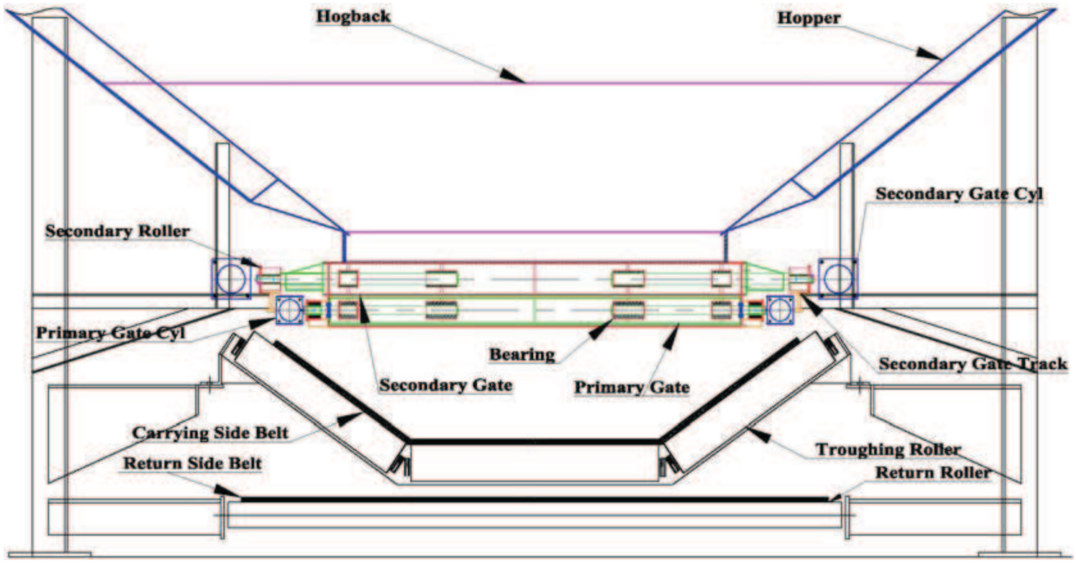


Figure 6.7 Multi-function Roller Gate – Section Elevation, (Welcome, H. 2008).

6.4.2 Design Benefits of the MRG versus RTG

In section 6.3 of this Chapter, it was mentioned that one principal design benefit accompanying the MRG is that this gate possesses operational features of the current design RTG while having other additional characteristics. These are the comparative operational features of the two types of gates. The discharging operations of the existing RTG are:

- Discharging with the single gate – remote manual operations from the CCR; and
- Discharging with the single gate – local manual operations from the tunnel.

The proposed MRG design in Figures 6.8 and 6.9 provide sections through the gate arrangement to show the primary and secondary gates comprising this new development of Roller Track Gate type. Figure 6.8 shows the end elevation of the secondary gate section of the MRG that have some similarity to the existing RTG. However, the mechanical construction is not identical to the RTG, when comparing Figure 6.7 with Figures 6.5 and 6.6. This secondary gate section of the MRG is only capable of unloading the vessel under two conditions:

- Discharging with the Secondary gate – remote manual operations from the CCR;; and
- Discharging with the secondary gates – local manual operations from the tunnel.

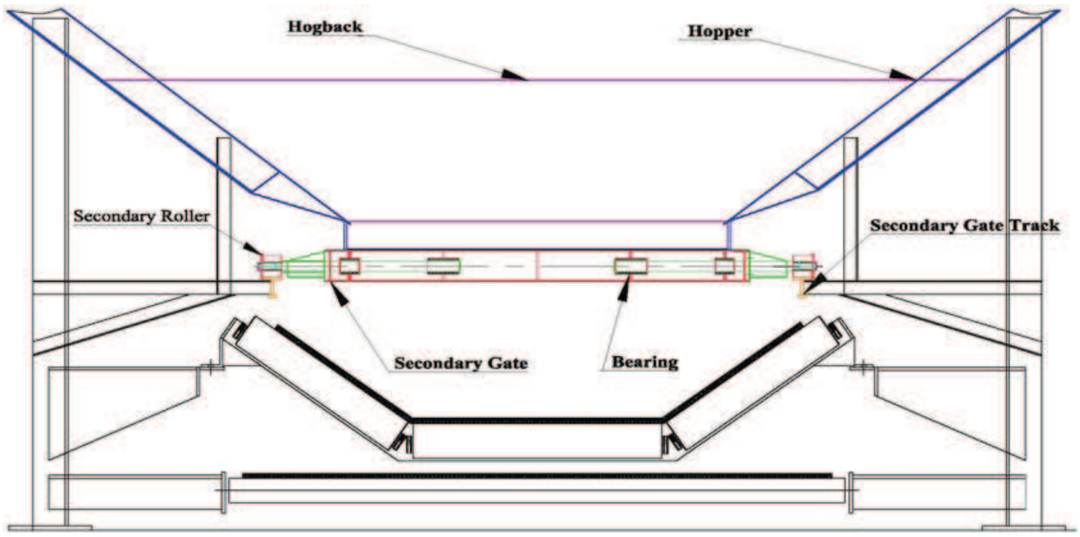


Figure 6.8 Multi-function Roller Gate – End Elevation Showing Secondary Gate, (Welcome, H. 2008).

Figure 6.9 shows the primary component of the MRG assembly. This portion of the MRG is mechanically supported by the secondary gate. However, in the standalone condition the primary gate is designed specifically to unload the vessel in the following mode and redundancy:

- Discharging with the primary gate – remote manual operations from the CCR; and
- Discharging with the primary gate – local manual operations from the tunnel.

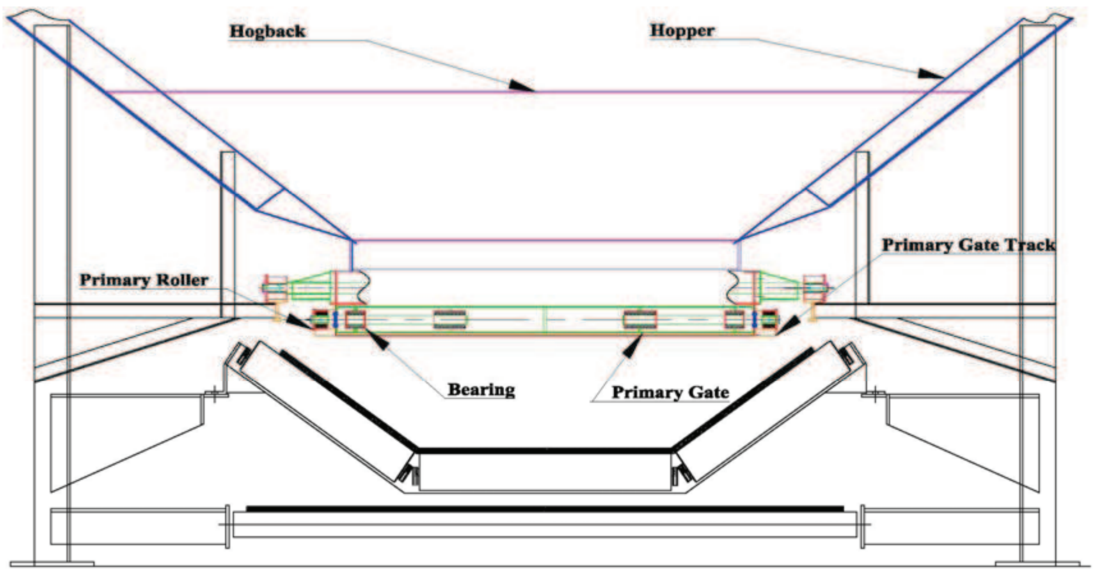


Figure 6.9 Multi-function Roller Gate – End Elevation Showing Primary Gate, (Welcome, H. 2008).

When the complete MRG is assembled as demonstrated in Figure 6.7 and as previously mentioned in Table 6.1, the design is capable of discharging SULS in four modes, three redundancies and seven unloading operations.

However, the normal and intended discharging operation with the MRG, is when using the 'Automatic Combination Unloading Mode' and reciprocating the gate assembly. This clearly demonstrates that the MRG design has six additional discharging redundancies or ways for operating the gates, when compared to the most recent RTG remote installation onboard SULS that has one redundancy. The older RTG installation onboard SULS has one method for operating the gates, which is local in the unloading tunnel. This original RTG unloading operation was by manual hand wheels in the tunnel and without redundancy or back-up emergency system, relevant to the gates functionality. Therefore, failure of the mechanical gate operating components would result in downtime and of-hire for the vessel.
The second operational and design benefit accompanying with the MRG, is the moving-hole principle. This feature allows for discharging of cargo automatically through longitudinal movement of the gate assembly. In reality, the primary gate slot can be reciprocated automatically under the cargo through a distance of 600 mm. Appendices VI.3 (a, b and c) shows three examples of the primary gate in the full opened position,

while moving longitudinally through a distance of 600 mm. The 600 mm moving-hole principle assists in collapsing hanging-up cargo that has bridged, resulting from arch formation due to natural compaction of material or the presence of moisture in the cargo. Cargoes with a tendency to compact are primarily: coal; iron ore fines; salt; sand (i.e. calcite and aragonite); construction sand, bauxite; gypsum, etc.

From an operational standpoint, the MRG moving-hole principle of discharging cohesive cargo is a very desirable feature of significant benefit to the unloading operations, as it results in less unloading delays and decreases the vessels turn-around time in port.

6.5 Design Advantages and Disadvantages of the MRG

Inevitably, as well as the proposed MRG design having the merits and advantages sought, there are some associated disadvantages. Both advantages and disadvantages are inherent attributes associated with any design and undoubtedly, certain impediments are link with the MRG development. Fundamentally, the principal design advantages and disadvantages can be summarized as follows.

6.5.1 Design Advantages of the MRG

The design advantages of the MRG can be summarised as:

- The design characteristics of the MRG resulted in one 'Automatic Combination Unloading Mode' and six redundancies for the discharging operations. These additional six discharging functions are for operating the gates by means of electro-hydraulic controls from both remote (i.e. CCR) and local (i.e. tunnel) locations. The existing RTG has one main discharging mode (i.e. CCR) and one redundancy (i.e. tunnel). Some designs have no redundancy with discharging operations only from the tunnel;
- The ability to discharge cargo with the primary gate, secondary gate or simultaneously with the two gates;

- Because the MRG design incorporates the moving-hole principle, there is a possibility of reducing cargo bridging from material arching. This, therefore, results in less hanging-up of cohesive cargoes that are either compacted naturally or from the ingress of moisture in the cargoes such as, coal, iron ore concentrates, gypsum, etc;
- Reduction in operating costs due to less manning personnel for unloading the cargo. Instead of having the usual three Tunnelmen, the number of unloading staff can be reduced to one Tunnelman in the case of the MRG;
- The moving hole principle allows for improved control of cargo discharging while unloading cohesive materials;
- The possibility of overloading the conveyors with the MRG is less, when compared to the existing RTG. This is because the gate controls are designed to close / control the gates automatically, when the discharge rate increases above the set discharging value; and
- Due to remote centralized discharging the turn-around time in port could be reduced, which could enhance the shipowners' revenue by allowing for more round trips per annum.

6.5.2 Design Disadvantages of the MRG

The design disadvantages of the MRG can be summarised as:

- The MRG is not an open-hole system and hogbacks are a part of the design. This results in the reduction of cargo hold volume that is essential to enhance revenue, when trading low-density or higher stowage rate bulk cargoes. However, in this design the hogbacks are necessary for sealing between the cargo gates. Also, the hogback areas allow for full retraction of the gates during the final phase of discharging, i.e. when cleaning-out and during washing down the cargo holds. The development of a roller track gate design without hogbacks to enhance the cargo hold volume will be referred to under further work as a further development of interest in the application of the MRG;
- The MRG has additional mechanical components, due to the more complex operating mechanism associated with the twin gate design, when compared to the

conventional RTG. The added cost for components would be offset by the reduction in manning costs and turn-around time in port (see Chapter 8);

- Increase in the ships' lightweight which reduces deadweight and revenue due to additional steel weight for constructing the primary gates. However, with careful planning in a new building or conversion project, this extra steel weight for the primary gates can be mitigated by careful structural design and potentially the use of higher tensile steel to reduce the lightweight in other areas of the vessel i.e. this is considered in Appendices VI.6.

It is considered that from a design and operational standpoint, the stated advantages outweigh the above disadvantages associated with the MRG. Therefore it is believed that this further innovation in roller track gate design would benefit SULS shipowners. This is justified in subsequent Chapters in terms of improved discharging operations and economic benefits.

6.6 Case Study: Installation of the MRG Onboard a Handymax SULS

The Multi-functional Roller Track Gate (MRG) concept is intended for installation onboard SULS of various deadweight's (i.e. handymax, panamax, aframax, capemax, etc…). However, the MRG described in this case study, is designed specifically for installation onboard handymax vessels, which are similar to that of model 'B' type SULS.

6.6.1 Installation of the Multi-functional Roller Gate

In terms of dimensions, the MRG presented here was intentionally designed for installation in handymax SULS of the Model 'B' Types. The midship section dimensions shown in Figure 6.10 are the exact measurements of an SULS similar to that, of the Model 'B' type vessel. This midship section is based on an existing vessel but the exact details and source of this data remain 'commercial-in-confidence'. Figure 6.11 shows the starboard cross sectional view of the MRG.

Prior to installation of the MRG, the cargo gates would be pre-fabricated in modules of two gates / module. Appendices VI.4a and VI.4b shows this design concept. The advantage of this idea would be to reduce the conversion time by having the gates manufactured, tested and ready for installation, upon arrival of the vessel at the shipyard. By simply utilizing the field splice illustrated in Figure 6.11 the original gates could be removed and replaced with the MRG.

Appendices VI.4a and VI.4b demonstrates the MRG module, which is 6300 mm in length per module comprising, 28 units and 56 cargo gates for each tunnel conveyor (or 112 gates in total) of the Model 'B' type SULS.

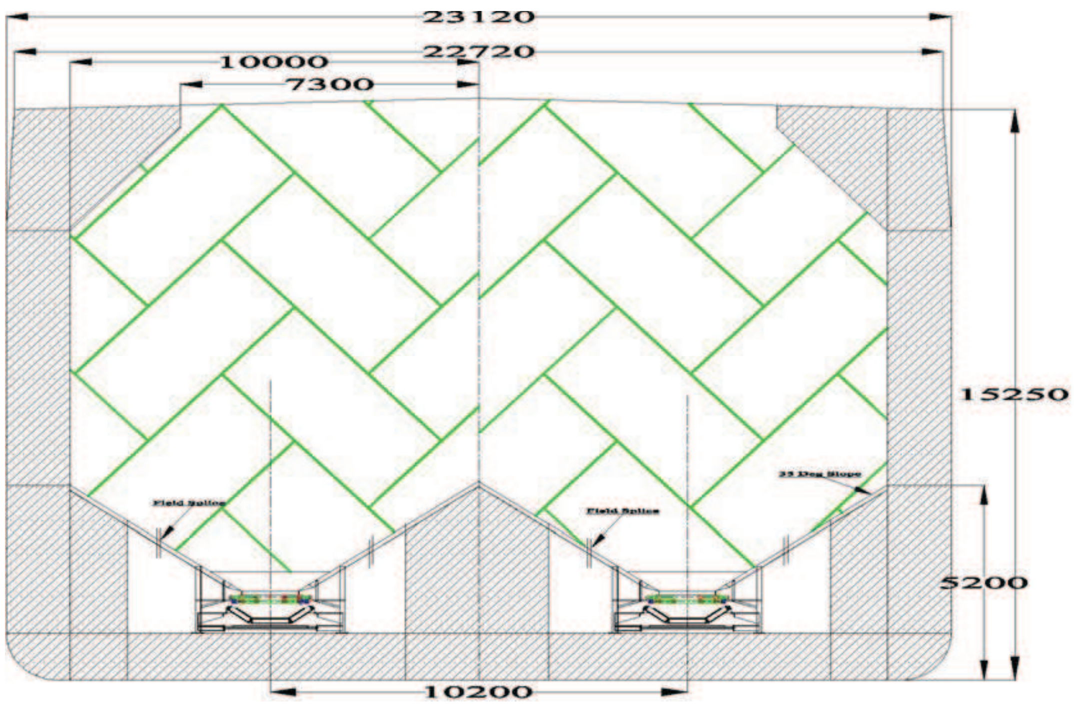


Figure 6.10 Midship Section with MRG Installed in Model 'B' Type SULS. Welcome, H. S. 2008.

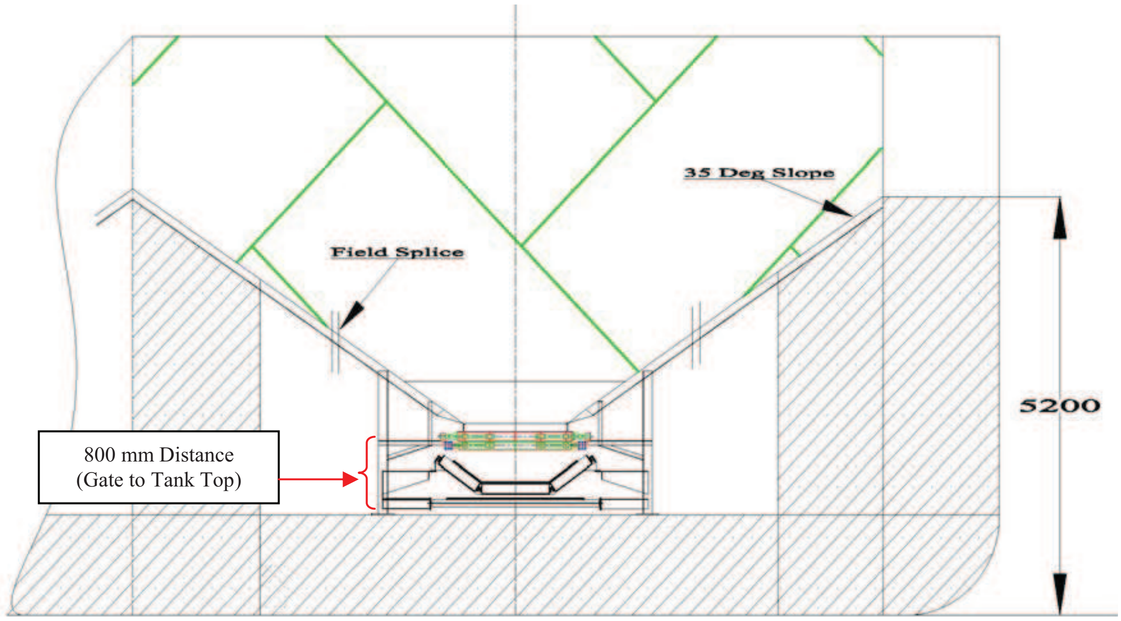


Figure 6.11 Cross Sectional View of MRG Installed in Model 'B' Type SULS. Welcome, H. S. 2008.

Table 6.2 Number of MRG Modules and Gates for Model 'B'.

Cargo Holds		**Module**	**Module/Gate**
No.	**Length (m)**	**Length (m)**	**No.**
1	31.110	6.300	5
2	36.600	6.300	6
3	36.600	6.300	6
4	36.600	6.300	6
5	31.110	6.300	5
Total (Port)			**28/56**
Total (Stbd)			**28/56**

Source Appendices VI.4a and VI.4b, Welcome, H. S. 2008.

Table 6.2 illustrates the locations of these modules onboard the vessel for installing the MRG. To reduce further the conversion time, the vessel hopper angles of 35 degrees would remain unaltered. However, by increasing the hopper angles to 37 or 40 degrees, the owners could potentially benefit from an increase in the cargo holds cross sectional area and total hold volume. Table 6.3 demonstrates detailed examples of the Model 'B' No.4 cargo hold cross sectional area for different hopper angles.

However, in all scenarios of cargo gates installation for the Model ‘B’, there should be approximately 800 mm distance between the bottom of the gates and tank top. This would ensure sufficient space for proper maintenance of the conveyors.

Table 6.3 Cross Sectional Areas & Gate Openings for No.4 Cargo Hold of Model ‘B’.

Hopper Angle (Degrees)	Cross Sectional Area (m^2)	Tank Top/Gate Distance (mm)	Gate Opening (mm)
35◦	225.6	800	1380
37◦	229.4	800	1489
40◦	232.5	800	2361

Source Appendices IV.1, IV.2 and IV.3. Welcome, H. S. 2008.

This required space, of 800 mm, between the tank top and cargo gates, resulted in larger cargo gate openings. Therefore, the advantages of increasing both the hopper angles above 35 degrees and cargo holds volume would be accompanying with the disadvantage of weight increase, resulting from having to install cargo gates and conveyor belts that are heavier and wider.

Subsequent to Penton and Sadler’s **(1924)** research on the flow of stone, hopper angles of 35 degrees became the norm for gravity type SULS. This was due to 35 degrees slope being the minimum angle at which the stone traded at that time would flow freely. With regard to hopper angles for the gravity type SULS, in this study the cargo holds side hopper angle is kept at 35 degrees.

6.6.2 The Design of Hold Conveyors for SULS with the MRG Installed

When designing conveyors for discharging specific capacity of dry bulk material onboard SULS with the MRG installed, there are numerous factors other than the flow rate from the cargo gates that have to be considered, namely:

- Belt widths;
- Lump size considerations;
- Belt speeds;
- Belt conveyor capacity;
- Troughed belt load area; and
- Inherent characteristics of the materials.

This last consideration is very much an unknown factor and varies according to the season and climate as well as demographic, storage area on vessel, etc.

This study is concerned with the development of cargo gates for SULS of the gravity type. Therefore, the discharging rate and capacity calculations for cargo unloaded will be restricted to the hold/tunnel conveyor belts, which receive the material after been discharged by the cargo gates. Obviously, the designs of the remaining downstream conveyors have to be of sufficient capacity to cope with cargo discharge by the hold/tunnel conveyor belts.

In this study, the hold/tunnel conveyors belt capacity calculations described in section 6.6.2.1 to 6.6.2.4 are based on the procedures manual published by the Conveyors Equipment Manufacturers Association, CEMA **(2007).** This is acknowledged as the industry standard by Self-unloader (SULS) designers. This manual has been highly recommended by dry bulk material handling design engineers from EMS Tech Inc and Seabulk System Inc. These two companies are the major designers in Canada for SULS systems.

6.6.2.1 Belt Widths

The conveyor belt width is a fundamental quantity that needs to be determined depending upon application. For example, conveyor belts for the boom, elevator, cross and tunnel could be of different width dimensions. The downstream conveyors, namely the cross, elevator and boom conveyors, must be of sufficient capacity to cope with the initial discharging rate by the upstream hold/tunnel conveyor belts. The hold conveyors discharge cargo directly on to the cross conveyors. Therefore, these two conveyors capacities have to be harmonized. As for the elevator and boom conveyors, the capacities have to be at least double that of each cross conveyor with a minimum of approximately 10% to 15% safety factor. This would ensure conveying the full load discharge capacity of the cross conveyors by both the elevator and boom conveyors. Figure 6.12 presents a flow diagram for the conveyors of a double hold/tunnel belt system onboard SULS.

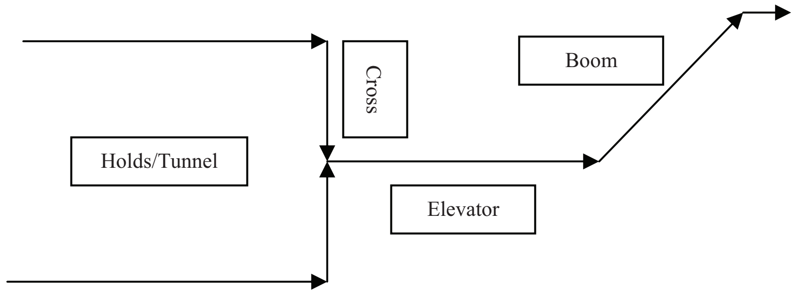


Figure 6.12 Conveyor Flow Diagram for Double Hold Conveyor Belts System. Welcome, H. S. 2008.

According to CEMA **(1994, p.47a)** *'the belts widths which are available from conveyors belt manufacturers in the United States-are as follows: 18, 24, 30, 36, 42, 48, 54, 60, 72, 84, and 96 inches'*. Companies such as Goodyear and Yokojama are famous manufacturers and suppliers of conveyor belts. Also, with regard to conveyors belt widths CEMA **(1994, p.47b)** stated that '*Generally, for a given speed, the belt width and the belt conveyor capacity increase together. However, the width of a narrower belt may be governed by the size of lumps to be handled. Belts must be large enough so that any combination of prevailing lumps and fine material does not load the lumps too close to the edge of the conveyor belt. Also, the inside dimensions of loading chutes and the distance between skirt-boards must be sufficient to pass various combinations of lumps without jamming'*

The capacity calculations for the hold/tunnel conveyor belts in this case study will be based on the 2134 mm (84 inch) width belt. This is due to this size of conveyor being the standard width tunnel belt for handymax SULS of the model 'B' types.

6.6.2.2 Lump Size Considerations

When trading gypsum, the commercial contracts between the shipowners and charterers invariably have a clause stating the maximum lump size to be discharged. However, occasionally the lump sizes are larger than the cargo gate openings, resulting in great difficulties while discharging. This is why the MRG is designed to have an ample gate aperture for both the primary and secondary gates, 300 by 1350 mm and 900 x 1380 mm respectively, to accommodate bulk flowing material such as gypsum. EMS Tech Inc. **(2002, p.6)** stated that *'The normal receiving (tunnel) belt width would be in the range of 60" (1500 mm) through 84" (2134 mm). Normally operating gate opening, on the other hand, is expected to be in the range of 11' (280 mm) through 17" (430 mm). This assumes a need to pass lumps measuring up to 8" (200 mm) in size'*

This gate opening dimension of EMS Tech Inc. is based on their gate feeder design, which has a longitudinal opening of 3050 mm. Therefore, when the gate feeder is fully opened to a width of 430 mm, the total gate aperture area is 1.31 m^2; this compares to a secondary gate aperture of 1.24 m^2 for the MRG. However, the MRG has advantages in term of the secondary gate width, i.e. 1380 mm versus 430 mm, which would be better suited for discharging large lumps of bulk cargo. During discharging of large lumps with the MRG, it would be advisable to unload in the standalone mode with the secondary gate. With regard to lumps size, CEMA **(1994, p.47c)** stated that *'The lump size influences the belt specifications and the choice or carrying idlers. There is also an empirical relationship between lump size and belt width. The recommended maximum lump size for various belt widths is as follows: For a 20° surcharge, with 10% lumps and 90% fines, the recommended maximum lump size is 1/3 the belt width (b/3). With all lumps and no fines, the recommended maximum lump size is 1/5 the belt width (b/5). Another way to determine the belt width for a specific lump size is illustrated in Figure 4.1 (or Figure 6.13 of this Chapter). This simple chart shows the belt width necessary for a given size lump, for various proportion of lumps and fines, and for various surcharge loadings'.*

Figure 6.13 illustrate the belt width necessary for a given lump size. For a 2134 mm (84 inch) wide belt, the maximum discharging lump size according to CEMA is 427 mm (16.8 inches) for all lumps and 20 degrees surcharge. Clearly, this indicates that the MRG secondary gate opening width of 1380 mm is more than three times the recommended dimension of CEMA, when the hold/tunnel conveyor belts are 2134 mm in width (84 inches).

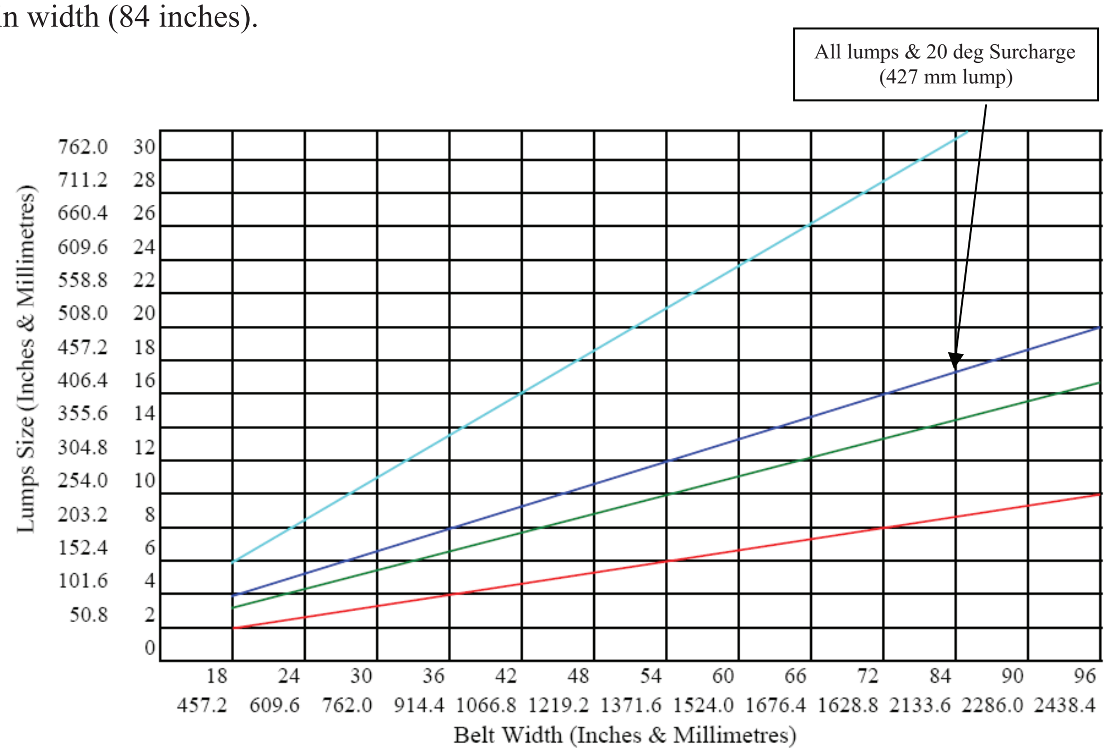


Figure 6.13 Belt Width Necessary for a Given Lump Size. Fines: No Greater than 1/10 Maximum Lump Size. CEMA, 1994.

All Lumps and 30º Surcharge
All Lumps and 20º Surcharge
10º Lumps, 90º Fines and 30º Surcharge
10º Lumps, 90º Fines and 20º Surcharge

6.6.2.3 Belt Speeds

As previously mentioned, for a given speed, the conveyor capacities increase as the belt width increases. CEMA **(1994, p.47d)** stated that *'suitable belt conveyor speeds depend upon the characteristics of the material to be conveyed, the capacity desired and the belt tensions employed'.* Obviously, excessive belt tension would result in braking action on the drive motor, which influences the belt speed. Insufficient belt tension causes the belt to slip, this again has an effect on the belt speed and is extremely dangerous when the pulley is rotating and the belt remains static. Low tension on conveyor could result in the ultimate failure of the belts. For this reason, with properly designed conveyor systems, the belts are not allowed to start until such time when there is sufficient operating belt tension, in accordance with the manufacturer recommendations. The issue of preventing destroying the conveyor belts due to low tension is addressed in the next Chapter as it is an important aspect of the design of the accompanying belt system.

With regard to belt speed, CEMA **(1994, p.47e.48)** also stated that *'general recommendations for maximum speeds of belt conveyors are shown Table 4-1' (or Table 6.7 of this Chapter).*These recommended maximum belt speeds suggested by CEMA are given in Table 6.7 of this Chapter.

6.6.2.4 Capacity and Troughed Load Areas of Conveyor Belts

According to CEMA **(2007, p.49c)**, *'the capacity of a belt conveyor depends on the surcharge angle and the inclination of the side rollers of the three-roller troughing idlers'.* Figures 6.14 and 6.15 illustrate the details of the Model 'B' types SULS standard size hold/tunnel conveyor belts of 2134 mm wide with cargo areas amounting to 352,104 mm^2 at the base and surcharge of 200,775 mm^2 inclined upward to 20 degrees on each side.

The hold/tunnel conveyor belts configuration on the Model 'B' types SULS are inclined at one end in order to discharge the material into the feed hoppers of the cross conveyors. Despite the inclined arrangement of the tunnel belts, the material is likely to conform to its surcharge angle as measured in the vertical plane for conveying the cargo from the tunnel to cross conveyor belts. This incline of the tunnel conveyor belts according to CEMA **(2007, p.49,50d),** *'decreases the area A_s, as the cosine of the angle of conveyor slope. However, in most cases, the actual loss of capacity is very small. Assuming a uniform feed to the conveyor, the cross-sectional area of the load on the conveyor belt is the determinant of the belt conveyor capacity'*.

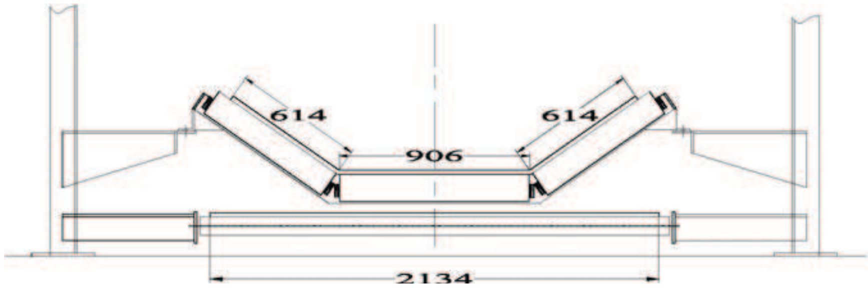


Figure 6.14 End Elevation View of Tunnel Conveyor Rollers for Model 'B'. Welcome, H. S. 2008.

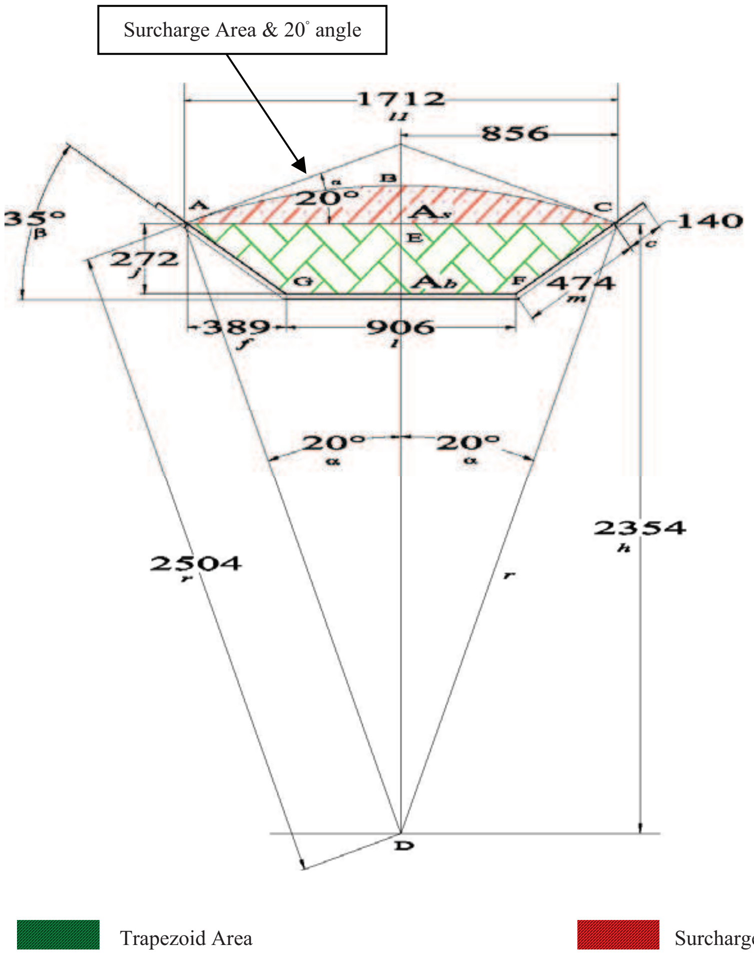


Figure 6.15 Cargo Areas of Tunnel Conveyor Rollers for Model 'B'. Welcome, H. S. 2008.

