Decreasing the running cost of ships by implementing the maintenance and repair strategy for hull structural

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Abstract

Operational costs taking a large part of the life cycle cost of the ship. Some of these costs are constant and it is not easy to reduce the costs like manning and crewing and insurance costs. However there are some costs like maintenance and repair cost which is taking a large part in the life cycle cost, can be reduced by design improvements and adapting suitable/optimum maintenance strategies.

Generally the reason for high maintenance and repair cost is dry docking when all the major repair and maintenance issues are done. Steel replacement is one of the basic repair works of dry docking.

In order to show the effect of repair and maintenance on life cycle cost, availability analysis and running cost analysis were made in this study. With reliability analysis of ship hull structure the critical points are determined and also the analysis of these points on availability of ship is made. By running cost analysis the part of the maintenance and repair expenses seen in running cost. With combination of reliability analysis results and running cost analysis results decision making improved.

A case study is performed concerning tankers, general cargo vessel and ropax vessels. An analysis using the structural reliability model is developed for these particular vessels. Also running costs for each tanker and ropax vessel are analysed for low, likely and high maintenance and repair works to see the difference between the well maintained and the not well maintained vessels on running cost discussed.

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CHAPTER 1 INTRODUCTION

Global trade is increasing at a high rate and as a result shipping is continuously growing due to high demand. 80 percent of world cargo trade is transported by shipping industry. Naturally, this high demand keeps ship operators, shipyards, suppliers as well as ship repair activities very busy. Such high demand and timely delivery of good means it is very important for a ship operator to keep the ship on operation to provide reliable and cost effective service. The daily running cost for a ship is very high and if the repair and maintenance cost are added to this value the cost is even increased to large amount. It is very important to keep the daily running cost as low as possible. In addition, keeping the ship in business is equally important. Therefore keeping the ship in repair and maintenance yard as short as possible is very important for operators; however, the demand to keep the vessel in operation can affect the quality of repair and maintenance. Some repair works can be omitted easily to finish the repair work quickly and deliver the ship back to operation. Of course this always backfires in the long run.

Classification societies have an important role in ship repair and maintenance activity. Especially repair time, repair cost and repair types are directly influenced by classification societies as all the repair activities are carried out according to their inspection and repair requirements. The balance between cost, time and safety is very important and it can be developed by establishing a good communication between ship operator, ship repair yard, classification society and supplier.

A ship operation may be disadvantaged due to lack of this balance. Unfortunately high operational cost especially high maintenance and repair cost are not considered during the design phases as life cycle cost in shipping is considered properly only recently.

High life-cycle costs, particularly maintenance costs can account for as much as 25-35% of an operator's direct operating costs and have remained at this level for many years. Furthermore, with the increase in oil prices, the budgets have gone up additionally 25% more (plus world inflation) in the last 6 years [1] [2].

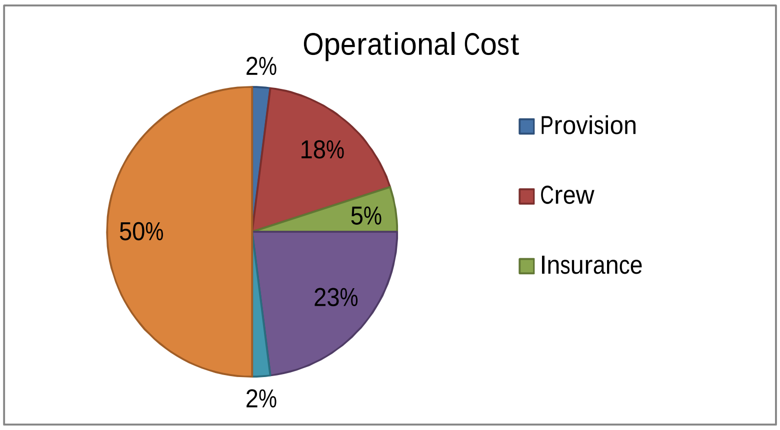

Figure 1.1.Operational cost [2]

High inspection costs are one of the deterrent factors for condition assessment of the ship regularly [1] [2] except for high risk vessels. Although shipyard, operator and design office have large data base they do not know how to utilize them fully to improve the design, repair and maintenance for higher operational availability as they do not communicate effectively with each other [2].

Ship owners would like to save money as much as they can in the design and production stage, however according to operational data analysis spending some more money in the design and production stage will bring more income due to reduced the life cycle costs [2] [3]. Shipyard at the same time are trying to reduce the cost of shipbuilding by not choosing the more reliable equipment and construction technique.

Inspection, data collection and especially data processing requires significant amount of human intervention/resources as well as experts in particular areas. People in the ship management do not know what to do with the gigabytes of data, as it does not give them any processed information. Key point here is that ship operator requires knowledge and information rather than unprocessed data. ‘One operator said ‘it will take them years to analyses the data to find specific trends and problems in maintenance as each month ship produces 200 gigabyte data without any advise [2].

Personal interviews with operators and superintendents indicated that even the big companies with good data collection systems admit that they do not have the decision support system to give them the information (problem, where, criticality and what action may need to be taken)[2].

Lack of effective communication between operators, supplier and shipyard to plan the repair and maintenance of a ship causes unnecessary delays. Due to the ineffective communication, it becomes very difficult to make the repair and maintenance at the yard as a planned maintenance. It takes more time than the initially predicted time, ships wait in the queue in repair shipyard while equipment supply takes more time than the expected repair time [2] or it is not ordered in timely manner.

Although shipping is a global market, ship operators, given the opportunity, would like to work with same shipyard. Operators establish good personal relationship with repair yards in time and it brings some advantages like saving money, work quality and delivery on time. However, ship operators making contact with the shipyard 5 or 6 months before the dry docking time and because of the short notice, it is very difficult to find place in shipyard and operators have to wait in a queue or find any other available shipyard.

Currently available ship management systems are mainly concentrating on the information management in the financial operation of ships while technical maintenance issues are not taken into account in an integrated manner [2]. Technical maintenance data are kept only until the next maintenance time. It is not possible to collect all the technical maintenance data and analyze them. Of course, there are very well organized shipping companies but very a few.

The corrective maintenance due to failures unplanned maintenance can introduce costly delays and cancellations if the problem cannot be rectified in a timely manner. Deviations from sailing route may be required to reach maintenance yards causing downtime. Further delays can be expected due to waiting time for the availability of yards [2] [3].

Machinery failure can result in serious or even hazardous incidents, mostly due to un-predicted required maintenance. Corrective maintenance of machinery in ship is difficult due to limited maintenance facilities on board [2]. The overhaul periods for machinery are determined by manufacturer. The overhaul manual is being kept by all ships and according to this manual all repair and maintenance works are done. For machinery overhaul the main engine and the auxiliary engines need to be cleaned and oiled. Therefore it is not possible to make total overhaul while ship in operation. Only small works can be done while ship is in operation. 40% of machinery failure arose during the first 100 hours from the latest maintenance (mainly due to human factor, incomplete low quality work) [2]. Machinery overhauling is sensitive work and needs to be done in a good condition. Because of the time limitation, maintenance work done in a hurry as well and it causes problem again just after the maintenance.

Ship operators want to save money as much as they can and therefore they do not want their ship spend more time than necessary in the dry docking and they postpone some repair work although the classification society advise them to do so. Although ship operators think they save time and money with putting the pressure on the shipyard to finish the work in a short time and not doing the other advised repair works, these postponed works will come next time with bigger problem, more repair work and expenses.

Errors in the maintenance process can impact on ship safety, e.g. in a recent survey the incidence of human error in the maintenance task has been estimated as contributing to 15% of ship accidents [2]. During the maintenance process, ship operators obtain prices from shipyard as well as from sub contractors. Mostly sub contractors do the repair work cheaper as ship operators in general prefer cheaper contractors. Sub contractor companies usually work with less qualified workers and engineers so it affects the repair work unless, there is a quality check in place. Ship operators first think about the cost and then they care the safety.

In this thesis, the effect of improving the hull structure reliability through maintenance and repair on the operational availability of ships is investigated. It is believed that high reliability and high availability of hull structure will improve ship operational reliability profit as well as ship safety. It is possible to minimize the repair and maintenance cost and to improves the operational availability of ship by higher hull structural reliability and by adapting a good maintenance and repair strategy.

The thesis introduces the subject in chapter 1. In chapter 2 aim and objectives of the study are presented together with adapted approaches.

In chapter 3 critical review of running cost, maintenance types and reliability analysis is presented. In running cost part, operating cost, voyage cost, cargo handling cost, periodic maintenance cost and capital cost are demonstrated. In chapter 3 existing life cycle cost models are also covered and it is followed by different maintenance types as well as their advantages and disadvantages. Chapter 3 is concluded with presentation of reliability analysis methods.

In chapter 4 field study carried out by the author in a ship repair yard is demonstrated. In order to gain better understanding of repair activities in ship yards, relation between repair yard and ship operator as well as to collect repair data the author spent 1 month in a repair yard. Observed repair and maintenance works are reported in while management policy for ship yard and operators are discussed in this chapter. Furthermore classification society rules for ship repair and maintenance is also demonstrated as well as how classification societies work and what the survey types and survey times are discussed.

In chapter 5 the collected data in relation to ship repair are analyzed and results are presented. The database includes ropax vessel, chemical tanker, general cargo vessel and their reliability analyses. These reliability analyses include criticality and availability analysis as well. In criticality analyses the most critical parts for hull structure for each ship types are identified and discussed. Also amount of steel replaced and unavailability time, due to different ship types, size and age, analyses are carried out.

In chapter 6 model development including running cost model is presented for ropax and tanker vessel. This model includes the repair and maintenance cost, voyage cost, unavailability cost and dismantling fee. Each cost values for ropax vessel and tanker modeled using the character ships of each vessel type.

In chapter 7 case study for running cost model is carried out for ropax vessel and tanker. The relationship between light weight and repair work cost as well as other parameters are also discussed in this chapter.

Finally lessons learned, future recommendations and conclusion are presented in chapter 8.

CHAPTER 2 PROJECT DEFINITION

2.1 Aim of the project

The main of the thesis is to develop a model aiming at minimizing the running cost of ship by cost effective inspection, maintenance and repair of ships that will to minimisation of failures and corrective maintenance, reduction of the maintenance cost and finally increasing the availability of the ship in operational activities.

2.2 Objectives of the project

Specific objectives of the project can be listed as:

Observing how the repair yard, ship operator and classification society work in repair yard, learning about their management ship repair policy by field study

To collect hull repair data and identify the critical parts/sections of the hull structure for various ship types by reliability analysis

Improve the operational availability of ship by minimizing the delay in repair yard

Identify the critical parts/sections of the hull structure for various ship types by reliability analysis

Establish the influence of well maintained and not well maintained vessel on operational unavailability time and replaced steel work

Establish the influence of age on replaced steel work and unavailability of various ship types

Establish the influence of maintenance and repair cost on running cost and develop running cost model

2.3 Approach adopted

Review of the relevant publications and articles; in this study running cost elements and the existing running cost model published in relevant publications and articles are reviewed. In addition various approaches adopted to decrease these cost are searched from relevant publications and articles.

Also the maintenance and repair types and their advantages and disadvantages and their implementation to ship operation are studied. Maintenance and repair types adopted by other industries and their applications as well as their applicability to ship operation are studied.

Reliability analysis methods their inputs and outputs are reviewed and the best method for ship hull structural reliability analysis is discussed.

In order to perform the relative reliability analysis for ship hull structure such as reliability, availability and criticality analysis reliability software Relex was utilised.

For better understanding of existing maintenance and repair strategies and their applications as well as advantages and disadvantages one month field study in ship repair yard is performed. General hull structural problems for different ship types are observed as well as their reasons. The management policy of the shipyard is observed as well as the relation between the ship operator, ship yard and suppliers.

Also in one month field study, relevant data collection for reliability analysis as well as running cost analysis is carried out.

Data analysis is made to better understanding of collected data, which are revised and put in a good format and then the data analyses are made for each ship type.

According to data and knowledge which are gained from one month field study and as well as discussions with classification society surveyors, ship operators and suppliers, running cost model developed. This model includes maintenance and repair cost, voyage cost, unavailability cost and dismantling fee. For repair and maintenance cost, case studies are carried out for the same ship with different maintenance and repair strategy which are well maintained and not well maintained ship.

Developed running cost model is adapted for tanker and ropax vessel and their calculation results are discussed. Outline of the adapted approach is given in Figure2.1

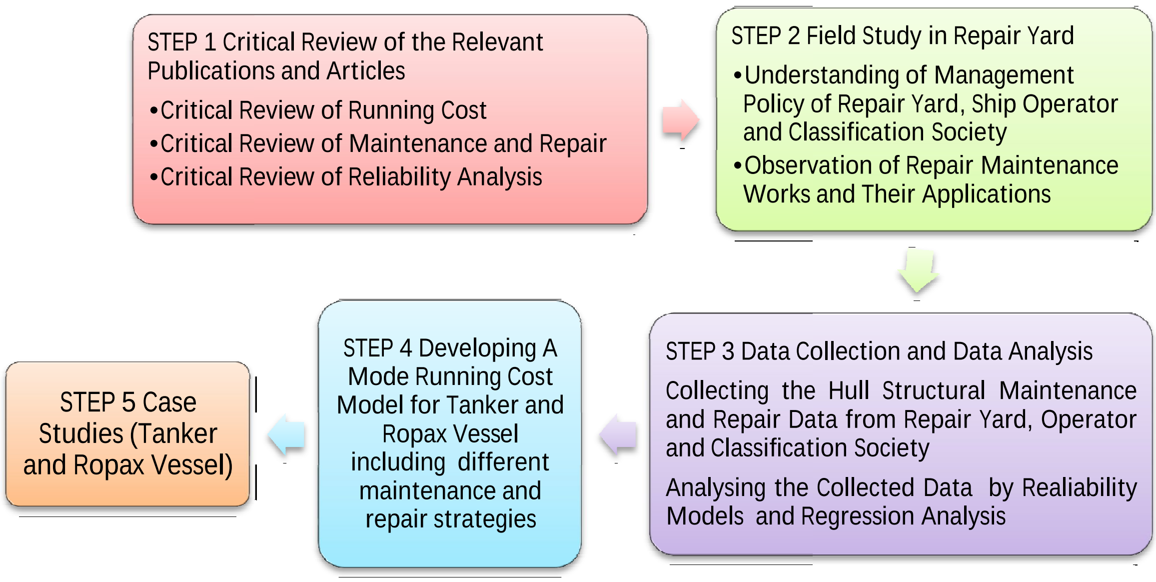

Figure2.1 Approaches adapted

CHAPTER 3 CRITICAL REVIEW

The critical review is carried out under three sub headings, which are running cost, reliability analysis and maintenance. Although the subjects may look unrelated they are strongly connected to ship operation and maintenance strategy. As an example, it is easy to improve the reliability of the vessel by implementing good maintenance and repair strategy. By increasing the reliability of the vessel, unavailability time will be decreased. That means the vessel will be on operation more than before. Therefore the running cost of the vessel will be decreased and the profit will be increased.

In order to understand the running cost better, sub categories of running cost will be determined. Also which of these costs are constant and which are not, will be discussed.

The methods for reliability analysis will be argued and which reliability analysis is suitable for maintenance and will be discussed.

3.1 Running Costs

Running cost is covering all the expenses of the vessel between the production and dismantling. These costs include the operational costs, voyage costs, cargo handling costs, periodic maintenance and capital costs. As shown in Figure3.1, ship running costs are variables and these variables are mostly external variables like oil prices, port charges which are parts of voyage cost. Generally, it is not possible to reduce these expenses unless fuel consumption of ship is reduced through improving the hull form and propulsion efficiency. However it is possible to reduce the other expenses.

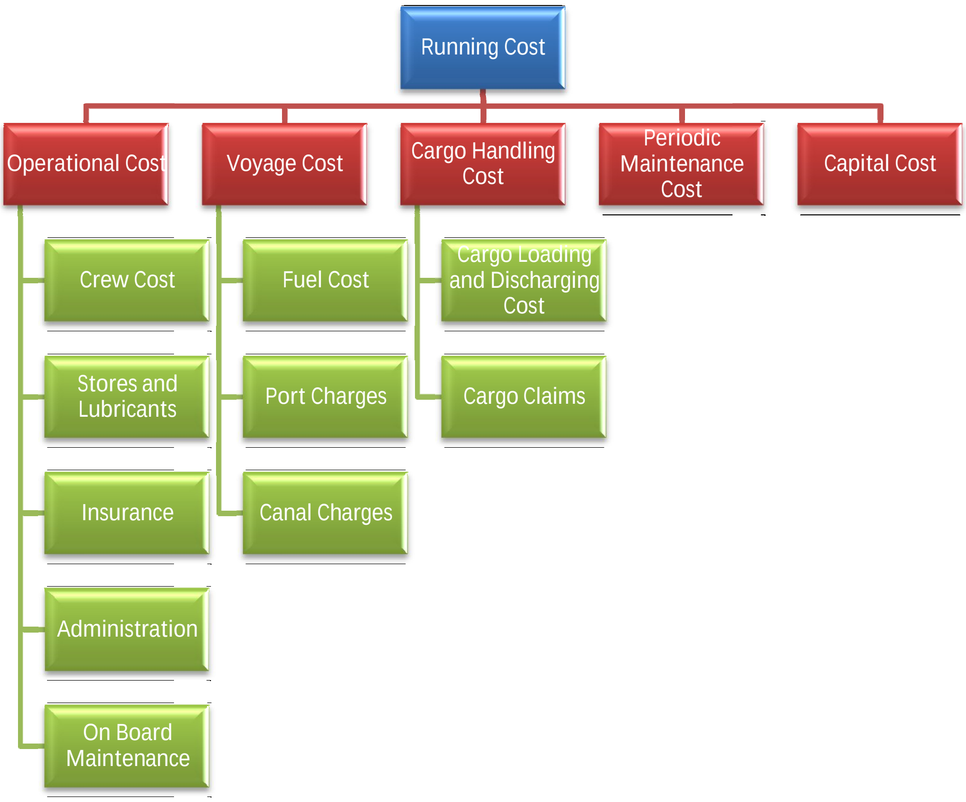

Figure3.1 Running cost table

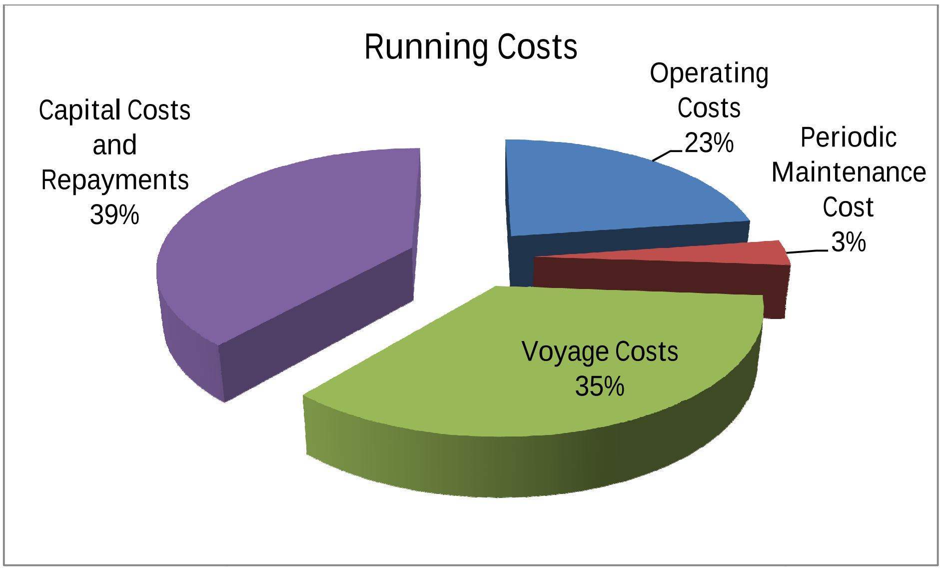

Figure3.2 Analysis of the major costs of running a bulk carrier [4]

The distribution of the running costs elements for 10 years old bulk carrier is presented in Figure3.2. According to Figure3.2, capital costs and repayments are the highest cost items. This figure is prepared based on a annual expenses at the age of 10. Therefore some of the cost such as periodic maintenance can be increase by time.