Source Conveyors Equipment Manufacturers Association (CEMA), 2007.

Figure 6.15 shows the vertical plane of the cargo cross sectional area, which is necessary for calculating the capacities of the hold/tunnel conveyor belts installed onboard the Model 'B' type SULS. The linear dimensions and angles on the drawing of Figure 6.15 were obtained from an AutoCAD model of the configuration. However there was uncertainty in locating the end points of surcharge segment so all subsequent area calculations were completed independently to reduce the possibility of any errors in the calculation of the cargo cross sectional area.

By simple calculation of the area of the enclosed trapezium and the associated surcharge area, the total cargo area in the vertical plane was determined to be 0.53 m^2 (or 5.71 ft^2). The detailed calculations of the trapezium and surcharge areas are illustrated in Appendix VI.8a.

From the cargo areas in the vertical plane it is then possible to calculate the capacity for the hold/tunnel conveyor belts. In addition to the belt width, speed and surcharge angle, the capacity also varies with different material density. In this study, the belt capacity calculation for drawing in Figure 6.15 is based on coal, which is categorized as an 'average free flowing' material with a 20 degree surcharge angle, having a possible repose angle between 30 to 35 degrees and density of 833 kg/m^3.

Where according to CEMA (**2007**): α = angle of surcharge, degrees; β = angle of idler roller, degrees; A_s = area of surcharge, square inches; A_b = base trapezoidal area, square inches; l = length, one edge of trapezoidal area, inches; l_1 = length, other edge of trapezoidal area, inches; h = height of triangular area, inches; j = height of trapezoid area, inches; m = slant length of trapezoid, inches; r = radius of surcharge arc, inches; f = horizontal projection of slant side of trapezoid, inches; c = edge distance, edge of material to edge of belt, inches; b = width of belt, inches*; Standard edge distance c =* 0.055b + 0.9, inches = 0.055*84+0.9 = 5.52 inches or 140.2 mm.

<u>Note</u>: in Figure 6.15, the values were converted from inches to millimetres. However, according to CEMA **(2007)** all values are in imperial units.

Tables 6.4 and 6.5 illustrate these values of material category, density, surcharge angle and possible repose angle. The cargoes density in Table 6.4 are some of the materials that are normally transported by the Model 'B' type SULS.

Table 6.4 Density of Some Cargoes Transported by SULS.

Material Category	**Density kg/m^3**
Grain – Wheat	780-800
Iron Ore	2100-2900
Coal, Bituminous, broken	833
Gypsum, crushed	1602
Salt, course	800
Sand, loose	1442

Source http://www.simetric.co.uk/si_metals.htm

Table 6.5 Values of the Surcharge Angle for Different Materials.

Material Category	**Surcharge Angle**	**Possible Repose Angle**
Fluid Material and Grain	0-5	0-20
Fine Dry and Free Flowing	10	20-25
Free Flowing and Lumpy	15	25-30
Average Free Flowing	20	30-35
Non-flowing	25	35-40
Lumps in Matrix of Fines	30	>40

Source Coursework of Greenwich University, Dr. Bradley, M. 2008.

CEMA, the specialist in providing guidelines relevant to designing conveyors for dry bulk handling materials, has prepared and published handbooks/catalogues with detailed and comprehensive references for those companies and Engineers in the business of designing and maintaining conveyors. The handbook ‘Belt Conveyor for Bulk Material’ is widely used as reference by those involved in the maritime sector of SULS Technology and industrial dry bulk handling systems. Tables 6.6a, 6.6b and 6.7 show some of the references published by CEMA as guidelines for conveyor designing Engineers.

Table 6.6a Thirty-five (35^o) Degrees Troughed Belt – Three Rollers Standard Edge Distance – 0.055b + 0.9 Inch.

Belt Width (Inches)	A_t - Cross Section of Load (ft^2)							Capacity at 100 ft/min (ft^3/h)						
	Surcharge Angle							Surcharge Angle						
	0	5	10	15	20	25	30	0	5	10	15	20	25	30
18	0.144	0.160	0.177	0.194	0.212	0.230	0.248	864	964	1066	1169	1274	1381	1492
24	0.278	0.309	0.341	0.373	0.406	0.440	0.474	1668	1857	2048	2241	2438	264	2847
30	0.455	0.506	0.557	0.609	0.662	0.716	0.772	2733	3039	3346	3658	3975	4300	4636
36	0.676	0.751	0.826	0.903	0.980	1.060	1.142	4058	4508	4961	5419	5886	6364	6857
42	0.940	1.044	1.148	1.254	1.361	1.471	1.585	5644	6266	6891	7524	8169	8830	9511
48	1.248	1.385	1.523	1.662	1.804	1.949	2.099	7491	8312	9138	9974	10825	11698	12598
54	1.599	1.774	1.950	2.128	2.309	2.494	2.686	9598	10646	11700	12768	13855	14969	16118
60	1.994	2.211	2.429	2.651	2.876	3.107	3.345	11966	13269	14580	15906	17257	18642	21058
72	2.913	3.229	3.547	3.869	4.197	4.532	4.879	17484	19378	21285	23215	25182	27196	29275
84	4.007	4.44	4.876	5.317	**5.766**	6.226	6.701	24043	26641	29256	31902	**34597**	37360	40210
96	5.274	5.842	6.415	6.994	7.584	8.189	8.812	31645	35058	38490	41966	45506	49134	52876

Source Table 4.3, Page 54, Conveyors Equipment Manufacturers Association (CEMA), 2007.

Note: Original Table.

Table 6.6b Thirty-five (35^o) Degrees Troughed Belt – Three Rollers Standard Edge Distance – 0.055b + 22.9 mm.

Belt Width (mm)	A_t - Cross Section of Load (m^2)							Capacity at 30.48 m/min (m^3/h)						
	Surcharge Angle							Surcharge Angle						
	0	5	10	15	20	25	30	0	5	10	15	20	25	30
457.2	0.013	0.015	0.016	0.018	0.020	0.021	0.023	24.47	27.30	30.19	33.10	36.08	39.11	42.25
609.6	0.026	0.029	0.032	0.035	0.038	0.041	0.044	47.23	52.58	57.99	63.46	69.04	7.48	80.62
762.0	0.042	0.047	0.052	0.057	0.062	0.067	0.072	77.39	86.05	94.75	103.58	112.56	121.76	131.28
914.4	0.063	0.070	0.077	0.084	0.091	0.098	0.106	114.91	127.65	140.48	153.45	166.67	180.21	194.17
1066.8	0.087	0.097	0.107	0.116	0.126	0.137	0.147	159.82	177.43	195.13	213.06	231.32	250.04	269.32
1219.2	0.116	0.129	0.141	0.154	0.168	0.181	0.195	212.12	235.37	258.76	282.43	306.53	331.25	356.74
1371.6	0.149	0.165	0.181	0.198	0.215	0.232	0.250	271.79	301.46	331.31	361.55	392.33	423.87	456.41
1524.0	0.185	0.205	0.226	0.246	0.267	0.289	0.311	338.84	375.74	412.86	450.41	488.66	527.88	596.30
1828.8	0.271	0.300	0.330	0.359	0.390	0.421	0.453	495.09	548.72	602.72	657.38	713.07	770.10	828.98
2134	0.372	0.412	0.453	0.494	**0.536**	0.578	0.623	680.82	754.39	828.44	903.36	**979.68**	1057.92	1138.62
2438.4	0.490	0.543	0.596	0.650	0.705	0.761	0.819	896.09	992.73	1089.92	1188.34	1288.59	1391.32	1497.28

Source Table 4.3, Page 54, Conveyors Equipment Manufacturers Association (CEMA), 2007.

Note: Reproduced in SI Units from the Original Imperial Table of CEMA.

CEMA **(2007, p.53)** also states, that to benefit from their published tables when designing conveyor capacity, there are 8 steps which should be taken into account:

> *'1. Determine the surcharge angle of the material. The surcharge angle, on the average will be 5^o to 15^o less than the angle of repose;*
> *2. Determine the density of the material in pounds per cubic foot (lb/ft^3) – kg/m^3;*
> *3. Choose the idler shape suited to the material and to the conveying problem – SULS standard angle is 35^o;*
> *4. Refer to CEMA Table 4.1, "Recommended Maximum Belt Speed". Select a suitable conveyor belt speed – See Table 6.7 of this study;*
> *5. Convert the desired tonnage per hour (tph) to be conveyed to the equivalent in cubic feet per hour (ft^3/h);*
>
> $$ft^3/h = \frac{tph \times 2000}{material\ density} \qquad 6.1$$
>
> *6. Convert the desired capacity in cubic feet per hour (ft$^{3/}$/h) to the equivalent capacity at a belt speed of 100 feet per minute.*
>
> $$Capacity\ (equivalent) = (ft^3/h) \times \left(\frac{100}{Actual\ belt\ speed\ (fpm)}\right) \qquad 6.2$$
>
> *7. Using the equivalent capacity so found, refer to Tables 4-2 through 4-5 and find the appropriate belt width - see Tables 6.6 and 6.7 of this study; and*
> *8. If the material is lumpy, check the selected belt width against the curves in CEMA Figure 4.1 (i.e. Figure 6.13 of this study). The lump size may determine the belt width in which case the selected belt speed may require revision…'*

The references and guidelines illustrated in Tables 6.4, 6.5, 6.6a, 6.6b, 6.7 and Figure 6.15 give sufficient information for calculating the capacity of the hold/tunnel conveyor belts.

Obviously, the MRG was designed for unload cargoes of all natures that are transported by SULS of the Model 'B' type vessel. Nevertheless, because of the 'moving-hole' principles, the owners would benefit when utilising the remote automatic mode while discharging coal with moisture contents, which has the tendency to hang-up due to bridging as a result from arching.

Table 6.7 Recommended Maximum Belt Speeds.

Material Being Conveyed	Belt Speed (m/s)	Belt Speed (ft/min)	Belt Width (mm)	Belt Width (Inches)
Grain or Other Free-flowing Nonabrasive Material	2.54	500	457.2	18
	3.56	700	609.6-762.0	24-30
	4.06	800	914.4-1066.8	36-42
	5.08	1000	1219.2-2438.4	48-96
Coal, Damp Clay, Soft Ores, Overburden and Earth, Fine Crushes Stone	2.03	400	457.2	18
	3.05	600	609.6-914.4	24-36
	4.06	800	1066.8-1524.0	42-60
	5.08	1000	1828.8-2438.4	72-96
Heavy, hard, Sharpe-edge Ore, Course-crushed Stone	1.78	350	457.2	18
	2.54	500	609.6-914.4	24-36
	3.05	600	Over 914.4	Over 36
Foundry Sand, prepared or damp, shakeout sand with small cores, with or without small castings (not hot enough to harm belting)	1.78	350	Any Width	Any Width
Prepared foundry sand and similar damp (or dry abrasive) materials discharged from belt by rubber-edge plow	1.02	200	Any Width	Any Width
Nonabrasive materials Discharged from belt by means of plow	1.02 Except for wood pulp where 1.52 to 2.03 is preferable	200 Except for wood pulp where 300 to 400 is preferable	Any Width	Any Width
Feeder belts, flat or troughed, for feeding fine, nonabrasive, or mildly abrasive materials from hoppers and bins	0.25 to 0.51	50 to 100	Any Width	Any Width

Source Table 4.1, Page 49, Conveyors Equipment Manufacturers Association (CEMA), 2007.

The capacity calculations for the hold/tunnel conveyor belts, is based on the assumption of trading coal with the Model 'B' type SULS and discharging with the MRG. The characteristics of the coal are:

- Surcharge angle of 20 degrees;

- Repose angle between 30 and 35 degrees; and
- The coal having density of 833 kg/m^3.

Depending on the cargo moisture contents, the flow of coal can be erratic and inconsistent. Therefore, in this study, coal has been categorised as an 'average flowing material'. Tables 6.4 and 6.5 describe the materials with accompanying conditions that would normally be traded by the Model 'B' type SULS. The capacity of the hold/tunnel conveyor belts in this study are calculated by two methods, namely:

- The empirical formulae (i.e. Principles of Design for Troughed Belt Conveyors; and
- The calculation guidelines by Conveyor Equipment Manufacture Association (CEMA).

The empirical approach is similar to *'Principles of Design for Troughed Belt Conveyors' Bradley,* **(2008)**. The conveyor capacity is calculated from the simple expression given in Equation (6.3).

$$\text{Conveyor capacity (tonnes/hour)} = A \times \rho \times V \tag{6.3}$$

Where:

A = Cross sectional area of the vertical cargo plane (m^2); ρ = Density of cargo (kg/m^3); V = Belt Speed (m/s).

From Equation (6.3), for a given conveyor capacity, density of cargo and vertical plane cargo area, the belt speed can be simply determined. In this case, where these values correspond to 2,000 tonnes/h, 833 kg/m^3 and 0.53 m^2 respectively, the speed is 1.26 m/s (249 ft/min).

When calculating the discharging rate for coal based on such empirical formulae, each hold/tunnel conveyor belt has to discharge 2,000 tonnes/h, in order to achieve a total unloading rate of 4,000 tonnes/h. Technically, in this study the Model 'B' type SULS are designed to unload coal at a rate of 4,000 tonnes/h. Therefore, it would be advisable to add a safety factor of 10% to account for influences that could possible reduce the discharging rate, such as:

- Mechanical friction;
- Future wear and tear of the equipment; and
- Miscellaneous interruptions during discharging.

Including a safety factor of 10% increases the belt velocity to 1.38 m/s. (272 ft/min). According to CEMA, the maximum recommended speed for belt width of 2134 mm (84 inches) is 305 metres/min (1,000 ft/min). This belt speed of 1.38 m/s (272 ft/min) would increase each of the hold/tunnel conveyor belts capacity to 2,200 tonnes/h or a total discharging rate of 4,400 tonnes/h for both belts. However, this discharging rate would be dependant on that the cargo measurements and characteristics remain the same as stated in Figure 6.13 and that Equation (6.3) applies.

Clearly, this indicates that the design of the hold/tunnel conveyors should be of higher capacity, in order to accomplish confidently the ultimate discharging rate of 4,000 tonnes/h.

If the CEMA guidelines **(2007)**are used, then as stated in Tables 6.7, 6.8a and 6.8b, the maximum recommended speed for conveyor belts 2,134 mm (84 inches) in width are 305 metres per minute (1,000 feet per minute).

Table 6.8a Thirty-five (35^o) Degrees Troughed Belt 84 Inches – Three Rollers Standard Edge Distance – 0.055b + 0.9 Inch.

Belt Width (Inches)	A_t - Cross Section of Load (ft^2)							Capacity at 100 ft/min (ft^3/h)						
	Surcharge Angle							Surcharge Angle						
	0	5	10	15	20	25	30	0	5	10	15	20	25	30
84	4.007	4.44	4.876	5.317	5.766	6.226	6.701	24043	26641	29256	31902	34597	37360	40210

Source Table 4.3, Page 54, Conveyors Equipment Manufacturers Association (CEMA), 2007.
Note: Original Table.

Table 6.8b Thirty-five (35°) Degrees Troughed Belt 2134 mm – Three Rollers Standard Edge Distance – 0.055b + 22.9 mm.

Belt Width (mm)	A_t - Cross Section of Load (m^2)							Capacity at 30.48 m/min (m^3/h)						
	Surcharge Angle							Surcharge Angle						
	0	5	10	15	20	25	30	0	5	10	15	20	25	30
2134	0.372	0.412	0.453	0.494	0.536	0.578	0.623	680.82	754.39	828.44	903.36	979.68	1057.92	1138.62

Source Table 4.3, Page 54, Conveyors Equipment Manufacturers Association (CEMA), 2007.

Note: Reproduced in SI Units from the Original Imperial Table of CEMA.

Therefore, operating each of the hold/tunnel conveyor belts at 1.26 m/s (249 ft/min) and 1.38 m/s (272 ft/min) for discharging coal, are well within the suggested belt speed parameters recommended by CEMA.

Table 6.9 Discharging Capacity of Tunnel Conveyor at Various Belt Speed.

Belt Speed (m/s) or (ft/min)	Density (tonnes/m^3)	Volume (m^3/h)	Capacity (tonnes/h)
0.51 or 100	0.833	980	816
1.26 or 249	0.833	2439	2032
1.38 or 272	0.833	2665	2220

Source Compiled by Welcome, H. S. 2009.

The total cross sectional area of the cargo, in accordance with Figure 6.15, is 0.53 m^2 (5.71 ft^2) at surcharge angle of 20 degrees. This cargo area of 0.53 m^2 (5.71 $ft^{2)}$ for each belt resulted in a discharging capacity amounting to 979.68 m^3/h (34,597 ft^3/h), when the hold/tunnel conveyor belts are operating at a speed of 0.51 m/s (100 ft/min). Table 6.9 shows the discharging capacity for each tunnel conveyor belts at various belt speeds. When allowing for a design safety factor of about 10%, the discharging rate would increase to approximately 2,220 tonnes/h for each hold/tunnel conveyor belts. Appendix VI.8 shows the detailed calculations of the tunnel / hold conveyors capacity.

In summary, for discharging coal of density 833 kg/m^3, the selected hold/tunnel conveyor belts of 2,134 mm (84 inches) wide has technically fulfilled the cargo discharging requirements, while operating the belts at a speed 1.26 m/s and 1.38 m/s.

Amongst all factors mentioned in this Chapter regarding the hold/tunnel conveyor belts capacity, the final criterion for maintaining the discharging rate is to ensure uniform cargo flow to the conveyors. This would maintain the required cargo cross sectional area to the belts in all scenarios. However, it is not always possible to maintain steady cargo flow to the belts, simply because of the commodity inherent nature, resulting in hang-up due to bridging from arch formation. Nevertheless, with 56 cargo gates per tunnel conveyors and proper flowing cargo, the discharging rate could obviously be achieved.

6.7 Capacity of Cargo Gates Actuators / Operating Cylinders

With regard to the cargo gate functionality, the ability of the operating cylinders is of utmost importance to ensure effective opening and closing of the gates. In practice SULS incur tremendous delay in the unloading ports, due to poor operations of the cargo gates not opening, resulting from improper engineering of the cylinders. The cylinders must be designed with sufficient capacity to overcome both the static and frictional forces resulting from the weight of the gates, the column of cargo weight acting downward onto the gates and mechanical frictional in the gate mechanism. When the vessel is fully loaded, the head of cargo extends from the cargo gates upper surfaces to the hatch covers underside. This scenario is relevant to when the vessel is transporting low density cargo, such as coal, grain, etc. This condition is shown in Appendix VI.8 when transporting coal by SULS.

Additionally, it is imperative to incorporate an ample safety factor when designing the cylinders to ensure proper opening and closing operations of the cargo gate under the most severe load conditions likely to be encountered in service, such as cargo becomes compacted after several days of rough weather on passage. Appendix VI.8 illustrates the gate cylinders designed with sufficient reserve force to ensure proper operations of the MRG.

6.8 The Models and Experiments of the Multi-functional Roller Gate

Two models of the Multi-functional Roller Gate were fabricated to both provide a physical iconic representation of the design concept and a model to allow some simple experiments to be conducted. Using this second model, the performance of different cargoes was investigated, including coal, oats, soya bean and corn. These two iconic models are subsequently referred to as the 'conceptual model' and the 'test model' respectively.

6.8.1 The Conceptual Model

The conceptual model of the Multi-functional Roller Track Gate (MRG) was made by Mr. Zhu Zhilong of Shanghai Qianlong Process Model Production Co. Ltd., The Peoples Republic of China **(2008)**. The model was fabricated from plastic and scaled 1:10 of the actual size (see Appendix VI.4). This replica model has features identical to the AutoCAD design in terms of the gate assembly integral parts (i.e. cylinders, rollers, dimensions, primary and secondary gates, etc), structure members, angles of hopper and hogback. These characteristics are authentically mock-up of the MRG as would be when this gate is installed onboard SULS. Fundamentally, the conceptual model reveals those details of the MRG that are not possible to clearly illustrate on the AutoCAD drawings from which the model was reproduced / built. Showing the MRG model in an actual pictorial view was the author's intention, as this would allow better / closer examination and understanding of the MRG functionality. See Figures 6.16 to 6.20.

Figure 6.16 End View of Conceptual Model-Development Stage. Welcome, H. S. 2008.

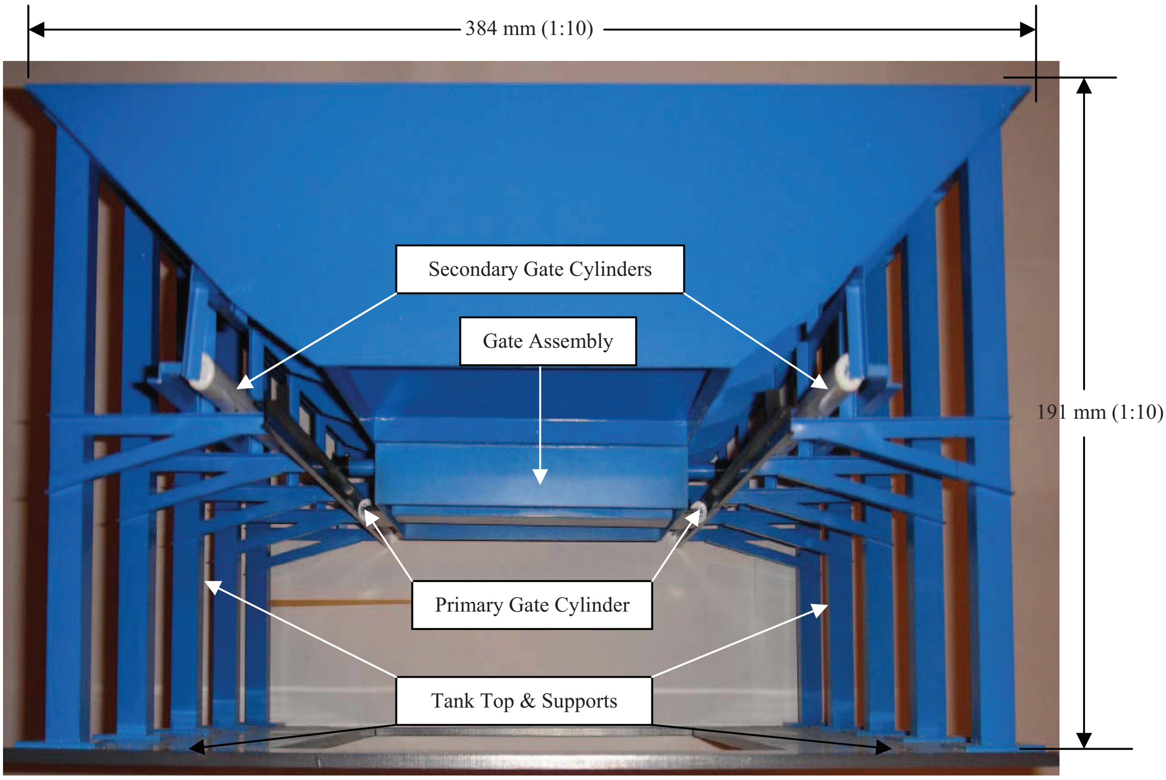


Figure 6.17 End View of Conceptual Model-Completion Stage. Welcome, H. S. 2008.

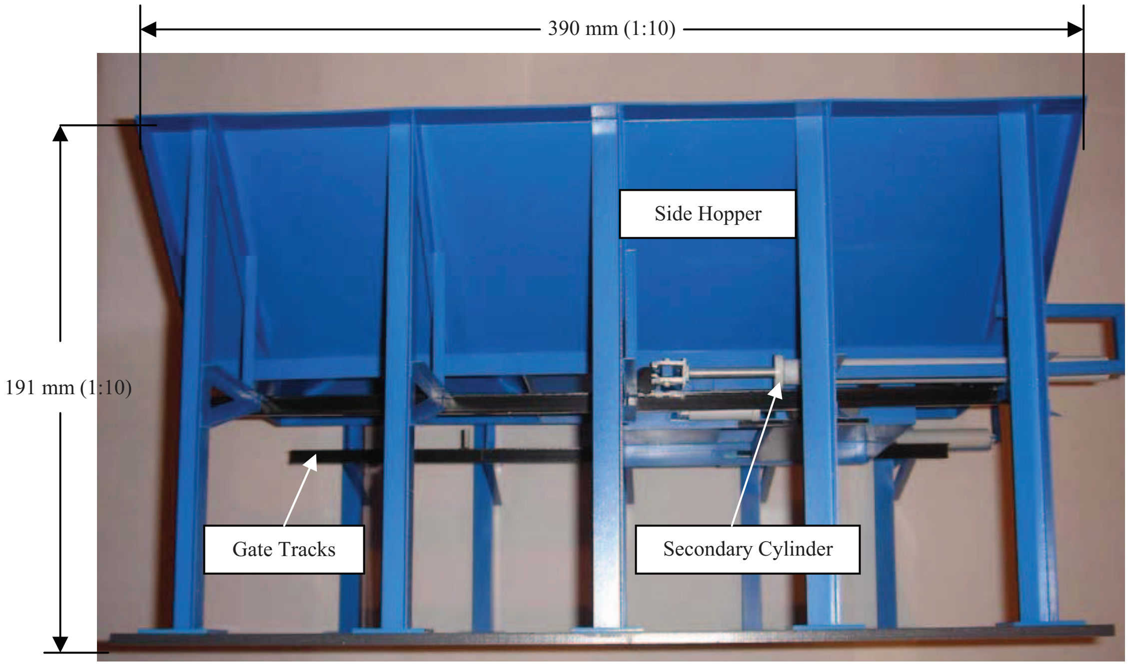


Figure 6.18 Side View of Conceptual Model-Completion Stage. Welcome, H. S. 2008.

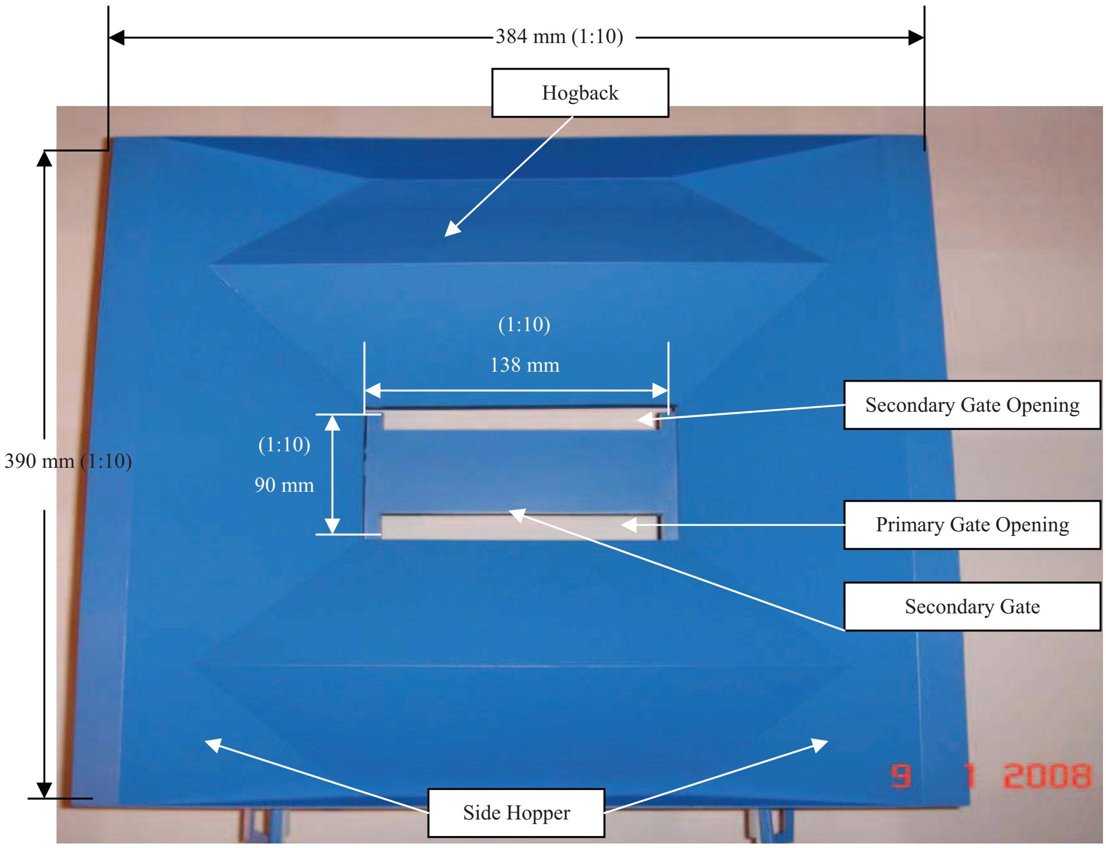


Figure 6.19 Plan View of Conceptual Model-Completion Stage. Welcome, H. S. 2008.

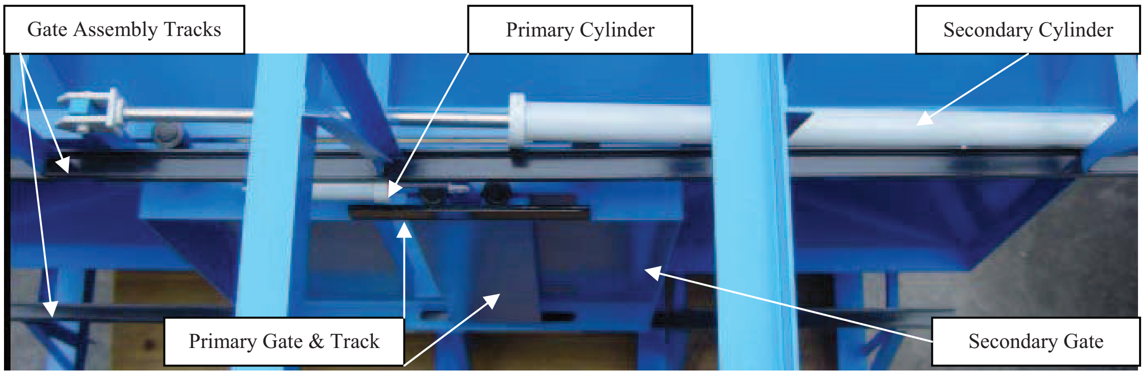


Figure 6.20 Underside View of Conceptual Model-Completion Stage. Welcome, H. S. 2008.

Despite the model size scale of 1:10, Appendices VI.12a, VI.12b and VI.12c show the actual size of the MRG for installation onboard handymax SULS of the Model 'B' type. Figures 6.16 to 6.20 illustrate various views of the MRG conceptual model. Figure 6.16 shows the initial stage of construction. Figures 6.17 to 6.20 demonstrate the finished product in 4 views of the MRG.

6.8.2 The Test Model

A 1:10 test model was also made. The test model was fabricated by the author from polished surface wood and painted with oil based paint. Figures 6.21 to 6.23 illustrate the finished product of the test model in the plan and elevation views.

Fabricating the test model from highly polished wood was primarily to avoid the possibility of moisture ingress into the wood, when testing material with moisture contents. Despite having moisture present while testing the material, the assumption is that friction would be insignificant between the materials and hopper surface and the cargo flow would not be interrupted.

The geometry of the 1:10 test model was similar to the conceptual model and AutoCAD design. The particles of cargoes used for the experiments were not scaled. However, the materials tested were identical in type and size to that transported by SULS. This was to ensure that the model test would simulate the MRG in real life scenario. Carson and

Royal **(1991, p.257a)** stated that '*When designing a model of full scale bin, it is vitally important that the model be geometrically similar to the full scale equipment. Most important is that the hopper slopes be the same as in the full scale equipment and that any internal devices (e.g. inserts) be properly scaled in size and position. When scaling a mass flow bin, the size and height of the cylinder section are unimportant if one is only concerned with conditions at or near the outlet'*.

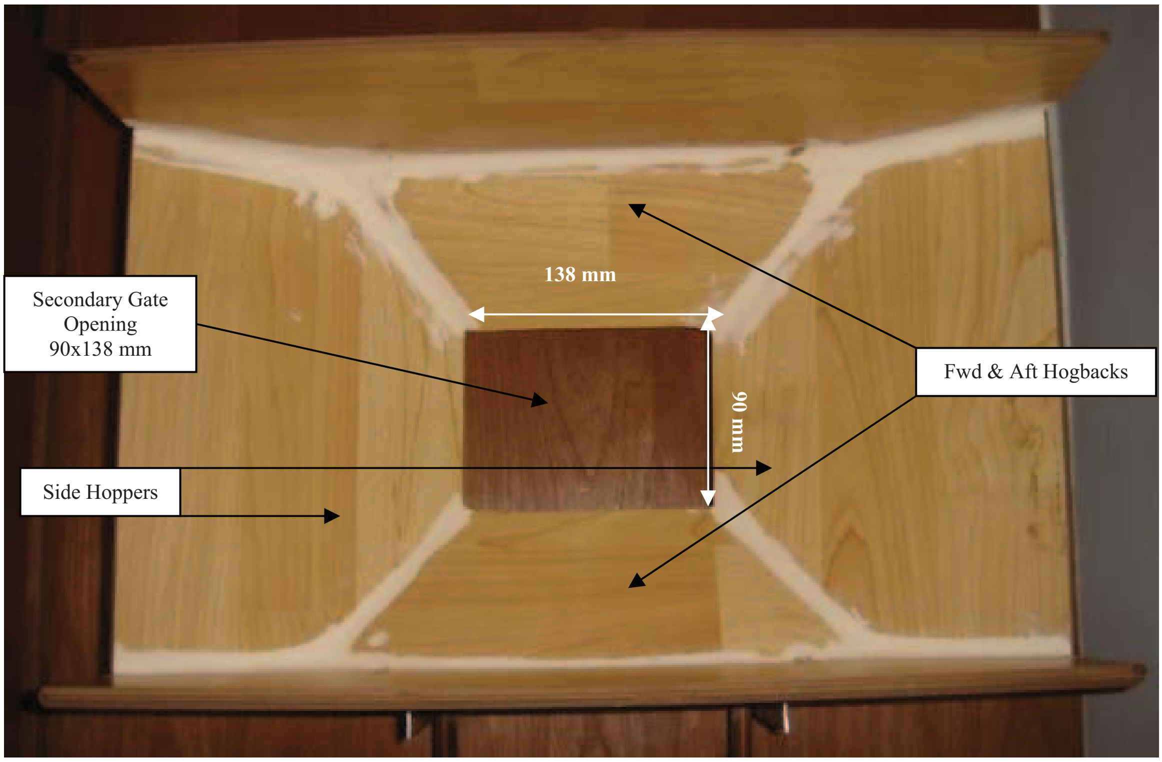


Figure 6.21 Plan View of Test Model During Construction Stage. Welcome, H. S. 2008.

Carson and Royal **(1991)** views on designing test models for dry bulk material handling was considered. For this reason, the MRG test model hopper slopes i.e. angles and hogbacks are scaled to represent the cargo holds internal structure of the Model 'B' type SULS (see Figures 6.21 to 6.23).

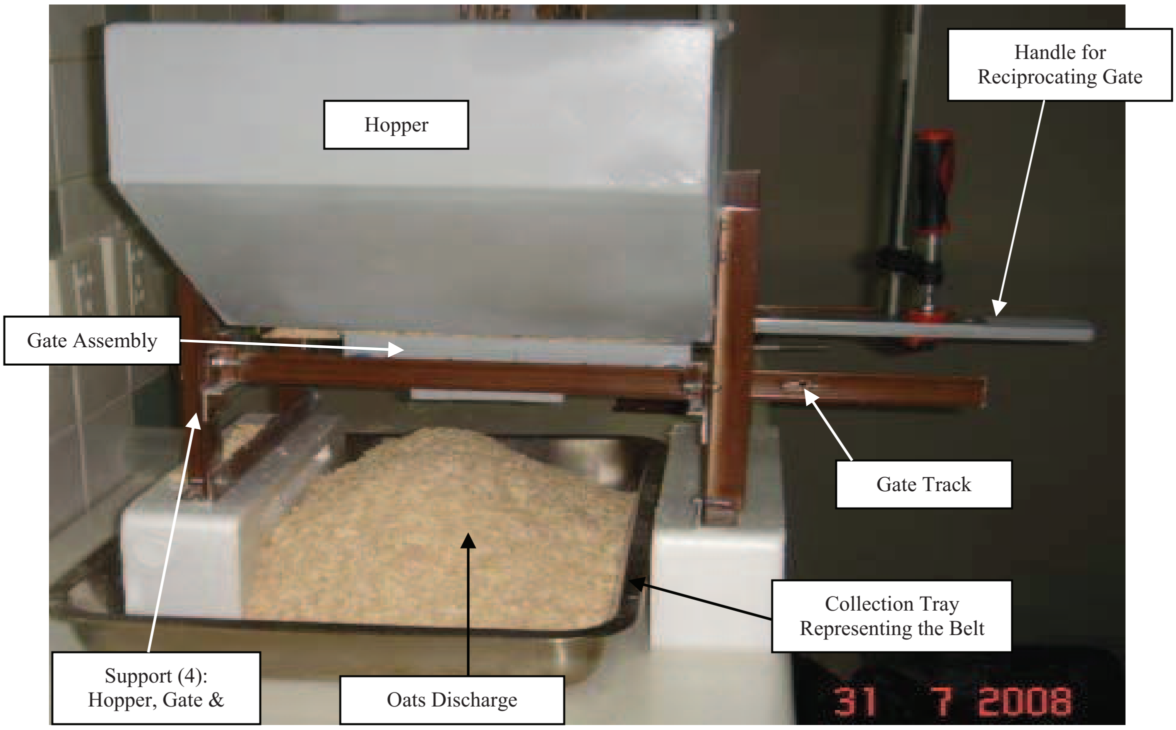


Figure 6.22 Side View of Test Model-Experiment with Oats. Welcome, H. S. 2008.

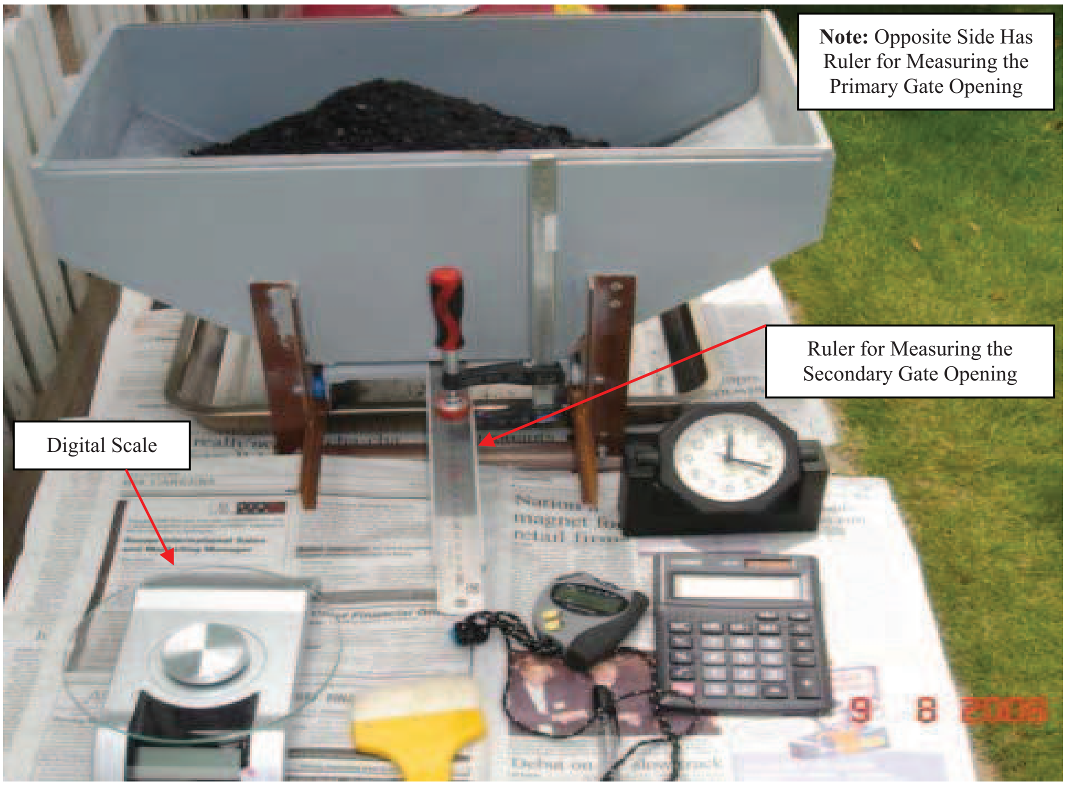


Figure 6.23 End View of Test Model-Experiment with Coal. Welcome, H. S. 2008.

6.8.3 Overview of the Experiments - Test Model

Clearly this research of designing the Multi-functional Roller Track Gate is a development to improve the discharging of previous Roller Track Gate for gravity SULS. The test model through experiments with different cargoes was designed principally to verify the functionality of the MRG concept, as a gravity gate for unloading SULS. The MRG design in this study is strictly for marine applications and it is not designed or intended to verify quantitative values of discharging rate onboard SULS. This is because there are numerous aspects other that cargo gate which governs the discharging rate onboard SULS e.g. belt speed; belt width; surcharge angle of cargo; vertical cross sectional area of cargo on the belt; lump size; inherent cohesive nature of the commodity, etc… Normally the discharging rate of SULS can be achieved with a single cargo gate per tunnel conveyor and occasionally it is impossible to ascertain the unloading rate with one gate per tunnel belt. However, quantitative values were investigated with the test model (i.e. single gate), primarily to establish the MRG concept and ability to discharge various cargoes. Figures 6.22 and 6.23 show the test model used for the discharging experiments with coal, oats, soya bean and corn.

Experiments with the test model of this research address the discharging operations with dry bulk materials such as coal, oats, soya and corn. Similar to the conceptual model, the test model was constructed with the two gates system. The primary gate is the development which optimizes the Multi-functional Roller Track Gate (MRG), when compared to the original and existing Roller Track Gates (RTG), while the secondary gate operations are similar to the original and existing RTG. However, in some respects the secondary gate construction details are not identical to previous RTG e.g. the supporting arrangements and structure is different (see Figures 6.5, 6.6 and 6.7). The test model experiments with the development gate section i.e. primary gate proved the effectiveness of the MRG concept. This was verified during the discharging of real low-density cargoes (i.e. oats and coal) of a compact nature, in comparison to previous RTG, which have similar discharging operations to the secondary gate.

Nevertheless, the experimental discharging rates were indicative tests and this was due to problems with scaling the cargoes and their behaviour to the model scale. According to Carson and Royal **(1991, p.257b)**, *'many researchers consider it important to use the same bulk solid in the model as in the full scale and vary the particles sizes of the bulk solid consistent with the scale of the model'*. However, Carson and Royal *'consider that scaling of material is not only unnecessary but likely to lead to erroneous conclusions'*... For this reason scaling was not done for the material tested. It should be clearly noted that scaling, flow rates and angle of repose for the materials tested is not part of this thesis or study.

Prior to affecting the cargo flow experiments, the density was measured for the four products selected for testing and were categorized into two groups or densities, namely:

- **Low Density** - Oats (Density of 0.3333 g/cm^3) and Coal (Density of 0.2806 g/cm^3); and
- **Medium Density -** Soya (Density of 0.6606 g/cm^3) and Corn (Density of 0.7632 g/cm^3).

Despite the differences in material densities, a precise volumetric capacity of cargo was decided for carrying out the experiments (i.e. both low and medium density products). Fundamentally, this criterion of placing a specific quantity of cargo into the hopper was to ensure volumetric standardisation of each experiment at commencement of each test. This would result in improve linear values, when comparing the flow outcome, principally because of identical volumetric cargo head above the gravity gate. The volume of cargo placed into the hopper for the low density cargo experiments (i.e. oats and coal), amounted to 8019 cm^3 comprising of 22 equal samples and for the medium density products (i.e. soya and corn) 5832 cm^3 consisting 16 equal samples (see Table 6.10).

Table 6.10 Details of Cargoes Utilized for Testing with the Test Model.

Sample No.	Sample (g)			Product (volume, density and mass)		
	Total	Container	Product	Volume (cm^3)	Density (g/cm^3)	Mass (g)
Coal - 22	10566	8316	2250	8019	0.2806	2250
Oats - 22	10989	8316	2673	8019	0.3333	2673
Soya - 16	9901	6448	3853	5832	0.6606	3853
Corn - 16	10499	6448	4451	5832	0.7632	4451

Source: Results of Experiments Compiled by Welcome, H. S. 2008

Each test was completed when about 70% to 80% of the product by volume was discharged. This test was primarily to simulate a constant volumetric flow, due to erratic flow during the final 20% to 30% before emptying the hopper. Table 6.10 illustrates the summary of cargoes which were utilized for the experiments with the test model. The details of the experiments and additional figures are illustrated in Appendix VI.13. Generally, the dry bulk products used for this experiment have variable densities, depending on the material. However, Table 6.10 demonstrates the particular cargoes utilized for the experiments. Table 6.11 shows the variation in densities for oats, coal, soya and corn.

Table 6.11 Variation in Densities for Cargoes Utilized for Testing with the Test Model.

Product	Density (g/cm^3)
Oats	0.432
Oats, rolled	0.304
Coal, Anthracite, solid	1.506
Coal, Anthracite, broken	1.105
Coal, Bituminous, solid	1.346
Coal, Bituminous, broken	0.833
Bean, Soya	0.721
Corn, on the cob	0.721
Corn, shelled	0.721
Corn, grits	0.673

Source: http://www.simetric.co.uk/si_metals.htm. 2008.

Subsequent to measuring and calculating the test coal density, the result was 0.2806 g/cm^3. This value is somewhat low, when comparing with the figures in Table 6.11 that amounted to a density for coal ranging from 0.833 g/cm^3 to 1.506 g/cm^3.

Nevertheless, despite the material density, SULS of the gravity types would discharge any commodity that gravitates through the cargo gates and onto the hold/tunnel conveyor belts.

6.8.4 Verification of the MRG Concept by Experiments with Coal

The test coal was lumpy (i.e. various shape about 3 mm to 5 mm) in characteristic with considerable fine particles, (not measured) which was obviously beneficial for the experiment due to the cargo compaction and cohesive nature. Therefore, allowing the MRG moving-hole concept to be tested in accordance with the design principles. Cargoes that are compacted from cohesion have a tendency to hang-up, resulting in bridging from arch formations.

6.8.4.1 Secondary Gate Experiment (Standalone Mode with Coal)

The secondary gate was opened from 10 mm to 40 mm in stages of 5 mm at a time and for periods of five seconds. During these tests, the flow of cargo was minor and in some cases there were no flow. Upon opening the gate to 50 mm (i.e. equal to 500 mm of the design), initially there was no flow and suddenly the cargo released that was directly above the gate in-way-of the gate opening. Table 6.12 shows the results of these tests.

Table 6.12 Summary of First Attempt of the Secondary Gate Experiment with Coal.

Gate	Flow		
Opening (mm)	Total (g)	Time (s)	Rate (tonnes/h)
10	0	5	**0.00**
15	0	5	**0.00**
20	0	5	**0.00**
25	0	5	**0.00**
30	0	5	**0.00**
40	0	5	**0.00**
50	0	5	**Overloaded**

Source: Results of Secondary Gate Experiments with Coal. Welcome, H. S. 2008

During the 50 mm gate opening experiment, the cargo collection tray representing the belt was overloaded spilling cargo out of the tray. In this scenario the hold/tunnel conveyor belts could become overload and therefore plugging the conveyors due to excess cargo. This occurrence is typical situation onboard SULS, primarily when unloading compact cargoes like coal that has bridged from arching. In this circumstance when discharging hang-up cargoes with the secondary gate, the operators have to exercise care and focus on the discharging rate to prevent plugging/overloading the belts. When cargo is hang-up, it would be advisable to unload the vessel using the remote automatic mode that is based on the moving-hole principle or from the local position in the tunnel.

A second attempt to discharge cargo with the secondary gate was carried out as illustrated in Table 6.13. These tests also resulted in trivial flow rate of cargo and in most cases there were no flow. The discharging rates resulting from these experiments confirm the cohesiveness of the coal and the danger of overloading the conveyors if the gate is opened too large. In this scenario, it would also be advisable to discharge the vessel in the remote automatic mode, as this could prevent the possibility of overloading the conveyors by using the moving-hole principle to discharge. Technically, the moving-hole has the advantage of preventing material bridging due to arching and rat-holing, when discharging cohesive cargoes that are hanging-up.

Table 6.13 Summary of Second Attempt of the Secondary Gate Experiment with Coal.

Gate	Flow		
Opening (mm)	**Total (g)**	**Time (s)**	**Rate (tonnes/h)**
10	0	10	**0.00**
15	0	10	**0.00**
20	0	10	**0.00**
25	0	10	**0.00**
30	0	5	**0.00**

Source: Results of Secondary Gate Experiments with Coal. Welcome, H. S. 2008

As mentioned before, the MRG secondary gate has some similarities to the existing RTG. Thereby, a number of operational issues encountered with previous RTG would inherently form part of the secondary gate for the MRG. The issue of cargo not falling during various opening attempts of the gate is common. For this reason, hydraulic or pneumatic structure vibrators are occasionally used to release the cargo. An inexperienced operator (i.e. local or remote operation) could easily overload the hold conveyors, when the secondary gate is opened too large. Therefore, a sudden release of cargo would result in plugging the system with excess cargo. Nevertheless, this study allows for closing the gates and stopping the conveyors in the event of an overload situation, but the unloading system must be in the remote automatic mode (see Chapter 7).

The third stage experiment continued by opening the secondary gate twice to 35 mm for a period of five seconds each time. During the first attempt, the cargo flow amounted to 0.43 tonnes/h. The second attempt resulted in a flow of 0.04 tonnes/h and suddenly the flow stopped. In this scenario, again it would be necessary to employ structure vibrators to release the cargo.

Table 6.14 Summary of Third Attempt of the Secondary Gate Experiment with Coal.

Gate	**Flow**		
Opening (mm)	**Total (g)**	**Time (s)**	**Rate (tonnes/h)**
35	595	5	**0.43**
35	53	5	**0.04**
40	706	2-3	**1.27**

Source: Results of Secondary Gate Experiments with Coal. Welcome, H. S. 2008.

Note: Discharging rates are considered to be +- 10%.

Finally, the secondary gate was open to 40 mm for two to three seconds, resulting in a flow rate of 1.27 tonne/h. With this sudden flow rate, a negligent operator could easily plug the tunnel conveyors. Table 6.14 illustrates the summary of these final three discharging rates for the secondary gate in the standalone mode, while unloading coal of density 0.2806 g/cm^3.

6.8.4.2 Primary Gate Experiment (Standalone Mode with Coal)

Various experiments were conducted while opening the primary gate from 10 mm to 30 mm and increasing the openings dimension by 5 mm for periods of five seconds. These openings of the primary gate resulted in zero discharging rate. Table 6.15 exhibits these values. However, on the second attempt when opening the gate from 0 mm to 30 mm for two seconds, the discharging rate of cargo amounted to 1.04 tonne/h.

The test model primary gate opening area amounts to 0.00405 m^2 and the actual design gate opening is 0.405 m^2 that is 100 times larger in area, when compared to the test model gate. Based on this principle, the primary gate discharging rate should equate to 104.2 tonnes/h, when the gate is fully opened i.e. 30 mm. However, this calculation would be incorrect, for the reason that dry bulk material is not liquid flowing at a constant velocity through a predetermined opening.

Table 6.15 Summary of Final Attempt of the Secondary Gate Experiment with Coal.

Gate	**Flow**		
Opening (mm)	**Total (g)**	**Time (s)**	**Rate (tonnes/h)**
10	0	5	**0.00**
15	0	5	**0.00**
20	0	5	**0.00**
25	0	5	**0.00**
30	0	5	**0.00**
30	579	2	**1.04**

Source: Results of Primary Gate Experiments with Coal. Welcome, H. S. 2008.

Note: Discharging rates are considered to be +- 10%.

The discharging rate of dry bulk material onboard SULS is base on many factors (i.e. belt speed, belt width, cargo cross sectional area, lump size, density of product, material characteristics, etc.) other than just the ability for the gates to maintain cargo on the belts. Nevertheless, without uniform discharging flow by the cargo gates, the rate of discharge would be unachievable. In this study, SULS of the Model ‘B’ have 56 cargo gates per tunnel conveyor. Therefore, providing that the cargo gravitate through the gates and onto the hold/tunnel belts, the numbers of gates (i.e. 56×2=112) would certainly supply more cargo than is required to achieve a discharging capacity of 4,000 tonnes/h. However, the gate control is designed to adjust the gates and maintain the preset discharging rate to avoid overloading the conveyors. With the MRG installation, the flow rate is not controlled by the speed of the tunnel/hold conveyors like the basket gate (see the MRG control system in Chapter 7). In the sub-section 6.6.2.4 and Appendix VI.8 of this Chapter, the discharging capacity for the hold/tunnel conveyors belt was calculated.

6.8.4.3 Reciprocating the MRG Assembly with Dry Coal

Reciprocating the cargo gate assembly while having the primary gate opened, is the development that optimizes the MRG design, when compared to previous and existing RTG. During the experiment with coal that was absolutely dry, the gate assembly was reciprocated by hand at a constant rate of 21 strokes in 30 seconds. This action simulated the secondary gate cylinders when operated by hydraulic oil onboard the vessel. See Figure 6.22 that illustrates the gate operating handle for simulating the secondary cylinders action. Table 6.16 demonstrate the summary of discharging rates during the reciprocating experiment with dry coal.

Table 6.16 Summary of Experiment with Coal - Primary Gate Opened and Reciprocating.

Gate		Flow		
Opening (mm)	**Reciprocation (strokes)**	**Total (g)**	**Time (s)**	**Rate (tonnes/h)**
10	21	185	30	**0.02**
20	9	527	15	**0.12**
30	1	554	1-2	**1.99**
30	1	550	1-2	**1.98**

Source: Results of Reciprocating Experiments with Coal. Welcome, H. S. 2008.

Note: Discharging rates are considered to be +- 10%.

When the primary gate opening was 10 mm and upon completing 21 strokes in thirty seconds, the total cargo flow was 185 grams. In this scenario, the flow of cargo was 0.02 tonne/h, which is a minor quantity. However, the discharging rate was important enough to ascertain that the moving-hole concept for the MRG is functional.

The experiments in Table 6.16 resulted in even and constant flow of cargo through the primary gate. The discharging condition while the primary gate was opened to 20 mm, proved to be highly significant and this scenario is what would be expected onboard SULS, in order to achieve a successful unloading.

Finally, when the primary gate was in the fully opened position i.e. 30 mm, the discharging rate was 1.98 tonne/h.

While conducting these final experiments with the primary gate fully opened, the quantity of cargo above the gate suddenly released in approximately one to two seconds. Obviously, this situation could result in overloading the belts. For this reason, when unloading cohesive and bridge cargoes similar to some coals (not all), it would be appropriate to partially opened the primary gate, reciprocate the gate assembly and then apply vibrator action.

Depending on the cargo flow while reciprocating the gate assembly, the primary gate dimension could either be increased or decreased to maintain the desired unloading rate. Figures 6.24 and 6.25 exhibit rat-holes after discharging the coal, which was above the primary gate while reciprocation the gate assembly. During these experiments, the primary gate was opened to 20 mm and 30 mm. To demolish these rat-holes, it would require the use of vibrators.

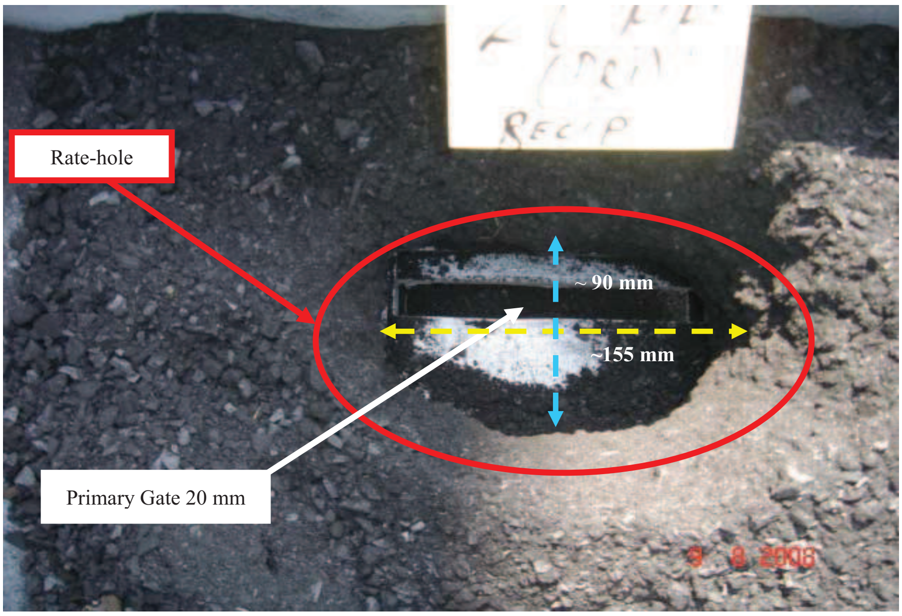


Figure 6.24 Gate Assy. Reciprocating – Primary Gate Opened 20 mm. Welcome, H. S. 2008.

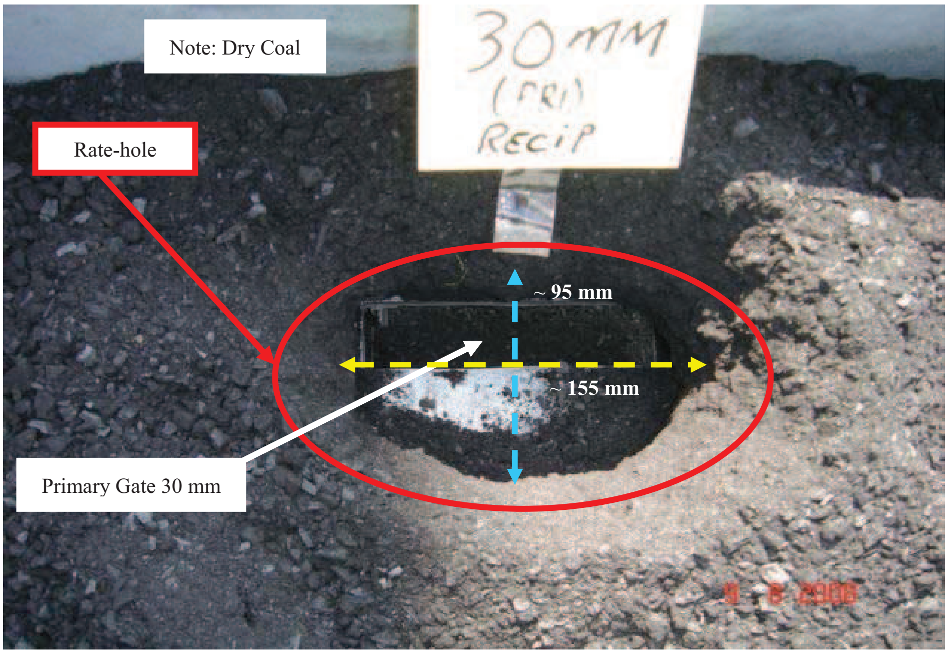


Figure 6.25 Gate Assy. Reciprocating – Primary Gate Opened 30 mm-Dry Coal. Welcome, H. S. 2008.

6.8.4.4 Reciprocating the MRG Assembly with Coal Containing 5% and 10% Moisture

Additional experiments (see Table 6.17) were affected subsequent to adding 5% and 10% moisture contents (i.e. water) by volume to the cargo, which was thoroughly mixed with the product prior to conducting the test. Invariably coal loaded onboard ships are from stockpiles that has various degrees of moisture contents, due to storage in open areas. Also after loading coal onboard the vessels, the moisture contents occasionally increases.

Table 6.17 Summary of Experiment with Coal Having 5% & 10% Moisture - Primary Gate Opened and Reciprocating.

Gate		Flow		
Opening (mm)	**Reciprocation (strokes)**	**Total (g)**	**Time (s)**	**Rate (tonnes/h)**
20	13 (5% Moisture)	168	15	**0.04**
20	21 (10% Moisture)	207	30	**0.02**
30	25 (10% Moisture)	362	30	**0.04**

Source: Results of Reciprocating Experiments with Coal. Welcome, H. S. 2008.

Note: Discharging rates are considered to be +- 10%.

By and large the percentages of moisture increase onboard the vessel depends on numerous factors such as, season of the year; demographic (i.e. loading and unloading port); storage onboard the vessels (i.e. moisture transferred from empty ballast tanks and heated fuel oil tanks, etc…); chemical reaction resulting in increasing the temperature of the coal, etc... Table 6.17 demonstrates the test results when the coal contained moisture.

In all three cases when the coal contained moisture of 5% and 10%, the gate assembly was reciprocated, resulting in a cargo discharging rate which was minor. However, the flow of coal was steady. This discharging situation continued until the total quantity of coal above the gate was unloaded. When the cargo stopped flowing, there was rat-hole that would require collapsing by utilizing vibrator to continue discharging. Figure 6.26 illustrates the rate-hole subsequent to discharging the moist coal, which was directly above the gate. In the experiment exhibited in Figure 6.26, the primary gate was opened to 30 mm and the coal had 10% moisture by volume. It should be noted that when the coal contained 10% moisture, the rat-hole diameter was smaller, when compared to the dry coal in Figure 6.25. This resulted from the cohesiveness by adding moisture to the coal.

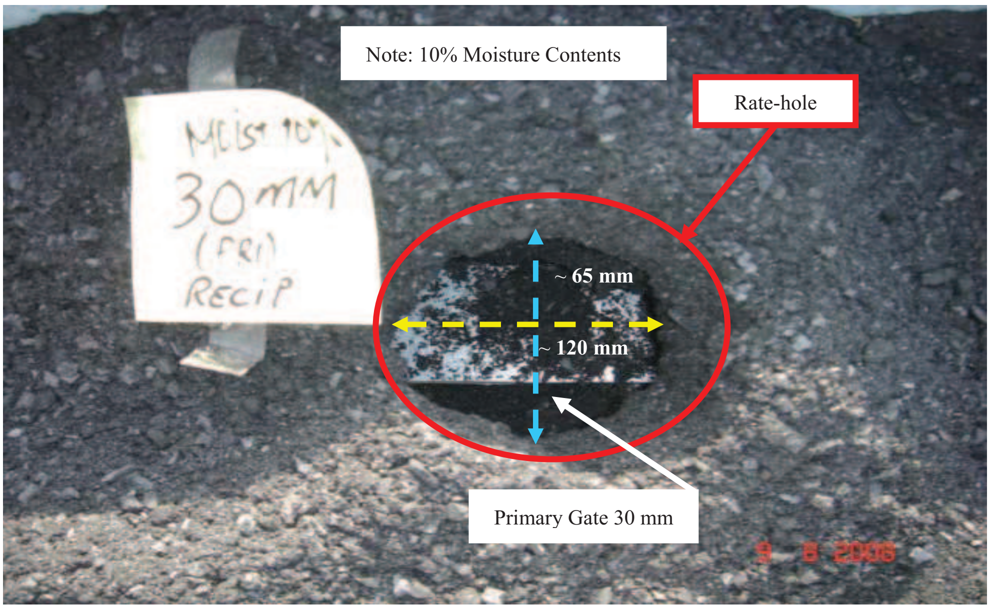


Figure 6.26 Gate Reciprocating–Primary Gate Opened 30 mm-10% Moisture. Welcome, H. S. 2008.

Some coals are difficult cargoes to discharge due to its cohesive nature and the discharging of coal onboard SULS becomes even more challenging when the material contains moisture. However, this experiment of discharging moist coal with the MRG test model proved that the 'moving-hole' theory is functional. The coal experiments revealed optimum results during the discharging of dry coal at gate opening of 20 mm and with wet coal (i.e. 5% and 10% moisture) at gate openings of 20 mm and 30 mm.

In summary, the discharging experiments conducted with the iconic model gate confirmed the design concept of the Multi-functional Roller Track Gate (MRG) while discharging real cargoes, such as oats, soya beans, corn and coal. The discharging rates were measured and recorded. Nevertheless, the quantitative analyses were fundamentally to substantiate the MRG concept and not to establish the discharging rate of Self-unloader Bulk Carriers (SULS). The results from the discharging experiments for the commodities (i.e. Oats, Soya Beans and Corn) forming part of this research are exhibited in Appendix VI.13.

6.9 The Design and Operational Risks

All engineering designs are accompanied by both design and operational risks and the Multi-functional Roller Track Gate (MRG) is no exception to this rule. Unlike the economic risks (see Chapter 8) that are uncontrollable due to the shipping market, the design and operational risks of the MRG are to some extent controllable.

Prior to deciding on installing a newly developed cargo gates onboard SULS, it is standard practice to construct a full-scale prototype gate. At this stage it would be appropriate for the full-scale mock-up (or prototype) to undergo tests thoroughly in the most severe manner to substantiate operational functionalities and deficiencies. However, the simple iconic model allowed some experiments to verify the MRG concept and the next stage, if commercially adopted, would be to construct a full-scale prototype. This would provide further justification of the concept and absence of any numerical modelling. Fundamentally, this approach of testing a full-scale MRG is not only to ensure the integrity of the design concept, but also allows the designers to effect necessary modifications and retest the gate before installing onboard SULS.

Nevertheless, there is one operational risk that is utterly uncontrollable by the designers and this is the cargo natural ability to flow freely. The cargo gates could function to their utmost mechanical efficiency. However, commodities with inherent cohesive nature that absolutely hangs-up and forms solid bridge will simply not flow through the gate. In this scenario, to promote flow the cargo consolidation requires demolishing by external force such as:

- Vibrator;
- Pneumatic hammer;
- Air/CO_2 cannon; and/or
- Degradation of cargo by using high-pressure water hose.

Alternatively, cargo gates having the ability to function under the moving-hole principle will discharge cohesive cargoes, which have inherent characteristics to form arches. For the reason that arches formation of sizes less than the gate aperture cannot supports themselves when the gate opening is reciprocating under the cargo. This concept was demonstrated with the MRG, when rat-holes were developed during the discharging experiments with coal (i.e. dry and with moisture).

6.10 Summary

This Chapter presents the design of a new gravity Roller Track Gates (RTG) for Self-unloader Bulk Carriers (SULS) called the Multi-functional Roller Track Gate (MRG). This Chapter also explains the design methodology of the MRG and the reasons for developing this new type of roller track gate.

The design comparisons of existing RTG with the MRG are established and the outcome substantiated that the MRG is an enhanced gravity gate for SULS, when compared to the current RTG. The previous design roller track gates have a maximum of two discharging modes and in some cases one. To enhance discharging of cargoes, the proposed gate has incorporated the moving-hole principles, four separate modes and three redundancies. This gate operating feature i.e. moving-hole principle and discharging options accompanying with the MRG, confirms that this new design is indeed an improved gravity gate for SULS. This novel design gate with associated benefits for the SULS shipowners will certainly reduce turn-around / unloading time and operating costs.

Like any equipment, the MRG has accompanying disadvantages. This is mainly due to having hogbacks resulting in a reduction of cargo hold volume and additional mechanical components that increases the ships' lightweight. Hogback can be made smaller to reduce lightweight, increase deadweight and increase cargo hold volume. However, smaller hogbacks would result in a flatter slope causing decrease in the flow of material. Except for the inherent characteristics of the cargoes, the drawbacks are primarily offset by:

- Introducing high tensile steel for fabricating the gate and constructing certain sections of the ships' hull, for weight reduction;
- Reducing operating costs due to less manning; and
- Reduce turn-around time due to automatic discharging and having incorporated the moving-hole principle, when compared to the existing RTG.

The MRG was designed specifically for installation in handymax SULS. Though, by adjusting the dimensions, this gate can be used for discharging Self-unloader Bulk Carriers' of the larger size, such as panamax and even aframax and capesize.

Each tunnel / hold conveyor in this study is designed for discharging 2,220 tonnes of coal per hour. This discharging capacity can be increased by installing wider conveyor belts and improving other design aspects of the unloading plant (i.e. belt speed, surcharge of cargo, vertical area of cargo, etc). Nevertheless, these changes would result in higher ship's lightweight, decrease cargo lift and less income for the shipowners.

Proper functionality of the gate depends on the ability to open and close effectively. Therefore, appropriate design of the operating cylinders for functioning the gates is imperative, to prevent delays in discharging. This concern is addressed (see Appendix VI.8) by ensuring the cargo gate cylinders are engineered with sufficient reserve operating force to overcome the mechanical flexing and possible jamming of the gates.

Two models of the MRG were fabricated, one to demonstrate the design concept and the other an iconic model to test the design theory, while discharging various cargoes (i.e. coal, oats, soya and corn) transported by SULS. These cargoes were discharged satisfactorily by the iconic model and the discharging rates were recorded. However, the flow rates were primarily to confirm the design concept and not to measure quantitative values. Numerical, graphical and pictorial models were also developed to further establish the gate discharging flow rates with various products.

The experiments in the simulated 'remote automatic reciprocating mode' while discharging dry and moist coal were outstanding and as expected; especially when the primary gate was opened from 20 mm to 30 mm. These discharging functions were a verification of the moving-hole principle, which is the fundamental intention of the MRG design. Because the MRG has large secondary gate aperture, this gate addresses bulk flow discharging issues and would competently discharge dry bulk cargoes that is lumpy, moist and cohesive.

In summary, the experiments while discharging coal proved that the MRG is truly an enhanced gravity Roller Track Gate design, particularly when operating in the 'remote automatic reciprocating mode'. The MRG is also capable of unloading cargoes similar to those discharged by the original and existing RTG. However, when discharging cohesive cargoes, the MRG capability surpasses the previous RTG. The intended aims for the MRG have been achieved by having combination gate openings for discharging and incorporating the 'moving-hole' principle into the design (see Appendix VI.13).

Finally, it would be advisable to manufacture a full size prototype MRG that should be tested for design and functionality issues prior to installing this new gate in a vessel.

Chapter 7

7. THE DESIGN OF A CONTROL SYSTEM FOR A NEW ENHANCED GRAVITY ROLLER TRACK CARGO GATE

7.1 Introduction

In the previous Chapter the design of a new Multi-functional Roller Track Gate (MRG) has been described. The intention of this gate design is to improve the discharging of dry bulk cargoes onboard Self-unloader Bulk Carriers (SULS) by enhancing the unloading operations, when compared to the original and existing Roller Track Gates (RTG). If this is to be achieved and the benefits of the new gate to be fully exploited, then the complete unloading control system presented in this Chapter and Appendix VII.1 needs to be considered and modelled onboard the ship to ensure maximum reliability of the MRG discharging operations. The other modelling approach would be to test the control system with a full size prototype MRG prior to installing in SULS.

This Chapter and Appendix VII.1 present an original control system designed specifically for the MRG type of RTG and the integrated conveyors on SULS. The MRG design provides the definition required for all the associated systems invented for the implementation of the proposed unloading system onboard Self-unloader Bulk Carriers'. The originality of the proposed gate also requires equal originality of the accompanying control system.

The MRG encompasses two integrated gates having incorporated control system for discharging with either gate independently or both gates simultaneously. This discharging concept addresses the moving-hole principle that is unlike previous RTG. These features of two discharging gates and the 'moving-hole' theory make the MRG invention a novel design.