3.1.1 Operating Costs

Operating costs are day to day running costs of the vessel. Operating costs depend on number and nationality of the crew, maintenance strategy, age of the ship, insured value of the ship and administrative efficiency of the owner [4]. Operating costs include manning cost (crew costs), stores and lubricants, insurance, administration and the day to day repairs and maintenance on board but it does not include the dry docking because dry docking, repair and maintenance are another major part of running costs. Also the fuel costs are excluded in operation cost as it is calculated in voyage costs.

Crew costs (manning costs) and insurance costs are the major costs in operation costs. Crew costs include direct and indirect costs which include basic salaries, wages, insurance and pensions. The crew costs are directly related with size of the crew and the employment policy. Size of the crew is related the ship type, size and the employment policy which depends on owner`s policy as well as ship`s flag state policy on minimum manning requirements.

The minimum number of crew on a merchant ship is specified in regulations laid down by the flag of registration. However, it also depends on commercial factors such as the degree of automation of mechanical operations, particularly the engine room, catering and cargo handling; the skill of the crew; and the amount of on-board maintenance undertaken. Automation and reliable monitoring systems have played a particularly important part on reducing crew number [4].

It is now common practice for the engine room to be unmanned at night, and various other systems have been introduced such as remote control ballast, single-man bunkering and rationalized catering. As a result crew numbers declined from about forty to fifty in the early 1950s for merchant vessels to an average of twenty-eight in the early 1980s. With current technology, it is possible to reduce the number of crew. For example; deep sea vessel can be operated by seventeen basic crew, while experimental vessels can be operated with a crew of ten [1] while short sea ships (costal) with 6-7 crew as well.

Crew costs are certainly not standard. Ship owners have far more opportunity than land based businesses to determine manning costs. It is easy to find cheap crew around the world and also by operating under a flag which allows the use of a low-wage crew [1]. However sometimes working with the cheapest crew is not the right solution. Cheap crews are easy to find especially in Asia and South America as ship operators have a lot of choice but skill level is less than desired. Therefore for the operational safety and on board maintenance and repair activities experienced skilled crews are required.

Another operating cost of the vessel is related to stores and consumables. This cost includes the general stores used on board ship (such as spare parts, deck and engine room equipment; cabin stores cover the various domestic items). The largest item is lubrication oil as modern ships have diesel engines and it has big amount of lubrication oil consumption in a day [4]. The expenditure on spare parts and replacements of equipment is related with ship age as well as number of hour that they run. Old ships need more storage of spaces due to their consumption requirements.

There are two types of repair and maintenance types; Routine maintenance (preventive maintenance) and breakdown maintenance (corrective maintenance).

Routine maintenance is time based or condition based and applied to main engine, auxiliary engine, painting, superstructure and during the operation and safety and electrical equipments overhaul. Routine maintenance increases with the age of the ship [4].

Breakdown maintenance; this type of maintenance is done in shipyards or in ports so it is more expensive than the routine maintenance. Ship can be out of work for a while depending on the seriousness of breakdown. Because of the unexpected high unavailability, break down maintenance causes higher cost. Engine and propulsion related problems are most encountered problems for breakdown maintenance type [4]. Other parts can be repaired on board while the ship is in operation but generally engine and propeller problems make the vessel unavailable.

Insurance is the other operational cost. The marine insurance can be classified which as property and liability:

Property insurance is for against financial loss resulting from damage to, or destruction of, property in which the insured has an insurable interest [5].

The principal branches of marine property insurance are cargo insurance, hull and machinery insurance and loss of income insurance.

Cargo insurance; '*Cargo insurance covers the interest of shippers, consignees, distributors, and others in goods and merchandise shipped primarily by water or, if in foreign trade, also by air'* [5].

Hull and Machinery(H & M) insurance; '*H & M insurance protects ship-owners and others with an interest in vessels, and the like against the expenses that might be incurred in repairing or replacing such property if it is damaged, destroyed, or lost due to a covered peril' [5].*

Loss of income insurance; *'Marine loss of income insurance covers a ship-owner against loss of business income resulting from damage to or loss of the insured vessel'* [5].

Liability insurance is against for financial loss resulting from some person or organization making a claim against the insured for damages. These claims can be bodily injury, death, property damage, or some other injury for which the insured is allegedly responsible [5].

Liability insurance can also be divided into three categories; collision liability, protection and indemnity, and other liability insurances.

Collision Liability Insurance; '*Collision liability insurance is included in most commercial hull insurance policies. Due to reasons such as the size of the H & M policy deductible and prompt guarantees issued by the P & I Underwriters, it is often more prudent and practical* *to have this aspect of cover underwritten under the P & I policy. It covers the liability of the insured vessel for damage to another vessel and property thereon resulting from collision between the insured vessel and the other vessel'* [5].

Protection and Indemnity Insurance; Protection and indemnity (P&I) insurance is the major form of liability insurance for vessels. This insurance supply protection for against collision liability for bodily injury or property damage arising out of specified types of accidents, and protection and indemnity certain unexpected vessel-related expenditures [5].

Other liability insurance policies are for maritime businesses such as ship repairers, stevedores, wharfingers, marina operators, boat dealers and terminal operators [5].

The annual operating budget for the ship includes a charge to recover shore-based administrative and management charges, communications, owner's port charges, and miscellaneous costs. The overheads cover liaison with port agents and general supervision. The level of these charges depends on the type of operation [2]. For small shipping company with two or three ships it is not a big amount but for big fleet it should be considered with the other costs [4].

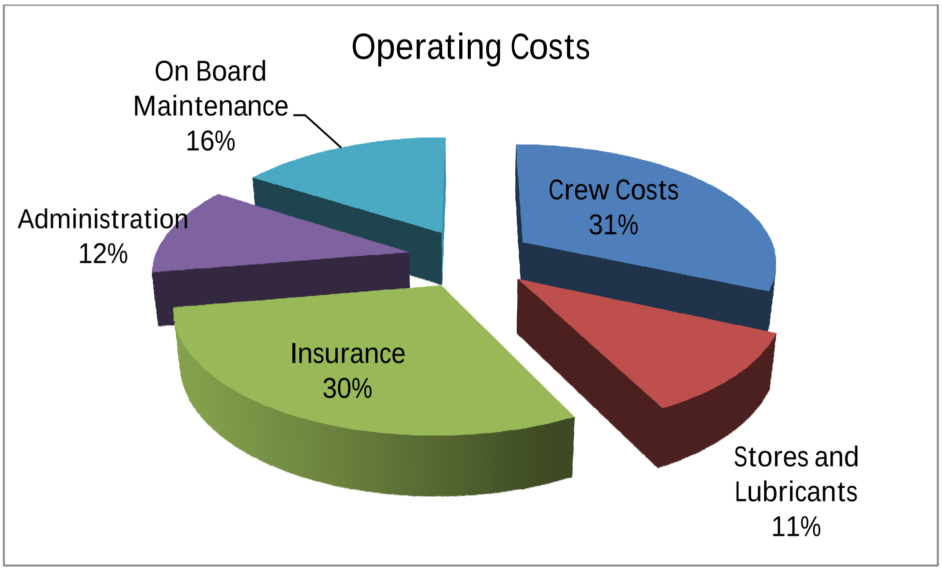

Figure3.3 Analysis of the major costs of operating a bulk carrier [4]

Figure3.3 is an example of major operating cost of 10 years old bulk carrier and as seen crew costs and insurance are the highest costs for operates on bulk carrier.

3.1.2 Voyage Costs

As shipping is a global market and the voyage cost is changing according to operation place. Especially the port charges, canal charges are changing country to country. Main items for voyage cost calculation are fuel costs, port charges, tug, pilotage and canal charges.

Fuel cost is the most important item of the voyage cost and with the increasing oil prices, the importance of fuel consumptions is increasing even more. New engine development with less fuel consumption is an important topic as well as optimized hull form and more effective propulsion system. According to the expert view fuel oil consumption can be categorized under two subheadings which are fuel oil consumption in port, and during the voyage. In the port, ship uses diesel oil for generators and also sometimes for cranes. During the voyage ship uses both diesel oil and fuel oil. A typical panamax size bulk carrier consumes 30 tons of bunker oil and 2 tons of diesel oil in a day at a speed of 14 knots.

Other factor for determining the fuel consumption is service speed of the ship. At a speed of 16 knots bunker oil consumption for panamax size bulk carrier increases to 44 tons a day. At a speed of 13 knots bunker oil consumption is 24 tons a day while at a speed of 12 knots bunker oil consumption decreases to 19 tons a day [1] [4]. Depending on the time essential of the cargo fuel consumption may be reduced.

Port charges are calculated in two categories. These are port dues and service charges. Port dues are use of port facilities, including docking and wharfage charges, and the provision of the basic port infrastructure. The charges may be calculated in four different ways, due to the volume of cargo, the weight of cargo, the gross registered tonnage of vessel, or the net registration of vessel. The service charge covers the services that the vessel uses in port, including pilotage, towage and cargo handling [4], and service charges depend on the vessel size, time in port and type of cargo loaded/discharged.

The main canal dues payable are for Suez and Panama canals transit. the canal dues for Suez Canal is calculated based on Suez Canal Net Ton (SCNT) and Special Drawing Rights (SDRs) [29].

While for Panama Canal tariffs, Panama Canal Net Ton (PCNT) is used [4].

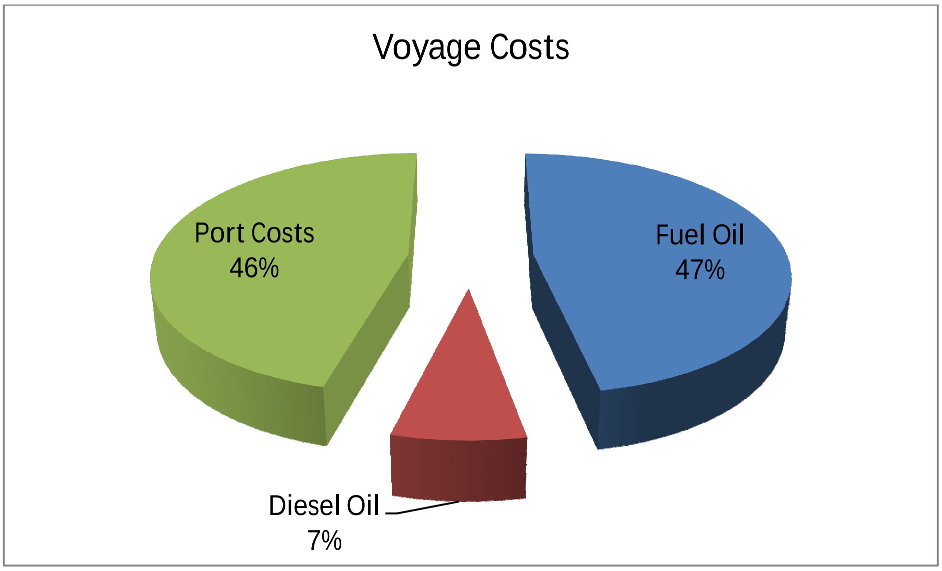

Figure3.4 Analysis of the major voyage costs for a bulk carrier [4]

As shown in Figure3.4 fuel oil cost and port costs are the major voyage costs of a bulk carrier.

3.1.3 Cargo Handling Costs

Cargo handling cost includes cargo loading and discharging costs and cargo claims. A traditional cargo liner can easily spend half of its time in port. This time can be reduced by improved ship design and faster loading and loading facilities.

Container ships are one of the designs which reduced the cargo loading/discharging time by standardization. Trade route is also important for design improvements. The type of vessel required depends upon the trade route. For example; containerization cannot be the answer for less developed country [6]. In developed countries ports are designed and developed for fast container loading and discharging activities and in addition port`s cranes are also utilised to increase the speed of loading/unloading and also there is an standardization in these countries for container transportation. However it is not possible to say this for undeveloped countries, although this is improving.

3.1.4 Periodic Maintenance Costs

Periodic maintenance period is changing depending on ship type. For the merchant ship there is an annual survey every year but there is no dry docking in this survey. For cargo ship is an intermediate survey and dry docking in every 2.5 years and special survey (class renewal survey) and dry docking in every 5 years. For passenger ship and passenger carrying ships dry docking period is every year.

In each class renewal survey period which is 5 years, all machinery is inspected and thickness of the steel in certain areas of the hull is measured and compared with the acceptable standards.

The periodic maintenance costs change according to type of the ship, age of the ship, state flag of the ship, classification society , size of the ship and the country of the ship yard.

3.1.5 Capital Costs

In cash terms capital cost is very different compared to the other costs. Crew costs, bunkers, insurance and the other cost items are paid for as they are used. Capital costs may appear in the cashflow in three ways. First, there is the initial purchase. Second there is a cash payment to banks equity investors who put up the capital to purchase the vessel. And third, cash received from the sale of the vessel [4].

3.2 **Life Cycle Cost Models**

Design & production, operation and dismantling are the stages of the ship life cycle and operational part (running cost) is the major part of the calculation of life cycle cost. Cashflow analysis is being used for examination the cost and revenue items. With cashflow analysis, it is also possible to understand how costs can be controlled and how revenue can be increased. The techniques for preparing cashflow calculations that can be used as a basis for decision making [4].

Four methods of cashflow analysis are widely used in the shipping industry, each of which approaches the cashflow is analysed from different perspective:

3.2.1 The voyage cashflow (VCF) analysis is the technique used to make day-to-day chartering decisions. It computes the cashflow on a particular ship voyage or combination of voyages. This provides the financial basis for operational decisions. Such as choosing between alternative charter opportunities [4].

3.2.2 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 a full financial year. It is possible to make assumptions with this analysis to generate enough cash to fund its operations after taking into account of tax liabilities, capital repayments and periodic maintenance [4].

3.2.3 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 revenue the ship needs to earn to cover its costs. This is useful for ship owners calculating whether a ship investment will be profitable. Also bankers making credit analysis to decide how much to lend. It can also be used to compare alternative ship designs [4].

3.2.4 The discounted cashflow (DCF) analysis is concerned with the time value of money. It is used for comparing investment options. For example, buying a new ship needs a large initial investment but it is cheap to run, whereas an old ship is cheap to buy but has higher operational costs. DCF provides a structured way of comparing the two investments [4].

According to existing cashflow analysis model, these models are mainly concentrating on profit calculations and these models are comparing the existing business opportunities. Although some of them include the periodic maintenance cost, mainly these models do not totally include maintenance and repair cost with implementing different maintenance and repair strategies.

There is no specific cost model for dismantling or design & production part. There are some parameters that determine the dismantling fee and design & production cost.

Cost parameters for design and production of ship changing according to parameters like type of ship, size, any sister ship or not, quality of materials.

Dismantling fee is depending on the parameters such as type of the vessels, vessel's conditions, built years, delivery under her power or under tow in full or missing equipments, technical details and particulars of the vessel. According to expert view, it is sold as the price per tonnage of lightship and rate changes significantly depends on the shipping and demands for ship to transport cargo price as changes between 180 dollars to 600-700 dollars.

3.3 Maintenance

Maintenance costs form a part of the overall operating costs in ship operations. Maintenance also affects reliability and can thus have environmental and safety consequences [10]. Therefore there are some reliability and risk based maintenance types (indicated later on) developed for especially industries which have more environmental and safety issues such as nuclear industry and aircraft industry. Especially in nuclear industry due to the high risk level, maintenance has important role than the other industries. Especially in this industry engineers developing new maintenance strategies and they are generally pioneers for the other industries. It is also possible to use these developed maintenance methods for shipping industry.

In recent tanker accidents in European waters and accident investigations accidents show the importance of the repair and maintenance. Repair, maintenance and inspection scheduling procedures are used by ship operators to maintain high standard of vessel`s structural integrity it is found that in most cases the repaired ship will be more reliable than if degradation or damage had been left with no repair undertaken [54].

Since the mid-seventies, the process of change in industry has gathered even greater momentum. The changes can be classified under the headings of new expectations, new research and new techniques. Maintenance has been developed over the year. First generation of maintenance was just to fix it when it is broken. And with the following generation it is improved to achieve higher plant availability, longer equipment life and lower cost expectations. Nowadays the expectation of maintenance is improved to higher plant availability, greater safety, better product quality, no damage to environment, longer equipment life and greater cost effectiveness.

3.3.1 Maintenance Types

Maintenance generally is categorised in three different types; corrective maintenance, preventive maintenance, and condition based maintenance including inspection[3]. The inspection can be categorized in two parts as shown in the Figure 3.5.

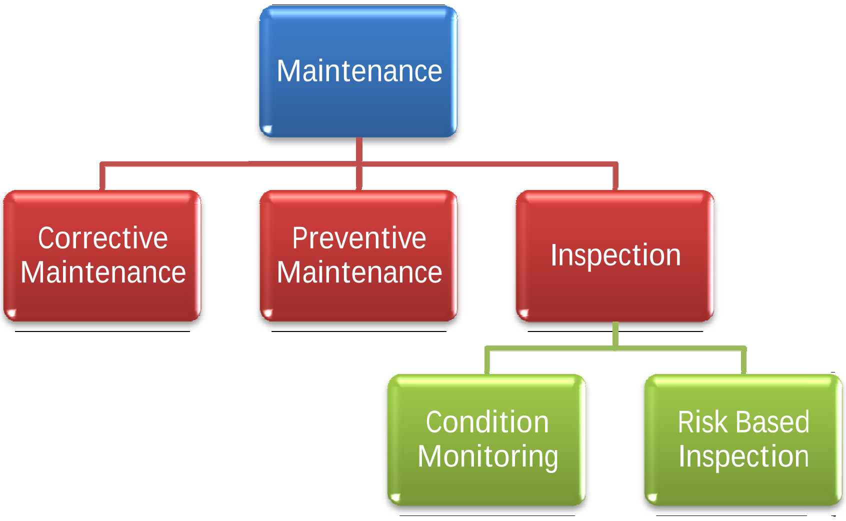

Figure 3.5 Maintenance types

3.3.1.1 Corrective maintenance

Corrective maintenance is also called breakdown maintenance, fire fighting maintenance or failure based maintenance. Normally, corrective maintenance is an unplanned maintenance action which requires urgent attention that must be added, integrated with, or substituted for previously scheduled work. Corrective maintenance or repair is an important element of overall maintenance activity.

Corrective maintenance has different types like breakdown repair, overhaul, salvage, servicing and rebuild. Breakdown repair is concerned with restoring the failed item or machine to its operational state. This corrective maintenance type is for the basic repair type. It meets with minimum requirements for the item or machine repair.

Overhaul corrective maintenance type is to repair or restore an item or machine to its complete serviceable state requirements with using the “inspect and repair only as appropriate” methods.

Other corrective maintenance type is salvage. `*This maintenance type is concerned with the disposal of no repairable materials and utilization of salvaged materials from items cannot be repaired in the overhaul, repair, or rebuild programs*` [3].

After a corrective maintenance action, servicing type of corrective maintenance may be required. For example, engine repair can result in requirement for crankcase refill, welding on, and so on.

Rebuild corrective maintenance is restoring an item or equipment to a standard as close as possible to its original state. It is covering the appearance, performance, and life expectancy. `*This is accomplished though actions such as complete disassembly, examination of all parts, replacement or repair of unserviceable or worn components according to original specifications and manufacturing tolerances, and reassembly and testing to original production requirements*` [3]. Therefore rebuild corrective maintenance takes more maintenance time and it generally costs more than the other corrective maintenance types [3].

Different authors and researchers have proposed different steps for carrying out corrective maintenance. Corrective maintenance can be classified in five steps. These are failure recognition, failure localization, diagnosis within the equipment or item, failed part replacement or repair and return system to service [3]. Corrective maintenance starts with recognizing the existence of a failure. After recognizing the failure second step is localizing the failure within the system and then third step is diagnosis within an item or equipment to identify specific failed part or component. Next step is replacing or repairing failed parts. And final step is checking out and returning the system back to service [3].

3.3.1.2 Preventive maintenance:

Preventive maintenance is a planned maintenance action. The aim of preventive maintenance is the prevention of breakdowns and failures. The primary goal of preventive maintenance is to prevent the failure of equipment before it actually occurs. It is designed to preserve and enhance equipment reliability by replacing worn components before they fail. Preventive maintenance activities include equipment checks inspection, partial or complete overhauls at specified periods, oil changes, lubrication and so on. The ideal preventive maintenance program would prevent all equipment failure before it occurs [22]. Also, preventive maintenance will result in savings due to an increase in system service life of effective system. However, preventive maintenance may end up replacing the parts too early before it is close to it`s end of service life. Especially manufacturers, in order to be on the safe side require replacements much too early.

Some of the benefits of preventive maintenance are improved system reliability, decreased cost of replacement, decreased system downtime, decreased rework, increase the quality of work, increase the availability of system, increase the safety of system and better spares inventory management.

There are seven parts of preventive maintenance inspection, calibration, testing, adjustment, servicing, installation, and alignment [3].

Periodically inspecting determines serviceability. It is comparing their physical, mechanical, and electrical and other characteristic to established standards. Second calibration is detecting and adjusting. Any discrepancy is compared to the established standard value. Testing is for periodically testing to determine serviceability. Also it detects mechanical or electrical degradation. An adjustment is making adjustments to specified variable elements to achieve optimum performance. Servicing is for periodically lubricating, charging and cleaning materials or items to prevent the failures. Installation is for periodically replacing limited-life items. Also installation is experiencing time cycle of item or wears degradation to maintain the specified tolerance level. Alignment is for making changes to an item's specified variable elements. Aim of alignment is to achieve optimum performance [3].

In order to develop an effective maintenance program test instruments and tool, accurate historical records of equipment, skilled personnel, service manuals, manufacturer's recommendations, past data from similar equipment, and management support and user cooperation are required[23].

3.3.1.3 Inspection

Periodically checking the items and the machines is another important maintenance action. The inspection method is different for the different equipments and the machine. The inspection periods generally depend on the manufacturer. Generally manufacturer determines the inspection type and the time for the items and the machines. Manufacturer determines the inspection date by analyzing the past data of the system and the manufacturer develops the inspection schedule.

Inspection is important for early maintenance principle appliers. Early maintenance means repair the problem while it is small and easy to do [51]. The ship operators want their ships on operation and the generally idea for them waiting in dry docking losing time and money. Therefore the repair works are postponed for the next dry dock or until the critical level is reached.

There are several inspection methods available; Risk Based Inspection (RBI) and Condition Monitoring (CM) are the most common methods.

Condition Monitoring (CM)

Condition monitoring measures health of the plant and machinery with regular schedule. Condition monitoring systems use tools to quantify plant health, so that change in condition can be measured and compared.

It is possible to measure mechanical, electrical and thermal condition of plant. Also identifying efficiency losses and safety critical defects can be done with condition monitoring. The object of condition monitoring is not only to identify defects, but also to identify the root cause of failure [24].

Condition monitoring in shipping industry is done by surveys. Generally surveys use visual inspection methods. Visual inspection is very dependent on the surveyor`s sensitivity and skill, limited accurate estimation of the condition can identified the problem such as degradation and corrosion [52]. For sensitive results electrochemical methods are used in laboratory until now so that degradation and corrosion can be measured long before they can be visually detected [52].

Risk Based Inspection (RBI)

Risk-based inspection is an application of risk analysis principles to manage inspection programs for plant equipment. RBI has been used in different industries like the nuclear power generation, refineries and petrochemical plant. RBI aims to develop a cost-effective inspection and maintenance program [25].

Risk-based inspection was firstly used in the nuclear industry in the 1970s. In the 1980s and 1990s it was applied to the petrochemical industry. Today it is easy to observe the application of Risk-based inspection in several industries as well as in maritime industry especially in offshore industry [53].

Risk is defined as the combination of probability and consequence. The highest risk is mostly associated with a small percentage of plant items. Risk based inspection procedures are based on qualitative or quantitative methodologies. `*Qualitative procedures provide a ranking of equipment, based largely on experience and engineering judgment. Quantitative risk-based methods use several engineering disciplines to set priorities and develop programs for equipment inspection*` [25].

A risk-based inspection planning is used to [25]:

- Ensure risk is decreased to as low as reasonably practicable
- Optimise the inspection schedule
- Focus inspection effort onto the most critical areas
- Identify and use the most appropriate methods of inspection

3.4 Reliability Analysis

Effective reliability analysis is important to develop efficient maintenance strategies. Depending on the types of ships, available data as well as the problem, different reliability models/methods can be developed or applied. There are some models and methods for reliability analysis and each model and methods have their own limitations and input requirements. Therefore reliability models and methods are discussed below to find out the most effective reliability calculation method for ship hull structure.

3.4.1 Reliability Models

Maintenance and Repair is the one of major part in the operational cost of ship. There are some approaches in order to improve maintenance and repair quality, decrease the maintenance time, decrease the maintenance work. RCM (Reliability Centered Maintenance), CBM (Condition Based Maintenance), RAM (Reliability Availability

Maintenance) are the current approaches to improve the system performance by using the efficient maintenance strategies [8].

3.4.1.1 Reliability-Centred Maintenance often known as RCM, which is an industrial improvement that focuses on identifying and establishing the operational, maintenance, and capital improvement policies. It also manages the risks of equipment failure most effectively [26] [27].

RCM (Reliability Centered Maintenance), RCM is the process which is used as one of the most effective approaches to maintenance. `*It involves identifying actions that, when taken, will reduce the probability of failure and that are the most cost effective. It seeks the optimal mix of Condition Based actions, other Time or Cycle-Based actions, or a Run to Failure approach. RCM is an ongoing process that gathers data from operating systems performance and uses this data to improve design and future maintenance*` [8].

RCM was developed by the commercial industry then it was adapted by the U.S. military in the mid-1970s. Then it was adapted again gain by the U.S. commercial nuclear power industry in the 1980s. RCM firstly used by nuclear power industry in the early stages and in the 1990s other commercial industries started to use this method such as air craft industry [26] [27].

3.4.1.2 Reliability Availability Maintenance (RAM)

Reliability- Availability Maintenance is often known as RAM, which is based upon historic plant data. The use of a RAM model was expected to increase the efficiency and effectiveness of preventive and corrective maintenance. RAM aims to higher plant reliability and less unexpected output shortfalls by increasing the effectiveness of maintenance. Also in some models safety is integrated to RAM so it becomes Reliability, Availability, and Maintainability & Safety (RAMS).

RAM is considered to be one of the significant areas for profitability improvement. Moreover, RAM modelling increases safety and environmental performance.

3.4.1.3 Other Methods

There are also some other maintenance methods such as Time Based Maintenance (TBM), Condition Based Maintenance (CBM), and Life Cycle Cost Based Maintenance (LCCBM).

Time based maintenance is utilised base on the wearing out or break down time period of the items or machinery. Using the time data of wear out or break down occurrence, Failure Rate, Mean Time between Failure (MTBF) can be calculated. From this data it is also possible to develop an advance maintenance schedule. In time based maintenance the main parameter to develop a maintenance schedule is time. Condition Based Maintenance and Life Cycle Cost Based Maintenance can be estimated using the same approach as time-based maintenance by using condition data or life cycle data.

3.4.2 Reliability calculation methods

3.4.2.1 Reliability Prediction

Reliability prediction analysis is a quantitative analysis technique which is used to verify process in reliability engineering. It is used to predict failure rate of a system based on its components and operating conditions. Reliability prediction analysis gives these results [7].

•Failure Rate (equation depends on model and part type)

•MTBF : $(1/\lambda)$ Mean Time between Failure (1)

•Reliability : $(R(t) = exp(-\lambda * t))$ (2)

•Availability : $MTBF / (MTBF+MTTF)$ (3)

•MTTR : Mean Time to Repair

Where;

λ : Failure rate

t : Time (hours)

R : Reliability

Reliability prediction analysis is performed in three stages. First stage is establishing reliability prediction standard, or model, determining failure rates of components using failure rate equations from models, along with part characteristics (quality, stress, environment, temperature, etc.), second stage is summing component failure rates to get subsystem failure rates, and third stage is summing subsystem failure rates to get system failure rate [7].

3.4.2.2 Reliability Block Diagram (RBD)

RBD is a graphical representation of the components of the system. And it also determinates how they are connected logically to fulfill the system requirements. RBD is used to represent the system success logic in terms of component success. RBD can handle a wide range of system configurations.

RBD is used to analyze the system reliability. Also the effects of various alternative designs can be compared with RBD [7]. It is possible to calculate the results failure rate, failure frequency, conditional failure intensity, expected number of failures, mean time to first failure, average time between failures, reliability, availability, steady availability, operational availability, cost, cut set and path set with RBD.

System can be defined in three different methods in Reliability Block Diagram, parallel, series, and mix (Figure3.6, Figure3.7 and Figure3.8). RBD series (Figure3.6) behave same as Fault tree Or gate. The distribution for RBD series is;

$$R_{TOTAL}=R_1+R_2 \qquad (4)$$

RBD parallel (Figure3.7) behaves same characters as Fault tree And gate. The distribution for RBD parallel is;

$$R_{TOTAL}=R_1+R_2-R_1*R_2 \qquad (5)$$

Where;

R Reliability

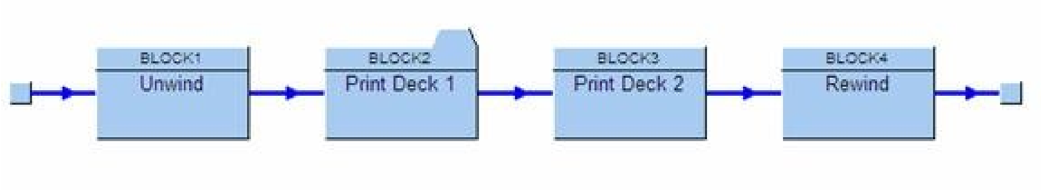

Figure3.6 RBD Series Diagram [7]

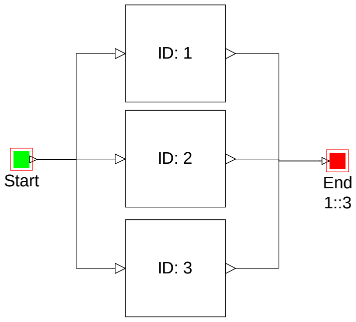

Figure3.7 RBD Parallel Diagram [7]

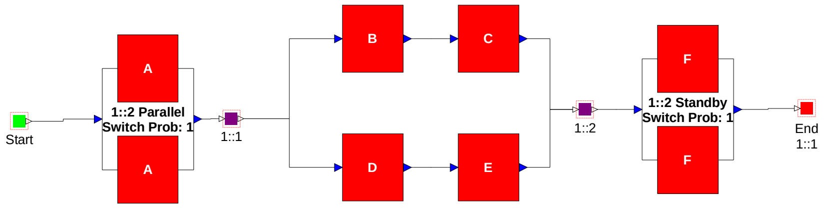

Figure3.8 RBD Mix Diagram [7]

`Commonly used distributions in RBD are Fixed Time – Constant time (no randomness), Exponential – Constant failure rate (memory less), Rayleigh – Linearly increasing failure rate, Weibull – Polynomial increasing failure rate, Uniform – Equal chances of occurrence over an interval, Normal – Symmetrical, Lognormal – Symmetrical in a logarithmic scale` [7].

3.4.2.3 Fault Tree Analysis (FT)

Fault Tree Analysis is a failure analysis which identifies an undesired event called a top event. It is possible to determine failures and also all the ways that the undesired event can happen. Fault Tree is a graphical method to analyze system reliability and safety. It is simple and powerful approach for reliability and safety analysis [7].

It is possible to calculate the results for unreliability, unavailability, failure frequency, number of failures, and cut set and importance measures by using fault tree analysis. A basic structure of fault tree diagram is shown in Figure3.9.

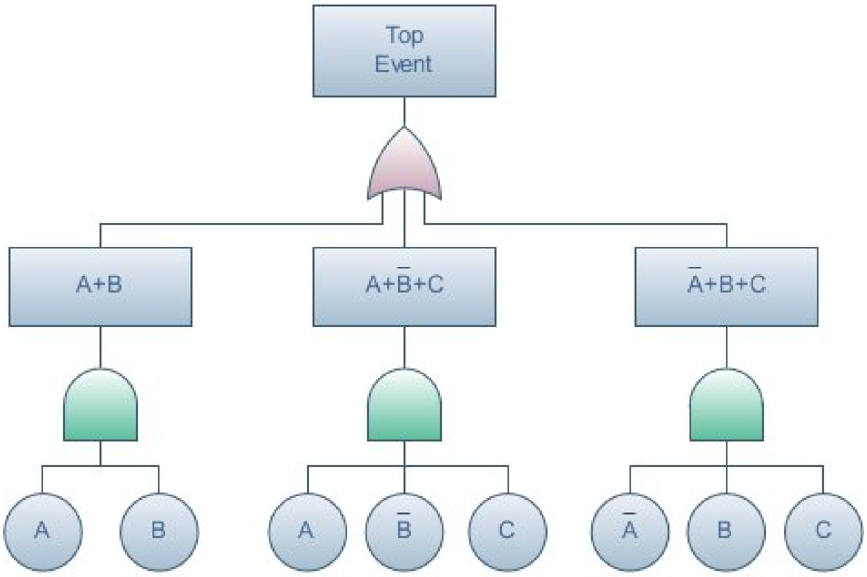

Figure3.9 Fault tree diagram [7]

3.4.2.4 Failure Mode Effect Analysis (FMEA)

Failure Mode Effect Analysis and Failure Mode Effect and Criticality Analysis are tools for preventing problems by developing quality designs, processes and services. FMEA is a procedure for developing new designs, processes, or services and also the diary of the design, the process, or the service.

FMEA is an early warning and preventive technique. FMEA provides the causes and effects of failures before the system, design, process, or service is finalized [7]. With failure mode effect analysis it is possible to get the results for risk priority number, criticality matrix, criticality rank, risk level and failure made probability.

Most recent maintenance expenses are characterized by bathtub curve (Figure3.10).