The proposed control system is designed to reduce operating costs by having reduced staff for unloading the vessel, while benefiting from less port turn around time. This system was primarily designed for controlling the discharging of handymax SULS. However, the proposed control system would also be suitable for discharging larger size SULS with MRG installed.

Models and matrices representing the principal discharging modes are presented to illustrate the functionality of the MRG. The gate control systems proposed include monitoring and safety precautions to protect both operators and the equipment when discharging cargo. The MRG integration with the upstream cargo holds and downstream conveyors are emphasized, demonstrating the importance of the cargo gates for effective unloading from the vessel to the customers facility.

Depending on the shipowners' desire, charterers request or trade demand, the all-belt SULS gravity systems are configured with one, two or three belt tunnel conveyors. However, the shipowner has to decide on the type of unloading installation for the trade selected. Appendix VII.2 accompanying this Chapter demonstrates some essential principles that are necessary, when selecting equipment for SULS.

Finally, this Chapter and Appendix VII.1 are applicable to the control systems for discharging operations with the MRG and integrated conveyors arrangement introduced in this study. The systems for controlling the discharging operations are illustrated, while incorporating detailed flowcharts with comprehensive functionalities, monitoring and safety precautions when using the MRG.

7.2 Operating Principles of the Multi-functional Roller Track Gate

The Multi-functional Roller Gate (MRG) is an enhanced type of Roller Track Gate (RTG), when compared to the original design **(1908)** and the developed versions currently installed onboard SULS. The MRG is specifically designed to maximise and increase the flexibility of unloading SULS trading on the Great Lakes of North America and internationally. The discharging principle of the MRG is by gravity which clearly indicates that this gate shares a common operational characteristic, when compared to other gravity unloading system onboard SULS. However, the MRG is an original multi-functional unloading concept of the gravity type with additional cargo discharging features, when weighed against both the original and existing gravity gates onboard SULS. Model scale experiments of the MRG have demonstrated that the design functions with actual commodities which are currently being transported onboard SULS. In Chapter 6 various tests undertaken with the MRG were illustrated while discharging oats, soya beans, corn and coal. These products are some of the cargoes presently being traded by SULS,

This new gate has operational characteristics that allow for combination discharging of the commodity simultaneously with two gates (i.e. primary and secondary), four separate ways or modes and three redundancies. These multiple discharging methods are the enhanced operations of the MRG design, when compared to the existing Roller Tack Gates (RTG) that have two discharging modes and sometimes one mode. The MRG design has incorporated the ‘moving-hole’ principle and requires a control system as presented in this Chapter and Appendix VII.1 for appropriate discharging operations. The ‘moving-hole’ concept is ideal for discharging cohesive dry bulk materials that are hanging-up, ‘bridging’ and ‘arching’ due to moisture. This novel and unique moving-hole feature of the MRG is not included with the RTG design; as a result the MRG is an improved gravity gate for SULS when compared to the RTG.

To guarantee appropriate functioning of the control systems, the discharging operations should be tested with a full size shore-based prototype MRG or onboard the vessel. The following section and Appendix VII.1 outline the control system with operational models for unloading cargo in four different modes and three redundancies with the MRG.

7.2.1 Model for Primary and Secondary Gate Operations-Automatic Discharging

This mode represents the principal or standard discharging operations with the MRG and is considered the automatic combination mode. While unloading in this mode, no gate operators are required locally in the unloading tunnel to address the functions of opening and closing of the gates. The discharging in this mode with the primary and secondary gates is affected remotely by a single operator from the cargo control room (CCR). Prior to unloading the ship in this mode, there are three major and important pre-requisites which have to be complied with before the operator is allowed to operate the gate, namely:

- All conveyors downstream of the tunnel belts, i.e. transfers, elevator and boom must be operating at the design speed;
- The tunnels conveyors must also be operating at the design speed; and
- The hydraulic system pressure must be in accordance with the design parameter for functioning of the gates and ensure proper belt tension.

When the above three conditions are fully satisfied, this would allow the operator access for opening and closing the gates remotely from the CCR. Subsequent to having all conveyors operational and appropriate hydraulic system pressure, the discharging of the vessel can commence by:

- Utilizing the remote gate controls for opening and closing of the primary gates to a length, from 0 to 300 mm and vise-versa, that is required to achieve the unloading rate;
- Once the primary gates are remotely opened or closed, the gates position can be monitored in the CCR. In the monitor, the exact positions of the gates are verified as a percentage of opened or closed. This information is relayed or transmitted to the CCR computer monitor by the linear transducers, which are embedded in the gates cylinder shafts or by proximity switches attached to the gates;
- At this point of the unloading process, cargo has been discharged onto the tunnel belts and load signals from the kW meters for the tunnel belt motors are transmitted to the secondary cylinder controls;
- The kW signal initiates the reciprocating action of the secondary gates assembly that allows automatic movement longitudinally from 0 to 600 mm and vise-versa. In the

event that the tunnel belt load, kW, is reduced to a no-load condition or no cargo on the belts, then this scenario results in automatic stopping of the secondary gates reciprocation action to avoid compaction of commodity above the gates in the cargo hold, due to no flow of material through the gates;

- The primary and secondary gates are amalgamated and comprise one unit. This clearly indicates that the entire gate assembly, of both primary and secondary gates, can be moved together longitudinally within the limits of the hogbacks base, which are spaced 900 mm apart. Technically, the gate assembly reciprocates automatically 600 mm while the primary gates are opened, results in bridged cargo falling through the primary gate openings and onto the hold conveyors. This automatic gate action is based on the ‘moving-hole principle’, where arched cargo over a slot cannot support itself when the slots, i.e. primary gates, are continuously moving back and forth to new positions, therefore causing the arch to collapse and cargo falling through the slots or gates;
- The tunnel conveyor scales indicate the actual discharging rate in tonnes/h for each tunnel belt, while the traffic lights confirm the discharging ranges i.e. low, set rate and overloaded. This information is relayed, monitored and recorded in the CCR computer;
- The discharging rate is set at a predetermined value and depending on the actual unloading rate, the tunnel belt scale automatically transmits a signal to the remote gate controls in the CCR to either open or close the primary gates; and
- Finally, the material on the tunnel belts is conveyed to the remaining downstream conveyors and to the customers’ facility ashore.

Figure 7.1 and Table 7.1 illustrate the flowchart and matrix of the functionality for the primary and secondary gates remote automatic unloading mode. Appendix VI.12 (a, b and c) shows the MRG in its entirety; three orthogonal views of the gate with the accompanying mechanism.

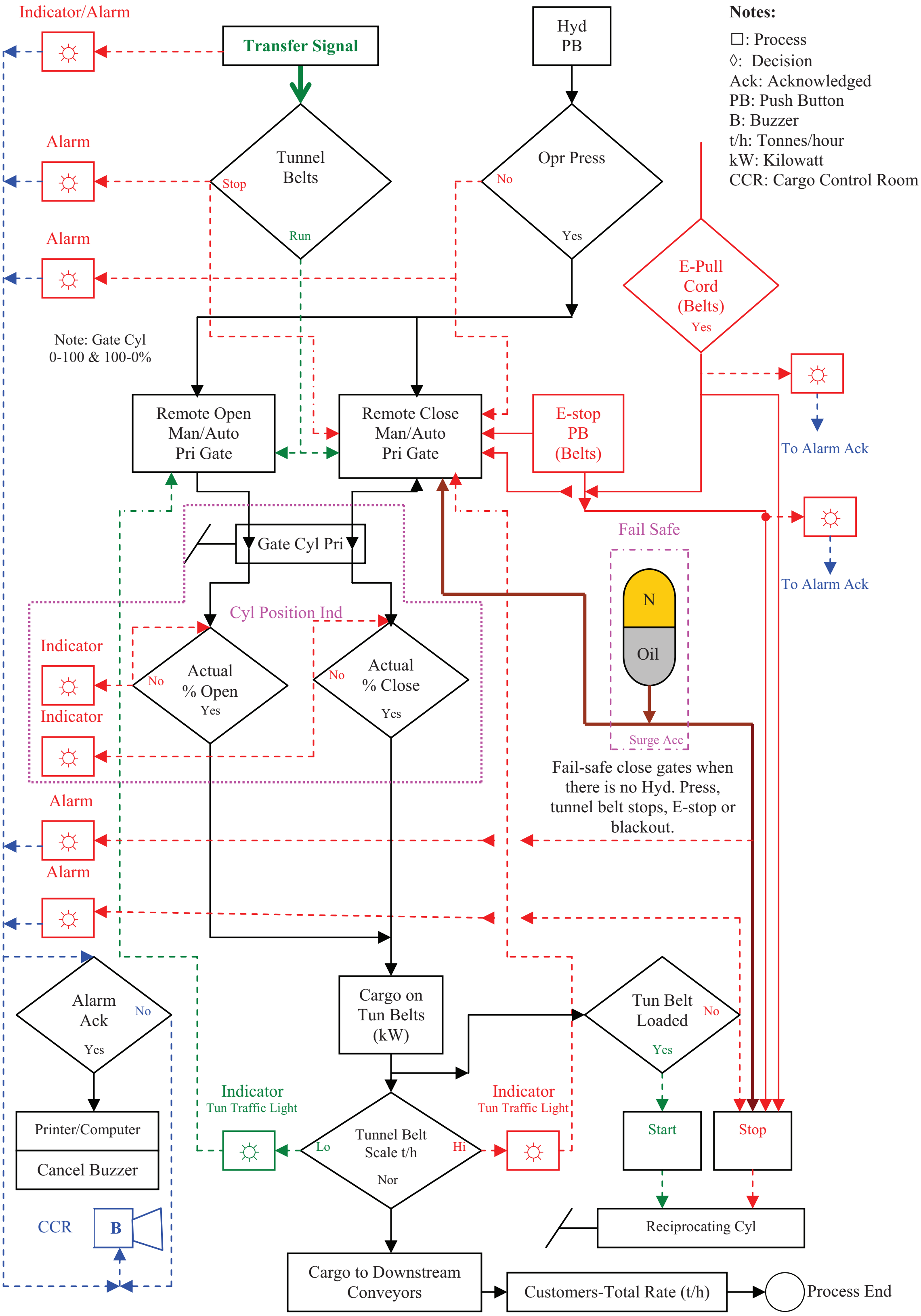


Figure 7.1 Model for Primary and Secondary Gate Operations – Automatic Discharging (Welcome, H. 2008).

Table 7.1 Matrix for Primary and Secondary Gate Operations – Automatic Discharging (Welcome, H. 2008).

Sequential Function	**Remote Manual Operations (CCR)**							**Results and Display (CCR)**
	YES	**NO**	**Run**	**Stop**	**Lo**	**Hi**	**Safety**	
Transfer Belts Healthy	O	-	-	-	-	-	Indicator	Tunnel Belt Operation Permissible
	-	X	-	-	-	-	Alarm	Tunnel Belt Operation Not Permissible
Hydraulic Pressure	O	-	-	-	-	-	Indicator	Belt Tension OK - Operations of Gates and Tunnel Belts Permissible
	-	X	-	-	-	-	Alarm	Gates Close by Failed Safe
Tunnel Belt	-	-	O	-	-	-	Indicator	Gate Open & Close Permissible
	-	X	-	-	-	-	Alarm	Operator Close Gates - Avoid Flooding
Man/Auto Open Gate	O	-	-	-	-	-	Indicator & Control	Gate Opening 0 to 100% Permissible
Man/Auto Close Gate	O	-	-	-	-	-	Indicator & Control	Gate Closing 100 to 0% Permissible
Actual % Gate Open	O	-	-	-	-	-	Indicator	Transducer Confirms Gate Open Position
Actual % Gate Close	O	-	-	-	-	-	Indicator	Transducer Confirms Gate Close Position
Cargo on Tunnel Belt	O	-	-	-		-	Indicator	kW Meter Confirms Load on each Tunnel Belt & Start or Stop Reciprocating Cylinder
Tunnel Belt Scale	O	-	-	-	-	-	Indicator & Control	Indicator Confirms Discharging Rate of each Tunnel Belt and Allows for Auto Gate Opening or Closing
Downstream Conv	-	-	O	-	-	-	Indicator	Discharge Cargo to Customer
Customers	O	-	-	-	-	-	Indicator	Boom Discharging Meter Confirms Unloading Rate & Total Cargo Discharged
Alarm Acknowledge	O	-	-	-	-	-	Buzzer	Data Printed & Recorded in Computer
	-	X	-	-	-	-	Buzzer	Audible Signal Until Acknowledge-print data
E-stop All Belts	O	-	-	-	-	-	Alarm	Close Gates - Avoid Flooding Belt
E-Pull Cord (Tun Belt)	O	-	-	-	-	-	Alarm	Close Gates - Avoid Flooding Belt
Conditions	**Fail Safe System (Surge Accumulator)**							**Results and Display (CCR)**
Hydraulic Pressure	-	X	-	-	-	-	Alarm	Close Gates – Avoid Flooding Belt
Tunnel Belt	-	-	-	X	-	-	Alarm	Close Gates – Avoid Flooding Belt
Power Failure	O	-	-	-	-	-	-	Close Gates – Avoid Flooding Belt

O: Yes/Run/Lo **X: No/Stop/Hi/Safety** **-: N/A**

During discharging in the automatic mode with both the primary and secondary gates, the safety monitoring system is enabled and can be viewed in the CCR. These protective devices are described in Figure 7.1 and Table 7.1, namely:

- Transfer belts healthy signal;
- Tunnel belts operating conditions (i.e. running or stopped);
- Hydraulic oil pressure;
- Remote operation of gates (i.e. opened or closed);
- Actual percentages of gates opened or closed;
- Tunnel belts load (motors kW or cargo on tunnel belts);
- Gates reciprocating conditions with secondary cylinders (i.e. started or stopped);
- Tunnel belt scales and traffic lights (i.e. tonnes/h of cargo discharging);
- Running condition / indication of tunnel belts and other downstream conveyors;
- Customer (i.e. total discharging rate in tonnes/h);
- Buzzer, indicators and alarms;
- Alarm acknowledgement;
- Log printer and computer;
- Emergency pull cords for tunnel belts;
- Emergency stop (all conveyor motors); and
- Fail safe to close gates when tunnel belts stopped, no hydraulic pressure and loss of ship's power supply.

With properly flowing cargoes, such as dry iron ore pellets, stone, sand, grain, etc., it would be unnecessary to reciprocate the gates assembly automatically from the CCR. This is because the discharging rates can easily be accomplished by using only the primary gates for unloading the cargo. This mode also allows the operators to manually open the secondary gate or reciprocate the gate assembly remotely from the CCR. However, because of the ability to have large gate openings and the possibility of overloading the hold conveyors, it would be advisable for the operators to limit remote manual opening of the secondary gates from the CCR. Reciprocating the gates assembly manually from the CCR should only be attempted when cargo is flowing through the primary gates as this would avoid compacting the commodity in the cargo holds above the gates assembly, resulting from friction between the gates surface and cargo. Adhering to the tunnel belts traffic light signals would guide the operators to the appropriate time to manually operate the remote reciprocating mechanism for the gate assembly.

In the event of moisture presence in the cargo causing hang-up and bridging resulting from arching and rat-holing, the automatic discharging mode would undoubtedly be the most appropriate unloading method to enhance both cargo flow and discharging rate.

7.3 Integration of the MRG with Cargo Holds and Conveyors

As has already been discussed, Self-unloader Bulk Carriers (SULS) technology was developed in the early 20th century. Subsequent to the inception of SULS, the cargo gates have developed significantly and are obviously the fundamental facet of the self-unloading system. However, without the integration of cargo holds with cargoes and the conveyors, the cargo gates alone are insufficient to achieve the reliable discharging of SULS. According to Wright **(1990, pp.78-79),** '*the main area of technical development has been the gates which releases cargo from the cargo holds onto the belt'.* The cargo holds arrangement onboard full gravity SULS are similar in most respects and over the years there have been only minor variations in design relevant to both hopper and hogback angles. However, the conveyors for conveying the cargo ashore to the customer facilities are somewhat different in configuration and there are various conveyor arrangements i.e. one, two or three belts depending on the shipowners' preference and trade. For example, as discussed in Chapter 4, Appendix VII.1 and the subsequent section, the multiple conveyors system has more discharging options and offers great cargo hold volume.

7.3.1 Configuration of the All-belt installations for Self-unloader Bulk Carriers

The all-belt full gravity type Self-unloaders Bulk Carriers predominantly has three different types of tunnel belt arrangements, while utilising various designs of gravity gates for discharging their cargoes. The MRG are included in the category of gravity gates that can be use for unloading SULS of the various known configuration of tunnel belts, namely:

- The single belt system;
- The double belts system; and
- The triple belts or "W" configuration system.

By and large the double and triple belt configurations are the most common installations, simply because these systems allow for greater cargo hold volume. Obviously, when SULS are designed primarily for trading high density cargoes, the cargo hold volumetric capacity is unimportant because the maximum draft is attained before filling the cargo holds to maximum volumetric capacity. Therefore, in the scenario of SULS designed for high density trades, the single tunnel belt system is normally considered to be the appropriate installation.

Figure 7.2 and Appendix VII.1 illustrate the different views of the various and most popular configuration of conveyor systems employed onboard the full gravity discharging SULS of the all-belt type installations.

Onboard some of the modern SULS, the conveyors have variable speed that can be adjusted to suit the desirable unloading rate. This speed control function also allows for the reduction of cargo spillage that ultimately results in product wastage and degradation from contamination with the tank top debris, such as sea water, grease, etc after spillage of cargoes occurred.
The Multi-functional Roller Track Gate (MRG) discharging operations in the four modes are in combination with either the one, two or three tunnel belt arrangements. The fundamental principles of cargo operations for the two tunnel belt installation are outlined in the next section.

7.3.2 Cargo Operations with Two Tunnel Belts Onboard All-belt SULS

The two tunnel belts installation is employed when both high discharging rates and increased cargo hold volume is required; see Figure 7.2. The commodity can be gravitated simultaneously from both sides, i.e. port and starboard, of the vessel's cargo holds through the cargo gates and onto the respective tunnel belts. Alternatively, for a lower unloading rate, only one conveyor is used and cargo can also be discharged from either the port or starboard side of the cargo holds. The individual tunnel conveyors discharge cargo into the transfer belt feed chutes. Subsequently, cargo from the transfer conveyors are discharged directly into the elevator feed hopper, where the product from both the port and starboard side of the cargo holds are mixed in preparation for elevation to the upper deck by the elevator and discharged into the boom feed chute. At this point, the product is conveyed ashore to the customer's facility by the boom conveyor.

The unloading installations with two tunnel belts have operational advantages when compared to the single belt system. For the reason that during malfunction of either tunnel conveyor, the unloading operation can continue with one belt, while compensating with ballast to maintain the vessel in an upright condition. Keeping the vessel upright would avoid detraining of the tunnel belts that could result in mechanical damages to the belt edges. In reality, the second tunnel belt allows for greater unloading rate and also functions as redundancy for the unloading system. However, the drawback with multiple belt installations is increased cost and maintenance due additional components and moving parts.

Figure 7.2 exhibits the layout diagram and understanding of the cargo flow for a two belt conveyor system employed on the gravity all-belt SULS. Appendix VII.1 illustrates the one and three tunnel belt arrangements with the accompanying control systems (i.e. flowcharts) for SULS discharging conveyors in their entirety.

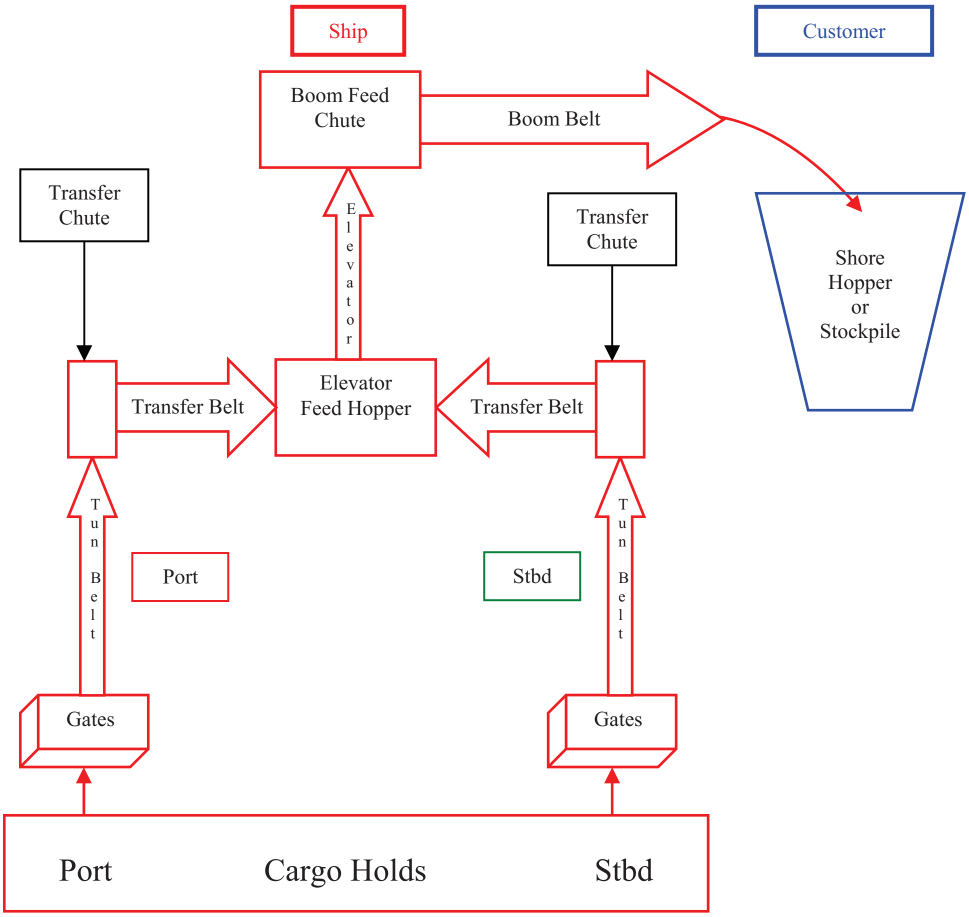


Figure 7.2 Plan View for Double Tunnel Conveyors System Onboard SULS (Welcome, H. 2008).

7.4 Summary

Fundamentally, Chapter 7 and Appendix VII.1 describe a control system designed for discharging dry bulk material with the proposed new enhanced gravity gate for Self-unloader Bulk Carriers, called the Multi-functional Roller Track Gate (MRG). The continuation of this Chapter is Appendix VII.1 discusses the importance of correct system modelling and the control system for operating conveyors which are integrated with the MRG.

This control system primarily focuses on improving the discharging operations of the Multi-functional Roller Track Gate (MRG) onboard SULS. The control system for discharging with the previous Roller Track Gate (RTG) has a maximum of two discharging modes and in some cases one mode. This new MRG gate have four discharging modes and three redundancies for controlling the unloading of cargo onboard SULS and the design also has characteristics included that addresses the 'moving-hole' principle. Clearly, this moving-hole feature is excluded from the existing design of RTG, making the MRG invention an improved type of Roller Track Gate, when compared to previous RTG. Appendices VII.3, VII.4 and VI.12 (a, b and c) demonstrate this new design gravity gate for SULS with details that undoubtedly result in a comprehensive development of the Roller Track Gate.

Models of discharging operations, with accompanying operational matrices, were designed for controlling the gate and integrated conveyors of various configurations, comprising cargo discharging plants for Self-unloader Bulk Carriers' of the one, two and three tunnel belt installation. The controlling systems proposed are intended to maximise the stated advantages of the MRG design, while ensuring safety to personnel and equipment. The resulting system would benefit from reduced labour during unloading and also reduce port turn-around time while discharging. These benefits would reduce operating costs and improve the economic performance of a design incorporating this new system. This is justified in a formal techno-economic study in the subsequent Chapter.

The MRG design proposed is for installation in a handymax SULS. However it could be scaled up for use in larger size vessels. Prior to installing the MRG in SULS, the vessels' trade would have to be considered carefully in terms of an appropriate fleet analysis and techno-economic study. This would ensure the correct selection of the accompanying equipment forming part of the unloading system, i.e. control system, conveyors, prime movers, etc. for the most economic operation.

In summary, the control system in this Chapter and Appendix VII.1 is an original concept designed specifically for operating the MRG. The MRG is not an open-hole design, although it is an original design comprising the moving-hole principle. In addition to the improved discharging modes with the MRG, the control system and accompanying moving-hole theory enhances the discharging of SULS while trading cohesive cargoes, when compared to previous RTG's. It is believed that this design of gravity Roller Track Gate and associated control system for unloading SULS with the MRG, will contribute significantly to future technology of Self-unloader Bulk Carriers'.

Chapter 8

8. THE ECONOMIC EVALUATION OF THE MULTI-FUNCTIONAL ROLLER TRACK GATE

8.1 Introduction

The economic study presented in this Chapter relates to the scenario of a shipowner purchasing a second hand SULS of the Model ‘B’ type. Subsequently, refitting and upgrading the vessel structure as well as replacing the existing Roller Track Gates (RTG) with the new Multi-functional Roller Track Gates (MRG) previously proposed. These changes to the vessel structure and cargo gates would result in a life extension and would improve the trading ability and cargo discharging performance. The following study seeks to establish the potential economic advantages to the owner of undertaking such a refit.

Feasibility studies were conducted in many areas, such as the trade; the charter party; purchasing the vessel; financial planning for the 6 year project and benefits resulting from the cargo gates conversion. These investigating assumptions were necessary for determining the possible return from the investment, before deciding to purchase the vessel. The expected return from the investment was assumed to be 10% for 6 years on the capital invested.

Subsequent to affecting the feasibility studies, the purchasing of the vessel to some extent was based on results obtained from various financial studies, such as the predicted annual and discounted cashflows. The final decision to implement the project was subject to outcomes from the sensitivity analysis, relevant to time charters income, conversion time and cost for steel. In an event of the time charter cancellation, fuel cost was another facet analysed as this would form part of the owner’s operating costs.

The economic risks were addressed primarily to highlight the financial threats that could occur, throughout the course of the project. Fundamentally, the analyses conducted were to confirm if there would be a profit or return from investment after the 6 year project.
To complete this economic case study on SULS, data was collected from real life shipping scenarios, confidential literatures of shipowners' and in some respects the author's experience.

8.2 The Collection of Economic Data

For reasons of confidentiality most shipowners' decline to reveal their operating costs and other financial information. SULS owners are primarily private-owned shipping companies and are notorious for not disclosing their operating costs. In 1973, Jones, Smith and Wright **(1973, p.241)** encountered a drawback with the accuracy of shipowners' operating costs while carrying out a study on large SULS and stated that *'annual maintenance costs have been found to range from USD 35,000 up to well over USD 100,000 on the units studied'* and went on by saying that *'such costs are not considered absolutely accurate, since many owners do not like to release their operating costs'*. Nevertheless, the vast majority of the economic model developed in this research originated from credible sources and data. This allowed both real life scenarios from the SULS sector of the maritime industry to be used and confidential data collected from SULS shipowners'. However, some assumptions have been made based on the author's experience.

The author's extensive experience in this sector includes the inspections of second hand SULS, recommendations to purchase vessels, and suggestions as to how to improve the discharging efficiency and preventive maintenance of the unloading equipment. During these inspections of SULS for sale and purchase, examination of the vessels in their entirety was important. However, in detail, it is of utmost importance to emphasize the unloading equipment condition and the ability of the vessel to discharge her cargoes effectively. SULS trade to remote ports without unloading infrastructure and the vessel must be capable of discharging her cargoes autonomously without failing.

8.3 Economic Feasibility Study

Business feasibility studies are effective ways to safeguard against wastage of further investment and resources. Thompson **(2000, p.185)** stated that *'A business feasibility study can be defined as a controlled process for identifying problems and opportunities, determining objectives, describing solutions, defining successful outcomes and assessing the range of costs and benefits associated with several alternatives for solving a problem'.*

Prior to purchasing the Model 'B', the new owner carried out a feasibility study into the economic viability of the project. This study resulted from the charterer approaching the proposed owner, confirming that upon expiration of the bareboat charter in 2005, the charterer intention was to continue chartering the vessel for 6 years on a Time Charter (TC) basis. This was the inception of the project and subsequently the new owner became interested and started:

- Investigating the trade possibilities;
- Reviewing the charter party offered by the client;
- Formulating the business and purchasing plan;
- Investigating the possibilities of injecting additional capital to enhance profit, resulting from upgrading the vessel structure and converting the unloading system, to gain higher income/revenue;
- Method of financing the project; and
- Developing a financial plan for the 6 year project with the intention of optimizing return from investment. The intended return was 10% on capital invested.

8.3.1 The Trade – Great Lakes and International

Depending on weather conditions, the yearly navigational season for this type vessel on the Great Lakes would normally be from the beginning of March to the end of October. During this period, the standard loading and unloading practices for the Model 'B' type vessels trading in the Lake Erie region between ports of USA and Canada are:

- 8 hours loading;
- 6 hours sea leg from the loading to unloading port;
- 8 hours unloading; and
- 6 hours sea leg from the unloading to loading port.

The SULS trading pattern is 24 hours/day and 7 days/week. Therefore, the trip time amounts to 28 hours/trip or 1.2 days/trip. However, based on the author's sailing experience onboard these type vessels and the norm of the Great Lakes trade i.e. Lake Erie, the average trip time/navigational season is 2.4 days or 100 trips per season. The additional delay of 1.2 days/trip resulted from:

- Poor or adverse weather conditions;
- Time for berthing/un-berthing of the vessel;
- Time waiting to berth at the loading port;
- Time for ballasting/de-ballasting of the vessel;
- Custom and immigration formalities at the arrival ports; and
- The underlined inefficiency of the crew (e.g. delay in positioning the unloading boom; delay in starting the unloading plant; inexperienced Tunnelmen or gate operators; general negligence of the Tunnelmen or gate operators to focus on speeding-up the unloading; time for the Tunnelmen to move from one cargo hold to another in accordance with the unloading plan; meals breaks; etc…).

The main issue that causes unnecessary unloading delays is the operators' attitude and trade union rules. For example, the Model 'B' type SULS of the two holds conveyor arrangements have one Electrician and three Tunnelmen (i.e. one Head Tunnelman and two Tunnelmen) for unloading the cargo. Clearly, from the number of Tunnelmen currently assigned to these types of vessels, the unloading operations should be continuous and without any interruption. This is providing that there is appropriate co-ordination between the Tunnelmen. However, the simple issue of meal breaks causes delay, due to poor harmonization in the issuing of meal breaks, resulting in a lapse of unloading cargo during the meal periods. The meal time regulations of the Seafarers' International Union Canada **(2008, pp.16.17)** are.

> *'14. MEALS, COFFEE TIME AND LUNCHES:*
> *Breakfast from 07:30 hrs to 08:30 hrs.*
> *Lunch from 11:30 hrs to 12:30 hrs.*
> *Dinner from 17:00 hrs to 18:00 hrs.*
>
> *(g) Should an employee not receive one (1) full- unbroken hour to eat a meal, he shall have one-half (1/2) an unbroken hour in which to eat a meal and be paid straight through the hour at the overtime rate Monday through Friday and at the double (2) time rate outside an employee's regular hours of work and on Saturday, Sunday and Statutory Holidays.*
>
> *Should an employee not receive one-half (1/2) an unbroken hour in which to eat a meal, he shall be paid in addition to his wages earned one (1) hour at the overtime rate Monday through Friday and at the double (2) time rate outside his regular hours of work on Saturday, Sunday and Statutory Holidays'.*

Providing that the shipboard operators adhere to the working time (i.e. hours) and meal breaks agreed between the owner and trade, then obviously the owners would benefit from both reduced unloading and vessel turn-around times in port. However, reducing time in this area i.e. meal breaks is unlikely, because this operators' habit has been in place and practiced for decades.

The other concern that have caused minor delays in unloading SULS, is the time taken by the gate operators / Tunnelmen to actually walk from one cargo hold to another. This delay primarily occurs after discharging a cargo hold and in accordance with the vessel's unloading plan to ensure that the hull structure is not over stressed; the adjacent cargo hold is not the next sector to be unloaded.

Adding the delays for all the above reasons contributes to increasing the trip time from 1.2 to 2.4 days/trip:

- March
  To Average trip unloading = 240/100 = 2.4 days
- October or 12.5 discharges/month or 100 discharges in 8 months.

With the MRG functioning in the remote automatic mode where only one Tunnelman is required in the unloading tunnel, these lapse times resulting from operator negligence can obviously be reduced to a minimum of at least 1 hour/trip, when trading in the Great Lakes region and by approximately 2 hours/trip on the international trades. In addition, the remote operations of the cargo gates by one operator, would undoubtedly reduce the unloading time, for the reason that the entire unloading operations are accessible from one remote station i.e. cargo control room.

For the remaining 4 months of the year when the Great Lakes navigational season is closed (i.e., November, December, January and February), the Model 'B' type of vessels trade internationally, averaging 2.5 discharges/month. For example, Figure 8.1 shows the international trading routes that would be similar to:

- Canada east coast to US gulf (loaded) - 7 days;
- US gulf to Bahamas (ballast) - 3.5 days;
- Bahamas to US gulf (loaded) - 3.5 days;
- US gulf to Canada east coast (ballast) - 7 days; and
- Loading and unloading times - 3 days.

These trade routes average two discharges in 24 days or one discharge in 12 days, which clearly indicates that in 4 months (i.e. November to February) there are ten discharges:

- November 30 days;
- December 31 days; Total of 120 days / 12 = 10 Unloading
- January 31 days; and or 2.5 discharges/month or 10 discharges in 4 months.
- February 28 days.

Figure 8.1 Trade Route for Four Months When the Great Lakes are Closed for Navigation.

Canada East Coast/US Gulf Coast/ Canada East Coast

US Gulf Coast/Bahamas/US Gulf Coast

The international trading pattern for SULS is unlike the Great Lakes trade, where the average monthly unloading time during the navigational season amounts to 12.5 trips per month, when comparing with international trade that are 2.5 trips per month. Therefore, for this vessel, the current numbers of discharges in a calendar year would average 110 trips (i.e. 100 Great Lakes and 10 International). By addressing and resolving the current delay issues for the Model 'B' type SULS, the unloading time could easily be reduced by at least 100 hours (i.e. 4.2 days) in 8 months on the Great Lakes and by 24 hours (i.e. 1 day) in 4 months while trading internationally. Thereby, increasing the numbers of trips or unloading per year on the Great Lakes from 100 to 102 would result in additional revenue of 5 days time charter (TC) annually. There would also be minor benefits when the vessel is trading in foreign trades (i.e. 1 day TC). These decreases in unloading times or additional trips/year are of obvious economic advantage, primarily when trading in the Great Lakes region.

8.3.2 The Charter Party - Contract

Upon expiration of the bareboat charter (late 2005 to early 2006) and the new owner purchasing the Model 'B' vessel, the ship was chartered for 1 year time charter at the market rate of USD 19,900/day. The charterer previously promised the new owner to charter the vessel for 5 additional years upon expiration of the 1 year time charter in 2007. This extended 5 years time charter agreement was optional at the charterers' discretion. However, the time charter renewal (i.e. 2007-2011) would be at the market rate upon expiration of the previous contract in January 2007. Thereby, allowing the owner to develop plans for the project in 2006. When the contract was due to be renewed in January 2007, the market rate for 1 year time charter according to Compass Maritime Services **(2007)** had increased by approximately 106% (i.e. USD 19,900/day to USD 40,900/day), when compared to the 2006 rates. The daily time charter rate in 2007 was somewhat higher than predicted by the charterer. Therefore, the charterer re-negotiated with the owner for a reduced long-term time charter at a rate of USD 36,900/day for the 5 subsequent years (i.e. 2007 to 2011). Unconditionally, the owner agreed with the long-term time charter rates proposed by the charterer, for the reason that perhaps the market could possibly reduce during the following 5 years (refer to the original time charter rates in Appendix VIII.1a for the daily rates in 2007).