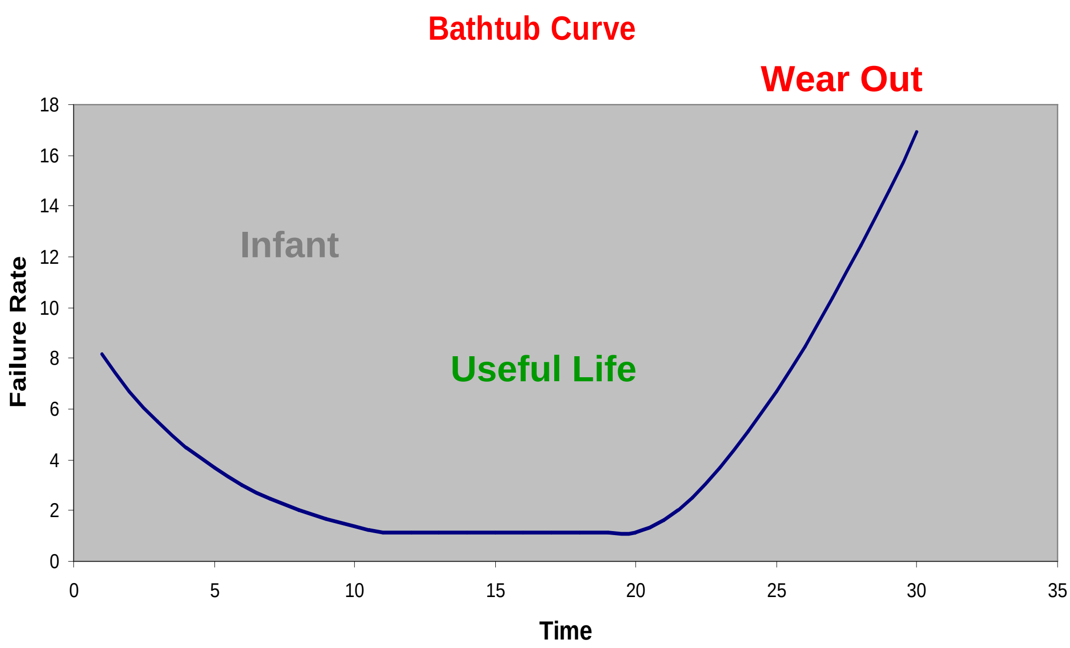

Figure3.10 Bathtub Curve [7]

As can be seen in Figure3.10 maintenance expenses are high in the early part of life cycle of the item or machine as well as at the last part of the life cycle. Generally the reason for high maintenance expenses for early working time is due to the problems due to design and production stage. The problem from design and production stage can be observed in the early working time of the item or machine.

In order to reduce the early life cycle maintenance cost, maintainability of the item or equipment is extremely important. There are some methods to improve the maintainability of the item such as standardization, simplicity, accessibility, and identification. These methods help to decrease the problems out design and production stage therefore decreases the maintenance expenses in the early working time.

With regards to the other high maintenance expenses part, last 10 years of the life cycle, it is also possible to decrease the maintenance expenses for this part by implementing good maintenance and repair strategies. It is normal to observe more maintenance and repair expenses at the last part of the life cycle. However this time period and the maintenance expenses directly related with previous maintenance and repair actions. Correct and good maintenance and repair actions in the right time will improve the availability of item and machine. Delaying the maintenance and repair action may cause more repair work, and hence loss of time and money.

CHAPTER 4 FIELD STUDY IN A SHIP REPAIR YARD

For better understanding of hull structural problems and identifying the reasons for hull structural problems, one month field study was carried out in a ship repair yard. A practical knowledge about how ship operators, ship yard, sub contractor, classification society and supplier are working has been collated by this field study. The ship yard is based in Tuzla, Istanbul, Turkey and mainly doing repair works. However due to market demand ship yard can easily adapt to new building as well. Shipyard is based in Tuzla which is well known ship building site where more than 40 small-medium size yards are located. Shipyards, sub contractors, suppliers, classification societies and even related universities are based in this area. Due to this high demand and limited area it is very difficult to find place to expand. Because of limited area, shipyards are very close to each other. Although there is a big demand in shipping industry, ship yards are not able to increase their capability due to limited place.

4.1 Shipyard Technical Analysis

The shipyard has an ability to handle any type of repair. Dry cargo vessels, ro/ro, tankers, container vessels, river and sea going vessels, livestock carriers, tug boats, barges, passenger vessels and fishing vessels repair and maintenance work has been done by the shipyard before. The ship yard has a good repair and maintenance experience especially for dry cargo vessels, tankers and container vessels.

The ship yard repairs an average of 130 ships, 400.000 Dwt in total, annually. Over 1500 vessels have been repaired by the ship yard since 1986. Also ship yard has ability to perform repairs while ships are floating along the 200 m length pier.

The shipyard`s repair services include : steel work, piping, propeller, rudder, shaft, ventilation, equipment insulation, electric-electronic, carpentry, main engine works, renewal, maintenance and repair, hydro blasting (2500 bar) tank cleaning, water blasting

(750 bar)tank cleaning and coating. In addition shipyard has a lengthening and deepening modification services.

Ship yard has one floating dock. The floating dock has a 2750 ton lifting capacity, and dimensions 115,3 m full length, 22 m outer width and 16 m inner width. The floating dock does the lifting activity by 2 cranes with 10 ton lifting capacity each.

The ship yard has 3 cradles. The biggest vessel can be moved to the land is 7.500 dwt. Cradle 1 has 90 m length, 20 m width and 3500 dwt capacity. Cradle 2 has 110 m length, 25 m width and 5000 dwt capacity. Cradle 3 has 120 m length, 25 m width and 7500 dwt capacity.

New building capacity for the ship yard is 9000 dwt. The shipyard built different types of ships such as chemical tanker, tanker and dry cargo vessels.

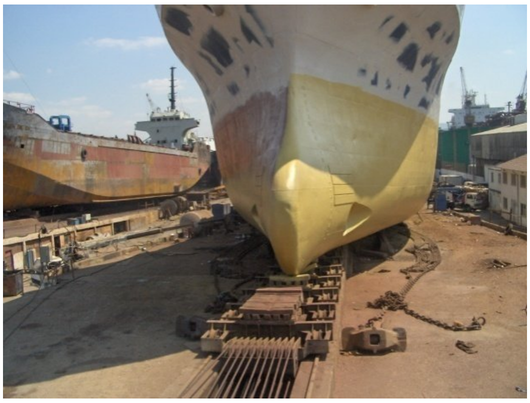

Figure4.1. Cradle 1

Figure4.2. Cradle 2

4.2 Management Policy

Hidrodinamik Shipbuilding and Trading Co. is a full service shipyard involved in ship construction, repair and conversion. The shipyard has a highly skilled workforce, ABS certified welders and montage workers and management team experienced in dry cargo, container vessels, tankers, livestock carriers, river-sea going vessels, tugboats, passenger vessel etc. over 15 years.

Shipyard has full woodworking, machine shop, fabrication, electrical and mechanical departments.

In author`s time in the yard, there were 12 ships in shipyard for repair. Some of them were completed and ready to go but due to the financial problem between the operator and shipyard. Shipyard was keeping these vessels until the owners pay the cost of repair.

Generally operators contact shipyard 5 or 6 months before the dry docking is due. Ship owners make the inspection and thickness measurements with their engineers. Then operators send the report to ship yard and they obtain the cost and the time estimation for repair and maintenance work for the ship. Generally ship operator's first choice is the ship yard which they worked with before. However the ship operators may need to work with different ship yards due to the problem with ship yard`s availability.

Personal relationship between the ship operator and ship yard is very important to make business. It is also very common to see family members are working in different branches of shipping industry. Family members keen on to work together. There are a lot of advantages working with relatives but there is also some disadvantages as well. Due to the good personal relationship between shipyard and ship operator, ship operator can easily insist on to make his vessel`s repair work quickly. Therefore it is very easy to observe some problems due to this tight scheduling to accommodate friend`s requests.

Sometimes the thickness measurements are done while ship is on cradle so this causes time and money losses for operators. For example; plate thickness measurements and inspection for a vessel was carried out on a cradle and it took 10 days. This means a loss of time without any repair work on the ship. The ship yard also wanted to add the 10 days cradle hire money to total repair work cost but ship operator does not want to pay this money.

Another problem between operators and shipyards is the differences between the thickness measurements carried out by operator`s engineer compared to measurements by the shipyard and classification society. Generally operators find less failure so operators get the price according to their estimated amount of steel to be replaced. However, difference between the operator`s estimation and shipyard`s or classification societies estimation is around %20. Even sometimes this amount can increase to %40. This extra work means extra time in shipyard, extra repair and maintenance cost. Operators do not want to pay more so operators try to find out solutions for this problem. Sometimes they change the classification society in order not to carry out more steel replacement.

4.3 Repair Work Cost Calculation

Shipyard generally calculates the steel work cost based on per kg. If the steel work is not big plate, it needs extra effort and extra time, then shipyard calculate the steel work costs based on hourly rate. Shipyard has different cost calculation tables for per kilo and for hourly rate.

Generally up to 20 tons shipyard prefers to work based on hourly rate while for higher amounts of steel it is calculated according to per kilo. These values are based on the approach adapted by hidrodinamik shipyard and my change depending on the shipyard.

Steel work price list table which is collected from other Turkish repair yard is given Table4.1. In this table steel replacement below 20 ton is also calculated based on price per kilo. There are price differences between repair yards even they are based in the same city.

Steel Works	Unit	Price (USD)
General steel repair		
Above 100 ton	kg	2.85
Between 50-100 ton	kg	3
Between 25-50 ton	kg	3.15
Between 1-25 ton	kg	3.3
Between 60 kg - 1 ton	kg	4.05
Small Pieces		
Below 15 kg	pc	62
Above 15 kg	pc	100
Above 30 kg	pc	150
Between 45-60 kg	pc	200
Welding renewals with normal electrode	m-row	14
Filled pitting (up to 25 cm3)	pc	14
Unit price is increased for following areas as follows		
Fore peak, aft peak, DB and ballast tanks	15%	
Cargo tanks and engine room	15%	
Single curved plates	15%	
Double curved plates	25%	
Bulbous bow area	60%	
Holland profiles	25%	
Oil & Oily tanks	20%	
Less than 10 mm and more than 20 mm	15%	
Brackets and such unshaped materials	5%	
High tensile steel	15%	

Table4.1. Steel work price list table (year 2007)

The shipyard categorises the price list under three headings which are general steel repairs, small pieces, welding renewals with normal electrode. Some steel repair works in particular areas needed extra effort and time and therefore shipyards increase the unit price for these areas. Bulbous bow area is most expensive with unit price increase of 60%. Due to shape of the bulbous bow area, it needs extra effort and time to carry out the steel replacement in this area. Shipyards prefer to give the prices in US dollar as indicated in Table4.1.

Quantity of steel work in terms of weight is calculated by multiplying length, width and thickness. Then additional 2.5% loss is added this weight which is then multiplied with price per kilo that may change according to agreement between shipyard and operators.

Formula for steel work cost calculation per kilo;

Steel Work Cost (per kilo) = Length (mm) Width (mm) * Thickness (mm)* Density of Steel* (kg/mm^3)*1.025 (Loss %2.5) * Cost per kilo (dollar)* (6)

Some operators prefer to buy the steel themselves so these operators just pay shipyard for labour cost, cradle cost, crane and other hire costs. Ship operators need to do all buying transferring and keeping activities by themselves therefore most of the ship operators want shipyard to buy the steel for themselves. In this position shipyard is earning more money. Shipyards already have well established contacts with suppliers so the price for shipyard is less than the price for the price for operators.

After the dry docking some ship operators keep the extra steel as well as the extra paint in the ship for the next dry docking period and this is a common practice for a ship operator. The store space under fore castle deck is generally used for this purpose. Also it is observed that because of variant steel prices some operators buying the steel from other countries where the steel prices are low. Ukraine is one of these countries for Turkish ship operators who buy the steel from these countries just before the dry docking period and operators carry the steel with their ships to the dry dock yard.

An example of steel work calculation for a vessel is given in Table4.2 which belongs to a general cargo vessel.

Area	Length mm	Width mm	Thickness mm	Loss %2,5	Weight kg	Weight kg
SHELL PLATE						
MRK FR:90-96	2000	3450	14	1.025	772.8	792.12
MRK FR:75-78	2000	1650	14	1.025	369.6	378.84
MRK FR:58-62	2000	2150	14	1.025	481.6	493.64
MRK FR:43-46	2000	2050	14	1.025	459.2	470.68
STB-A FR:70-81	2000	8000	14	1.025	1792	1836.8
STB-A FR:43-46	2000	2050	14	1.025	459.2	470.68
STB-B FR:51-62	2000	8000	14	1.025	1792	1836.8
STB-B FR:100-103	800	2050	14	1.025	183.68	188.272
STB-C FR:100-103	1950	2050	14	1.025	447.72	458.913
STB-C FR:33-35	700	1500	14	1.025	117.6	120.54
STB-E FR:86-95	1000	6000	13	1.025	624	639.6
STB-E FR:39-83	1000	30800	13	1.025	3203.2	3283.28
STB-E FR:29-39	1800	6000	13	1.025	1123.2	1151.28
STB-F FR:100-107	2000	5400	11	1.025	950.4	974.16
STB-F FR:72-80	2000	5400	11	1.025	950.4	974.16
STB-F FR:29-39	2000	6000	11	1.025	1056	1082.4
STB-G FR:72-83	2000	8000	11	1.025	1408	1443.2
STB-G FR:45-67	2000	13000	11	1.025	2288	2345.2
STB-G FR:27-40	2000	10000	11	1.025	1760	1804
STB-H FR:39-83	2000	32000	11	1.025	5632	5772.8
PORT-A FR:75-81	2000	5800	14	1.025	1299.2	1331.68
PORT-A FR:43-46	2000	2050	14	1.025	459.2	470.68
PORT-B FR:	2000	2000	14	1.025	448	459.2
PORT-B FR:	2000	2200	14	1.025	492.8	505.12
PORT-B FR:69-85	2000	11700	14	1.025	2620.8	2686.32
PORT-B FR:43-46	2000	2050	14	1.025	459.2	470.68
PORT-C FR:	2000	2400	14	1.025	537.6	551.04
PORT-C FR:95-107	1000	8900	14	1.025	996.8	1021.72
PORT-C FR:70-81	2000	8000	14	1.025	1792	1836.8
PORT-C FR:51-63	2000	9700	14	1.025	2172.8	2227.12
PORT-C FR:29-34	1800	3500	14	1.025	705.6	723.24
PORT-E FR:39-101	1000	44500	13	1.025	4628	4743.7
PORT-E FR:29-35	2000	6300	13	1.025	1310.4	1343.16
PORT-F FR:	2000	4200	14	1.025	940.8	964.32

Table4.2. Steel Work Calculation per kg

Generally cost of steel for shell plate, cargo hold area and double bottom work are calculated according to price per kilo due to amount of work and the thickness of the steel, which is higher in these areas. There are some examples of repair work for which cost calculation is based on weight. Figure4.3 and Figure4.4 are examples of shell plate steel renewal which are big size steel replacements and therefore cost is calculated based on weight.

Figure4.3. Shell plate steel replacement

Figure 4.4. Front shell plate steel replacement

The double bottom is the other critical steel replacement part where the thickness of the steel in double bottom area is higher so the weight. As shown in Figure4.5 and Figure4.6 below.

Figure4.5. Double bottom repair work

Figure 4.6. Double bottom repair work II

Another way to calculate the steel work cost is based on hourly rate. In super structure, generally there are a lot of small steel repair works to be carried out and the cost for these works is not very much and therefore the shipyard does not want to do these works unless it is profitable. Generally shipyards give these works to sub constructor to carry out. Shipyard prepares a steel work table for the sub constructor and one engineer from shipyard control this table daily. After the steel work is finished shipyard get the cost from the sub constructor and shipyard adds the profit on this price and passes it onto ship operators. Generally there are 5-6 different sub constructor working in shipyard depending on the shipyard`s capacity. This provides the shipyard an extremely good opportunity to receive the cheapest offer very quickly as all sub constructors would like to maintain good relationship with the shipyard. Therefore the earning from all steel work brings the biggest earning to shipyard even the shipyards does not do the work itself.

Table4.3 provides the steel work cost calculation based on hourly rate which also includes the work description and worker`s qualifications. The cost per man hour is calculated based on number of hours the workers work and the type of work. The shifts are also calculated according to working hours; from 8am to 1pm, from 1pm to 5 pm is half shift, from 5pm to 8pm and from 8pm to 10 pm are taken as half shifts. If the workers work from 8am to 5pm in the table it is written as 1. Most of the disagreements between the ship operators and shipyards are due to the calculation of these shifts. Although sometimes the workers just work 2-3 hours ship yard calculates the shift as half shift. The ship operators say the worker worked just 2 hours not half shift. However shipyards argues that the worker was there and the shipyard did not give the worker any other work except the work for that particular ship. Therefore shipyard wants to calculate it as a half shift but the operator does not accept it. The ship operators want the worker to work for 8am to 1pm and even the worker finishes the work early the operator wants to give them extra small additional works like cleaning, painting etc. to worker until the shift ends. However sub constructor company does not want the worker spend too much time to do hour based works because it does not provide big earning. The sub constructor would like to use the workers in other steel related work as soon as possible but, the sub constructor was forced to carry out these types of works by the shipyard.

There is a shortage with montage and welding workers. Although there is no problem with the number of assistant workers the skilled welding workers and montage workers are very important to complete the work on time. Sometimes sub constructors send the assistant worker as a welding worker and although the worker does not have the right qualification and experience he performs the welding work. If the ship operator or classification society recognizes it, the work is repeated otherwise the ship goes to operation like that. This highlights the need for the well established procedures for the management of the work performed by the sub constructors.

Rates for montage workers and welding workers are more expensive than assistant workers. Sometimes one welding or montage worker`s hourly rate is equal to 2 assistant workers rate.