In summary, rather than the owner speculating on the time charter market, it was obviously beneficial for the owner to have a fixed income for 5 additional years until the vessel completed 30 years of service; at which time, a corporate decision would have to be made whether to invest additional capital, sell or scrap the vessel. This would depend on the market. For the record, it should be noted that SULS operating in the Great Lakes region have a life exceeding 30 years and this is due to reduced hull corrosion from operating the vessels in a fresh water environment.

Despite the business holidays, on the first of January 2006 and 2007, the contracts were renewed for:

- One year in 2006 at the market rate of USD 19,900/day; and
- Five years in 2007 at the negotiated rate of USD 36,900/day.

Due to the strenuous trading pattern for this vessel on the Great Lakes, by having to complete 100 trips in approximately 240 days/year (or 8 months/year), the charter party had inserted clauses that allowed time for repairs and maintenance. The time charter permitted the owner to take the vessel out of service, to address deficiencies that could not possibly be rectified while the vessel was trading. However, the clauses accompanied certain conditions imposed on the shipowner by the charterer:

- The shipowner reserved the right to take the vessel out of service for a maximum period of 15 days/year without penalty to the owner;
- During the 15 days/year while the vessel is out of service, this time would be considered an off-hire period;
- The charterer reserved the right to sub-charter the vessel, providing that the trade and routes are safe and in accordance with the owner's safety practices and policies; and
- The charterer reserved the right to alter the charter party from time charter to contract of afreightment, providing that the owner's revenue is equal or greater than the original time charter rate.

These conditions were accepted by the owner and the contract was signed for the project, from 2007 to 2011.

8.3.3 The Purchasing / Investment Plan

The Model 'B' vessel was designed specifically for trading on the Great Lakes and Internationally. This vessel was built in 1981 and is currently trading on the Great Lakes and internationally. Therefore, the economic model in terms of the vessel as an asset is based on the following assumptions:

- The vessel's bareboat charter period was completed (2005) and the original owner decided to sell the vessel. Obviously, the vessel initial mortgages have been paid in full and the original owner has profited from their 25 years (1981 to 2006) investment; and
- The charterer has other vessels on time charter with the proposed purchasing owner and would like to continue chartering the Model 'B', but only on time charter contract. The charterer negotiated with the purchasing owner and promised to charter the vessel at the market rates for two time charter contracts i.e. from 2006 to 2007 and again from 2007 to 2011. Due to the long-term business relationship between the charterer and owner, in 2006 the new owner decided to purchase the vessel for USD 8.6M from the second market.

At the beginning of 2006, this vessel completed her economic trading life plus 5 additional years of service. However, because of the long-term time charter intentions by the charterer, the new owner decided that after purchasing the vessel it would be necessary to invest additional capital in two different stages between 2006 and 2011. The investments were primarily focused on the owner profiting in the future from improved performance of the vessel, resulting from a steel renewal programme to extend the vessel's life, enhance cargo unloading operations and a reduction in operating costs. These were the capital investment plans:

- One investment (2006) would be for USD 2.9M from the company fleet reserve cash. This fund was used as capital investment to cover the costs for renewing approximately 1942 tonnes of steel (or about 19% of the ship's lightweight) and the 5th

special survey, in order to extend the vessel's life (see Appendix VIII.1a for verification of calculations) ; and

- The second investment (2008) of USD 1.2M would also be capital borrowed from the company fleet reserve cash. This additional investment was for converting the existing RTG to the MRG and the intermediate docking (see Appendix VIII.1b for verification of calculations).

Prior to using the fleet reserve to finance the project, the owner intention was to seek other financing methods, providing that the outcome would be profitable at the end of the project.

Early in 2006, according to Compass Maritime Services **(2007)**, *'the second hand cost for 20+ years bulk carrier of this vessel deadweight (i.e. 32,000 tonnes) averaged USD 8.6M…'* and by adding the capital investments of USD 2.2M and USD 0.7M, the vessel total asset value would amount to USD 11.5M. Clearly, by investing this USD 2.9M, the reserve cash of the owner fleet was reduced by the same amount (i.e. USD 2.9M). Tables 8.1 and 8.2 illustrate the price for second hand bulk carriers in 2006 and 2007.

Table 8.1 Compass Maritime Services Monthly Report (2006).

Month	Date	52,000 (tonnes)		32,000 (tonnes)	
		DWT (tonnes)	Vessel Cost ($M) (20 Yrs +)	DWT (tonnes)	Vessel Cost ($M) (20 Yrs +)
1	Dec/2006	52,000	14	32,000	8.6
	Total		**14**		**8.6**

Source: Compass Maritime Services Report, 2006.

After purchasing the vessel in 2006, the debt for this vessel amounted to USD 2.9M. However, the vessel's net asset value was USD 8.6M, with the intention being that this amount could be utilized as collateral for future loans. The second hand price for the Model 'B' was obtained from available data expressed in term so USD/tonne deadweight and using 52,000 DWT bulk carriers as the base figure.

Table 8.2 Compass Maritime Services Monthly Report (2007).

Month	Date	52,000 (tonnes)		32,000 (tonnes)	
		DWT (tonnes)	Vessel Cost ($M) (20 Yrs +)	DWT (tonnes)	Vessel Cost ($M) (20 Yrs +)
1	Jan/05/07	52	14	32	8.6
2	Feb/02/07	52	14	32	8.6
3	Mar/02/07	52	17	32	10.5
4	Apr/05/07	52	17	32	10.5
5	May/04/07	52	17	32	10.5
6	Jun/01/07	52	20	32	12.3
7	Jul/06/07	52	23	32	14.2
8	Aug/03/07	52	26	32	16.0
9	Sept/07/07	52	30	32	18.5
10	Oct/05/07	52	32	32	19.7
11	Nov/02/07	52	37	32	22.8
12	Dec/07/07	52	39	32	24.0
	Total		**286**		**176**
	Average		23.8		14.7

Source: Compass Maritime Services Report, 2007.

In 2008, the second sale and purchase price increased drastically and according to Compass Maritime Services **(2008),** *'during the first 8 months of 2008, the market price for bulk carriers of this vessel deadweight (i.e. 32,000 tonnes) averaged USD 22.8M…',* when compared to the second hand prices in 2006 and 2007 for this vessel which were estimated at USD 8.6M and USD 14.7M. Also, at the beginning of 2008 the time charter rates were lucrative for bulk carriers of all types. Therefore, a capital investment of USD 0.7M to improve the vessels' unloading performance appeared to be an obvious choice for the owner, subsequent to purchasing the vessel. With this capital investment of USD 0.7M, the vessel asset value in 2008 was increased to USD 23.5M. Nevertheless, based on the 2008 second hand price, the net asset value in August 2008 for the vessel was USD 22.8M. Figure 8.2 demonstrates the average time charter rates trend for Handymax bulk carriers from 2004 to August, 2008.

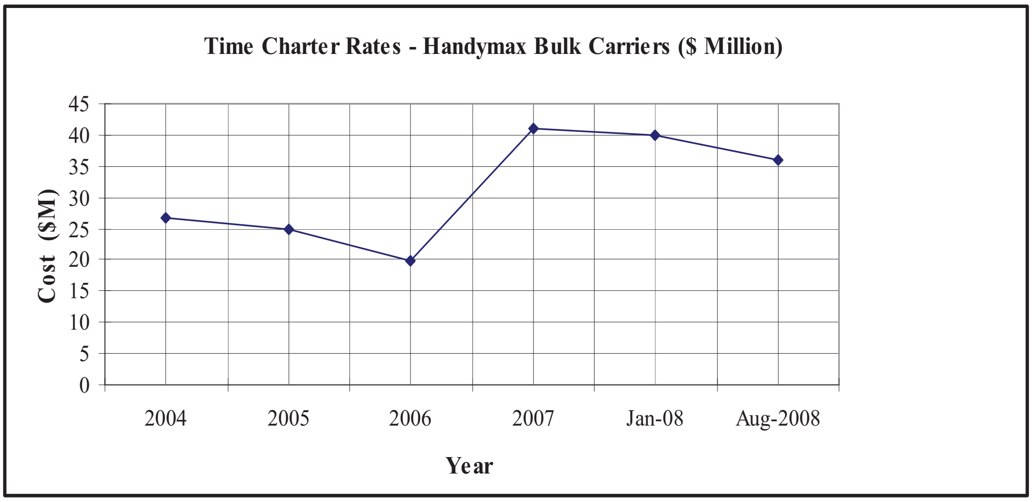


Figure 8.2 Time Charter Rates for Handymax Bulk Carriers, Welcome, H. S. 2008.

Source: R. S. Platou Monthly Reports, 2004 to 2008.

Year	2004	2005	2006	2007	Jan-208	Aug-2008
Average ($M)	26.8	25.0	19.9	40.9	40.0	35.9

8.3.4 The Conversion of Existing RTG to MRG and Accompanied Benefits

Clearly, during the economic life of the Model 'B' SULS, this vessel had undergone numerous intermediate and special surveys by the Classification Society. For the Model 'B' and similar ships, the steel renewal is less due to these vessels trading 66% of their time in fresh water on the Great Lakes of North America. However, because of this vessel age, the Classification Society imposed conditions that intermediate surveys must be carried out every 2 years without extension. Some of these surveys were:

- In 2001 the 4th special survey was due;
- In 2003 an intermediate survey was due;
- In 2006 the 5th special survey was due; and
- In 2008 another intermediate survey was due.

The assumption is, at the beginning of 2006 while carrying out the 5th special survey, the steel renewal programme was effected for life extension of the vessel. During late 2007 to early 2008 (i.e. beginning of November 2007 to early March 2008), the vessel was scheduled for another intermediate survey while trading internationally. At that time, the owner decided to invest additional capital in the vessel for converting the existing older style Roller Track Gates (RTG) to the Multi-functional Roller Track Gates (MRG). This investment was for performance improvements of the unloading plant, which obviously would produce cost savings by reducing both the discharging time and manning.

Table 8.3 illustrates the benefits for the Owner resulting from their investment of converting the RTG to MRG.

Table: 8.3 Benefits from Conversion of Gate - Great Lakes and International Trades.

Trading Period (Months)	Reduction of Unloading Time per Season (Hr)	Benefits			
		Seasonal (Trip)	Seasonal (Days)	Daily (USD)	Total (USD)
8.0 (GL)	100	2.00	5	36,900	184,500
4.0 (Int'l)	20	0.83	1	36,900	36,900
Revenue due to Enhanced Unloading Performance of new gate					**221,400**
Operating Cost Savings (Less 2 Tunnelmen Wages and Victual Costs)					275,655
TOTAL YEARLY SAVINGS FROM 2008 TO 2011					**497,055**
Cost for Converting Gate (RTG to MRG)					700,000
Payback Time in Years for Converting the Gate (RTG to MRG)					**1.4 Years**

Implementing the above economic measures (i.e. Table 8.3) while trading this vessel on the Great Lakes and internationally would result in additional revenue and reduction in operating costs for the owner. The yearly (2008 to 2011) savings from improvements in unloading performance and reduction in manning cost amounted to USD 497,055 while the payback time for converting the gate is 1.4 years.

Tables 8.4 and 8.5 illustrate the summary of annual cashflows and Appendix VIII.1a and VIII.1b demonstrate details of annual cashflows, showing revenues, operating costs and profits before and after the conversion for the 6 year project (i.e. from beginning of 2006 to end of 2011).

The other significant benefit resulting from the conversion is a newly modified unloading system, which would certainly reduce future labour costs (i.e. overtime) due to less maintenance.

Table 8.4 Annual Cashflow before Conversion (Million USD).

Description	2006	2007	2008	2009	2010	2011
Opening Balance	2.40	-7.56	-3.32	2.41	9.01	15.47
Time Charter	6.90	12.60	13.0	12.9	12.9	12.9
Sale of Ship	0.0	0.0	0.0	0.0	0.0	5.6
Revenue	9.27	5.05	9.67	15.33	21.93	33.99
Operating Costs	5.83	5.97	6.12	6.29	6.46	6.64
Improvements	2.40	0.0	0.50	0.0	0.0	0.0
Purchase of Ship	8.60	0.0	0.0	0.0	0.0	0.0
Total Costs	16.83	5.97	6.62	6.29	6.46	6.64
Balance - Gross Profit	-7.56	-0.92	3.05	9.04	15.47	27.35
Loan Repayment	0.0	-2.40	-0.50	0.0	0.0	0.0
Interest (6%)	0.0	0.0	-0.14	-0.03	0.0	0.0
Net Profit	-7.56	-3.32	2.41	9.01	15.47	27.35
Average Net Profit/Year	**7.22**					

Source Compiled from Various sources by Welcome, H. S. 2008.

Table 8.5 Annual Cashflow after Conversion (Million USD).

Description	2006	2007	2008	2009	2010	2011
Opening Balance	2.40	-7.56	-3.32	1.51	8.85	16.37
Time Charter	6.90	12.60	13.21	13.14	13.14	13.14
Sale of Ship	0.0	0.0	0.0	0.0	0.0	5.6
Revenue	9.27	5.05	9.89	14.65	21.99	35.11
Operating Costs	5.83	5.97	5.85	5.73	5.61	5.49
Improvements	2.40	0.0	1.20	0.0	0.0	0.0
Purchase of Ship	8.60	0.0	0.0	0.0	0.0	0.0
Total Costs	16.83	5.97	7.05	5.73	5.61	5.49
Balance - Gross Profit	-7.56	-0.92	2.85	8.92	16.37	29.62
Loan Repayment	0.0	-2.40	-1.20	0.00	0.0	0.0
Interest (6%)	0.0	0.0	-0.14	-0.07	0.0	0.0
Net Profit	-7.56	-3.32	1.51	8.85	16.37	29.62
Average Net Profit/Year	**7.58**					

Source Compiled from Various Sources. Welcome, H. S. 2008.

To effect the conversion and minimize loss of revenue from off-hire time, the owner decided to utilize the contractual maintenance period of 15 days/year plus 5 additional days for carrying out simultaneously the intermediate survey and conversion of the cargo gates.

Therefore, upon completion of the Great Lakes navigational season in 2007, the charterer co-operated with the owner by fixing certain voyages from North America to China and return to North America at the beginning of the navigational season in 2008.

This arrangement by the charterer was to assist the owner in carrying out the conversion smoothly with minimum lost revenue. The charterer also realized that, the conversion would also be to their benefit by having a vessel on time charter with enhance unloading performance. The voyages arranged by the charterer to transport cargo from North America to China and return to North America were:

- Grain from Thunder Bay, Canada to Halifax, Canada;
- Gypsum from Halifax, Canada to New Orleans, USA;
- Grain from New Orleans, USA to Qingdao, China;
- Ballast from Qingdao, China to Dalian, China;
- Repairs and conversion Dalian, China;
- Ballast from Dalian, China to Qinhuangdao, China;
- Coal from Qinhuangdao, China to Boston, USA;
- Ballast from Boston, USA to Sydney, Canada; and
- Coal from Sydney, Canada to Hamilton, Canada.

These scheduled voyages amounted to 122.9 days, starting from November 1st 2007 to March 3rd 2008 (i.e. Canada to USA, USA to China, repair/conversion, China to USA and USA to Canada). Of these 122.9 days round trip (i.e. North America/China/North America), the off-hire time amounted to 21.2 days and 20 days of this time was utilized for the survey and conversion. This voyage plan reduced the off-hire time, especially when the MRG was pre-fabricated and ready for installation on arrival of the vessel at Dalian, China. The above voyage/repair/conversion plans ensured that the vessel returned to Canada on March 3rd 2008, in order to start trading on the Great Lakes at commencement of the 2008 navigational season. Table 8.6 illustrates the details of the voyage time, operating and conversion costs for the period from November 1st 2007 until March 3rd 2008. Table 8.6 also demonstrates the details of this round trip in terms of revenue, operating costs, conversion costs and profit.

Undoubtedly, subsequent to replacing the existing cargo gates with the MRG, the original ship's lightweight would increase by approximately 73.6 tonnes (or 10,300 + 73.6 = 10,373.6 tonnes) or approximately 0.71% of the original lightweight (see Appendix VI.6). This increase in the lightweight resulted from the additional weight of the primary gates. The weight of the secondary gates is assumed to be equal to that of the existing Roller Track Gates. However, the extra weight of 73.6 tonnes for the primary gates were offset and nullified during the steel renewal programme. This was accomplished by reducing the hull plating weight by more than 73.6 tonnes (i.e. by 208 tonnes), due to employing high tensile steel (AH32) to replace certain sections of mild steel plates. Therefore, the ships' lightweight can be assumed to be unchanged or reduced by 134.4 tonnes after the gate modification and weight reduction exercise (i.e. 208 − 73.6 = 134.4).

In Appendix VI.6, the experiment of reducing the Model 'B' lightweight concludes that 208 tonnes could easily be reduced from the hull shell plating, by utilizing lighter high tensile steel to replace some mild steel plates. After carrying out the experiment with the loading programme designed for this ship, it was verified that the vessels' stability, bending moment and shearing force were acceptable.

TABLE 8.6 CASHFLOW DETAILS FOR CONVERSION PERIOD - 123 DAYS - MODEL 'B' TYPE SULS (USD)
(TRADING PERIOD - BEGINNING NOVEMBER 2007 TO MARCH 3rd 2008 - 123 DAYS)

Item	Description	Distance	Speed	On-Hire		Of-Hire		Revenue	Costs (USD)		Profit	Remarks
		NM	KN	Days	TC/Day	Days	TC/Day		Operational	Conversion		
TRADE	Thunderbay/Halifax	2010	12.5	6.7	36,900	0	0	247,230	0.00			Loaded with grain
	Unloading Halifax (0.5 day)	0	0	1.0	36,900	0	0	36,900	0.00			Unloading port
	Loading Halifax (0.5 day)	0	0	1.0	36,900	0	0	36,900	0.00			Loading gypsum
	Halifax/New Orleans	2148	12.5	7.2	36,900	0	0	264,204	0.00			Loading to unloading port
	Unloading New Orleans (1.2 day)	0	0	1.2	36,900	0	0	44,280	0.00			Unloading port
	Loading New Orleans (0.5 day)	0	0	1.0	36,900	0	0	36,900	0.00			Loading grain
	New Orleans/Qingdao	10072	12.5	33.6	36,900	0	0	1,238,856	0.00			Loading to unloading port
	Unloading Qingdao (0.5 day)	0	0	1.0	36,900	0	0	36,900	0.00			Unloading port
	Qingdao/Dalian (1.2 days)	356	12.5	0.0	0	1.2	36,900	0.00	44,280			Unloading port to Dock
	FO (Qingdao/Dalian) 29.88t-1.2d	356	12.5	0	0	0.0	0	0.00	20,378			24.9t/d @ $682/t
	MDO (Qingdao/Dalian) 3.0t-1.2d	356	12.5	0	0	0.0	0	0.00	3,072			2.5t/d @ $1024/t
	Dalian (Dock/Repairs/Conversion)	0	0	0	0	20.0	36,900	0.00	738,000			Repairs and conversion
	MDO (Dalian Drydock) 2.5t-1d	0	0	0	0	0.0	0	0.00	2,560			2.5t/d @ $1024/t
	Dalian/Qinhuangdao (0.5 day)	142	12.5	1.0	36,900	0.0	0	36,900	0.00			Dock to load port
	Laoding Qinhuangdao (1 day)	0	0	1.0	36,900	0.0	0	36,900	0.00			Bunker: Charterer Acc
	Qinhuangdao/Boston	11874	12.5	39.6	36,900	0.0	0	1,460,502	0.00			from dock to unloading
	Unloading Boston (0.5 day)	0	0	1.0	36,900	0.0	0	36,900	0.00			port
	Boston/Sydney	600	12.5	2.0	36,900	0.0	0	73,800	0.00			Unloading to loading port
	Loading Sydney	0	0	1.0	36,900	0.0	0	36,900	0.00			Loading coal
	Sydney/Hamilton	1049	12.5	3.5	36,900	0.0	0	129,027	0.00			Loading to unloading port
DAILY COSTS	Manning								844,175			Std running costs for 120
	P&I Insurance								78,528			days (Thunderbay/China/
	Store, Supplies & Lube								314,112			Boston)
	H&M Insurance								117,792			
	Repairs & Maintenance								333,743			
	Others								274,848			
	TRADE / DAILY COSTS BALANCE	**28963**		**101.7**		**21.2**		**3753099**	**2771488**	**0.0**	**0.0**	

Item	Description	Distance	Speed	On-Hire		Of-Hire		Revenue	Costs (USD)		Profit	Remarks
		NM	KN	Days	TC/Day	Days	TC/Day		Operational	Conversion		
	TRADE / DAILY COSTS BALANCE	**28963**		**101.7**		**21.2**		**3753099**	**2771488**	**0.00**	**0.00**	
CONVERSION	Gates Pre-fabrication & Mechanical									84,000		56 Gate Modules @ $1500
	Pri Gates Installation ($1.18/kg)									86,829		657kg/ Gate (112 gates)
	Sec Gates Installation ($1.18/kg)									111,014		840kg/ Gate (112 gates)
	Scrap steel - Original Gate ($0.19/kg)									-17,875		840kg/ Gate (112 gates)
	Hydraulic piping, controls & Cyl									176,000		Purchase of materials
	Pre-fab Hyd Pipes (Riding Team)									50,000		Change size 50 to 65 mm
	Hydraulic and Electrical Installation									60,000		By shipyard
	Engineering (Elect & Hyd)									120,000		Design changes
	Commissioning									30,000		Consultant hired to yard
	TOTAL	**28,963**		**101.7**		**21.2**		**3,753,099**	**2,771,488**	**699,968**	**281,643**	

Remarks

a. Compiled from Various Sources in the Reference Table. Welcome, H. S. 2008

b. The operational costs related to others are expenditures from the shorebased standpoint (i.e. Superintendence, legal, chartering, accounting, etc).

Sources:

a. FO Price. http://www.bunkerindex.com/prices/namerica/php. September 9th 2008

b. FO Consumption. http://www.cslintl.com - Reference for similar type vessel as Model "B". September 9th 2008.

c. MDO. http://www.bunkerindex.com/prices/namerica/php. September 9th 2009

d. MDO Consumption. http://www.cslintl.com - Reference for similar type vessel as Model "B". September 9th 2008

c. Freight Rate. RS Platou monthly report - average rates for 2006 and 2007, 2008.

d. Manning Costs for Masters and Chief Engineers. Confidential source, 2008.

e. Manning Costs for Officers. Canadian Marine Officers Union (CMOU) - Canada - Ratee, 2008.

f. Manning Costs for Crew. Seamen International Union (SIU) - Canada - Rates, 2008.

g. Other Operational Costs. http://www.marinetalk.com/articles-marine-companies/art/Ship-Costs.html

h. Routes and port distances. Compass Maritime, 2008.

i. Conversion Costs. Dalian Shipyard, China, 2008.

8.4 Economic Evaluation

Fundamentally, this sub-section relates exclusively to the strategy implemented by the owner to acquire finance for purchasing the vessel, revenues to support the project and a yearly profit from the investments. The various options for financing the project were examined, to determine the optimum method for the owner to benefit from capital invested at the end of the project. The most favourable method for financing the project was decided after evaluating various cashflow outcomes. Ultimately, upon completion of the 6 year project, the owner intends to sell or scrap the vessel and benefit from a 10% per annum return on their investments.

8.4.1 Financing the Project

In 2006, the Model ‘B’ vessel completed 25 years of services trading dry bulk commodities of all types in the Great Lakes region and internationally. A standard ocean going bulk carrier of 25 years, which has exceeded her economic life by 5 years would normally be scrapped. Therefore, shipowners sometimes encounter difficulties raising finance from the bank while using a vessel of this age as collateral. However, because the steel renewal for this vessel was reduced, due to trading the majority of time in fresh water (on the Great Lakes) and having been promised by the charterer a 6 years time charter; the owner decided to purchase the vessel and approached the bank for loan to finance the project. The bank agreed to finance the entire project, primarily because of their long-time relationship with the owner and the vessel’s intended income, resulting from a confirmed time charter for the duration of the 6 year project.

The banks normally offer the shipowners’ a loan for 50% to 70% of the ship’s value, depending on the vessels’ condition. In 2006 and 2008, after careful examination and evaluation of the vessel, the owner’s bank offered three separate loans (i.e. USD 11.5M) for purchasing the vessel, steel renewal and expenses for the 5th special survey. In 2006, another bank offered the owner a loan (i.e. USD 1.2M) for the gate conversion and expenditures for the intermediate survey. These are the details of the loans:

- In 2006 one loan for 70% (or USD 6.0M) of the vessel purchasing price (i.e. USD 8.6M). This loan was guaranteed by vessel;
- In 2006 a second loan for 30% (or USD 2.6M) of the vessel purchasing price (i.e. USD 8.6M). This loan was guaranteed by another vessel from the fleet;
- In 2006 a third loan for USD 2.9M which was also guaranteed by the second vessel from the fleet; and
- In 2008 a fourth loan for USD 1.2M that was guaranteed by other vessels from the fleet.

The first, second and third loan repayments were for 72 months or 6 years (i.e. 2006 to 2011) at an interest rate of 6.5% (or LIBOR + 2%). The fourth loan was for 38 months at an interest rate of 6.5% (or LIBOR + 2%). The repayment plans for these loans are exhibited in Appendix VIII.1h.

During the same period, the bank lending rates for other investments were 7.5% per annum, while Guaranty Investment Bonds and Treasury Deposits were yielding 6.0% per annum. These were the investment alternatives, which the bank could offer the owner.

These investment options presented to the owner by the bank, did not meet the shipowner's minimum expectation, which was 10% per annum return from their investments. Historically, the owner's investment policy has always been somewhat risk averse and preferred investing in ventures that are tangible assets (e.g. ships and real estate i.e. land and buildings). Nevertheless, the owner had a limited portfolio in stocks and Mutual Funds from which the returns are also highly dependent on the stock market.

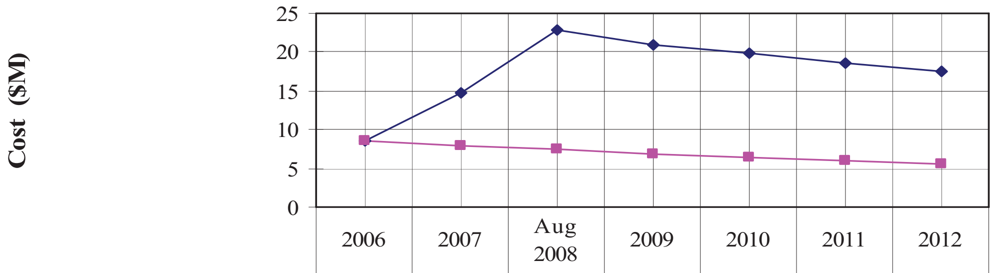
The owner further analyzed the financing options offered by the banks and the possible future revenues to support the 6 year project with profit, which were:

- USD 12.7M loan in four parcels for 72 and 38 months at 6.5% interest rate;

- One year firm time charter (2006-2007) from the owner's reputable client; and
- Five years unconfirmed time charter (2007-2011) from the owner's reputable client.

Based on the above options, there was a corporate decision to invest USD 8.6M, utilizing funds from the company's reserve to purchase the vessel. Additionally, the owner planned to invest capital amounting to USD 4.1M. This capital would be used for steel renewal to extend the vessel's life (i.e. Class surveys) and for upgrading the unloading system. Upon completion of the project (late 2011 or early 2012), the owner intends to sell the vessel on the second hand market for USD 5.6M. There was another alternative at the end of the project; the vessel could be sold on the scrap market for a possible USD 3.35M at a price of USD 325/lightweight tonnes (i.e. 10300 tonnes × USD 325 = USD 3.35M). Figures 8.3 and 8.4 illustrates the second hand depreciation price and scrap value for the vessel, which are based on average published prices by R. S. Platou **(2005-2008)** and the owner's view of 7% depreciation/year. Figure 8.3 also demonstrates a conservative prediction of the owner for second hand price for the Model 'B' type SULS. This owner forecast of the second hand market for this vessel, is base on intuition or 'rule of thumb' criterion used by the various shipowners'.

Upon purchasing the vessel, the capital investments relevant to Class surveys were imperative for the vessel to continue trading, primarily because of the vessels' age. The remaining capital investment was to enhance the unloading performance resulting in the reduction of future operating costs.



	2006	2007	Aug 2008	2009	2010	2011	2012
Published Price ($M)	8.6	14.7	22.8	21	19.8	18.5	17.6
Owners View ($M)	8.6	8.0	7.4	6.9	6.4	6.0	5.6

Figure 8.3 Predicted Depreciation - Second Handmax Bulk Carrier. Welcome, H. S. 2008.

Source Compiled from Compass Maritime Reports and Assumptions by Welcome, H. S.

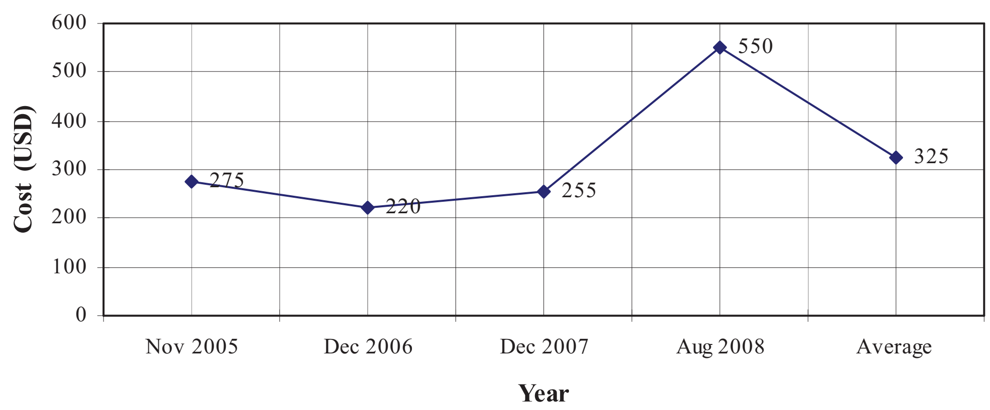


Figure 8.4 Predicted Scrap Price - Second Handmax Bulk Carrier, Welcome, H. S. 2008.

Source Compiled from R. S. Platou Reports and Assumptions by Welcome, H. S.

Certainly, this investment decision of the owner to purchase this vessel in 2006 was speculative due to a variety of reasons:

- The steel renewal programme costing USD 2.2M was mandatory for the life extension of the vessel, in order for the vessel to continue trading. This was due to the vessel's age;
- The 5th special survey costing USD 0.7M was due and could not be extended;

- Unconfirmed time charter from 2007 to 2011 i.e. speculation, due to both revenue and profit were dependant on the market rates for time charter;
- Operating costs of USD 5.83M in 2006; and
- The agreed time charter (2006-2007) for USD 19,900/day, resulting in an income of USD 6.87M for the year, which resulted in USD −7.56M profit.

Obviously, based on the above income and costs when excluding the investment of USD 8.6M for purchasing the vessel, the net profit was USD −7.56M for 2006. Figures 8.5, 8.6a, Appendix VIII.1a, and VIII.1b exhibit these figures.

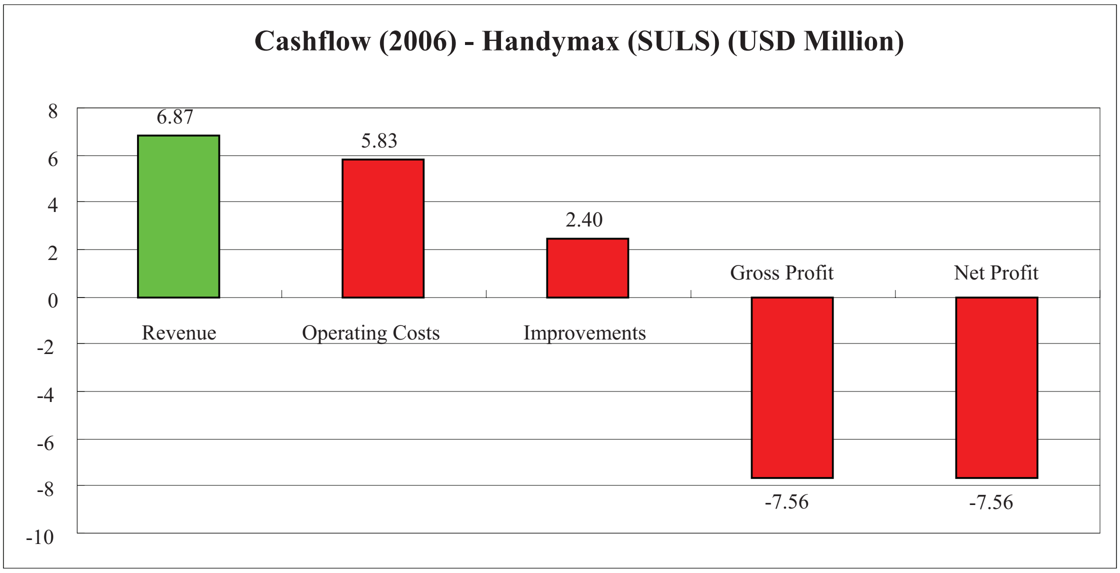


Figure 8.5 Cashflow for 2006 Time Charter – Model 'B', Welcome, H. S. 2008.

Sources Compiled by Welcome, H. S from R. S. Platou (2007), Seafarers Intl Union-Canada (2008), Canadian Marine Officers Union-Canada, Drewry Shipping Consultants, Ltd and www.marinelink.com

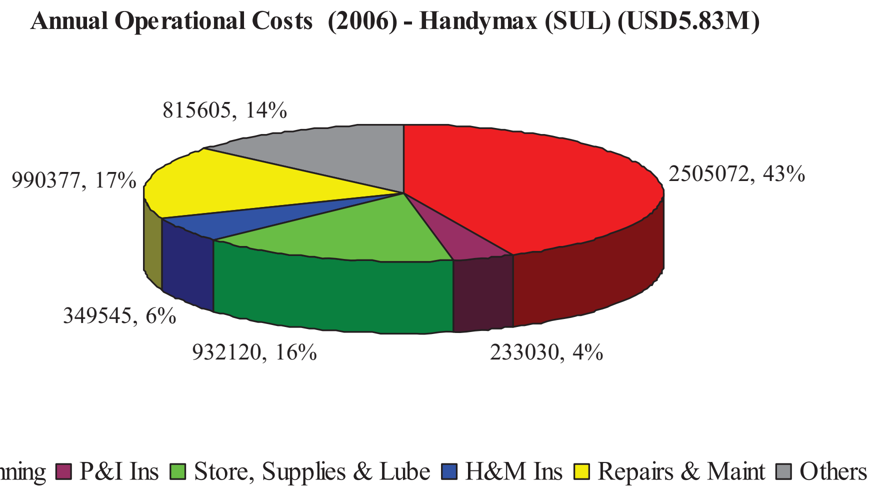


Figure 8.6a Operating Manning Costs for Model 'B' Type SULS. Welcome, H. S. 2006.
Sources Compiled by Welcome, H. S from Seafarers Intl Union-Canada (2008), Canadian Marine Officers Union-Canada, Drewry Shipping Consultants, Ltd and www.marinelink.com

Operating costs are highly speculative for various reasons. Therefore, the shipowners' yearly expenditures could increase with accompanying reduction in profit. For example, the oil market is unpredictable and cost for fuel and lubrication oil could suddenly change resulting in either an increase or decrease in price. According to OPEC **(2008)**, the prices per barrel of oil for certain periods were (see Appendix VIII.8):

- *'In 2006 the yearly average price for oil was USD 61.08/barrel;*
- *As of December 12th 2008 the yearly average price for oil was USD 97.94/barrel;*
- *The month average price for oil in December 2007 was USD 87.05; and*
- *As of December 12th 2008 the monthly average price for oil was USD 40.23.'*

The other typical example that increases operating cost is the unexpected change of trade unions attitude resulting in higher wages demand, despite having signed labour agreement between the shipowners' and trade union. Figure 8.6b shows higher operating costs for 2008, resulting from the union request due to inflation.

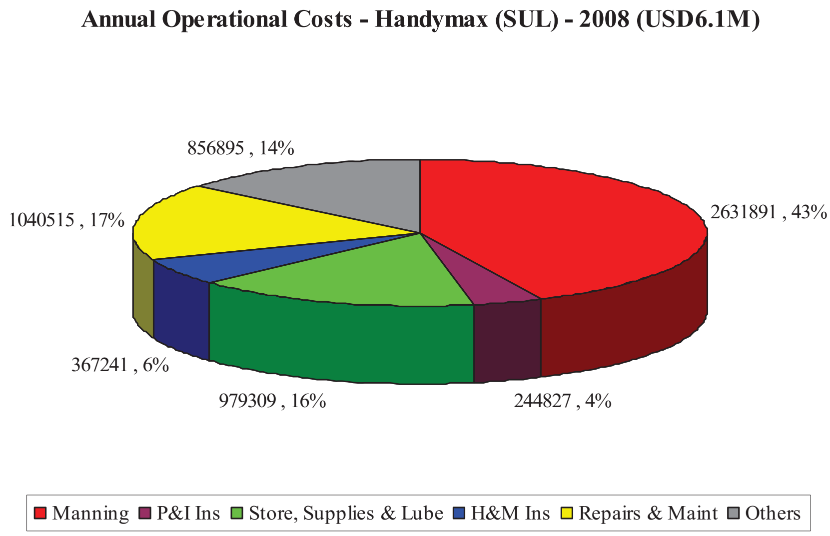


Figure 8.6b Operating Manning Costs for Model 'B' Type SULS. Welcome, H. S. 2008.
Sources Compiled by Welcome, H. S from Seafarers Intl Union-Canada (2008), Canadian Marine Officers Union-Canada, Drewry Shipping Consultants, Ltd and www.marinelink.com

In 2006, the operating cost for the Model 'B' was USD 5.8M and due to an increase in inflation (i.e. 2.5%) the estimated operating cost for 2008 amounted to USD 6.1M. This increase of USD 0.3M, resulted primarily from additional manning cost. Clearly, these changes in operating costs substantiated the uncertainties, which the owner has to factor into his plan to predict the expected yearly profit or return from investment on completion of the project.

Self-unloading Bulk Carriers (SULS) capital costs are higher resulting primarily from extra operating costs for manning, unloading machineries and special structure in the unloading tunnel. These costs are often offset due to SULS ability to discharge cargo autonomously, when compared to the conventional bulk carriers. A study on 'Delivered Cost Benefits with Self-unloading Vessel' was conducted by Wright, Whittington and Carruthers **(1980s')**, which concluded the operating costs (i.e. 350 days operations) for SULS as USD 4,469/day versus USD 3,629/day for conventional bulk carriers. According to Wright, Whittington and Carruthers **(1980, p.1)**, *'Self unloaders have been around since the turn of the century although they have been considered something of an oddity as one of the many side-lines of specialized marine activity. The perception is*

now changing as shippers and operators begin to appreciate the high productivity of this type of vessel and its inherent ability to reduce total distribution costs. These attributes have been well understood in the Great Lakes system and by a number of deep sea operators, who have run fleets for many years. In fact the German company of Sauber Bros. certainly appreciated the efficiency of this unique types of ship when they took delivery of the Doxford designed as built self-unloader colliers "Emma and Herman Sauber" in 1911 and 12 for the North Sea coal trade.
Although Self-unloaders can demonstrate economics in direct competition with conventional bulk carriers, it is when they are incorporated into a distribution system that the full benefit can be achieved.'

The 1980s' operating costs difference for SULS versus conventional bulk carriers at that time accounted for an increase of USD 840/day when utilizing SULS. This amount was minor, when compared to the benefits gained by the owners and shippers while trading with SULS and requiring not external source to discharge the cargo. The MRG design would reduced operating cost in terms of manning and port turn-around time, resulting in higher yearly income and profit for the owners.

In the 1980s', the difference in operating cost, for operation in the 'Great Lakes region', between a handymax SULS and a handymax conventional bulk carriers was USD 0.29M/year (i.e. USD 1.56 – USD 1.27 = USD 0.29M). These costs according to Wright, Whittington and Carruthers **(1980s', p.15) we**re the **'***mid range crewing costs* for *operating Self-unloader and conventional bulker…'* Figures 8.6c and 8.6d demonstrate comparisons and distribution of crew costs for the two types of bulk carriers on the Great Lakes during the 1980s'. Figures 8.6b and 8.6c show the operating costs difference for SULS during the 1980s' and 2008, in the Great Lakes region. When comparing operating costs for SULS in the 1980s' with that of 2008, the increase is approximately USD 4.5M. This increase of USD 0.23M/year is understandable, when considering inflation over a period of about 2 decades (1988-2008).

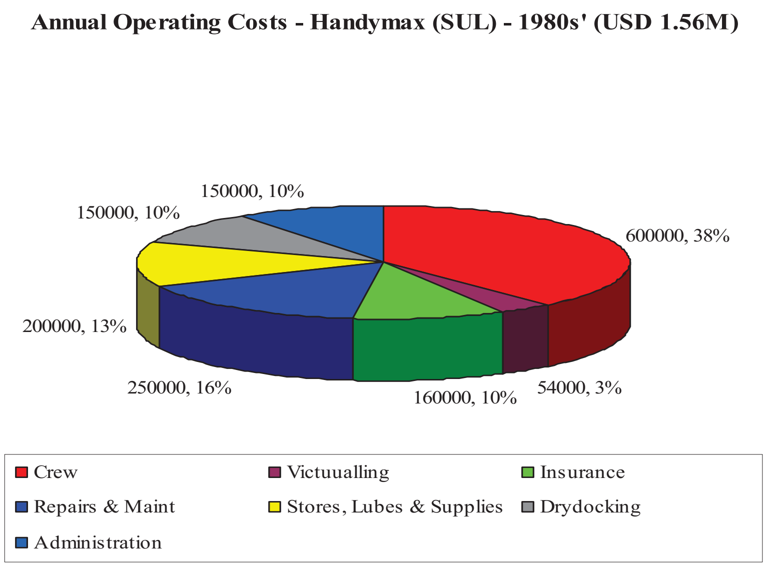


Figure 8.6c Operating Manning Costs for Handymax Type SULS. Wright, C. 1980s'.

Sources Compiled by Welcome, H. S from Wright, Whittington and Carruthers Research on 'Delivered Cost Benefits with Self-unloading Vessel', 1980s'.

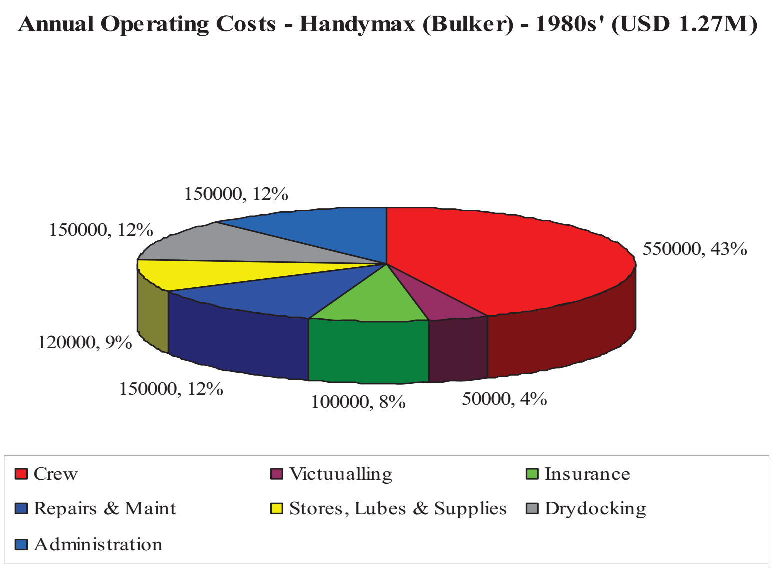


Figure 8.6d Operating Manning Costs for Handymax Type Bulker. Wright, C. 1980s'.

Sources Compiled by Welcome, H. S from Wright, Whittington and Carruthers Research on 'Delivered Cost Benefits with Self-unloading Vessel', 1980s'.

With regard to SULS operating costs, the above information is the current available data. SULS market researcher Wright **(2008)** and confidential sources also confirmed that there is no recent updated information published on SULS operating costs.

The second hand price for the Model 'B' SULS in 2006 was USD 8.6M. This price was somewhat lower than anticipated by the owner and this was one reason that prompted the owner into purchasing the vessel with the intention to invest additional capital after owning the vessel. During 2007 Compass Maritime Services **(2007)** indicated that *'the sale trend for second hand bulk carriers of 32,000 DWT increased when compared to 2006, showing a low of USD 8.6M and high of USD 24.0M with an average of USD 14.7M for the year...'* In addition, despite the owner and charterer agreed time charter rate for USD 36,900/day, R. S. Platou **(2007)** *'reported that the average time charter rate for Handymax 2007 was USD 40,900/day…'*. Therefore, these market indications of favourable second hand price and time charter rates led the owner into believing that the vessel asset would continue to grow from 2008 until 2011. This was another perceived reason by the owner to invest capital (2008) for improving the unloading system, which would eventually result in improving the ship's unloading performance and reduce the operating costs.

By August 2008, Compass Maritime Services **(2008)** reported that *'the second hand price for bulk carriers of 32,000 DWT average USD 22.8M...*'. Due to the continuing increase in price for second hand bulk carriers, when compared to the previous 2 years (i.e. 2006 and 2007), the owner predicted that this trend could possibly continue until expiration of the time charter in 2011. However, the owner was also concerned that the market rates for both second hand sale and time charter could reduce in subsequent years.

8.5 The Cashflow - 2006 to 2011

The cashflow is most essential to verify the capability of any business to continue to exist during recessions. According to Stopford **(2004, p.180.181a)**, cashflow is the crucial role *'in determining the ability for a shipping business to survive the long* *depressions that are such a feature of the shipping market'*. Stopford **(2004, pp.180.181b)** further describes that *'four methods of cashflow analysis are widely used in the shipping industry, each of which approaches the cashflow from a different perspective'*, namely:

> *'1. The voyage cashflow (VCF) analysis is the technique used to make day-to-day chartering decision. It computes the cashflow on a particular ship voyage or combination of voyages. It provides the financial basis for operational decisions such as choosing between alternatives charter opportunities where there are several options, or in a recession deciding whether to lay up the ship or fix it.*
>
> *2. The annual cashflow (ACF) analysis calculates the cashflow of a ship, or a fleet of ships on a year-by-year basis. It is the format generally used for cashflow forecasting. By projecting the total cashflow for the business during the full financial year, it shows whether, on specific assumptions, the business as a whole will generate enough cash to fund its operations after taking account of complicated factors such as tax liabilities, capital repayments and periodic maintenance...*
>
> *3. The required freight rate (RFR) analysis is a variant on the annual cashflow analysis. It focuses on the cost side of the equation, calculating the freight rate the ship needs to earn to cover its costs. This is used for shipowners calculating whether a ship investment will be profitable and bankers carrying out credit analysis to decide how much to lend. It can also be used to compare alternative ship designs...*
>
> *4. Discounted cashflow (DCF) analysis is concerned with the time value of money. It is use for comparing investment options where the cashflows differ significantly over time. For example, a new ship involves a large initial investment but is cheap to run, whereas an old ship is cheap to buy but has higher costs later in its life. DCF provides a structured way of comparing the two investments...*
>
> *These methods are complementary and each approaches cashflow in a different way, appropriate to the needs of different decisions.'*

In this economic study, the cashflow analysis is based on two approaches; the annual and discounted methods (see Appendices VIII.1 and VIII.3). The annual system of calculations will be used to forecast the cashflow for the 6 year project under two different scenarios to verify the benefits before and after converting the cargo gates.

The second analysis is based on discounted the cashflow method. In this analysis, the Net Present Value (NPV) method of discounting the cashflow will be used to convert each cash payment receivable in the future into a present value. In other words, throughout the project (2006 to 2011), the owner expects an annual return of 10% from their investment and requires knowing the actual value of the project in 2006. Upon completion of the project, the owner intends to sell or scrap the vessel. The bank offered the owner guaranty investments with return of 6% per annum. Therefore, an analysis to determine the NPV when using a discount rate of 6% will also be calculated. This is primarily to compare the two different NPV scenarios, when using the discount rates of 6% and 10%.

8.5.1 The Annual Cashflow before Conversion

Obviously, the 2006 and 2007 cashflow resulted in net negative profit. This was a known factor prior to purchasing the vessel. However, purchasing the vessel was based on the speculation of a 6 year project, conditional that the owner being awarded 5 additional years time charter, from 2007 to 2011. The 6 year investment plan before the conversion would result in an average net profit of USD 7.22M/year. The total invested capital for 6 years were USD 12.7M as follows: the cost of USD 8.6M to purchase the vessel and USD 4.1M for improvements to the vessel (i.e. steel renewal, surveys and cargo gates conversion). Had the owner invested the USD 12.7M in fixed Treasury Deposit or Guaranty Investment Bond for 6 years at 6% interest rate compounded as suggested by the bank, then the return on the investment would have been USD 5.12M for 6 years or USD 0.85M/year. In addition, after investing USD 12.7M for 6 years with the bank, the principal and interest would have amounted to USD 17.80M (i.e. 12.70 + 5.12 = USD 17.80M). Table 8.7 illustrates the return from investing USD 12.70M with the bank in a fixed deposit for 6 years at 6% interest rate.

The alternative investment would have been to purchase the vessel and commence trading without the cargo gate conversion. However, the reduction in investment for the project would have only amounted to the USD 0.70M for the gate conversion.

Fundamentally, because the steel renewal and Class surveys costing USD 3.4M were mandatory in order to put the vessel into service.

Table 8.7 Six Years Investment in Bank Treasury Deposit (Million USD).

Year	Invested	Interest		Principal & Interest			Total
	Principal	6%	Interest	Principal	6%	Interest	Principal/Int
06-07	11.50	0.06	0.69				
07-08	12.19	0.06	0.73				
08-09	12.92	0.06	0.78	1.20	0.06	0.07	
09-10	13.70	0.06	0.82	1.27	0.06	0.08	
10-11	14.52	0.06	0.87	1.35	0.06	0.08	
11-12	15.39	0.06	0.92	1.43	0.06	0.09	
	16.31			1.51			
	16.31			**1.51**			**17.8**
Return for 6 Years							**5.12**
Return/Year				—	—	—	**0.85**

Source: Compiled by Welcome. H. S. 2008.

There was another alternative, in August 2008 Compass Maritime Services **(2008)** reported that the second hand price for bulk carriers of 32,000 DWT was USD 22.8M. Therefore, at that time the owner could have decided to sell the vessel with the time charter, simply because the charter party had no binding clause regarding the selling of the vessel during the 6 year project. In August 2008, the total capital invested was USD 12.70M (i.e. USD 8.60M + USD 4.10M = USD 12.70M) for purchasing the vessel, steel renewal, surveys and cargo gate upgrades. Therefore, by selling the vessel in August 2008, the net profit would have amounted to approximately USD 9.73M (i.e. -7.56 + -3.32 + 20.61 = USD 9.73M) from investing 12.70M in 2.7 years. This return on investment was about 77% of the invested capital in 2.7 years. Table 8.8 and Appendix VIII.1f show the summary from selling the ship in August 2008. Table 8.4 and Appendix VIII.1a illustrate the details of revenues, costs and profit before the conversion. Nevertheless, the owner decided to trade the vessel until completion of the 6 year project. This decision resulted from the owner and client long-term relationship.

Table 8.8 Annual Cashflow after Conversion & Selling the Vessel in August 2008 (Million USD).

Description	2006	2007	2008
Opening Balance	2.40	-7.56	-3.32
Time Charter	6.87	12.61	8.64
Sale of Ship	0.0	0.0	22.8
Revenue	9.27	5.05	28.12
Operating Costs	5.83	5.97	4.89
Improvements	2.40	0.0	1.20
Purchase of Ship	8.60	0.0	0.0
Total Costs	16.83	5.97	6.09
Balance - Gross Profit	-7.56	-0.92	22.03
Loan Repayment	0.0	-2.40	-1.20
Interest (6%)	0.0	0.0	-0.22
Net Profit	-7.56	-3.32	20.61
Average Net Profit/Year	3.60		

Source Compiled from Various Sources. Welcome, H. S. 2008.

Upon completion of the 6 year project without the cargo gate conversion, the average net profit before selling the ship amounted to USD 6.29M/year. After selling the ship for USD 5.6M, the net profit would be USD 7.22M/year. Appendix VIII.1a illustrates the details of the cashflow before converting the cargo gates.

8.5.2 The Annual Cashflow after Conversion

Prior to converting the cargo gates in 2008, the cashflow for 2006 and 2007 resulted in net negative profit before and after the conversion. However, for the remaining 4 years (i.e. 2008 to 2011) of the project after converting the cargo gates, there are beneficial returns from the investments. The average net profit before selling the ship amounted to USD 6.64M/year. After selling the ship for USD 5.6 M, the net profit would be USD 7.58M/year. Table 8.4 and Appendix VIII.1b illustrate the details of the cashflow after converting the cargo gates.

When comparing the cashflow before and after the conversion, the increase in revenue yearly after the conversion in 2008 amounted to USD 497,055 (i.e. 275,655 + 221,400 = 497,055). This saving resulted from the improvements made to the unloading system, which would allow the reduction in unloading time by 5 days (or 2 additional trips/year) on the Great Lakes, 1 day internationally and reducing manning by two Tunnelmen. This yearly added revenue of USD 497,055 could be utilized for offsetting the cargo gate conversion cost. Clearly, this indicates that the conversion could be paid for in about 1.4 years or by mid 2009 (i.e. USD 700,000 / 497,055 = 1.4). Appendix VIII.2a and VIII.2b illustrates the manning costs for both officer and crew onboard Canadian vessels.

8.5.3 The Discounted Cashflow before Conversion

When discounting the cashflow using the NPV method, according to Stopford **(2004, p.189a)**, *'the first step is to determine the discount rate which represents the time value of money to the company…'* . Stopford **(2004, p.189b)** also said that there are several ways of determining which discount rate is appropriate and that *'The simplest way, if the company has cash surplus, is to use the interest rate which the company would receive if it invested the cash in a bank deposit. Or the discount rate might be set at a level which reflects the average return on capital obtained from investments in other parts of the business.'*

In the scenario of the discounted cashflow analysis before the conversion, the owner decided to apply a discount rate of 6% and 10%, in order to compare four different types of investments, namely:

- Case-1: Invest the entire USD 12.70M in bank Treasury Deposit at 6% interest rate per annum compounded;
- Case-2: Take a loan from the bank for the entire investment of USD 12.70M at 6.5% interest rate per annum as follows (USD 11.5M for 72 months and USD 1.2M for 38 months);
- Case-3: Invest the entire USD 12.7M in 2 different types of investments. Sixty percent with shipping companies involved in the sale and purchase of ships (i.e. newbuilding and second hand) and the remaining 40% in oil stocks. The expectation was to have 10% per annum return from these investments; and

- Case-4: Purchasing the Model "B" SULS for USD 8.6M and investing an additional USD 4.1M for steel renewal, surveys and converting the existing cargo gates to the MRG.

Table 8.9 Six Years Investment in Shipping Co. & Oil Stocks (Million USD).

Year	Invested	Interest		Principal & Interest			Total (Million USD)
	Principal	10%	Return	Principal	10%	Return	Principal/Int
06-07	11.50	0.10	1.15				**-12.7**
07-08	12.65	0.10	1.27				
08-09	13.92	0.10	1.39	1.20	0.10	0.12	
09-10	15.31	0.10	1.53	1.32	0.10	0.13	
10-11	16.84	0.10	1.68	1.45	0.10	0.15	
11-12	18.52	0.10	1.85	1.60	0.10	0.16	
	20.37			1.76			
	20.37			**1.76**			**22.1**
Return for 6 Years							**9.43**
Return/Year				—	—	—	**1.57**

Source: Compiled by Welcome. H. S. 2008.

Table 8.7 illustrates the returns when investing the entire USD 12.70M in the bank Treasury Deposit for 6 years at 6% interest rate per annum compounded. Table 8.9 demonstrates the returns when the USD 12.70M is invested in Shipping Ventures and Oil Stocks for 6 years at 10% interest rate per annum compounded. Tables 8.7, 8.9, Appendices VIII.1g and VIII.1h exhibits the return, repayment and interest when the entire USD 12.70M is borrowed from the bank. For the complete project the actual return on investment were USD 0.85M/year in case-1, USD 1.95M/year in case-2 and USD 1.57M for case-3. These investments with the bank were the optimum scenarios. However, it is unlikely that the interest rates would remain the same for 6 years consecutively. The return before and after the conversion were USD 7.22M/year and USD 7.58M/year, when the project is financed by the owner and using his fleet reserve cash. When comparing the returns of the bank options and the investments from shipping venture/oil stocks with the discounted cashflow analysis method of 6% and 10%. The actual returns are much higher when the project is financed with the owner cash surplus.

Table 8.10 shows the annual cashflow after the conversion, if the project was 100% financed by the bank (USD 12.7M). Tables 8.11, 8.12 and Appendix VIII.**3** exhibit the NPV values at the discount rates of 6% and 10% before the conversion.

Table 8.10 Annual Cashflow @ 100% Loan after Conversion (Million USD).

Description	2006	2007	2008	2009	2010	2011
Opening Balance	2.40	-9.86	-5.52	-1.95	2.85	7.77
Time Charter	6.87	12.61	13.12	13.14	13.14	13.14
Sale of Ship	0.0	0.0	0.0	0.0	0.0	5.6
Revenue	9.27	2.75	7.69	11.19	15.99	26.51
Operating Costs	5.83	5.97	5.85	5.73	5.61	5.49
Improvements	2.40	0.0	1.20	0.0	0.0	0.0
Loan to Purchase Ship	8.6	0.0	0.0	0.0	0.0	0.0
Total Costs	16.83	5.97	7.05	5.73	5.61	5.49
Balance - Gross Profit	-7.56	-3.22	0.65	5.46	10.37	21.02
Loan Repayment	-.1.92	-1.92	-2.22	-2.22	-2.22	-2.22
Interest (6%)	-0.380	-0.380	-0.383	-0.383	-0.383	-0.383
Net Profit	-9.96	-5.52	-1.95	2.85	7.77	18.41
Average Net Profit/Year	1.95					

Source Compiled from Various Sources. Welcome, H. S. 2008.

Table 8.11 Discounted Cashflow @ 6% - before Conversion (USD).

Item	Description	Summary	Year 1 (2006)	Year 2 (2007)	Year 3 (2008)	Year 4 (2009)	Year 5 (2010)	Year 6 (2011)	Total
1	Ship Purchase	8.6							
2	Ship Sale							5.6	
3	Time Charter (Rate/day)		19900	36900	36900	36900	36900	36900	
4	Time Charter (Revenue)		6.87	12.61	12.99	12.92	12.92	12.92	71.23
5	Operating Costs (Maintenance)		-5.83	-5.97	-6.12	-6.29	-6.46	-6.64	-37.38
6	Projects (Enhancement)		-2.40	0	-0.50	0	0	0	-2.90
7	Cashflow		-1.36	6.64	6.37	6.63	6.46	11.88	36.62
8	Discount Rate (6%)		0.9434	0.8900	0.8396	0.7921	0.7473	0.7450	
9	Discounted Cashflow	**28.4**	**-1.28**	**5.91**	**5.35**	**5.25**	**4.83**	**8.37**	28.43
10	Net Present Value (NPV)	**19.83**							

Source Compiled by Welcome, H. S. 2008. Note: TC in thousand USD – other figures in Million USD.

By purchasing and trading the ship, without converting for 6 years, the NPV at the beginning of the project (2006) resulted in returns of USD 19.83M and USD 15.71M at the discounted rates of 6% and 10%. However, it is not standard practice for shipping companies to use a discount rate of 6%.

Table 8.12 Discounted Cashflow@10% - before Conversion (USD).

Item	Description	Summary	Year 1 (2006)	Year 2 (2007)	Year 3 (2008)	Year 4 (2009)	Year 5 (2010)	Year 6 (2011)	Total
1	Ship Purchase	8.6							
2	Ship Sale							5.6	
3	Time Charter (Rate/day		19900	36900	36900	36900	36900	36900	
4	Time Charter (Revenue)		6.87	12.61	12.99	12.92	12.92	12.92	71.23
5	Operating Costs (Maintenance)		-5.83	-5.97	-6.12	-6.29	-6.46	-6.64	-37.28
6	Projects (Enhancement)		-2.40	0	-0.50	0	0	0	-2.90
7	Cashflow		-1.33	6.64	6.37	6.63	6.46	11.88	36.65
8	Discount Rate (10%)		0.9091	0.8264	0.7513	0.6830	0.6209	0.5645	
9	Discounted Cashflow	**24.3**	**-1.21**	**5.49**	**4.79**	**4.53**	**4.01**	**6.71**	24.31
10	Net Present Value (NPV)	**15.71**							

Source Compiled by Welcome, H. S. 2008. Note: TC in thousand USD – other figures in Million USD.

8.5.4 The Discounted Cashflow after Conversion

The difference in the project cost after converting the existing cargo gates to MRG was USD 0.7M, when comparing with the scenario before the conversion. Due to the conversion of the cargo gates in 2008, the additional investment of USD 0.7M resulted in decreasing the cashflow from USD 6.37M to USD 6.16M, when the discount rate is 10% (see Tables 8.12 and 8.14). Similar to the scenario before conversion, two discounted cashflows were calculated using 6% and 10% discount rates. These calculations were primarily to compare the NPV prior to inception of the project in 2006. Therefore, allowing the owner to decide on the optimum manner to finance the project. Tables 8.13, 8.14 and Appendix VII.3 (b and d) illustrate the outcome of the discounted cashflows after the conversion, when applying the discount rates of 6% and 10%.

Rather than investing the USD 12.70M with the bank (i.e. Treasury Deposit) and/or other investment ventures (i.e. shipping sale and purchase/oil stocks), it was advantageous for the owner to buy and trade the vessel for 6 years and subsequently sell the ship on the second hand market, taking into account a depreciation value of 7% per annum.

Table 8.13 Discounted Cashflow @ 6% - after Conversion (USD).

Item	Description	Summary	Year 1 (2006)	Year 2 (2007)	Year 3 (2008)	Year 4 (2009)	Year 5 (2010)	Year 6 (2011)	Total
1	Ship Purchase	8.6							
2	Ship Resale							5.6	
3	Time Charter (Rate/day)		19900	36900	36900	36900	36900	36900	
4	Time Charter (Revenue)		6.87	12.61	13.21	13.14	13.14	13.14	72.11
5	Operating Costs (Maintenance)		-5.83	-5.97	-5.85	-5.73	-5.61	-5.49	-34.48
6	Projects (Enhancement)		-2.40	0.00	-1.20	0.00	0.00	0.00	-3.60
7	Cashflow		-1.36	6.64	6.16	7.41	7.53	13.25	39.63
8	Discount Rate 6%		0.9434	0.8900	0.83962	0.79209	0.74726	0.7050	
9	Discounted Cashflow	**30.6**	**-1.3**	**5.9**	**5.2**	**5.9**	**5.6**	**9.3**	30.64
10	Net Present Value (NPV)	**22.0**							

Source Compiled by Welcome, H. S. 2008. Note: TC in thousand USD – other figures in Million USD.

Table 8.14 Discounted Cashflow @ 10% - after Conversion (USD).

Item	Description	Summary	Year 1 (2006)	Year 2 (2007)	Year 3 (2008)	Year 4 (2009)	Year 5 (2010)	Year 6 (2011)	Total
1	Ship Purchase	8.6							
2	Ship Resale							5.6	
3	Time Charter (Rate/day)		19900	36900	36900	36900	36900	36900	
4	Time Charter (Revenue)		6.87	12.61	13.21	13.14	13.14	13.14	72.11
5	Operating Costs (Maintenance)		-5.83	-5.97	-5.85	-5.73	-5.61	-5.49	-34.48
6	Projects (Enhancement)		-2.40	0.00	-1.20	0.00	0.00	0.00	-3.60
7	Cashflow		-1.36	6.64	6.16	7.41	7.53	13.25	39.63
8	Discount Rate 10%		0.90909	0.82645	0.75131	0.68301	0.62092	0.56447	
9	Discounted Cashflow	**26.1**	**-1.2**	**5.5**	**4.6**	**5.1**	**4.7**	**7.5**	26.10
10	Net Present Value (NPV)	**17.5**							

Source Compiled by Welcome, H. S. 2008. Note: TC in thousand USD – other figures in Million USD.

However, based on the second hand price of USD 22.8M for this vessel in August 2008 and by adding a reduction factor of 7% per annum, the forecast value for the ship upon completion of the project could be USD 18.3M. This price is only an estimate and there is no guarantee that the second hand market price for handymax bulk carriers will cost

USD 18.3M at the end of 2011/beginning of 2012. Figure 8.7 shows the forecast price for second hand handymax bulk carriers from 2006 to 2011.

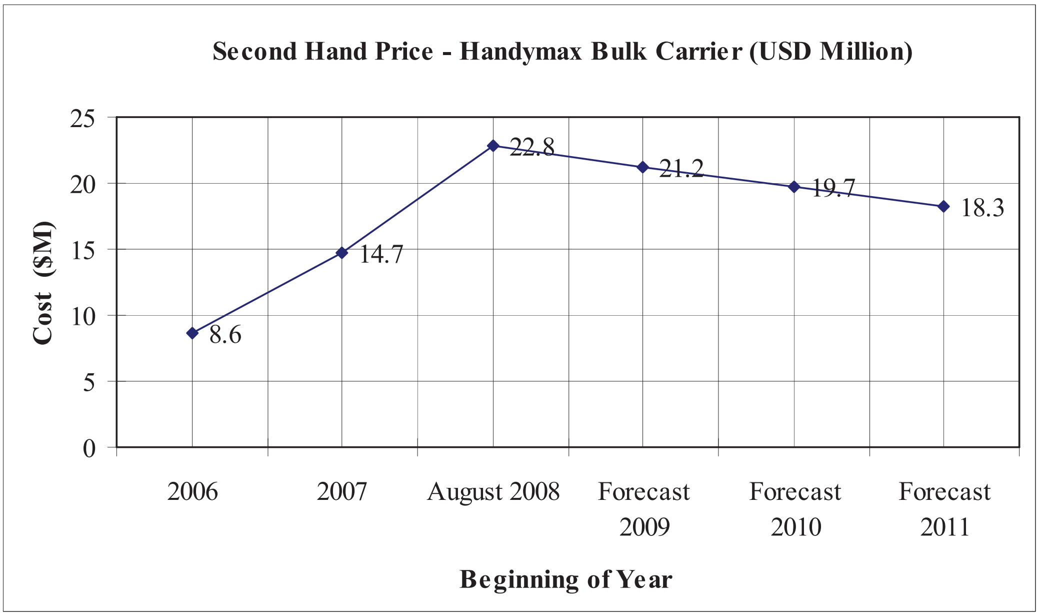


Figure 8.7 Estimated Second Hand Price – Handymax Bulk Carrier. Welcome, H. S. 2008.

In the event that the second hand price for handymax bulk carriers remain from 2006 to 2011 as forecast in Figure 8.7, then the owner would profit tremendously from the vessel sale on completion of the project. By using the discount rate of 10% as illustrated in Table 8.15, the NPV (2006) would have amounted to USD 14.30M after the conversion. This price depends on whether the vessel second hand sale price is USD 18.3M in 2011.

The discounted cashflow exercise of 6% discount rates was used primarily for comparison of two cases (i.e. 6% and 10% before and after converting the vessel). However, Stopford **(2004, p.189c)** said that in real life *'many businesses use a discount rate of 15% per year. If a company has to borrow to finance the project, the marginal cost of debt would be more appropriate'*.

Newcastle University coursework of 'Application of Basic Economic Principles - Module No: MAR301/302/303/304 **(2006, pp.1-7)** was also utilized *'to calculate the NPV, which is based on the discounted cashflow method of calculations...'*

Table 8.15 Discounted Cashflow @ 10% - after Conversion and Selling Vessel for USD 18.3M.

Item	Description	Summary	Year 1 (2006)	Year 2 (2007)	Year 3 (2008)	Year 4 (2009)	Year 5 (2010)	Year 6 (2011)	Total
1	Ship Purchase	8.6							
2	Ship Sale							18.3	
3	Time Charter (Rate/day)		19900	36900	36900	36900	36900	36900	
4	Time Charter (Revenue)		6.87	12.61	13.21	13.14	13.14	13.14	72.11
5	Operating Costs (Maintenance)		-5.83	-5.97	-5.85	-5.73	-5.61	-5.49	-34.48
6	Projects (Enhancement)		-2.40	0.00	-1.20	0.00	0.00	0.00	-3.60
7	Cashflow		-1.36	6.64	6.16	7.41	7.53	7.65	34.03
8	Discount Rate (10%)		0.9091	0.8264	0.7513	0.683	0.6209	0.5645	
9	Discounted Cashflow	**22.9**	**-1.2**	**5.5**	**4.6**	**5.1**	**4.7**	**4.3**	22.93
10	Net Present Value (npv)	**14.30**							

Source Compiled by Welcome, H. S. 2008. Note: TC in thousand USD – other figures in Million USD.

8.6 Sensitivity Analysis

When carrying out sensitivity analysis for any project, there are three main factors to consider: 'Performance', 'Assumptions' and 'Projections'. These factors are described as follows:

- Performance: is the results of activities of an organization or investment over a given period or time;
- Assumptions: are proposition that is taken for granted, that is, as if it were known to be true; and
- Projections: are quantitative estimates of future economic or financial performance.

The 'Sensitivity Analysis' of this study is relevant to the 6 year project, involving the purchasing and operations of the Model 'B' SULS. This ship is an existing SULS that is presently trading. However, for confidential reasons the company or the ship's name can neither be disclosed.

The economic case study of this research is based on a private owned SULS shipping company having employed a Managing Director, who undoubtedly is responsible to the shipowner for survival of the company and ensuring that the expected profit is achieved from investing in a project. The intended target Rate of Return (RR) from the investment was decided at 10% annually for the 6 year project. Various Discount Rates (DR) were applied by the Discounted Cashflow (DC) method of calculation to verify the project Internal Rate of Return (IRR). Figures 8.8 and 8.9 graphically illustrate the Internal Rate of Returns (IRR) for the original and revised time charters.

According to Buxton, I. L. **(1987, p.45)** interpretation, the IRR is *'That discount rate which gives zero NPV. Also, the IRR is called Discounted Cash Flow Rate of Return, yield or equivalent interest rate of return, or investor's method'.* In this case study the high Internal Rate of Return (IRR) resulted from the lucrative time charter (TC) rate (i.e. USD 40,900/day) at the beginning of 2007, when the TC was renew for 5 additional years (i.e. 2007-2011). However, the owner and charterer agreed on daily TC rates of USD 36,900/day and USD 34,900/day.