Cost of steel work based on hourly rate can be calculated as;

*Steel Work Cost = Worker Price (Montage, Assistant, Welding) * Number of Shift* (7)

Hourly rate steel work calculation

WORK	MONTAGE	ASSISTANT	WELDING
COMPASS DECK	-	-	-
COMPASS DECK AROUND LAMA 5300mm	**1**	**1**	**2**
COMPASS DECK PUTTING 2	X	X	X
COMPASS DECK AROUND LAMA	**1**	**1**	**1**
COMPASS DECK STICK PUTTING	X	X	X
COMPASS DECK STICK WELDING ON 2	**1**	**1**	**1**
COMPASS DECK PUNTEL PIPE MONTAJ	X	X	X
COMPASS DECK CABLE PIPE MONTAJ	**1**	**1**	X
COMPASS DECK BOX	**1**	**1**	X
COMPASS DECK FRONT IMO	**1**	**1**	**1**
FUNNEL			
FUNNEL CLEANING	X	X	X
FUNNEL FORS 2	**1**	**1**	**1**
FUNNEL TANK STB SIDE INSERT	**1**	**1**	**1**
FUNNEL DECK AROUND LAMA 11500mm	**1**	**1**	**3**
FUNNEL DECK UNDER DUBLIN 4	**2**	**2**	**4**
BRIDGE			
BRIDGE PORT DUBLIN	X	X	X
BRIDGE STB/PORT OLD SHIP NAME CLEANED	**1**	**1**	X
BOAT DECK			
BOAT DECK WINCH SET	X	X	X
BOAT DECK WINCH UNDER DUBLIN	X	X	X
BOAT DECK WINCH UNDER STIFFENER 2	X	X	X
BOAT DECK WINCH BRACKET 4	**2**	**2**	**2**
BOAT DECK LIFE BOAT FOUNDATION 2	**1**	**1**	X
BOAT DECK LIFE BOAT FOUNDATION CUT AND RE SET 2	**1**	**1**	**1**
BOAT DECK HAWSER REEL MONTAJ	**1**	**1**	**1**
BOAT DECK AROUND LAMA 22000	**2**	**2**	**4**
BOAT DECK PUNTELS INSERT	**1**	**1**	X
BOAT DECK OLD PUNTELS OUTFIT	**1**	**1**	**1**
BOAT DECK OLD MATAFORA LEGS CLEANED	X	X	X
BOAT DECK LIFE BOAT LEG INSERT	**1**	**1**	X
POP DECK			
POP DECK PARAMPET BRACKET INSERT 5	**1**	**1**	**2**
POP DECK AIR CONDITION TAVA 2	**1**	**1**	**2**

Table4.3. Steel work calculation based on hourly rate

Some examples of repair work cost calculation based on hourly rate figures are given below. The ladder which is renewed for the ship is less than 20 kilos. (Figure4.7.a and Figure4.7.b)

Figure4.7.a. Damaged ladder sample

Figure 4.7.b. New ladder sample

Figure4.8.a. Old opener

Figure4.8.b. New opener

The price given to operator is a fixed value for one opener. Shipyard calculates the price based on the unit price and number of units Figure4.8.a and Figure4.8.b. Below some examples of small work are given;

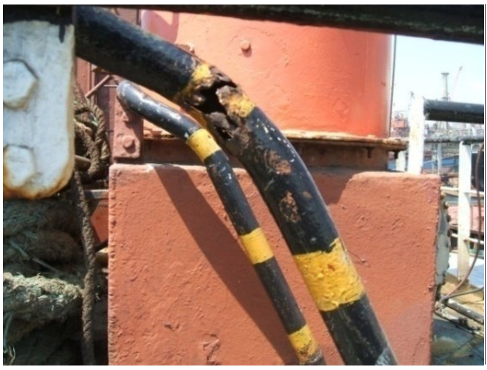

Figure4.9.a Old ladder handle

Figure4.9.b New ladder handle

Figure4.10. New covers

Figure4.11. New fasteners

There are also some small steel replacements on board such as renewal of 5 brackets (Figure4.12.a and Figure4.12.b).

Figure4.12.a Old brackets

Figure4.12.b New brackets

Pipes:

Shipyard calculates the pipe work prices according to size (diameters & length) and type of the pipe. Pipe diameters changes from 13mm to 200mm thickness of pipe works and prices are given in the Table4.4. Prices for pipes are further divided into the shapes such as elbow, flange, ring and u-bolt. Ship yard gives the prices in USD and the pipe work cost increases as the pipe diameter increases.

SIZE		PIPES(USD)	ELBOW(USD)	FLANGE(USD)	RING(USD)	U-BOLT(USD)
Nom dia.	MM.	sch40	sch40	pn16	sch40	sch40
1/2"	13	13		25	10	10
3/4"	20	17		30	13	12
1"	25	22	16	35	15	15
1 1/4"	33	27	22	40	20	18
1 1/2"	40	35	25	50	25	20
2"	50	45	35	60	35	22
21/2"	65	60	40	75	40	25
3"	80	75	45	90	45	30
4"	100	95	75	100	50	35
5"	125	12	125	120	55	45
6"	150	150	185	150	60	55
8"	200	200	225	180	75	65

Table4.4. Shipyard price list for pipes

Paint work:

Shipyard charges the painting cost as per square meter of steel painted, plus the purchase of paint if supplied by the shipyard as some ship operators provide the paints themselves. The paint companies have good delivery facilities. The paint companies bring the paints according to agreed details like when and where etc. There are big differences between the prices of paint according to paints qualities. It is interesting that although the ship operators do not want to pay too much for the steel works and other maintenance and repair facilities, the ship operators are keen on to paint the ships with high quality paints. According to author`s observation, ship operators prefer good quality paints. Similar to steel work, shipyards generally use sub constructor. Painting sub constructors are not working only with a specific shipyard, these companies working with all the shipyards and because of this, time is very important for these companies like the all other shipping industry companies. The sub constructor company gives the price for painting according to agreed work specifications. If the ship operator wants the sub constructor to do all the work including paint purchasing the price is going to be higher. Just painting work without any purchasing it is cheaper and the painting cost is calculated according to square meter. In some cases paint companies provide the painting job themselves as well to achieve good quality and guaranteed paint work.

4.4 Classification Society Policy

The classification society signs an agreement with ship operator for a specific period. This period is generally for 5 years. During this period, classification society inspects and checks the ship. These controls/inspections are carried out for hull, machinery and special equipments. Based on these controls classification society determines the required maintenance, repair and steel replacement to be carried out by the ship operators. If classification society and ship operator agree on the required works, contractual agreement between classification society and ship operators continues for a new 5 year period.

If ship operators does not agree to do the repair and maintenance works required by classification society, disagreement between ship operators and classification society may lead to severance of relation. Ship operators do not want to spend money on repair and maintenance works and it is very common for them changing to another classification society which is requiring less repair and maintenance work. It is also possible that classification society does not want to work with the ship operators anymore because of the bad condition of the ship which is generally due to high age of the ship.

According to Turkish Loyd the tolerance for steel thickness loss is %20 of original steel thickness. If the loss is bigger than %20 then this part of the steel needs to be replaced. The tolerance amount is changing by part of the hull. For some critical parts the tolerance amount can be decreased by surveyor.

Classification society is doing controls using their own surveyors, who generally come from repair and maintenance shipyards background with a good experience. Because of the work experience in shipyard, surveyors carry out the controls confidently and, furthermore the surveyors have experience about critical areas where generally failures occur. It is helpful for surveyors to make the inspections and controls in a short time as cost of the survey depends on number of hours they spend on board.

Shipyard and ship operators have an opinion about the surveyors. Most surveyors are known by ship operators and ship yard who become very familiar with the surveyor`s working style and they know which areas are priorities for which surveyors.

There are different kinds of surveys which are class renewal survey, annual survey, intermediate survey, bottom / docking survey, tailshaft survey, partial survey, boiler survey, and non-periodical survey are the kinds of surveys. Survey types are changing according to survey area, time and aim.

Class renewal survey or special survey is carried out every 5 years. Classification society and ship operators make agreements for 5 years and at the end of this period if classification society and ship operator agree to renewal the class after the special survey agreement between classification society and ship operator new 5 years period starts. In this 5 year period every year and annual survey is being carried out.

In annual survey;

- Hull test is carried out
- Machinery test is carried out
- Equipments tests are carried out
- Some witnessing tests are carried out

Every two and a half year intermediate survey is carried out. In intermediate survey ship needs to be dry docked. Same test in annual survey and intermediate survey carried out but in intermediate survey surveyors are stricter about inspection compared to the annual survey.

In intermediate survey following tests are carried out;

- Hull test
- Machinery test
- Equipments test
- Thickness measurements for hull and chain

There are also other types of surveys such as bottom / docking survey in which the examination of outside of the hull is carried out. Screwshafts, tube shafts, stern bearing surveys are carried out in tailshaft survey. Boiler survey is carried out twice in a 5 year period. Examination of steam boilers, superheaters and economisers examination are also carried out in this survey. Furthermore non-periodical surveys are carried out in update of classification society documents to deal with damage or suspected damage, repair or renewal work, alterations or conversion, postponement of surveys or recommendations / conditions of class, at the time of port State control inspections [14],[15].

Classification societies have an important role for safety like safety of crew, safety of environment, safety of ship and cargo, and the controls are carried out by surveyors. Therefore surveyors should be well educated and experienced. Most classification societies are applying good programs to educate/train the surveyors but not all of them.

Classification societies have a check list for each type of ship and they do this checking every dry docking period. Chain thickness measurement is one of these. Port and starboard chains are released to ground while ship on the cradle, and then they put the chain in order and class surveyor checks the thickness of the each chain. Normally shipyard engineers check the chain before the class survey and if there is a problem they sort it out before the class survey`s inspection. This is helpful for not to lose any more time.

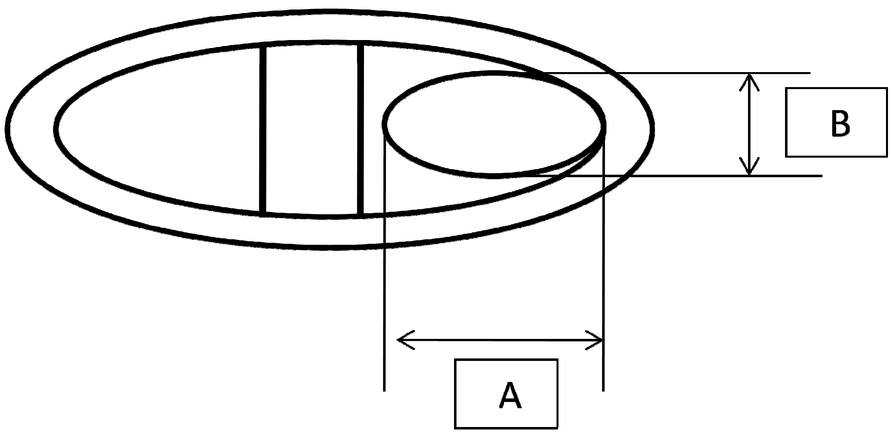

Figure4.13. Chain thickness measurement criteria

Chain cable thickness is measured by the inspection from the point A and point B (Figure4.13). Every A and B values are written down in a table for each part of the chain. There is a tolerance for %12 of chain thickness loss. If the loss is bigger than %12 then these parts of the chain need to be renewed. The operators prefer to change the part of the chain not all the chain. So the measurements are being done for each part. If any part has a problem, it is being replaced with new part.

Chain is one of the critical part of the vessel which can easily affect the operational availability of vessel. It was observed by author during the visit in ship yard, that after finishing the dry docking and delivering the ship back to operation, it has been realised that the ship had forgotten the chain on the cradle and she is in operation without any chain. The ship had to come back to shipyards but again waited for the cradle to be freed and got on the cradle and collected the chain and went back to operation. This caused more operational unavailability times for this ship because check list was not used properly.

CHAIN CABLES LENGTHS	PORT CHAIN CABLE			STB CHAIN CABLE			DIAM. OF LINK(mm)	LIMIT FOR RENEWAL
	A (mm)	B (mm)	(A+B)/2	A (mm)	B (mm)	(A+B)/2		
1	43.5	46.6	45.05	38.8	43.4	41.10	20	17.10
	45	44.6	44.80	39	46	42.50		
	44.4	45.6	45.00	40	45.6	42.80	22	19.35
2	42.9	45.5	44.20	40.6	46.2	43.40		
	42.8	45.7	44.25	39.6	46	42.80	24	21.10
	42.4	46.1	44.25	41.9	46.8	44.35		
3	43.8	45.4	44.60	40.5	45.3	42.90	26	22.90
	43.4	45.6	44.50	40.6	46	43.30		
	44.4	46	45.20	40.8	46.3	43.55	28	24.60
4	43	45	44.00	40.2	45.4	42.80		
	42	43.7	42.85	40.3	45.6	42.95	30	26.40
	42	45.2	43.60	40.6	45	42.80		
5	44	45.4	44.70	40.5	46.3	43.40	32	28.15
	42.7	45.7	44.20	37	45.9	41.45		
	41.8	45.5	43.65	40.5	46.3	43.40	34	29.90
6	43.6	44.6	44.10	40.8	45.8	43.30		
	41.1	45	43.05	40	45.3	42.65	36	31.70
	42	45.8	43.90	40.9	45.2	43.05		
7	32.2	35.6	33.90	41.6	46.1	43.85	38	33.45
	30.1	35.2	32.65	41.5	45.2	43.35		
	28.2	32.6	30.40	42.4	46.2	44.30	40	35.20
8	31.5	36	33.75	44	44.9	44.45		
	33	36	34.50	43.3	44.7	44.00	42	37.00
	31.5	32.8	32.15	43.5	45.8	44.65		
9	36	37.6	36.80	32.9	33.5	33.20	44	38.70
							46	40.50
10								
							48	42.25

Table4.5. Chain measurement table

Radiographic welding inspection report is the other inspection list to check the welding quality. Shipyard works with private companies to supply the radiographic welding inspection report. These private companies are located in close areas to shipyard. Metallurgy engineers are working for these companies to prepare radiographic welding inspection report. During author`s field trip it was observed that, engineer use gamma ray as a radiographic technique. According to observed colours in the report the problem can easily be determined. After applying the radiographic film these welding failures such as porosity, pipes, inclusions of any shape and in any direction, slag lines, lack of fusion, incomplete penetration, longitudinal crack, transverse crack, undercut (inside), undercut (outside), burn through, unexpected metal can be determined. And sometimes due to bad application of film, quality of film is not enough to understand the failures therefore new film application is required as well. For instance, if black colour observed after the film, it means good and if red colour observed, it means need a repair. After consulting company prepare this report for the shipyard, this report is sent to classification society, which requires the repair works to be carried out according to radiographic welding inspection report.

4.5 Repair Works and Structural Damages

4.5.1 Ship hull structure repair works

Most critical areas according to observation of steel replacement works in shipyard are cargo holds, double bottom tanks, deck plate, shell plate and top side tanks.

During the cargo loading and discharging activity on board the general cargo ship coating is easily damaged. Crane can hit the cargo hold area due to bad control. It is not always possible for crane operators to have the full view of cargo hold. Especially mobile cranes which are operated from outside is causing these damages. Mobile crane operators are working with assistants during the loading and discharging. Generally these types of cranes are used for equipment transfer and repair and transfer of maintenance devices as well as steel transfer. Generally mobile crane operators are from shipyard workers and assistant workers from sub constructor company and furthermore there is no good communication between them which may be due to the lack of training as a team. Due to bad communication mobile crane can easily hit the cargo area and damage it. Sometimes forklifts are also used for cargo loading and unloading activities. Forklifts are also used to carry and hold the heavy steel plates during the steel replacement works. During the loading and discharging some accidents/damages can occur. For example; due to forklift movements in cargo hold forklift is hitting the frames and forklift tyres are damaging the bottom of the cargo holds by scraping the coating. The view of cargo hold area for a general cargo vessel is given in Figure4.14.

Other critical part is the shell plate. During the ship operation shell plate is always in contact with port elements. Sometimes ships need to be escorted by tugs during their operations, such as passing through the canal or entering the port tugs. Physical contact between tugs and ship is very common and during these physical contacts shell plate can easily be damaged. Physical contact between shell plate of ship and pier takes places very regularly. Bad weather condition can easily increase the severity and occurrence of these damages.

Other critical area is double bottom area, as steel thickness at double bottom is decreasing due to corrosion and bad zinc system. Zincs are not working properly because the chosen location or due to the other reasons. Therefore more corrosion can be observed in double bottom area and it affects the life of the double bottom steel. The double bottom area is always under the sea so it is wet, coated with mud. This area continually experiences salt water. These reasons affect the life of the double bottom steel as well. Bad painting or coating and grounding are also other important reasons for more regular double bottom steel replacement work.

Figure4.14. Cargo hold area of a general cargo vessel

Shell plate area around the chain hole in front of the ship can easily be damaged due to the interaction between hull and chain. It is damaging the coating and even it is damaging the shell plate. To reduce the shell plate damage, extra plate is welded as shown in Figure4.15. This is not reducing the coating damage but it is helpful to protect the steel thickness.

Figure4.15. Damages of front area paint because of anchor

An example of failure in dry docking process can be observed in Figure4.16. Painters and the steel workers are from different sub constructor companies and although steel worker has not finished the welding work, painter finishes painting. As a result of burning paint on the outer shell can be observed. Painter company moves out of shipyard before the paint was burnt so burnt places have to be painted by shipyard workers.

Although during all stage of the painting activities supplier companies send their controllers, who are paint experts, these controllers do not have influence on shipyard or ship operators. Controller visits the shipyard and gives some advices and makes some measurements and then leaves the shipyard. Naturally, these mistakes affect the painting quality and also the steel`s life.