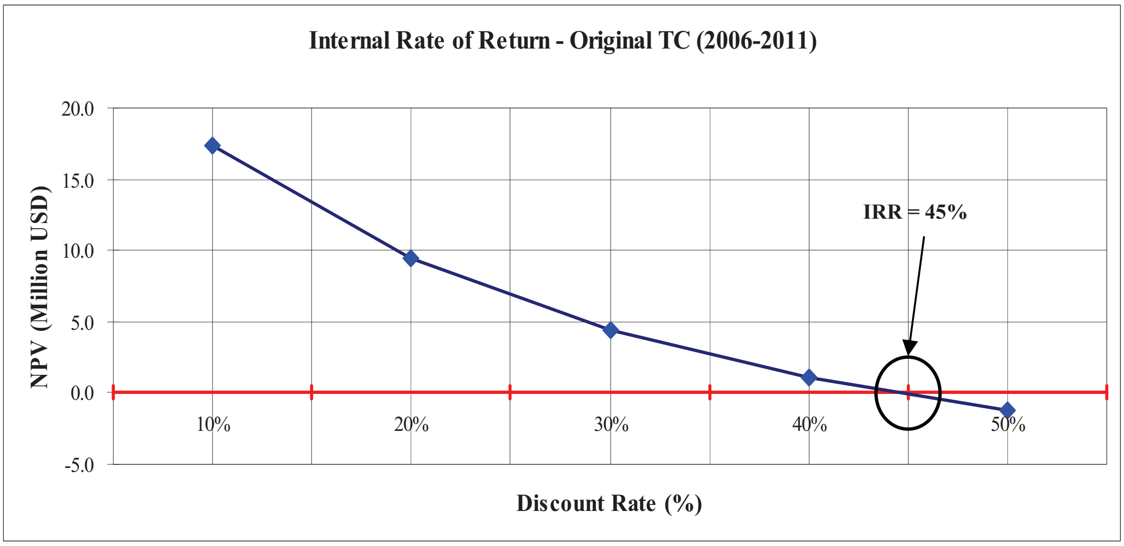


Figure 8.8 Graphical illustration of Internal Rate of Return – Original TC, Welcome, H. S. 2009.

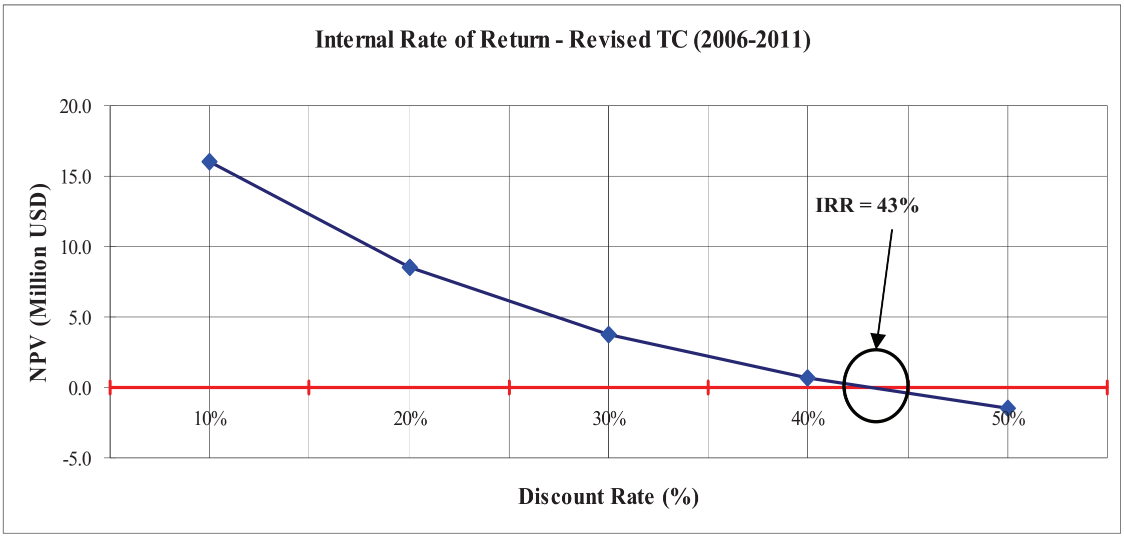


Figure 8.9 Graphical illustration of Internal Rate of Return – Revised TC, Welcome, H. S. 2009.

The owner carried out further investigation to determine the Rate of Return by sensitivity analysis at USD 36,900/day and USD 34,900/day. These exercises were primarily to confirm the return from investment with 2 different TC rates. Table 8.16 shows the resultant IRR for both TC scenarios.

Table 8.16 Internal Rates of Return for Original and Revised Time Charters.

Original TC (USD 36,900/day)		Revised TC (USD 34,900/day)	
NPV (Million USD)	**DR (%)**	**NPV (Million USD)**	**DR (%)**
17.4	10	16.0	10
9.4	20	8.5	20
4.4	30	3.8	30
1.1	40	0.7	40
0.0	**45 IRR**	**0.0**	**43 IRR**
-1.2	50	-1.5	50

Source Compiled by Welcome, H. S. 2009

Subsequent to completing the feasibility study and deciding on the method of financing the project, various sensitivity analyses in addition to the cashflow analyses were necessary to allow the senior management in deciding to implement the project. The final decision to proceed with the project was based on projections from these assumptions:

- Income annually from time charters (original and revised);
- Steel cost for the conversion; and
- Conversion time.

Due to the depressed dry bulk freight market (2009), there was other sensitivity analyses investigated. This was primarily to verify the return from investment for the 6 year project should the original or revised time charters cancelled and the vessel employed in the spot market (2009-2011). These sensitivity analyses were relevant to:

- Time charter for USD 10,500/day; and
- Fuel price.

The fluctuation of currency (i.e. exchange rate) was not a concern, simply because the conversion contract was based on USD and the ship's earning was in USD.

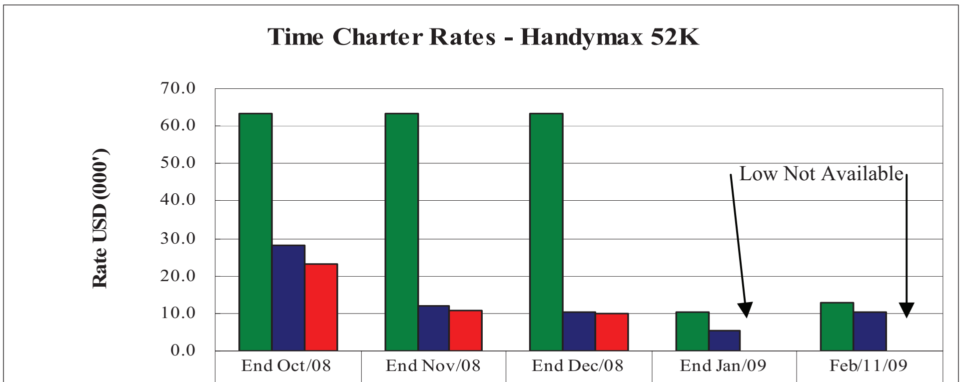
Upon effecting the sensitivity analyses, the performances output from three of the four key factors (i.e. time charter incomes, cost for steel, conversion time and cost for fuel) analysed, resulted in positive forecast profit on completion of the 6 year project. However, the profit was negative when chartering the vessel for USD 10,500/day and fuel cost forming part of the owner operating expenses. These analyses were based on non-uniform cashflow and according to Buxton **(1987, p.44a)**, when knowing '*The acquisition cost of a ship, the required rate of return on the capital invested (or discount rate), all the operating costs each year, the cargo quantity transported each year and the corresponding freight rate (i.e. annual income), we can calculate the present worth of each item of income and expenditure and add them to find the Net Present Value'*.

In this scenario, the ship and operating costs, the annual income and expected rate of return (i.e. 10%) from investment are known factors, Therefore, the above approach of Buxton **(1987)** was followed utilizing the discount rate or present worth [$PW = (1 + int)^{-N)}$] to calculate the Net Present Value (NPV). Buxton **(1987, p.44b)** also stated that *'if the cashflows are not uniform, the present worth for each annual cashflow can be* *calculated for each N years of the ship's life'.* These calculations in the form of spreadsheets are illustrated in Appendices VIII.4 and VIII.5 with summary tables and graphs in this sub-section (see Table 8.16). The project of purchasing and trading the vessel for 6 years was implemented.

It was assumed that the owner has chosen to convert the cargo gates in China. This is due to good relationship with a particular Chinese Shipyard, while converting and dry-docking other vessels of the fleet. In addition, the price was highly competitive, when comparing with prices from Shipyards in the Americas and Europe.

8.6.1 Scenario 1 - Sensitivity Analysis of Original and Revised Time Charter

Despite the owner having confirmed time charter for USD 36,900/day from 2007 to 2011, there was scepticism within the organization that the high market of 2007 could change to a reduced freight rate, prior to completion of the project. The owner has a long-term business relationship with the charterer. Therefore, in depressed times the owner would likely consider accepting a reduced time charter rate. In November of 2008 (after the conversion), the world was in a global recession. This resulted in the charterer approaching the owner requesting a reduction in the time charter rates from USD 36,900/day to USD 34,900/day, commencing from the beginning of 2009 until completion of the project in 2011. The owner conceded with the charterer's request taking into consideration the depressed market, resulting from the 2008 worldwide recession. However, there was one condition stipulated in the agreement, should the market recover before completion of the project, the charterer agreed to re-adjust the time charter rate to the original contract value (i.e. USD 36,900/day). In Appendix VIII.6, Fearnleys **(2008)** stated '*in week 48 report or November 26th 2008, the one year time charter rates for handymax bulk carriers of 53,000 DWT decreased from USD 63,500/day to USD 10,000/day and that the average low for one year time charter in November 2008 was USD 10,900/day ...'*. For this reason, the owner was prepared to accept USD 34,900/day from 2009 to 2011. Figure 8.10 illustrates the monthly average time charter rates from October 1st 2008 to February 11th 2009.



	End Oct/08	End Nov/08	End Dec/08	End Jan/09	Feb/11/09
High	63.5	63.5	63.5	10.5	13.0
Previous Week	28.2	12.2	10.5	5.3	10.5
Low	23.0	10.9	10.0	0.0	0.0

Figure 8.10 Average TC Rates for Handymax Bulk Carriers – 52K. Welcome, H. S. 2009.

Source Fearnley Weekly Reports, October 2008 to February 2009.

Upon the owner accepting a reduced time charter rate (i.e. USD 34,900/day) from 2009 to 2011, the project required re-assessing for performance. Fundamentally, this assessment was to ensure that there would be reasonably profit from the investment upon completion of the project. Despite the known IRR (i.e. 45% and 43%) for both the original and revised time charters (i.e. USD 36,900/day and USD 34,900/day), the owner decided to effect sensitivity analyses for both scenarios of the project (i.e. original and revised time charters). This investigation by the owner was primarily to determine the sensitive nature of the project with the changes in freight rates. The key assumptions used for conducting the sensitivity analysis were various 'inputs' of freight rates versus the 'outputs' NPV at the intended 10% rate of return from investment. The sensitivity analysis was also conducted with NPV at 20% discount rate, while using various freight rates above and below the original and revised time charter rates. By calculating the NPV at 20% discount rate, this allowed for comparison with the resultant NPV at 10% discount rate. In addition, the sensitivity analysis (i.e. Figure 8.11) shows how the project performance varies with changes, when applying 10% and 20% discount rates to obtain the NPV.

Table 8.17 illustrates the figures used for plotting the sensitivity analysis graph exhibited in Figure 8.11. These figures resulted from calculations of the annual and discounted cashflows after the cargo gates conversion in 2008. Appendices VIII.1 and VIII.3 demonstrate these annual and discounted cashflows.

Table 8.17 Various Freight Rates and NPV @ 10% and 20% Discount Rates.

Freight Rates (Input)	NPV (Output)	
	@ 10% DR	@ 20% DR
(USD*1000/Day)	(Million USD)	(Million USD)
30.9	14.7	8.0
32.9	16.0	8.8
34.9	17.3	9.7
36.9	18.6	10.4
38.9	19.9	11.4
40.9	21.3	12.3

Source Compiled by Welcome, H. S. 2009

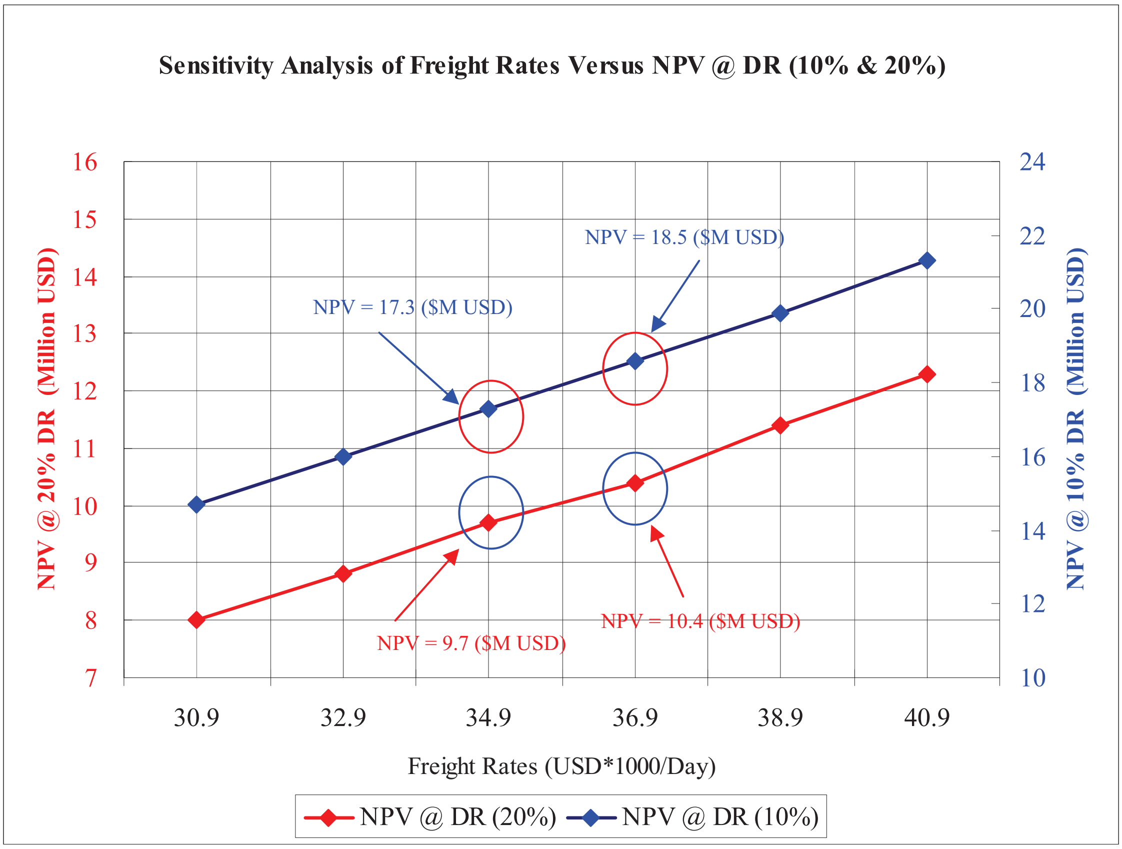


Figure 8.11 Sensitivity Analysis-Freight Rates Versus NPV - DR of 10% & 20%. Welcome, H. S. 2009.

__Note:__ Freight rates are relevant to the original and revised Time Charters (Table 8.17 and Figure 8.11).

Obviously, the sensitivity analysis in Figure 8.11 demonstrated that when the time charter was changed from USD 36,900M to USD 34,900M, the calculated NPV at 10% discount rate reduced by USD 1.20M (i.e. 18.5 – 17.3 = USD 1.20M). This difference of USD 1.20M in the NPV is noticeable. However, the project outcome remains a positive investment and according to the annual cashflows (i.e. Appendices VIII.1b and VIII.1c) the return from investment is above the predicted 10%, which was the major concern of the owner.

When using a discount rate of 20%, the difference in NPV between the original and revised time charter rates amounted to USD 0.70M (i.e. 10.4 – 9.7 = USD 0.70M). This figure again resulted in a positive NPV or optimistic return from investment.

With regard to the IRR as illustrated in Figures 8.8 and 8.9, the results are certainly unprecedented and above the shipowner's prediction. Nevertheless, as mentioned before, these high rates of returns (i.e. 45% and 43%) are outcomes from a lucrative time charter market when the contract was signed in 2007. In reality, according to R. S. Platou **(2007)** *'the average time charter rate for handymax bulk carriers was USD40,900/day'*. However, the time charter rate of 36,900/day and 34,900/day were negotiated by the charterer and the shipowner agreed. This agreement resulted from the long-term relationship between the two parties.

The revised time charter Internal Rate of Return was marginally reduced, when compared to that of the original time charter (i.e. 45% to 43%). However, these rates of return for the 6 year project were in excess to the 10% originally predicted by the shipowner after purchasing the vessel, upgrading steelworks and converting the cargo gates.

Based on the revised time charter outcomes from the annual cashflow, discounted cashflow and sensitivity analysis, the shipowner was satisfied with the return from his investment. Nevertheless, the owner expressed concern due to the global economic crisis in 2009 and proceeded to carry out alternative sensitivity analysis with figures from the 2009 time charter market.

8.6.2 Scenario 2 - Sensitivity Analysis of Alternative Time Charter

Subsequent to analyzing the 2009 depressed time charter market for handymax bulk carriers as demonstrated in Figure 8.10 (i.e. averaging USD 10,500/day for 1 year time charter - February 2009), the owner was concerned that the charterer could perhaps request further reduction in the time charter rate or even cancel the contract. Obviously, the cancellation of the contract would result in legal implications between both parties. In the event of cancellation of the existing time charter the alternative business would either be to employ the vessel at the market time charter rate (i.e. USD 10,500/day) or in the spot market that is highly unusual for SULS. Due to these apprehensions, the owner decided to formulate a sensitivity analysis primarily to establish what would be his financial position during 2009 to 2011 in terms of return from investment, if the time charter rate was USD 10,500/day. Upon completing the annual cashflow with time charter rates of USD 10,500/day (from 2009 to 2011), it was clear to the owner that chartering the vessel for a rate of USD 10,500/day would result in negative profit and the forecast target of 10% return per annum on investment would not be achieved. Appendix VIII.1d concluded that while employing the vessel under the alternative time charter, the net yearly profit would be USD -1.66M for the 6 year project.

In summary, the annual cashflow for the alternative time charter provided sufficient evidence, confirming that the owner expectation of 10% return annually from investment would not be achieved, when the time charter rate was USD 10,500/day (2009-2011). Therefore, the owner decided not to proceed with the sensitivity analysis for the alternative time charter, due to the fact that the profit was negative.

8.6.3 Scenario 3 - Sensitivity Analysis of Fuel Cost Versus Freight Rates

Should the original time charter cancelled and the vessel employed by an alternative contract other than time charter for USD 10,500/day, the existing operating costs for the vessel would remain unchanged. However, the fuel costs (MDO & IFO) would be additional operating expenditures for the owner's account, when chartering the vessel in the spot market. According to AXS Marine **(2008)**, *'Intermediate Fuel Oil (IFO 380) cost from October 2008 to December 2008 has reduced by more than 50% per tonne* *(i.e. USD 520 to USD 203).* AXS Marine **(2009)** also stated '*that the average fuel cost from January 15th 2009 to February 11th 2009, were USD 248 per tonne for IFO 380 and USD 588 per tonne for Marine Diesel Oil (MDO)…'* According to OPEC **(2009),** *'the average cost for crude oil in 2009 was USD 42.12 per barrel...'* Therefore, if the vessel is chartered on contracts other than time charter, the owner could possibly encounter increase in fuel cost resulting in a reduction of profit due to higher operating costs. Alternatively, the owner could reap some benefits from lower fuel cost providing that fuel price continues to reduce in 2009, when compared to the 2008 prices. For example, on August 26th 2008 AXA Marine confirmed that IFO 380 was USD 640/tonne and MDO USD 730/tonne.

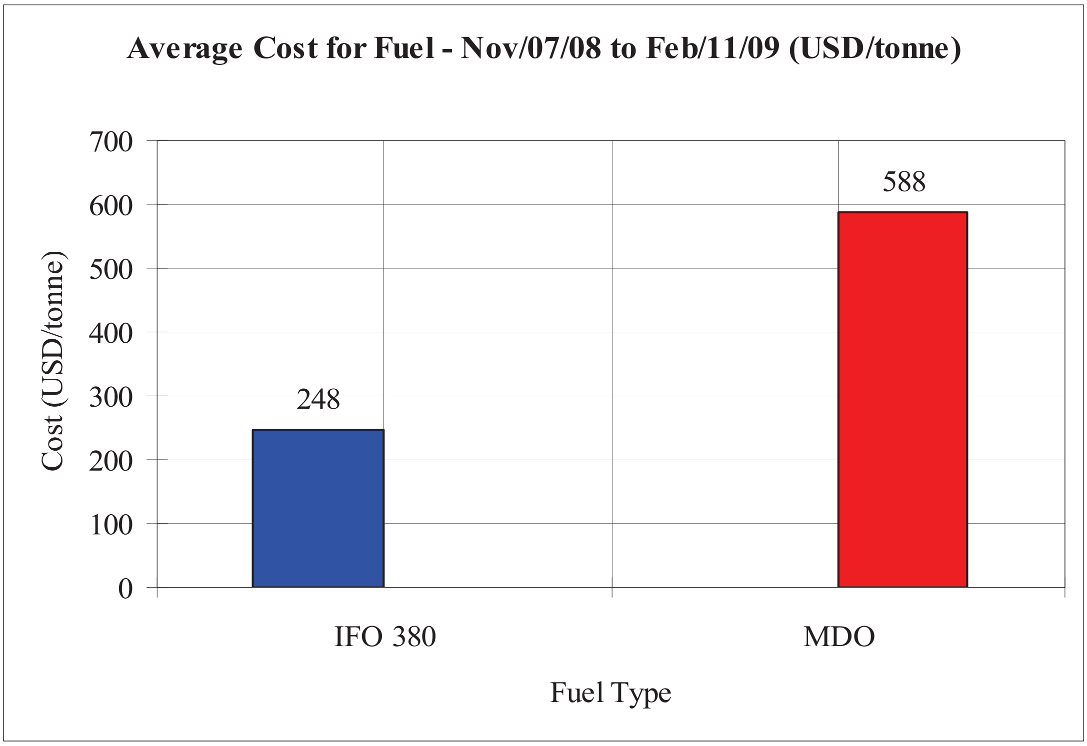


Figure 8.12 Average Fuel Oil Price for 40 Days. AXS Marine, 2008.
Compiled by Welcome, H. S. 2008.

Figures 8.12, 8.13, 8.14, Appendices VIII.7 and VIII.8 illustrate the costs for fuel oil and crude oil according to AXA Marine and OPEC. These costs would form part of the owner's operating expenses in the event of losing the revised time charter contract for

USD 34,900/day and having to charter the vessel in the spot market for USD 10,500/day. Both the Main and Auxiliary Engines consume fuel oil of the IFO 380 and MDO types.

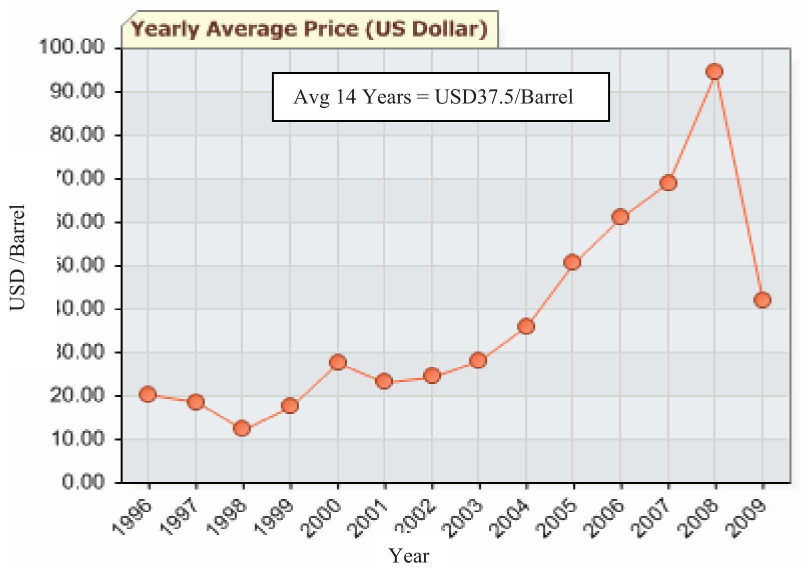


Figure 8.13 Average 14 Years Price for Barrel of Crude Oil. OPEC 2009.

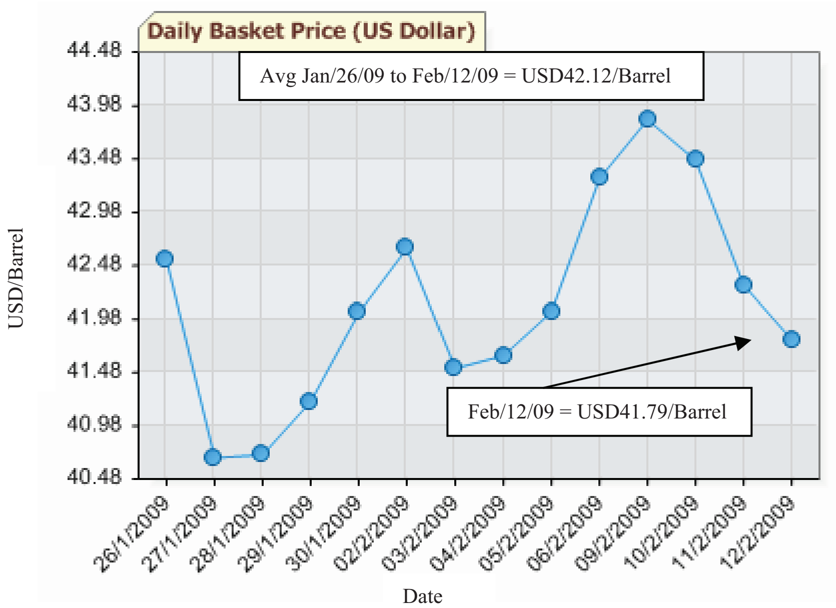


Figure 8.14 Average 14 Days Price for Barrel of Crude Oil. OPEC 2009.

The sensitivity analysis for average time charter (i.e. handymax bulk carriers – October 2008 to February 2009) versus fuel costs during the same period is illustrated in Figure

8.15. Table 8.18 shows the details plotted for the sensitivity analysis which is based on when the vessel is employed in the spot market for USD 10,500/day and fuel costs are for the owner's account.

Table 8.18 Average Time Charter Rates and Fuel Costs (Oct/08 to Feb/09).

Dates & Avg Time Charter Rate (Input) (USD*1000/Day)	Fuel Cost (Output)	
	IFO 380 (USD/tonne)	MDO (USD/tonne)
Oct/08 - 28.2	207	533
Nov/08 - 12.2	221	551
Dec/08 - 10.5	234	570
Jan/09 - 5.3	248	588
Feb/09 - 10.5	278	725

Source Compiled by Welcome, H. S. with Figures from AXA Marine and Fearnleys.

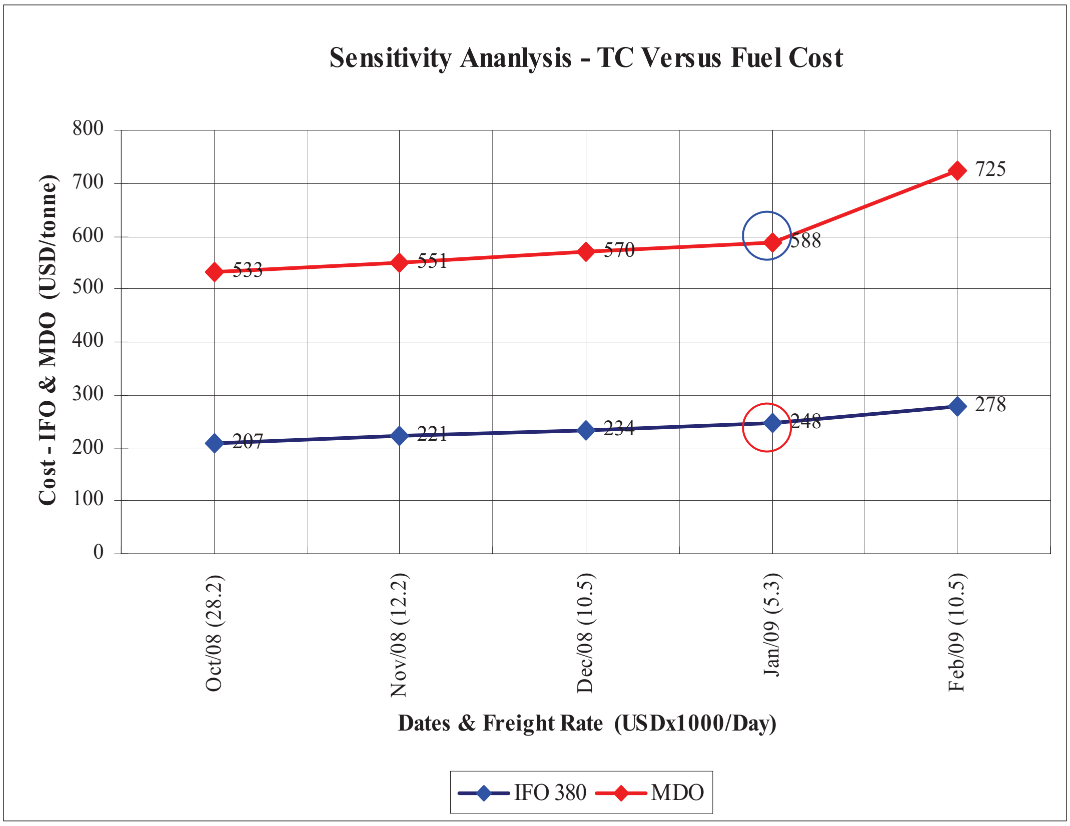


Figure 8.15 Sensitivity Analyses – TC versus Fuel Costs (Oct/08 to Feb/09). Welcome, H. S. 2009.

Obviously, the sensitivity analysis concluded that if the original time charter was cancelled in January 2009, the owner would have experienced high fuel costs while employing the vessel in a depressed freight market. Certainly, with charter earnings of USD 10,500/day as illustrated in Figure 8.10, the profit would had been less than the owner expected return from investment. Appendices VIII.1d verified that despite the positive profit in 2008 and 2011, the overall average profit for the 6 year project would result in negative return, when the time charter rate is USD 10,500/day. The target at commencement of the project was 10% return annually from investment for 6 years. Therefore, charters providing an income of USD 10,500/day before expenses would be unacceptable for the owner, primarily when fuel cost forms part of the owner operating costs. In February 2009, the fuel prices as well as the charter rates increased (see Figures 8.10 and 8.15). Nevertheless, the project would not be viable when the freight rate is USD 10,500/day (see Table 8.19) and fuel costs forming part of the owner operating expenses.

The discounted cashflow calculations in Table 8.19 verified that at 10% discount rate the NPV is USD -6.6M. This resulted from the fuel costs (2009-2011) forming part of the owner account, when the vessel is trading in the spot market.

Table 8.19 Discounted Cashflow - Fuel Costs for the Owners Account (USD).

Item	Description	Summary	Year 1 (2006)	Year 2 (2007)	Year 3 (2008)	Year 4 (2009)	Year 5 (2010)	Year 6 (2011)	Total
1	Ship Purchase	8.6							
2	Ship Sale (Resale)							5.6	
3	Time Charter (Rate/day)		19900	36900	36900	10500	10500	10500	
4	Time Charter (Revenue)		6.87	12.61	13.21	3.90	3.90	3.90	44.39
5	Operating Costs (Maintenance)		-5.83	-5.97	-5.85	-5.74	-5.62	-5.50	-34.51
6	Fuel (IFO & MDO)		0.00	0.00	0.00	-1.97	-1.97	-1.97	-5.91
7	Projects (Enhancement)		-2.40	0.00	-1.20	0.00	0.00	0.00	-3.60
8	Cashflow		-1.36	6.64	6.16	-3.81	-3.69	-3.57	0.37
9	Discount Rate 10%		0.9091	0.8264	0.7513	0.6830	0.6209	0.5645	
10	Discounted Cashflow	**2.0**	**-1.2**	**5.5**	**4.6**	**-2.6**	**-2.3**	**-2.0**	1.97
11	Net Present Value (NPV)	**-6.6**							

Source Compiled by Welcome, H. S. 2008. Note: TC in thousand USD – other figures in Million USD.

This discounted cashflow in Table 8.19 is based on yearly fuel costs for one Main Engine (i.e. USD 1,717,400/year - at sea 277 days) and two Auxiliary Engines (i.e. USD 257,544/year - at sea 277 days and in port 73 days). These fuel costs are relevant to USD 248/tonnes (IFO 380 - Main Engine) and USD 588/tonne (MDO - Auxiliary Engines). Fifteen days MDO fuel cost was included yearly for maintenance in port, while one Auxiliary Engine is operating.

In summary, the project would not be viable when the original time charter is cancelled and the vessel is employed in the spot market for USD 10,500/day, where fuel costs are part of the owner daily operating expenses.

8.6.4 Scenario 4 - Sensitivity Analysis of Steel Cost After Conversion

Prior to carrying out the cargo gates conversion, the agreed steel price was USD 1.18 per kilogram (kg) of steel installed all-inclusive (i.e. fabrication, steel preparation, surface preparation, coating, installation, staging, lighting, gas freeing, etc). The steel price agreement between the owner and shipyard is in accordance with the conversion contract. This steel price (i.e. USD 1.18/kg) is a credible cost for various ship conversions carried out by the author in China **(2007)**. However, during the second and third quarter of 2008, steel cost in China for ships repair and conversions were USD 2.40/kg to USD 3.00/kg, depending on the shipyard and quantity of steel renewed and installed. In 2009, steel renewal price in China was reducing and confidential sources indicated that steel prices for ships repair and conversions were in the range from USD 1.50/kg to USD 2.00/kg. According to China Metallurgical Information Centre Beijing **(2009),** *'the price for 6 mm thick steel plate from March 23rd 2009 to March 27th 2009 was Yuan 4048/tonne or USD 595/tonne…'* Table 8.20 illustrate steel costs in China for 6 mm thick plate during the conversion period.

Table 8.20 Steel Cost in China – 6 mm Thick Steel Plate (USD).

Dates	Cost (USD/tonne)
Dec/17/07-Dec/21/07	811.0
Dec/04/07-Dec/28/07	814.0
Dec/31/07-Jan/04/08	816.0
Jan/07/08-Jan/11/08	820.0
Jan/14/08-Jan/18/08	820.0
Jan/21/08-Jan/25/08	820.0

Source China Metallurgical Information Centre Beijing, 2009.

This case study is based on steel price for conversion in China during 2007, which was USD 1.18/ kg.

However, based on the author's experience, occasionally steel price could result in controversial issue despite the short period (i.e. 20 days) for the conversion. This is due to shipyards requesting cost adjustment, primarily when the price for steel increases in the region during the conversion stage and before completion of the project. Because of the possibility that the shipyard could request cost adjustment for steel, the owner decided to investigate the project performance by formulating a sensitivity analysis while assuming various steel prices. By using the discounted cashflow method of calculation (after conversion), a sensitivity analysis was carried out for various steel costs versus the NPV at 10% and 20% discount rates. The intended rate of return was 10% from investment and for this reason the analysis was affected at 10% discount rate. In addition, the NPV calculation at 20% discount rate was primarily for comparing the two NPV (i.e. 10% and 20%) and discounted cashflows.

Table 8.21 and Figure 8.16 illustrate the sensitivity analysis for steel cost versus the NPV. The results from this analysis substantiates that the owner has the flexibility to accept increase steel costs with marginal reduction in return from investment. This view is relevant to when calculating the NPV at 10% discount rate, which is important to the owner due to this percentage (i.e. 10%) being the initial forecast rate of return. At 10% discount rate the maximum difference in NPV amounted to USD 0.50M (i.e. 17.0 – 17.5 = USD 0.50M), while having discounted cashflows of USD 25.6M and USD 26.1M.