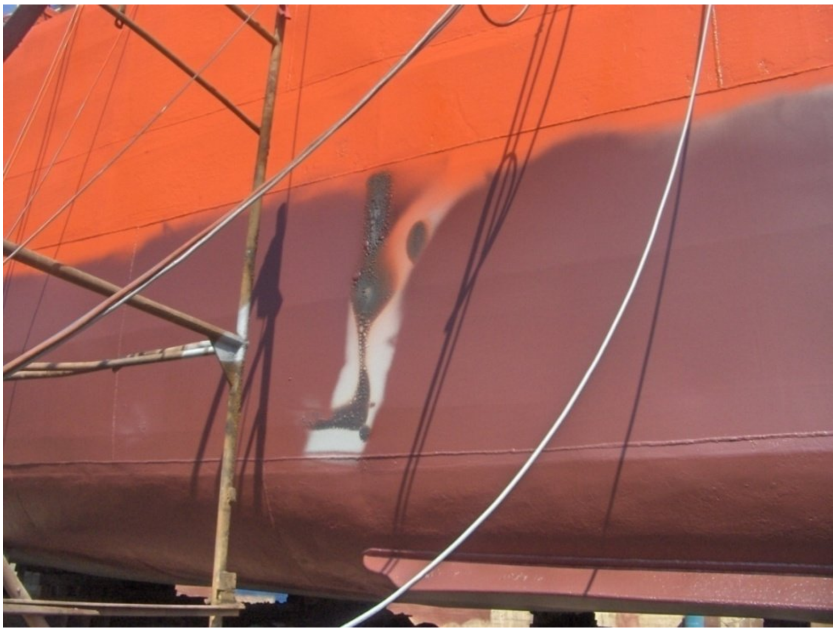

Figure4.16. Sample of paint burning due to wrong work order

Another major problem is cleaning the steel surface before the painting starts. In dry docking it is made by special equipments and it is a good cleaning (Figure4.18); however sometimes painting can be done at the sea by the crew of the vessel. In this situation crews used the hammer and basic stools for the cleaning and it is not effective as the dry dock cleaning. Because of the bad cleaning of the surface, paint can easily be deformed and from the deformed area air and water pass through between the coating and steel and it causes accelerated corrosion. The life of the steel is not long in this situation and the steel is renewed before the estimated time. An example of bad surface cleaning can be observed in Figure4.17.

International Maritime Organisation (IMO) has some standards for coating. With these standards IMO aim to improve coating quality and protect the hull structure from the corrosion and breakdown.

IMO categorizes the surface preparation as primary and secondary surface preparation. In primary surface preparation Sa2 or Sa2.5 surface cleaning should be done also water soluble salt equivalent to NaCl $\leq 50 mg/m^2$ is required. According to the secondary surface preparation, it is necessary to remove sharp edges, grinding weld beads, removing weld spatter and any other surface contaminant. Edges also have to be treated to a rounded radius of 2mm or three pass grinding.

According to IMO regulations it is important that getting coating right during new building. Examination of coating in design, construction, operation, maintenance and survey stages is important to check the quality of work.

Corrosion is one of the important failures for hull structure and it is possible to improve corrosion protection via, improved steelwork, better surface preparation and cleaning and better application of coating.

Figure4.17. An example of bad surface cleaning done by hammer

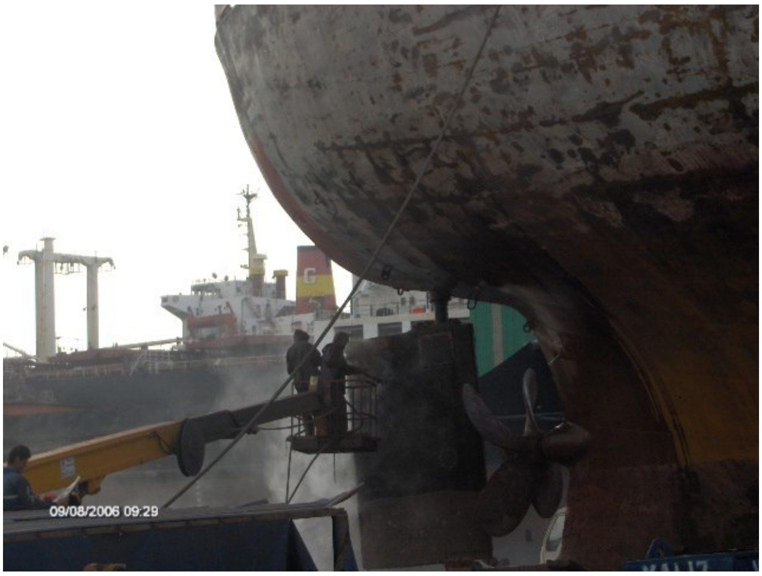

Figure4.18.Good surface cleaning done by 2500 bar water pressure

4.5.2 Machinery repair works

Machinery failures can cause unavailability for the ship easily that is why engines subject to preventive maintenance handbook and they are strictly implemented by engineers. The preventive maintenance time period is changing according to advice given by the manufacturers.

The unavailability time for machinery failures are also related with the quality and cost of the ship repair service. The delivery time depends generally on factors concerning: the particular works that have to be done within the ship repair project, the features of the shipyard, such as physical capacities and loading speed, facilities, technologies, tools and manpower available, experience and skill of people, delivery time of the materials and components, and the situation on the market, such as the corresponding delivery times of competitors. [19]. Machinery repair work is not the focus of the project but should be looked at in a separate project.

4.6 Data Collection

In order to achieve the aims of this study ship operational and repair data play extremely important role and therefore such data have to be constructed. Therefore ship operators and ship yards were contacted. However it became very clear that, it is very difficult to collect the repair data from the ship yards and ship operators. Generally repair shipyards prepare three copies of repair reports after the dry docking and ship yard keeps one of them itself and the other two are given to ship operators. Ship operators just keep the last repair work reports and they are not keen on keeping the others. One of the last repair work report kept in the captain`s office in the ship and the other is kept in ship operators based. This study shows that ship operators and ship yards do not have a good strategy with regards to collecting and forming ship repair data base. In addition ship operators and shipyards are not analyzing the repair data to develop maintenance and repair strategy either. Also in this study, contacts with classification societies are made to collect data. Classification societies are collecting the repair data in a more structured way. However classification societies are not keen on analysing these data.

Although significant effort was put in for contacting shipyards, ship operators and classification societies, obtaining the data is proven to be more difficult for following reasons

- People do not want to share data
- History of repair for one particular ship is not kept properly
- Author managed to get only one drydocking report for per ship as people did not know the where about of other data
- Ships go to the different shipyards due to pricing or operational area

It was observed during the field study that there is a big communication gap between ship operator, shipyard and sub constructor company. The communication starts 5-6 months before the dry docking time. The ship operators send their engineers to control the ship and make the marking for steel replacement. In this stage engineer does not want to mark a lot of steel work as he does not want to make ship operator angry. If the engineer mark a lot of steel work then ship operator try to find someone else to avoid marking of more steel work. After finishing the marking ship operators get the price from the shipyard and the available date for dry docking. Classification society, shipyard and ship operator need to work together at this stage and make the marking together to solve the marking problem. So the conflict between the repairs works and cost between shipyard and ship operators can easily be resolved. Moreover this will give shipyard an opportunity for better preparation as the shipyard knows the amount of steel work to be carried out 5-6 months before the dry docking time. So it is very easy for the shipyard to order the steel and the other things from the supplier and also it is possible to make all the preparations in advance. Preparing the frames, lamas, brackets etc. in advance is possible and just before the dry docking time it is also possible to put these parts near the cradle which the ship is going to be dry docked. And because the shipyard engineer is familiar with the ship and the work in advance, it is going to provide more quality work and less dry docking time.

Second stage problem is related to dry docking time. Ship operators want their ship to be dry docked when they want. Generally ship operators do not care whether the ship yard is really available or not for the particular time when his ship is to be dry docked. Ship operators get the time by insisting on ship yard so; although ship yard is not available, ship yard makes the date available which ship operators insist on. It is also possible that although the ship yard is not available in this particular date, ship yard agrees on the date which ship operator wants. In this position ship yard does not want to lose the customer. In both condition ship operator will not be happy. Because of the limited time the quality of the work will be low and work will not be completed in time. This stage problem can be easily solved with good communication between ship yard and ship operator.

Third stage problem is related to the work order and work quality of the ship yard. Ship yards use sub constructors and ship yards work with combination of different sub constructors. The communication gap between these sub constructors affect the work quality as sometimes it can even cause rework. This problem can easily be handled by arranging small regular meetings between the sub constructors and ship yard for the planning work. And also these meetings can be more effective if classification society and supplier can join these meetings.

Summary:

In conclusion, although ship yard facilities are mostly for repair and maintenance, it has a new building capability as well. Most of the vessels are handy size vessels which are generally operating between Turkey and neighbouring countries. General cargo vessels, bulk carriers and tankers the general type of the vessels which are repaired in shipyard. The area which shipyard located is known as a shipyards area and there is a limited place for each shipyard. This affects the capability of shipyard. Even sometimes accidents can happen due to this problem. Ship yard is working with sub contractor companies. The number of sub constructor company is changing due to the demand. Shipyard is giving some spaces for sub constructor companies as well to put their devices and offices. The sub constructor companies are generally making steel work, painting and coating. For propulsion system and electrical systems shipyard contact with sub constructors which are based outside the shipyard but close to shipyard area. Nowadays due to the high demand in shipping industry, sub constructor companies should do the repair work in a short time. The shipyard and the operator make pressure on sub constructor company and this pressure affects the quality of work. In this point classification society`s role starts. Surveyors are making inspections and controls in special periods. During dry docking time surveyors also check the repair and maintenance procedure in all stages. As a result these inspections are aiming to increase the quality of work, and ship yard and the sub constructor company works more carefully during these inspections times compared to the other times.

This one month field study was very helpful for understanding practical under taking of the ship repair activity and the relations between repair yard, sub constructor company, ship operator and classification society as well as their management policies. Also most of the repair and maintenance data, which are used in data analysis and case studies, are collected during this visit. Repair and maintenance work were checked with surveyors and shipyard engineers. This experience gave author an opportunity to identify the areas that can be improved in ship repair activities and direction for the study.

CHAPTER 5 DATA ANALYSIS

During dry docking period the ship is unavailable for hire while the daily running cost for the ship still exists except oil consumption cost. On the other hand if not organised properly dry docking may take much longer than planned and may increase the ship`s unavailability. Therefore dry docking is an important issue for ship operations.

The dry docking time and replaced steel amount have a direct relationship with maintenance strategy. Ship operators have their own maintenance and repair strategies however operators are not sure if it is the optimum or best strategy or not. For better understanding of the effect of maintenance and repair strategy on dry docking time and maintenance of hull structure of the collected dry dock data are analyzed in this chapter.

In order to carry out the reliability analysis for hull structure, unavailability of ship and ship`s repair work data is extremely important. The reliability analysis is focused on hull structural reliability. Therefore steel replacement data during the dry docking period is collected from ship repair yard. Furthermore, as part of running cost calculations we need to calculate the repair and maintenance cost which requires following information:

- Amount and cost of steel replacement
- Coating and painting cost
- Ship`s unavailability

This chapter looks into the data collection and data analysis.

Data Collection

First step of data analysis is data collection. Because of the shipping company’s policy, it is not easy to collect data. Data collection and analysis of these collected data is not yet really an interesting item for shipping companies but they are interested in the results. The companies need to spend some money on it. Also may be the companies need to take extra engineer for it. Therefore the companies are not really paying attention to maintenance and repair work. Also the companies are not really sure about the exact benefits of these analyses.

Ship yard and ship operators have a lot of data (not really systematic), however even putting these data in to a useful format takes really long time and big effort. Furthermore unless data is collected and analysed systematically, benefits of such data is minimal.

For data analysis product tanker, chemical tanker, tanker, general cargo vessels, bulk carrier and ropax vessel repair data are collected and used. These data are collected from shipyard visits and ship operator visits. Data base consists of repair and unavailability data for 200 ships but not systematic as it is not available.

The data base contains the following data

- Ship type
- Built year
- Survey period
- Repair place
- Age

Survey period of the vessel also specified in the table, however most of the survey period could not be specified exactly. For this data dry dock is written for the survey period.

In this data base it is possible to see the repair data for vessels whose age's variant between one and forty. Most of the vessels are repaired or dry docked in European and Turkish shipyards.

Table5.1, which is prepared for nine tanker vessels, includes deadweight and lightweight of the vessel, unavailable time, survey period and repair date.

The lightweight data was not available for all the vessel and for those ships lightweight was estimated using deadweight-lightweight relationship.

During the ship repair data collection some difficulties are encountered by the author and these difficulties can be listed as; reasons for steel replacement are not available, detailed locations are not available, history of steel replacement for particular vessel is not available and in most of 200 steel replacement cases just one repair data per vessel is available.

##	Code	Ship type	Built	Survey period	Date	Total time (days)	DWT	LWT
1	A1	Pr. Tanker	1987	Annual	1990	24	45,222	10,670
2	A2	Pr. Tanker		Annual	1991	13		
3	A3	Pr. Tanker		1st Sp.	1992	42		
4	A4	Pr. Tanker		1st Int.	1995	25		
5	A5	Pr. Tanker		2nd Sp.	1997	37		
6	A6	Pr. Tanker		2nd Int.	2000	31		
7	A7	Pr. Tanker		3rd Sp.	2002	44		
8	A8	Pr. Tanker		3rd Int.	2005	51		
9	A9	Pr. Tanker		4th Sp.	2006	7		
10	B1	Tanker	1994	Annual	1997	18	101,605	16,327
11	B2	Tanker		1st Sp.	2000	17		
12	B3	Tanker		1st Int.	2002	25		
13	B4	Tanker		2nd Sp.	2004	21		
14	B5	Tanker		2nd Int.	2007	30		
15	C1	Tanker	1996	2nd Sp.	2006	20	96,168	15,629
16	D1	Tanker	2004	Annual	2006	16	166,739	23,650
17	E1	Tanker	2000	Annual	2005	14	103,368	19,346
18	E2	Tanker		1st Int.	2007	14		
19	F1	Tanker	1994	2nd Int.	2007	23	110,461	21,066
20	G1	Tanker	1995	Annual	1996	11	101,605	16,327
21	G2	Tanker		Annual	1998	16		
22	G3	Tanker		1st Sp.	2000	18		
23	G4	Tanker		1st Int.	2003	41		
24	G5	Tanker		Repair	2004	5		
25	G6	Tanker		Repair	2005	16		
26	G7	Tanker		2nd Sp	2005	20		
27	H1	Chemical Tanker	1974	Dry Dock		6	3,433	2875*
28	I1	Tanker	1993	Dry Dock		1	2,878	2245*

Table 5.1 Tanker vessel general information (* estimated using relation between DWT/Lightweight)

Table5.2 is particularly prepared for general cargo vessel and the repair data are obtained from 29 different vessels.

##	Code	Ship type	Built	Survey period	Date	Total time (days)	DWT	LWT
1	A1	General Cargo Ship	1981	Annual		11	4,251	3,155*
2	B1	General Cargo Ship	1983	Annual		53		
3	C1	General Cargo Ship	1981	Annual	1996	11		
4	D1	General Cargo Ship	1974	Annual		9		
6	E1	General Cargo Ship	1971	Annual		2	3,581	2928*
7	F1	General Cargo Ship	1985	Annual		4	7,160	3,957
8	G1	General Cargo Ship	1987	4th Sp.		16	3,250	2788*
9	H1	General Cargo Ship	1974	Annual		12	3,880	3074*
10	I1	General Cargo Ship	1983	4th Int.		12	3,432	2,874*
11	J1	General Cargo Ship	1973	Annual		20		
12	K1	General Cargo Ship	1980	5th Int.		4	3,739	2983*
13	L1	General Cargo Ship	1978	Annual		12	3,150	2769*
14	M1	General Cargo Ship	1969	7th Int.		3	1115	988*

15	N1	General Cargo Ship	1981	Annual		13	3,376	2,854*
17	O1	General Cargo Ship	1988	Annual		1	4,950	3,370*
18	P1	General Cargo Ship	1983	4th Int.		1	2011	1,546*
19	R1	General Cargo Ship	1983	4th Int.		26	3,298	2,732*
20	S1	General Cargo Ship	1981	Annual		7	3,376	2,854*
22	T1	General Cargo Ship	1995	2nd Int.		30	4,745	3,309*
23	U1	General Cargo Ship	1977	6th Sp.		33	1,882	1,432*
24	V1	General Cargo Ship	1981	Annual		3	1,487	1045*
25	W1	General Cargo Ship	1983	Annual		11	3,230	2,799*
26	X1	General Cargo Ship	1983	Annual		4	3,850	3,021*
27	Y1	General Cargo Ship	1981	Annual		25	3,935	3,050*
28	Z1	General Cargo Ship	1967	7th Sp.		7	1,087	785*
29	AA1	General Cargo Ship	1974	6th Int.		22		

Table 5.2 Data for general cargo vessel general information

Table5.3 is prepared for bulk carriers for which the repair and maintenance data was collected for different repair periods.

##	Code	Ship type	Built	Survey period	Date	Total time (days)	DWT	LWT
1	A1	B/C	1977	Annual	1990	25	37,386	7,478
2	A2	B/C		Annual	1991	9		
3	A3	B/C		3rd Sp.	1992	14		
4	A4	B/C		Annual	1993	9		
5	A5	B/C		Annual	1994	17		
6	A6	B/C		3rd Int.	1995	23		
7	A7	B/C		4th Sp.	1996	31		
8	A8	B/C		Annual	1997	23		
9	A9	B/C		Annual	1998	9		
10	A10	B/C		Annual	1999	27		
11	A11	B/C		4th Int.	2000	23		
12	A12	B/C		Annual	2001	16		
13	A13	B/C		Annual	2002	23		
14	A14	B/C		5th Sp.	2003	12		
15	A15	B/C		Annual	2004	26		
16	A16	B/C		5th Int	2005	7		
17	A17	B/C		Annual	2006	14		
18	A18	B/C		Annual	2006	18		
19	B1	B/C	1978	Annual	1990	9	37,386	7,478
20	B2	B/C		Annual	1991			
21	B3	B/C		3rd Sp.	1992	141		
22	B4	B/C		Annual	1993	9		
23	B5	B/C		Annual	1994	17		
24	B6	B/C		3rd Int.	1995	23		
25	B7	B/C		Annual	1996	19		
26	B8	B/C		4th Sp.	1997	23		
27	B9	B/C		Annual	1998	52		
28	B10	B/C		Annual	1999	9		
29	B11	B/C			2000	7		
30	B12	B/C		4th Int.	2000	24		
31	B13	B/C		Annual	2001	9		
32	B14	B/C		Annual	2002	23		
33	B15	B/C		5th Sp.	2003	30		
34	B16	B/C		Annual	2004	9		

35	B17	B/C		5th Int.	2005	22		
36	B18	B/C		Annual	2006	30		
37	C1	B/C	1978	Annual	1991	15	22,651	5,707
38	C2	B/C		Annual	1992	9		
39	C3	B/C		4th Sp.	1993	19		
40	C4	B/C		Annual	1994	9		
41	C5	B/C		3rd Int.	1995	20		
42	C6	B/C		Annual	1996	9		
43	C7	B/C		Annual	1997	14		
44	C8	B/C		4th Sp.	1998	45		
45	C9	B/C		Annual	1999	9		
46	C10	B/C		4th Int.	2000	23		
47	C11	B/C		Annual	2001	25		
48	C12	B/C		5th Sp.	2002	23		
49	C13	B/C		Annual	2003	23		
50	C14	B/C		Annual	2004	31		
51	C15	B/C		5th Int.	2005	23		
52	C16	B/C		Annual	2006	13		
53	D1	B/C	2000	1st Sp.	2005	14	28,072	5,951
54	E1	B/C	1990	3rd Sp.	2005	25	39,847	6,505
55	F1	B/C	2000	1st Sp.	2005		28,355	6,437
56	G1	B/C	2000	1st Sp.	2005		28,355	6,437
57	H1	B/C	2000	1st Sp.	2006		27,889	5,951

Table 5.3 General information bulk carrier

Analysis of ship repair database as well as interviews with shipyard and with some experts indicated that the biggest share of maintenance and repair cost is steel replacement cost. Some analysis indicated that steel replacement cost generally depends on the age and size of the vessel. As there is a direct relationship between the light weight and replaced steel amount, size of the ship is determined as a light weight (tonne) in order to estimate the replaced steel work (tonne). It is also practical to develop a model to calculate maintenance and repair cost based on a relationship between light weight and replaced steel.

Observation at shipyard shows that generally operators do not have sufficient knowledge about the light weight of the vessel. Therefore as a first step relationship between DWT and Light weight for different types of ships are determined by using the information available on the existing vessels.

DWT and lightweight data for the existing ships are collected and the relation between DWT and lightweight are established for general cargo vessel, ferry, ro-ro, bulker, tanker and chemical tanker. Due to the limited availability of data of lightweight it is not possible to calculate the exact lightweight of the vessel but it provides a fairly good idea about LWT-DWT relation.

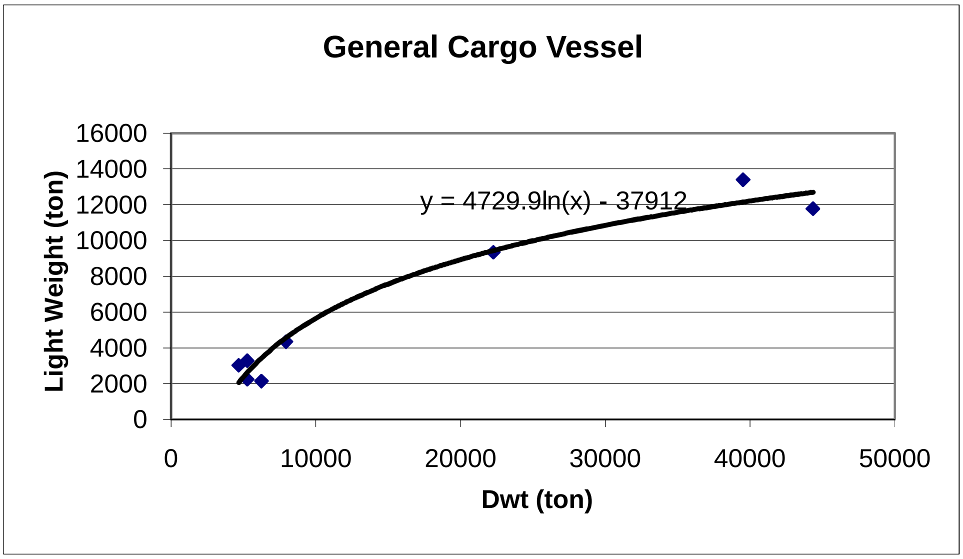

Figure5.1. For general cargo vessels relationship between light weight and deadweight

As it can be seen in Figure5.1, for general cargo vessel the relationship is established as

$LWT=4729.9ln\ (DWT)\ 37912$ (8)

Where

LWT is tonnes

DWT is tonnes

And formula is valid for DWT range between 6000 and 45000 tonnes.

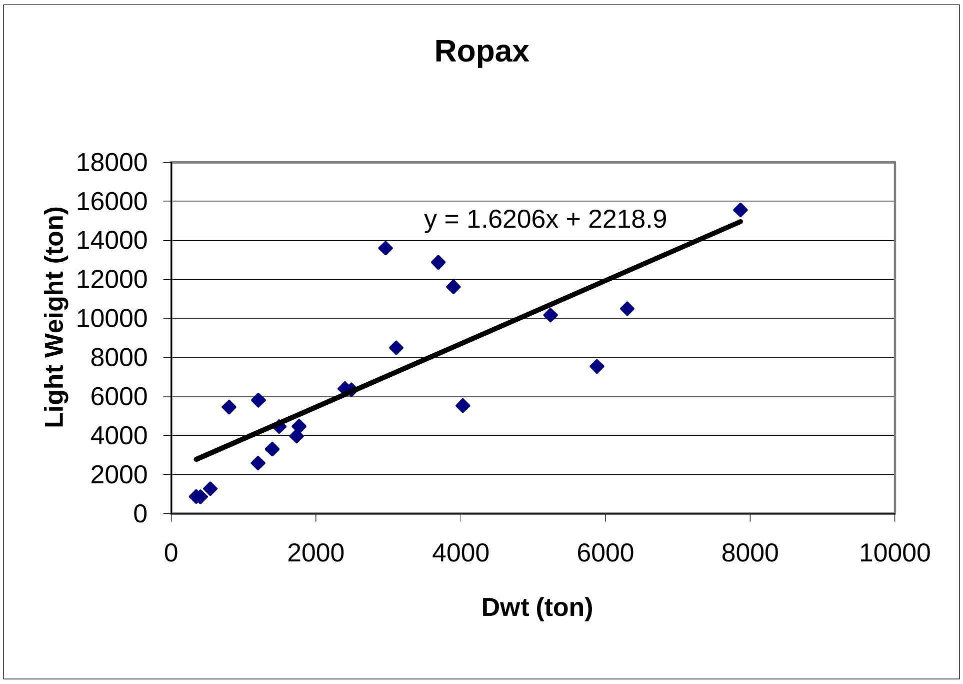

Figure5.2. For ropax relationship between light weight and deadweight

As it is in Figure5.2, for ropax vessel the relationship is established as

LWT=1.6206 DWT + 2218.9 (9)

And formula is valid for DWT range between 500 and 8000 tonnes.

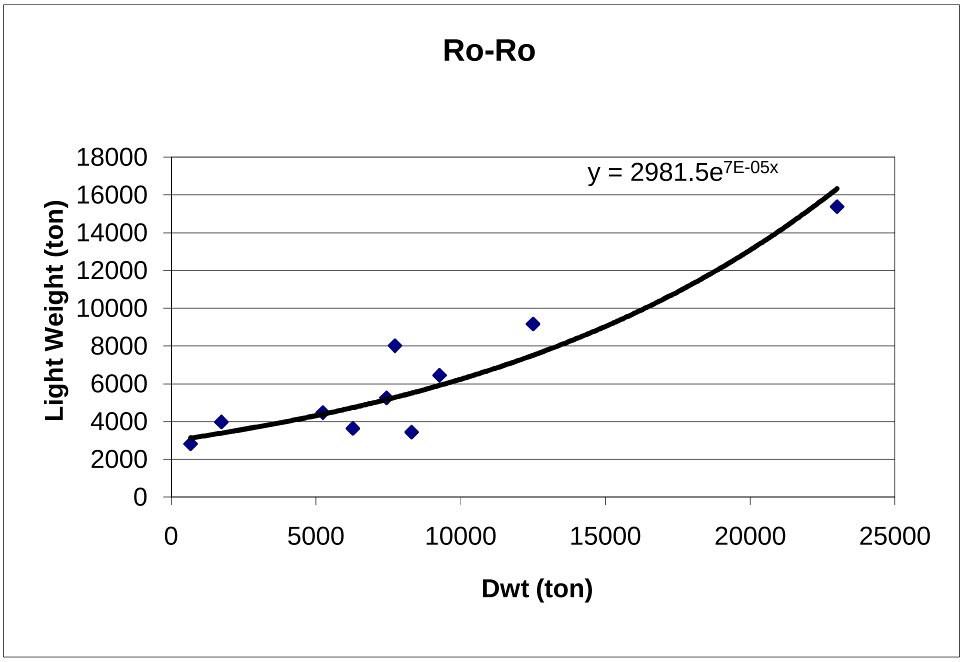

Figure5.3. For Ro-Ro vessels relationship between light weight and deadweight

As it can be seen in Figure5.3, for ro-ro vessel the relationship is established as

$$LWT=2981e^{7E\text{-}05DWT} \qquad (10)$$

And formula is valid for DWT range between 670 and 23000 tonnes.

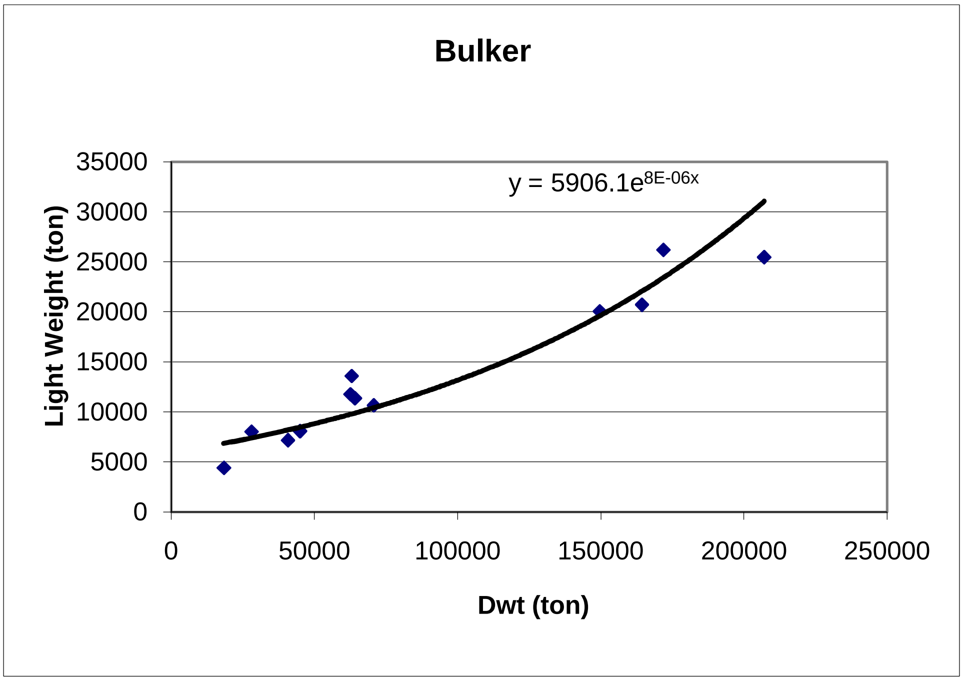

Figure5.4. For Bulker vessels relationship between light weight and deadweight

As it can be seen in Figure5.4, for bulker vessel the relationship is established as

$$LWT=5906e^{8E\text{-}06DWT} \qquad (11)$$

And formula is valid for DWT range between 4000 and 210000 tonnes.

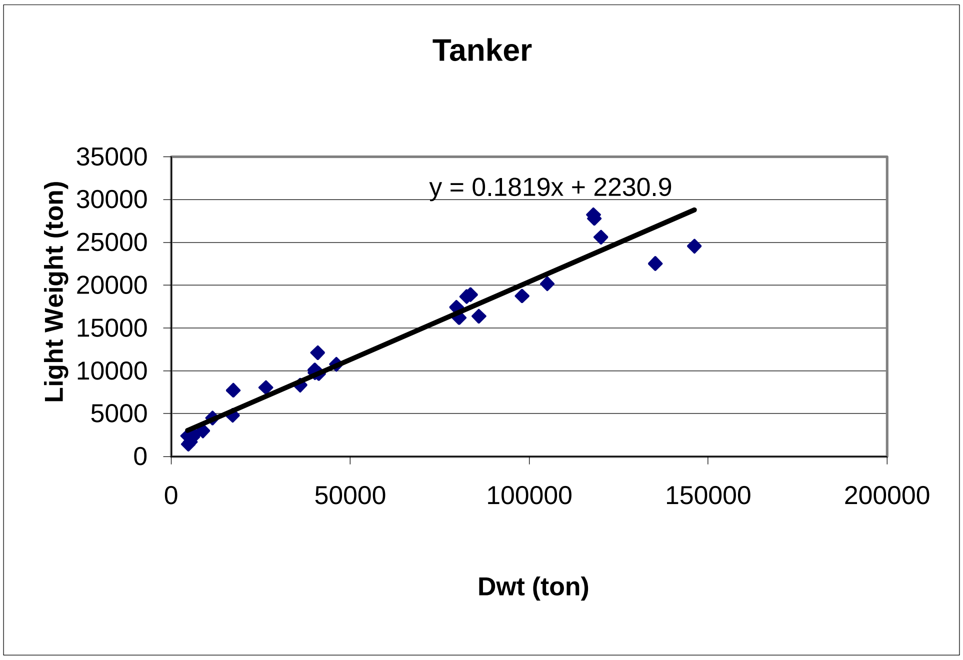

Figure5.5. For tanker relationship between light weight and deadweight

As it can be seen in Figure5.5, for tanker vessel the relationship is established as

$$LWT=0.1819\ DWT + 2230.9 \quad (12)$$

And formula is valid for DWT range between 4750 and 150000 tonnes.

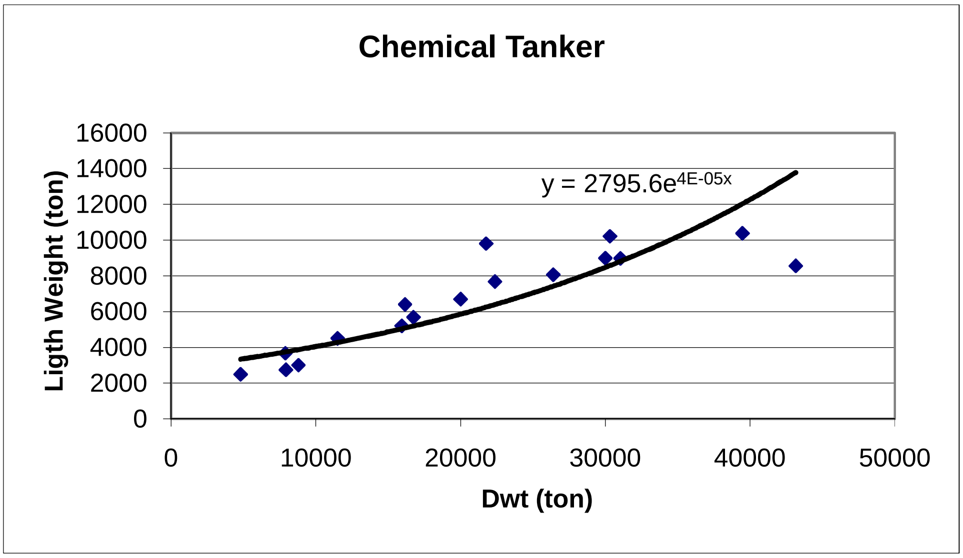

Figure5.6. For chemical tanker relationship between light weight and deadweight

As it can be seen in Figure5.6, for chemical tanker vessel the relationship is established as

$$LWT=2795e^{4E\text{-}05DWT} \qquad (13)$$

And formula is valid for DWT range between 4800 and 44000 tonnes.

Relation between replaced steel work & lightweight the data base supports that relation between the replaced steel and the ship may be established through the lightweight of the vessel as the steel replacement is calculated in term of weight and cost is mainly calculated using the cost per kg of steel replacement. However, the challenge is whether a healthy relationship can be established. This has to be studied in detail to establish the accurate relationship.

In order to test this relation the Figure5.7 is prepared using the database which is collected during one month field study in ship repair yard. Existing ship data are collected from the ship yard`s data base. Replaced steel amounts for 21 general cargo vessels during their periodic maintenance are used to prepare this figure. The location of these steel works is mostly cargo holds and side shell.

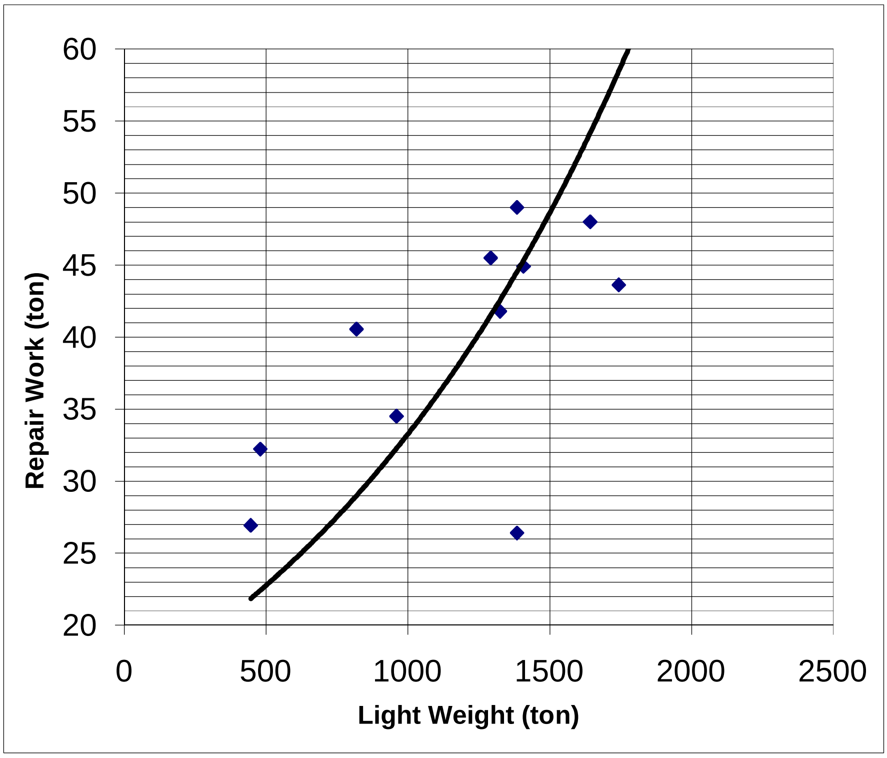

Figure5.7. General cargo vessels light weight repair work relationship

As Figure5.7 indicates for 500 ton light weight, steel repair work is changing between 25 ton and 35 ton. For 1000 ton light weight value steel replacement is changing between 30 ton and 45 ton. For 1500 ton light weight steel replacement is changing between 25 ton and 50 ton.