Clearly, this indicates that if the owner accepts steel cost of USD 1.35/kg, the discounted cashflow would be reduced by USD 0.50M.

Table 8.21 Discounted Cashflow - Steel Cost versus NPV after Conversion.

Steel Cost (Input)	NPV (Output)	
Predicted (USD/kg)	At 10% DR (Million USD)	At 20% DR (Million USD)
1.06	17.5	9.5
1.12	17.4	9.4
1.18 Contract Price	17.4	9.4
1.25	17.2	9.2
1.30	17.1	9.1
1.35	17.0	9.0

Source Compiled by Welcome, H. S. 2009

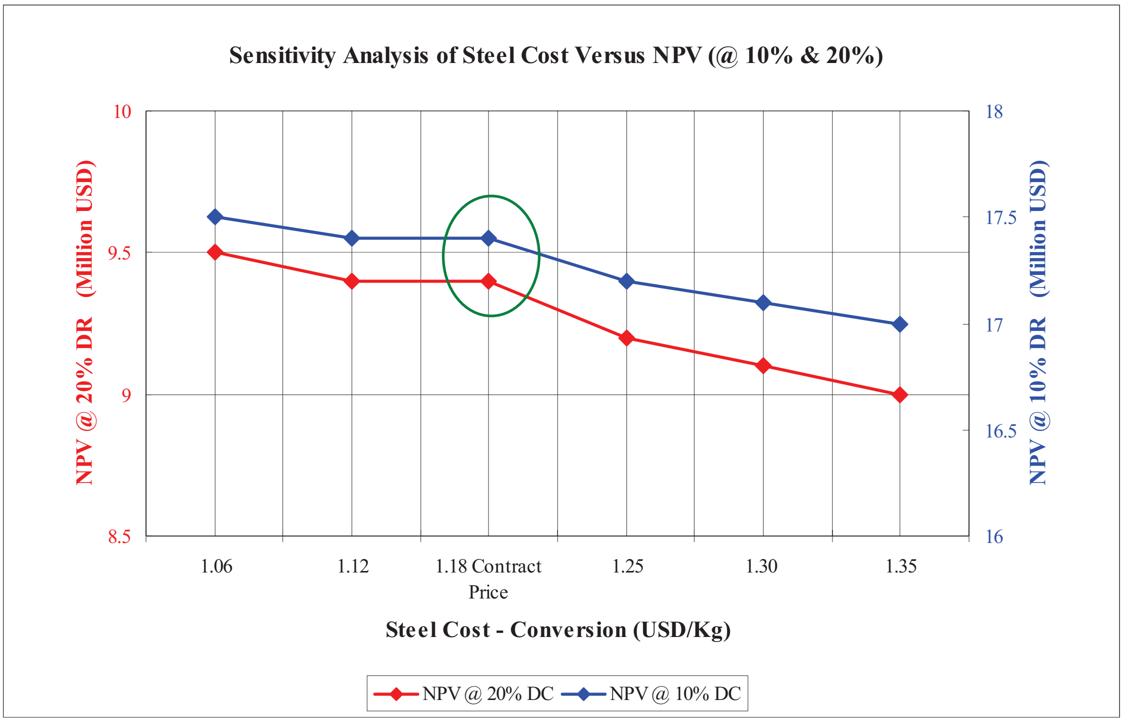


Figure 8.16 Sensitivity Analyses – Steel Cost versus NPV & DR of 10% and 20% after Conversion.
Source Compiled by Welcome, H. S. 2008. Based on the Discounted Cashflow Method.

The predicted increase in steel price from USD 1.18/kg to USD 1.35/kg is approximately 14.4% (or USD 0.17/kg) higher than the contracted cost.

In summary, this increase steel cost would result in having minor impact on the project return from investment. The owner by properly negotiating with the shipyard would unlikely have to pay USD 1.35/kg for steel renewed and installed. This is due to having a confirmed contract with the shipyard for USD 1.18/kg and the steel price in the region did not drastically increased during the conversion period.

8.6.5 Scenario 5 - Sensitivity Analysis of Conversion Time – Original Time Charter

Occasionally during repairs and conversions, the shipyard fails to re-delivery the vessel on time according to the scheduled contractual date. Therefore, a delay in re-delivering the vessel is a cost measure that is normally factored into repairs and conversions budget. For early delivery of a vessel, the owner's generally compensate the shipyard by offering a bonus which the norm is 50% of the daily late delivery penalty. In this scenario, the daily late delivery penalty is equal to 1 day time charter rate (i.e. USD 36,900/day). Table 8.22 and Figure 8.17 illustrate the sensitivity analysis of the predicted time for effecting the conversion.

Table 8.22 Discounted Cashflow – Conversion Time - Original TC.

Conversion Time (Input)	**NPV (Output)**	
Predicted (Days)	At 10% DR (Million USD)	At 20% DR (Million USD)
18	15.6	8.3
19	15.6	8.3
20 Contract	15.6	8.2
21	15.6	8.2
22	15.5	8.2
23	15.5	8.2

Source Compiled by Welcome, H. S. 2009

Figure 8.17 shows the result of two analyses, when applying discount rates (DR) of 10% and 20% to obtain the NPV. In both scenarios the NPV resulted in positive returns. However, the owner target is 10% return on investment and obviously this percentage (i.e. 10%) would be the focus point. The 20% DR was primarily for comparison of the two percentages. The graph in Figure 8.17 illustrates a constant NPV at 10% DR (i.e. USD 15.6M), corresponding to 18, 19, 20 and 21 days conversion time. The NPV at 10% DR is equal to USD 15.5M, when the conversion time is extended to 22 or 23 days.

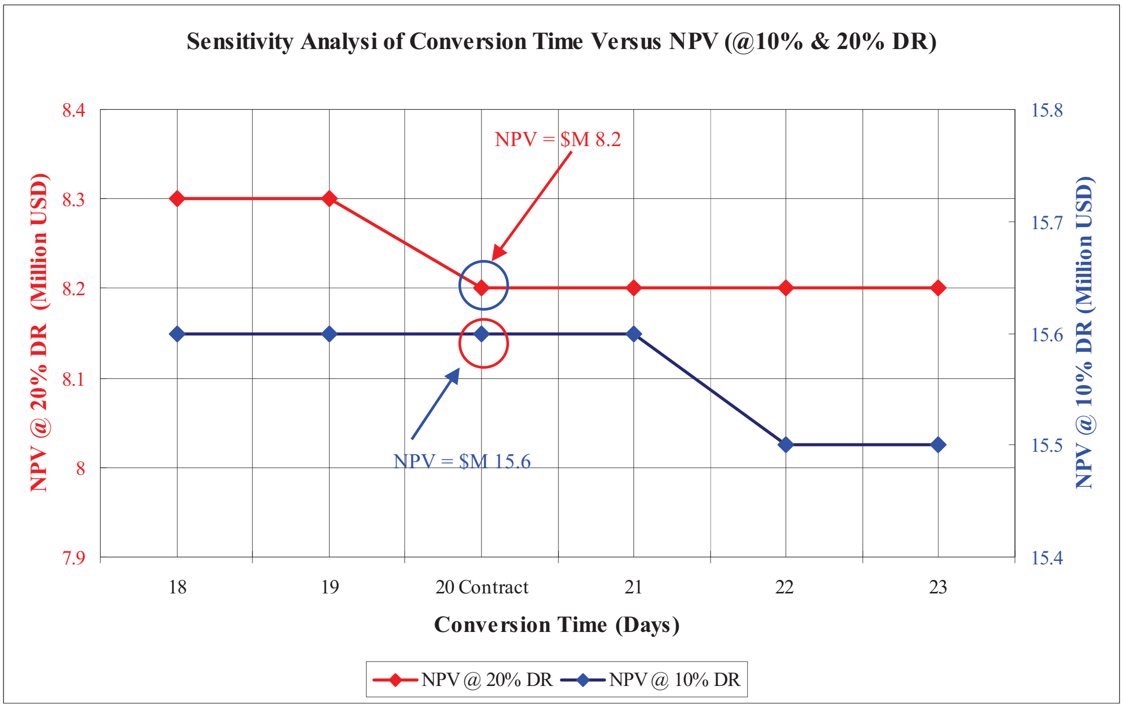


Figure 8.17 Sensitivity Analysis - Conversion Time – Original TC. Welcome, H. S. 2008.

According to the conversion contract, the gate refitting is schedule to be completed in 20 days. Therefore, the owner require compensating the shipyard for each day early the vessel is re-delivered, which amounts to USD 18,450/day (i.e. 50% of time charter rate). Any amount of bonus paid to the shipyard would require adding to the conversion budget (i.e. USD 700,000) for replacing the RTG with MRG. Nevertheless, the vessel would commence trading early at full time charter rate (i.e. USD 36,900/day). As a result, for every day early the vessel is re-delivery, the owner income would amount to 50% of the daily time charter rate or USD 18,450/day. Alternatively, for late delivery the shipyard would require compensating the owner daily for damages amounting to the full time charter rate of USD 36,900/day.

In addition, should there be a delay (in 2008); the daily operating cost incurred has to be taking into account, which would be an average of USD 17,381/day (i.e. USD 6,120,000 / 352.1 days = 17,381). This figure is demonstrated in the annual cashflow (i.e. Appendix VIII.1a) of operating costs for 2008.

In summary, the difference in the NPV at 10% discount rate for conversion time of 18 to 23 days amounts to USD 0.1M (i.e. USD 100,000). This reduction in earnings is only relevant to when the conversion is delayed for 2 and 3 days (or re-delivery in 22 or 23 days). Despite the sensitivity analysis results for the conversion time, the IRR is 45% for the 6 year project at the original time charter rates of USD 36,900/day. This concludes that the project is a viable venture.

8.7 The Economic Risks

Risks relating to the economic aspects of the Multi-functional Roller Track Gate are uncertain and not identifiable like the engineering and operational risks. The design and operational risks are normally visible issues, which could be addressed and rectified when fabricating and testing properly a full-scale prototype gate, prior to installation onboard an SULS. The economic risks for this project are largely subject to many factors, these are principally:

- The dry bulk market freight rates could change overnight to a depressed situation, despite that the conversion is only scheduled for 20 days (i.e. 2008 global market);
- The dry bulk market could drastically increase after committing to the conversion contract. Therefore, any delay in the shipyard production schedule and re-delivery of the vessel could result in lost revenue for the owner;
- An increase in the dry bulk market demanding for additional tonnage globally. This would probably cause the steel price to also increase, resulting in controversy with the shipyard due to the yard requesting increase cost for tonnes of steel used to convert the vessel. The owner should ensure that the contract has protective clause guaranteeing

no extra cost in this situation (i.e. steel price for 6 mm plate in China on Oct/24/08 was USD 697/tonne and on Feb/20/09 was USD 670/tonne);

- Currency exchange rate could result in additional cost. The owner should ensure that the conversion contract is formulated in USD, similar to revenue for freight;
- Ensuring that the contract has penalty clause, this would somewhat coerce the shipyard into re-delivering the vessel according to schedule. The penalty clause is always accompanying with a bonus clause. The owner should ensure that the bonus clause is not exorbitant – bonus is normally 50% of the penalty;
- If the freight market changes to favourable conditions during the conversion. In this case, it is sometimes advisable for the owner to offer the shipyard an increase in bonus to speed-up the vessel redelivery. However, conditional that the quality standards are maintained; and
- Economic losses due to force majeure that is beyond the control of human.

8.8 Summary

This Chapter is relating to a case study of a traditional shipping company, owning and operating a sizeable fleet of vessels, who decided to purchase and operate a second hand handymax SULS. The company has substantial cash reserves and subsequent to purchasing the vessel, the owner decided to extend the vessel life cycle and convert the existing Roller Track Gates (RTG) to Multi-functional Roller Track Gate (MRG).

Upon effecting the feasibility studies for the project, the owner was interested in the venture and proceeded to purchase the vessel for USD 8.6M with the intention to invest another USD 4.1M for improvements or a total investment of USD 12.7M for the project. Subsequently, the owner started to investigate the best possible way to finance the project. A minimum of 10% return from investment was expected upon completion of the 6 year project. The bank offered these financing options to the owner:

- Agreed to finance 70% (i.e. USD 6.0M) of the ship purchase price at an interest rate of 6.5% per annum for 6 years (i.e. using the vessel as guarantee for 72 months);

- Agreed to finance 30% (i.e. USD 2.6M) of the ship purchase price at an interest rate of 6.5% per annum for 6 years. Another vessel from the owner's fleet would be utilized as collateral to guarantee this loan;
- Agreed to finance USD 2.9M for improvements of the vessel at an interest rate of 6.5% per annum for 72 months. The second vessel from the owner's fleet would be used as collateral to guarantee this loan;
- Agreed to finance USD 1.2M for improvements of the vessel at an interest rate of 6.5% per annum for 38 months. Other vessels from the owner's fleet would also be utilized as collateral to guarantee this loan; and
- Invest USD 8.6M in Treasury Deposit at an interest rate of 6% per annum compounded for 6 years.

Rather than using the owner's reserve cash to finance the project, the bank options allowed the owner to borrow the entire USD 12.7M under various loan conditions.

There was another option available to the owner, which was investing the USD 12.7M in shipping purchase / sale and oil stocks for an annual return of 10% compounded for 6 years.

Subsequent to the owner analyzing the financing options presented by the bank and the ventures in shipping and oil stocks, the return from the bank was USD 0.85M/year (i.e. USD 5.12M in 6 years) and USD 1.57M/years (i.e. USD 9.43M in 6 years) from the ventures in shipping and oil stocks. These return options from investments for the 6 year project, were below the expectations of the owner. Therefore, the owner decided to finance the entire project (i.e. USD 12.7M) from the company fleet reserve cash. This decision resulted in a Net Present Value (NPV) amounting to USD 17.5M at the discount rate of 10%.

The owner investment in this venture amounted to USD 2.12M/year (or USD 12.7M) for the 6 year project. When the vessel is chartered under the original time charter for USD 36,900/day (2007 to 2011) and upon completion of the 6 year project, the owner's absolute net return from their investment after the conversion amounted to USD 7.58M/year. With the revised time charter for USD 34,900/day (2007 to 2011), the owner absolute net return from their investment after the conversion amounted to USD 6.88M/year. While employing the vessel under the alternative time charter for USD 10,500/day (2009 to 2011), the owner's absolute net return from their investment after the conversion amounted to USD -1.66M/year. Therefore, the project would not be a viable investment, when chartering the vessel for USD 10,500/day from 2009 to 2011.

These annual profits of USD 7.58M/year and USD 6.88M/year resulted from deducting the opening balance of USD 2.40M (see Appendices VIII.1b and VIII.1c) at the beginning of the project (2006), which was required to support the initial operating costs.

From the net profits of USD 7.58M/year and USD 6.88M/year, the amount of USD 0.49M/year is the actual benefit resulting from converting the Model 'B' type SULS existing RTG to the MRG design:

- USD 221,400 Increase income from 5 additional trading days while on time charter in the Great Lakes and 1 day internationally from 2008 to 2011.; and
- USD 275,655 Reduction in manning costs from 2008 to 2011.

The total yearly savings from 2008 to 2011 is USD 497,055

However, in addition to the financial benefits gained from the conversion of the cargo gates and return from investment, there are other benefits for the owner resulting from:

- Upgraded structure for life extension of the vessel which reduces the possibility of downtime by having to carry out unscheduled steelwork repairs, thereby enhancing the trading ability of the vessel;
- Improved unloading capability by replacing the existing cargo gates with the MRG, which reduces discharging and turn-around times in port, resulting in additional unloading trips/year, income and profit;

- Reduction in manning operating costs due to the remote automatic operating system of the MRG;
- Enhanced chartering ability due to upgrading of the unloading system and structure; and
- Good resale value in the second hand market, due to the upgrades.

By investing in this aged vessel to upgrade her trading capability, the above benefits gained by the owner would later be translated into monetary values, while trading the vessel.

Sensitivity analyses were carried out for the original and revised time charters income, conversion time for the cargo gates and cost for steel. The outcomes from these analyses were positive, resulting in the project being profitable. However, the project would not be viable when employing the vessel on charters for USD 10,500/day and when fuel costs are part of the owner's operating expenditures from 2009 to 2011.

In summary, the return from investment according to the owner's internal financing method was higher than investing the USD 12.7M in guaranteed returns, loan with the bank or investing in Shipping Purchase / Sale and Oil Stocks. Therefore, it was beneficial for the owner to finance the project, extend the vessel life cycle, convert the cargo gates and sell or scrap the vessel after the 6 year project. Clearly, this indicates that by replacing the ship's original RTG with the MRG, the owner benefited financially and improved the vessel's unloading performance. Nevertheless, the shipowner's financial benefit would be greater when trading the Model 'B' type SULS on the Great Lakes. The economic synopsis resulting from the case study for the 6 years project is.

Table 8.23 Summary of Economic Case Study.

Item	Description	Outcome
1	Purchase price of vessel	USD 8.60M
2	Upgrades - life extension of vessel and gate conversion	USD 4.10 M
3	Total investment	USD 12.70 M
4	Net profit per year – greater than 10% forecast on investment	USD 7.58 M
5	Net present value @ 10% discounted rate	USD 17.50 M
6	Internal rate of return (high freight rate when renewed TC for 5 years)	45%
7	Annual savings due to gate conversion	USD 0.49 M
8	Gate conversion cost (payback in 1.4 years)	USD 0.70 M
9	Resale price of vessel after 6 years @ 7% depreciation/annum	USD 5.6 M

Chapter 9

9 CONCLUSIONS AND FUTURE STUDIES

9.1 Overview

Shipping on the worlds' largest waterway of fresh water called the Great Lakes (GL) of North America, started during the 1600s'. The 1800s' industrial revolution of North America (NA) resulted in the discovery of large deposits of natural resources in the GL region. These unprocessed resources (i.e. ore, coal, stone, etc) were found in remote locations and required a unique logistics system for shipping to the processing and fabrication areas. Grain was another available trading good that needed transportation from the producing regions. The shipping of these commodities was the evolution of present day Great Lakes Dry Bulk Trade and the primary reason for the inception and development of these specialized ships, called 'Self-unloader Bulk Carriers' (SULS).

Precisely 103 years ago (1908-2011) the first commercial Self-unloader Bulk Carrier (SULS) commenced trading on the Great Lakes of North America. This vessel was of the gravity discharging type and subsequently, there have been numerous developments of both the gravity and hybrid types of SULS.

During the 1980s' shipping recession on the Great Lakes, some SULS migrated internationally from the GL. These ships form a niche sector of the worldwide dry bulk carriers' fleet, comprising 1.57% of global bulk carriers' in 2009. SULS are exceptional types of ships, due to their ability to discharge cargoes autonomously.

The shipboard improvements of SULS technology were / are primarily related to three separate areas. These technological advancements are:

- The design of cargo gates;

- The elevating of cargo from the unloading tunnel to upper deck; and
- The control and operating systems for the cargo gates and conveyors.

This study is about the design of a new enhanced gravity Roller Track Cargo Gate for Self-unloader Bulk Carriers, the mitigation of related development in the new gate that results in increasing the ship's lightweight and retrofitting the new gate in an existing SULS of the Model 'B' type. The objectives and benefits can be summarised as follows.

9.2 Development of the Roller Track Gate for SULS

The primary objective is the design of a new type of Roller Track Gate (RTG), called the 'Multi-functional Roller Track Gate' (MRG). This newly designed gate is accompanied with a control system that improves the discharging operations of dry bulk cargoes onboard Self-unloader Bulk Cariers' (SULS). The control system is also designed to enhance the operations of the tunnel / hold conveyors as well as the other belts, which are integrated with the tunnel / hold conveyors and MRG.

Eight existing cargo gates for Self-unloaders Bulk Carriers (SULS) of the gravity type were analysed, principally to verify the operational advantages and inherent disadvantages experienced with each of these gates. Essentially, the reviews of previous gates were to develop a new Roller Track Gate (RTG), which would address the operational drawbacks of the existing gravity gates for SULS. However, in this study the gravity gate design was narrowed to mainly focus on improving the current Roller Track Gates onboard SULS. The improvements of the RTG are the general mechanical structure and control system for operating the MRG. The enhancement of the MRG design resulted in this gate assembly having two independent gates, four modes and three redundancies for cargo discharging operations.

The intention of this gate design is to benefit the shipowners', providing that the design is exploited commercially to full potential. In summary, the MRG design focuses primarily on correcting operational issues experienced with RTG onboard SULS and the primary objective addresses two areas of SULS technological advancement; namely:

- Designing the Multi-functional Roller Track Gate (i.e. the two gates concept); and
- The design of a control system for operating the MRG and integrated conveyors, while discharging dry bulk cargoes with this new gate.

9.2.1 The Two Gates Concept of the MRG

Designers of previous cargo gates for the gravity type SULS, have always focused on developing designs to improve the flow of cohesive and hanging-up cargoes resulting from 'Bridging' due to 'Arching and Rat-holing'. In practice, these cargo flow impediments (i.e. Bridging, Arching and Rat-holing) for dry bulk materials have yet to be fully resolved and this stems mainly from the unknown or inherent characteristics of the products transported by SULS. Technically, dry bulk material flow is enhanced when discharging with cargo gates having incorporated either one or both the 'open-hole' and / or 'moving-hole' design principle. These design features of open-hole and / or moving-hole are not included with the original or existing RTG designs.

However, the MRG is a type of Roller Track Gate with two gates system and has included the **'moving-hole design'** principles **[1],** which have been proven. In Chapter 6, experiments were conducted with the MRG iconic model while utilizing the reciprocating mode for discharging actual cargo transported by SULS. The experiments with coal and oats confirmed that indeed the MRG automatic discharging concept is based on the 'moving-hole design' principles. This is the first benefit **[1]** and major contribution resulting from this research.

9.2.2 The Control and Operating Systems of the MRG

When considering the **'Control and Operating Systems' [2]** of the MRG, these design improvements surpass that of the original and existing gravity Roller Track Gates for SULS. The seven 'control systems' (i.e. modes and redundancies) for operating the MRG, while discharging cargo is the second significant benefit **[2]** and contribution resulting from this research. The analysis Chapter 7 illustrates the controlling and operating principles for both the MRG and integrated conveyors.

The Multi-functional Roller Track Gate comprises four modes and three redundancies. These seven different discharging operations are:

1. Primary Gate Remote Manual Unloading Mode;
2. Secondary Gate Remote Manual Unloading Mode;
3. Local Manual Unloading and Maintenance Mode;
4. Automatic Combination Unloading Mode of the Primary and Secondary Gates (i.e. moving-hole principle);
5. Primary Gate Local Manual Unloading;
6. Secondary Gate Local Manual Unloading; and
7. Simultaneous Discharging with the Primary and Secondary Gates – Remote and Manual.

With the existing Roller Track Gate, the discharging operations are limited to a maximum of two modes and in some cases one mode as follows:

1. Local Manual Unloading and Maintenance Mode; and or
2. Remote Manual Unloading Mode (i.e. only some of the existing SULS).

9.3 Reduction of Lightweight Displacement to Enhance Cargo Lift

The secondary objective is the investigation concerning the reduction of lightweight displacement for Self-unloader Bulk Carriers' (SULS). This is principally, to compensate for the added weight resulting from developing the existing RTG into the MRG design. Three SULS hulls referred to as Models 'A', 'B' and 'C' were examined for weight reduction to benefit from less lightweight and increased deadweight. The investigation confirmed that the reduction in these ships lightweight was greater than the extra weight required for designing the MRG. Therefore, the weight reduction exercise resulted in increasing the vessels cargo carrying capacity, which is linked to additional financial benefits for the shipowners. The manner of decreasing the ships lightweight was by utilising high tensile steel to replace mild steel for constructing certain sectors of the three Model SULS hulls examined.

There are several commercial and structural disadvantages associated with SULS, when compared to the ordinary bulk carriers'. These shortcomings are primarily:

- Loss of volumetric capacity in the cargo hold;
- Increased lightweight and total displacement with reduced deadweight;
- Higher vertical centre of gravity;
- Increased manning cost; and
- Higher capital cost.

However, with SULS these weaknesses are often offset by higher freight rates, when compared to the standard gearless bulk carriers' and this is due to not requiring external sources for discharging the cargo. Self-unloaders Bulk Carriers' have greater earning power than other bulk carriers', when chartered on short trades and trading to ports without unloading infrastructure. For example, the Model 'B' SULS in this study is designed for discharging 4,440 tonnes of coal per hour. This rate of discharge would be somewhat higher than most handymax bulk carriers' that are gearless and dependant on the port discharging facilities or geared with cranes.

As previously mentioned, three existing Self-unloading Bulk Carriers' were analyzed for lightweight displacement. The weight reduction experiments were only conducted for sectors of the shell plating between the forward engine room and collision bulkheads / bow. By examining the internal structures and accommodation for lighter weight consideration, the lightweight could further be reduced. Nevertheless, this would entail a separate detailed and comprehensive study in hydrodynamics, which is beyond the scope if this research and would be considered for future studies. The lightweight reduction exercise was primarily for two reasons:

- The MRG naturally is heavier than the existing RTG, thereby reducing the ships lightweight by using high tensile steel would create an offset for the additional weight required for constructing the new primary gates; and

- To demonstrate measures the shipowners could have pursued during the construction stage to increase cargo carrying capacity and earnings.

The outcome from the weight reduction experiments clearly substantiated that had the owners incorporated additional high tensile steel for the hulls shell plating during the construction stage, the benefits **[3]** from reduced lightweight would have amounted to approximately:

- Model ‘A’ 181 tonnes;
- Model ‘B’ 208 tonnes; and
- Model ‘C’ 212 tonnes.

These outcomes of reduced lightweights from the experiments were assumed to be replaced with cargo (i.e. coal). This resulted in enhancing the shipowners earning from increased cargo lift and deadweight of the ships. This is the third benefit **[3]** resulting from this research.

Upon conducting the lightweight reduction experiments, further analysis concluded that the vessels stability and strength (i.e. shearing forces and bending moments) were intact, without adverse affects and within limits recommended by both the members of the International Association of Classification Societies and the International Maritime Organization.

9.4 The Economic Case Study – Replacement of Existing RTG with MRG

A case study was formulated to substantiate the shipowners benefit, when purchasing a handymax SULS of the Model ‘B’ type from the second hand market for USD 8.6 M. Subsequently, an additional USD 4.1 M was invested (totalling USD 12.7 M) for life extension of the vessel and retrofitting / replacement of the original Roller Track Gate (RTG) with the Multi-functional Roller Track Gates (MRG). Numerous cashflows and sensitivity analyses were effected with actual current market figures. The discounted cashflows and sensitivity analyses for two different time charter scenarios resulted in annual net positive profits and rate of returns higher than the intended 10% from investment. These are the net annual returns and internal rate of returns (IRR) resulting from the original and revised time charters:

- Original time charter annual net return of USD 7.58M and IRR 45%; and
- Revised time charter annual net return of USD 6.88M and IRR 43%.

The sensitivity analyses also substantiated that chartering the vessel for USD 10,500/day, would result in a return less than the forecast 10% that was originally predicted for the 6 year project.

By replacing the RTG with the MRG, the vessel port turn-around time and operating costs (i.e. manning) were reduced. The annual financial benefits **[4]** gained (i.e. 2008 to 2011) by the owner from the conversion amounted to USD 497,055. This is the fourth benefit **[4]** resulting from this research. These are the detail yearly (i.e. 2008 to 2011) savings due to additional discharges and the reduction in manning cost:

- USD 221,400 Increased income of 5 additional trading days while on Time Charter in the Great Lakes and 1 day internationally;
- USD 275,655 Reduction in manning costs from 2008 to 2011; and
- USD 700,000 for the gate conversion would be paid for in 1.4 years.

In addition to the financial benefits gained due to converting the cargo gates and return from investment, the owner would reap other operational advantages. The following are considered the fifth benefits **[5]** resulting from this research that could obviously enhance the resale value of the vessel:

- Upgraded structure for life extension of the vessel;
- Improve the discharging operations resulting from replacing the existing Roller Track Gates with the Multi-functional Roller Track Gate
- Ability for chartering due to upgraded unloading system and structure; and
- Good resale value due to having upgraded the vessel.

The case study confirmed that purchasing, trading and selling or scrapping the vessel at the end of the 6 year project was a successful investment for the shipowner.

9.5 FINAL CONCLUSIONS

Upon reviewing the literature, the design and economic analyses of this study; the final conclusions are:

- **The MRG concept:** have discharging features of previous Roller Track Gate (RTG) and the 'Moving-hole' principle **[1]**.
- **The MRG has seven different discharging methods:** when compared to previous RTG that have a maximum of two discharging operations and in some cases one **[2].**
- **The reduction in hull lightweight when using high tensile steel as a replacement for mild steel:** was greater than the weight required for constructing the MRG and without adverse affects to the ships' stability and strength. The lightweights for the SULS examined were reduced with increase deadweight **[3].**
- **The economic case study:** showed that profit was greater than the 10% forecast for the 6 year project **[4].**
- **By upgrading the Model 'B' unloading system:** the discharging performance was improved, enhancing trade, marketability and resale of the vessel in the second hand market upon completion of the 6 year project **[5]**.

Conclusively, the Multi-functional Roller Track Gate is an original or novel design that undoubtedly, is a contribution to the technology of Self-unloader Bulk Carriers'. Providing that shipowners are prepared to exploit the design benefits of this gate, the financial return would be greater when the MRG is utilized for short sea trade rather than ocean going.

9.6 MAJOR CONTRIBUTIONS

The major contributions of this study can be summarized as:

A. New Gate Design and Operations:

- The MRG is the first Roller Track Gate having incorporated the 'Moving-hole' principle and 7 discharging options.

B. Steel Reduction Experiment:

- The steel reduction was greater than the new gate weight (i.e. 73.6).
- Use of high tensile steel, shipowners would benefit from greater cargo lift and profit.

C. Economic Benefits for Shipowners:

- The vessel turn-around time and manning costs were reduced.
- Annual savings are approximately half million US$ (i.e. US$ 497,055).
- Profit from trade is greater than the expected 10% return per annum.
- Gate conversion cost of US$ 700,000 would be paid for in 1.4 years.

9.7 FUTURE STUDIES

Experiments with the iconic model gate confirmed the MRG design concept, when discharging actual dry bulk materials transported by SULS. Nevertheless, with any design there is always room for improvements. Based on this study, the recommendations for future technological advancements of SULS are now considered.

9.7.1 Development of Multi-functional the Roller Track Gate

The Multi-functional Roller Track Gate (MRG) design has incorporated 'Hogbacks'. These structures reduce the volumetric capacity of cargo holds, resulting in less cargo lift and income for the shipowners. However, 'Hogbacks' are necessary with the MRG design for sealing-off cargo between the gates and during full retraction of the gates. 'Hogbacks' are also required for displacing the gate assembly during discharging in the reciprocating mode.

This design of the MRG is based on the 'Moving-hole' principle. For 'Future Studies' the author's recommendations would be to incorporate features in a new design gate that will result in enhancing SULS unloading performance and shipowners revenue. These are the major improvements to be considered:

1. Develop and convert the MRG into an 'Open-hole' gravity cargo gate for Self-unloader Bulk Carriers. This design would abolish the use of 'Hogbacks' structure. By not having 'Hogbacks', this design change would result in:

- Improving volumetric capacity of the cargo hold and cargo lift;
- Increase income for the shipowners; and
- Reduce the possibility of material hanging-up from bridging, arching and rat-holing.

2. Ensure that a full size proto-type gate is designed, fabricated and tested in the most severe discharging conditions with different cargoes actually transported by SULS. This type of modelling would confirm the functionality of the gate and allow the designers to implement changes, prior to installation of a complete unloading system onboard the vessels. It would also be advisable to investigate the 'mass flow discharging rate' of future gates. This would verify the gate functionality; however, the mass flow of a single gate will not conclude the unloading rate of an SULS. The discharging rate of SULS is by and large determined by various factors mentioned in Chapter 6 and primarily the conveyors design.

9.7.2 Enhancing Lightweight Displacement and Cargo Lift for SULS

Undoubtedly, Self-unloader Bulk Carriers' lightweight (LW) displacement will always be higher, when compared to the ordinary bulk carriers. For example, panamax bulk carriers' averaged lightweight are:

- Ordinary Bulk Carriers' 11,000 ~ 12,000 tonnes; and
- Self-unloader Bulk Carriers 16,000 ~ 17,000 tonnes.

This higher lightweight for SULS stems primarily from the added weight for the unloading machinery and complex structure in the unloading tunnel.

In order for SULS shipowners to acquire additional benefits from reduced lightweight and cargo lift, it would require detailed and comprehensive studies in developing measures to reduce the ship's hull weight. This would entail the use of large quantities of high tensile steel for construction and the installation of lighter unloading machinery. The reduction in lightweight is a benefit that is also applicable to the gearless bulk carriers, primarily to enhance cargo lift. However, when comparing both types of bulk carriers, the financial benefit from reduced weight would be greater with SULS that are engaged in short sea trades (i.e. faster turn around time) to regions without unloading infrastructure.

The author recommends that in order to enhance the benefit from lightweight reduction, it would be appropriate to carry out a joint study by researchers who are both academics and industry specialists. One individual should be qualified in the discipline of Marine Engineering (i.e. SULS Engineer) and the other in Hydrodynamics (i.e. Naval Architect). In addition, when considering the reduction of weight for SULS, the following should be addressed:

- The SULS machinery should be carefully selected by exercising weight constraints, while ensuring that the equipment is best suited for the intended purpose;
- The structures must be analyzed for strength by method of 'Finite Element Analysis' or alternative means for analysing the structure strength, guaranteeing that the stresses are within safe and acceptable limits; and
- While reducing lightweight and increasing freeboard, these measures conflict with the propeller immersion and ballast capacity. Therefore, the issue of reduced propeller immersion and ballast capacity during ballast voyage should also be addressed.

Upon designing the concept Self-unloader Bulk Carrier from the Marine Engineering and Hydrodynamic standpoints; further studies would be necessary in analyzing the project economic feasibility. Therefore, confirming categorically the project viability in terms of return from investment. Occasionally, concept projects are not feasible financially.

Despite the evolution of cargo gates, commodities behave mysteriously and perhaps there will be an ongoing concern to discover the exact science in finding a solution; that would utterly prevent ‘bridging’ due to ‘arching’ and ‘rat-holing’ of dry bulk cargoes onboard SULS. It remains mystifying to shipboard staff and operators, as to why certain portions of material loaded from the same batch of cargo will not flow adequately during discharging. Arching of dry bulk material appears to be a peculiar and undetermined phenomenon by researchers. This view is based on a study of ‘Arching Behavior of Cohesive Powders in a Pilot-Scale Plane-Flow Silo’ conducted by Berry, J. R., Birks, H. A. and Bradley, M. S. A. **(2003, p.498)**; where their observation from various tests concluded that *‘the enormous variability of the arch shape in plane flow of bulk solid behavior in silos is not more than half understood…’* The author of this study concurs with the above quote and has similar experience (i.e. 17 years involved with SULS) in determining what exactly causes hanging-up of dry bulk material while discharging SULS - when some cargoes of the same batch will flow while others will not.

Designers of the Controlled Feeder Gate and None Consolidating Feeder claimed that by removing ‘Hogbacks’ from cargo hold structures, the issue of cargo ‘bridging’ would be resolved. Unfortunately, materials’ hanging-up persists even when ‘Hogbacks’ are eradicated. Sea going staff stated that the ‘no Hogback’ theory is not the answer to avoid cargo bridging.

By eliminating ‘Hogbacks’ from SULS design, an element of cargo bridging is resolved. However, cargo holds side hoppers will indefinitely form part of the ships’ structure and this creates a support for the cargo and the possibility of cargo ‘bridging’ from ‘arching’ and ‘rat-holing’.