These results indicate that at each lightweight point replaced steel varies within a range. This clearly demonstrates that for the same lightweight different amount of steel replacement may take place. This could be due to various reasons which are age of the vessel and the quality of the maintenance strategy that company adapts.

5.1 Regression Analyses

Regression analyses are carried out for general cargo vessel, ropax, bulker and tanker vessels with regards to amount of steel repairs and unavailability times. For these analyses dry docking data which is obtained from shipping companies and shipyards are used. Two different approaches are adopted in order to predict the amount of steel replacement and unavailability times; approximation based on expert judgment and approximation under certain confidence level.

In expert oriented approximation, steel replacement obtained from steel repair data of different vessels is populated and then the tables are prepared. The population of unavailability is calculated according to vessel`s unavailability time data.

In the steel repair analysis, ARS represents the amount of steel replaced in one dry docking period and LWT represent light weight of the vessel. ARS/LWT gives the relationship of amount of replaced steel and light weight. ARS/LWT is related to the age of the vessels as shown in Figure5.8.

In addition to steel replacement data for each ship the main dimensions of the vessels are also collected from the ship operators. If the lightweight is obtained directly from database, it is used in the ARS/LWT value. If lightweight was not available then lightweight was obtained by using the relation between LWT and DWT as presented in Figure5.7 and estimated LWT was used, then ARS/LWT relation for that particular vessel was determined.

Considering the large spread of replaced steel weight for the same lightweight, the relation between lightweight and ARS/LWT is presented using the likely, high and low values relations and using the data three corresponding trends including the exponential regression formulas are developed. In this graphic high figure represents not well maintained vessel and low figure represents well maintained vessel.

In order to draw these curves standard deviation for ARS/LWT is calculated for each ship type. Likely figure includes all the ARS/LWT values, the high figure includes the values which are higher than standard deviation and the low figure includes the values which are lower than standard deviation.

In order to show the relationship between age and unavailability of vessels, same method is implemented on the unavailability data. Based on the dry docking period unavailability days of each vessel are calculated. The unavailability time calculation includes the waiting time in the shipyard due to limited cradle and waiting time for the arrivals material/equipment, and these data are presented with in respect to age.

In the confidence level oriented approximation, the regression model generates an exponential line for predicted steel replacement amount based on years. As an example; it is predicted that age 15 would produce 20 tonnes steel replacement for a lightweight of 10.000 tonnes. This number is not exact number determined but it is fairly close. Determination of range for actual steel replacement figure is performed in the same way as forming interval estimates. The predicted value is assumed as an average value.

There is a large difference between the replaced steel amount for the same light weight and same type of ships. According to expert view the age of the ship is important parameter for the steel work and also the classification society is the other important parameter. Due to the management policy of classification societies the inspection quality is changing. Some of the classification societies are very strict with the rules however some of them are not. Therefore depends on different classification society’s inspections. The required steel replacement amount for same vessel can be different.

In the following section regression analysis and deviation of trend lines are given for each ship type.

Ropax Vessel

The effect of the age on replaced steel work is determined for ropax vessels whose age varies between (Figure5.8) 10 and 40 years. Ratio between repair steel work and lightweight is varying between 0 and $25*10^{-3}$. For the numbers that close to zero the repair works are small works like replacing stairs, replacing covers and small brackets. Although this steel work takes time as the other steel works but not too much steel is used for this type of work so the weight is very low. Shipyards are calculating these repair works based on hourly rate rather than based on weight. Such repairs take place during normal docking period.

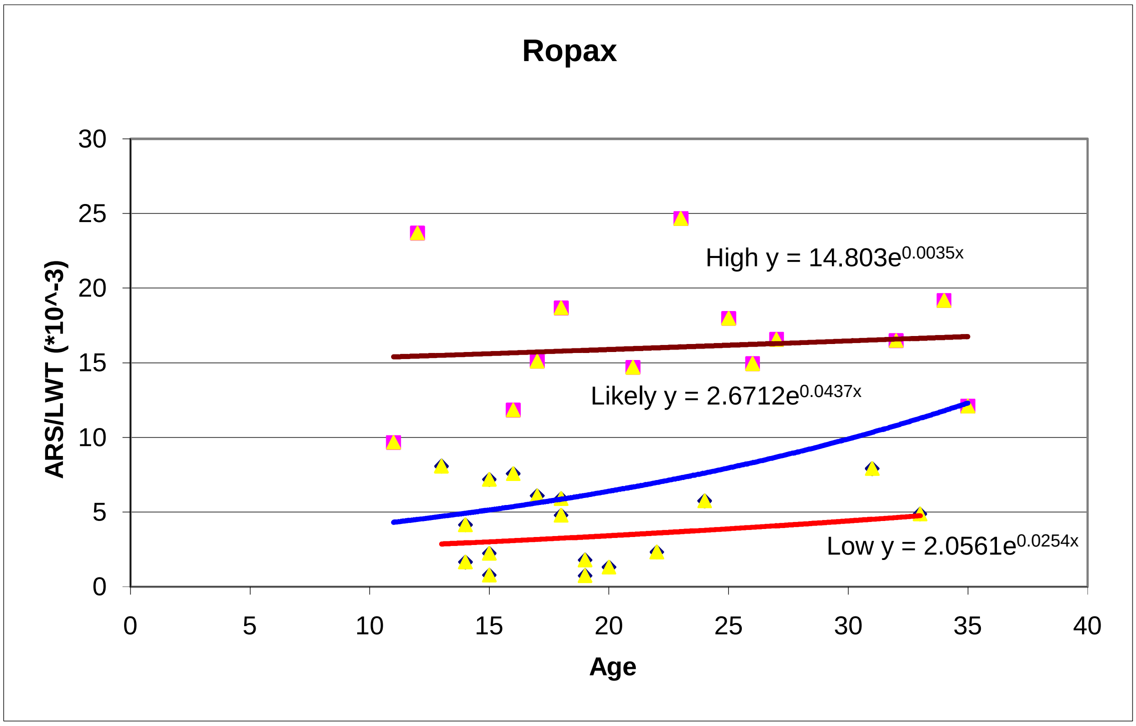

Figure5.8 Regressions for ropax vessel with respect to “steel replacement/lightweight vs. age”

General Cargo Vessel

Using the same approach as Ropax vessels, regression analysis is carried out and trends are established for the general cargo vessels. The data base for general cargo vessel contains ships whose deadweight varies between 2000 tonnes & 8000 tonnes. For these vessel lightweight varies between 500 tonnes & 2000 tonnes. For general cargo vessels average unavailability value is 14.4 days.

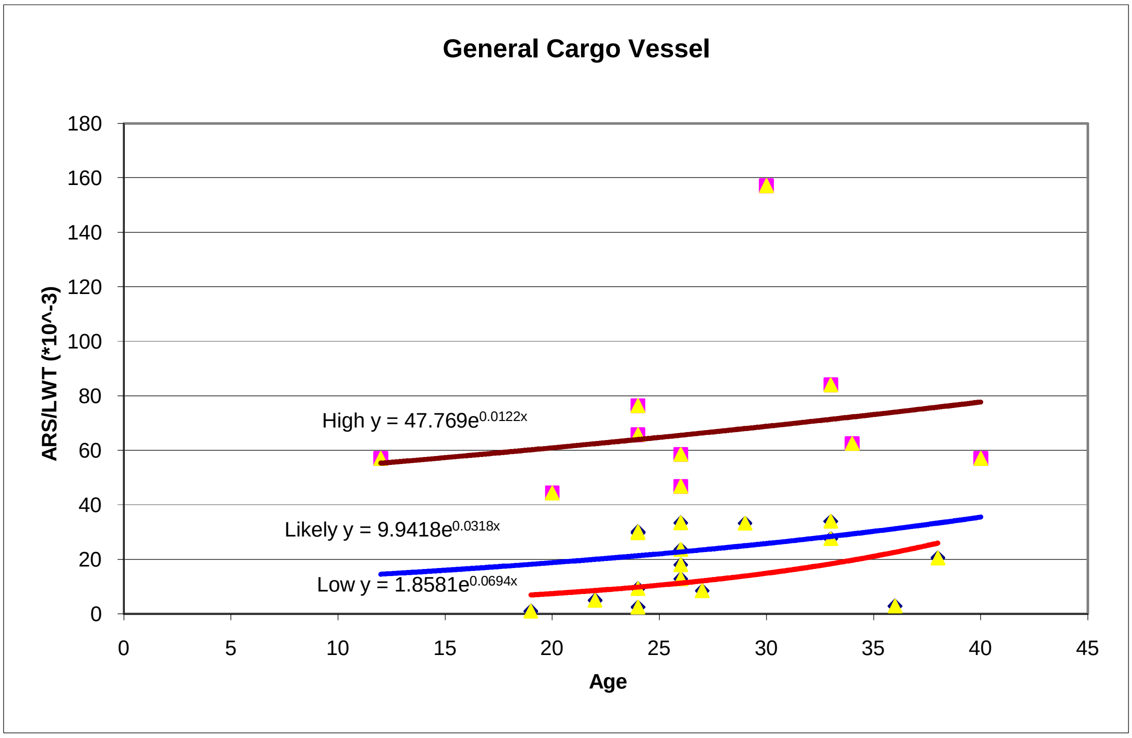

Figure5.9 Regressions for general cargo vessel with respect to "steel replacement/lightweight vs. age"

The regulated steel replacement (ARS/LWT) work varies between 0 and $90*10^{-3}$. There is a ratio of $160*10^{-3}$ which is an exceptional value for small size general cargo vessels. When the detail of steel replacement was examined the reason was found out to be the accident. When steel replacement trend for cargo vessels is compared to ropax vessels, cargo vessels have almost 4 times more steel replacement.

Other important parameter for repair and maintenance cost is unavailability of the ship. Unavailability may not have a direct effect on maintenance and repair cost but it has a direct effect on the running cost and income. Because of the repair and maintenance activity ship is unavailable for the operation (for hire).

During the maintenance and repair period, the ship is out of operation so operators are paying for repair works and running costs but they are not earning any income from the ship during this period. Daily running cost such as crew wages are the other large amount to be paid by operators during this period. Therefore unavailability time is very important for ship operators.

Using the data for dry docking times, the relationship between age and unavailability for general cargo vessel is established and presented in Figure5.10.

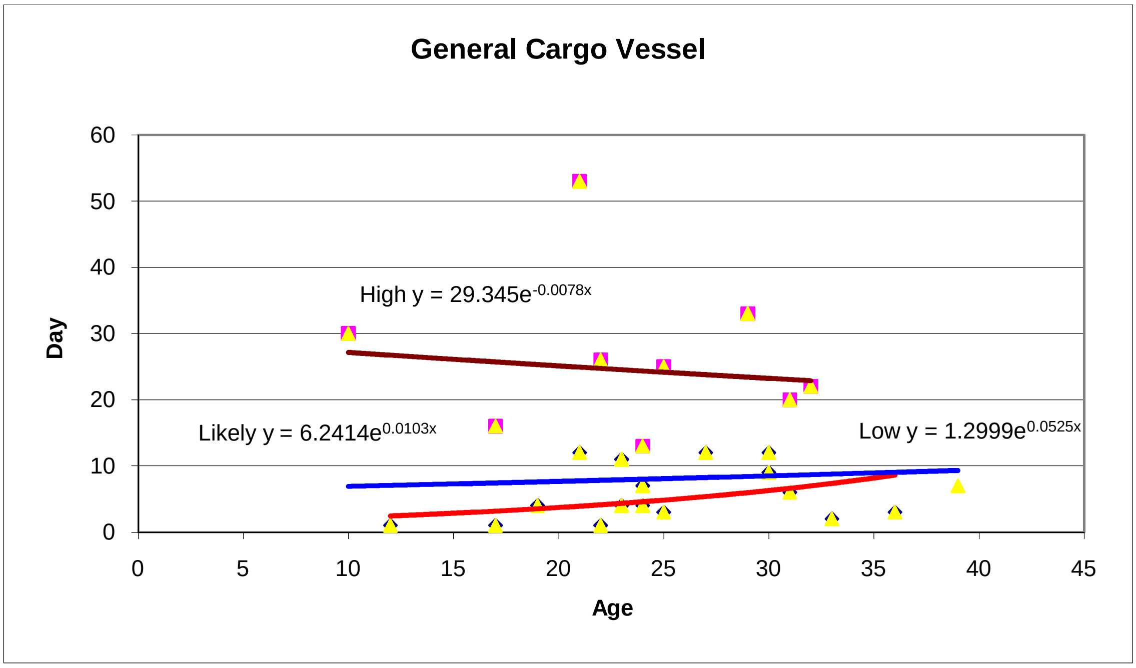

Figure5.10 Regressions for general cargo vessel with respect to “unavailability vs. age”

According to Figure5.10 unavailability of the general cargo vessel is increasing by the age. Minimum unavailability value is under 10 days and maximum unavailability value is more than 50 days. More than 50 days unavailability time is very high time therefore there can be a special circumstance for this value such as an accident. (Because of the limited data the reason for this value cannot be known accurately)

<u>Bulk Carrier</u>

Similar to other ships unavailability of bulk carrier is increasing with the age of the ship but rate of increase is different. Minimum unavailability value is under 10 days and maximum unavailability value is more than 50 days while average unavailability value is 20.14 days.

There are a few repair data available for less than 10 years and the majority between 10 to 30 years. This confirms with shipyard is experience that first 10 years ships do not require steel repair as good coating and steel corrosion margins are determined for around 10 years.

According to Figure5.11 for bulk carrier graphic, ARS/LWT (*10^-3) most of the values are very close for vessels. Therefore it is possible to say that the ship operators have similar approaches. For bulk carrier steel replacement analysis due to the huge difference between the data, only the close data which are collected from same shipyard are used for calculations.

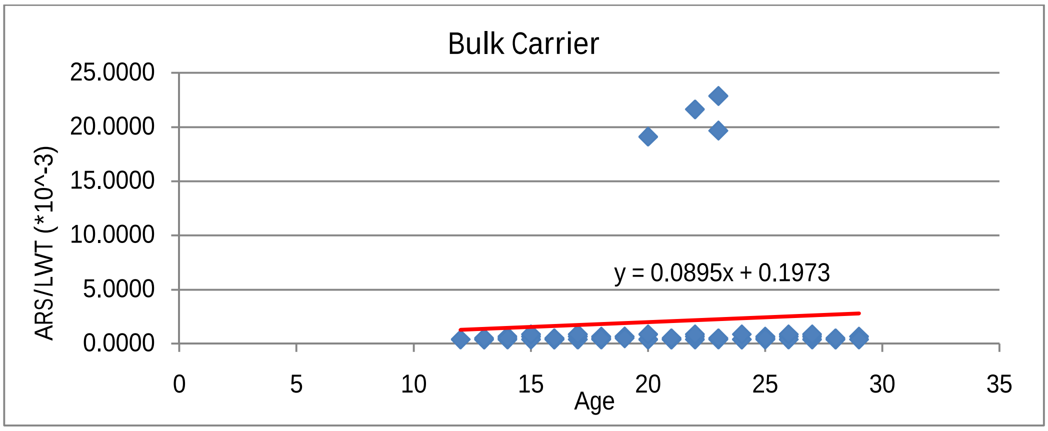

Figure5.11 Regressions for bulk carriers with respect to “steel replacement/lightweight vs. age”

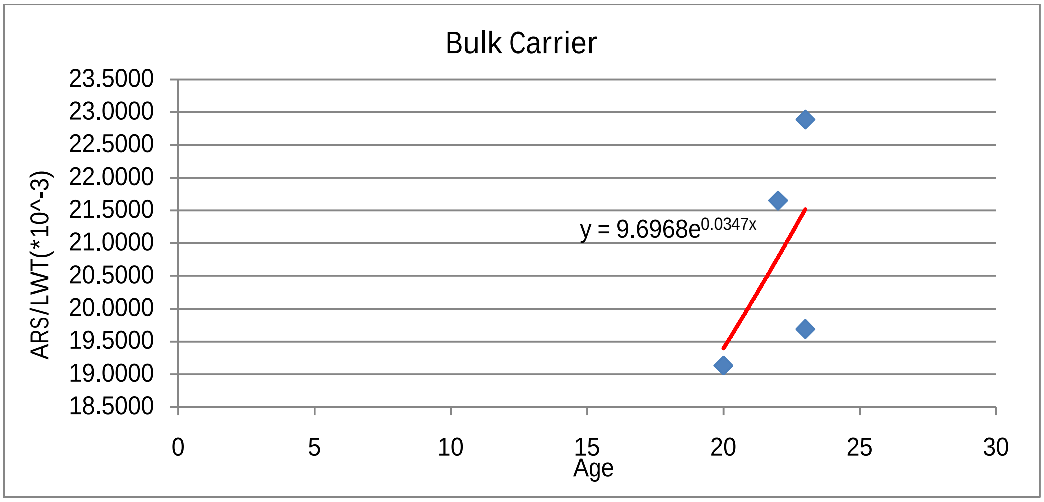

Figure5.12 Regressions for bulk carriers with respect to “steel replacement/lightweight vs. age”

Figure 5.11 is prepared by including all steel replacement data for bulk carrier, Figure 5.12 is prepared by including only high steel replacement data. There are two different data from two different bulk carrier operators and due to the high difference between the data, it is not possible to make efficient calculation by using all data together therefore the rest of the calculation carried out based one ship operator's data which is presented in Figure 5.13.

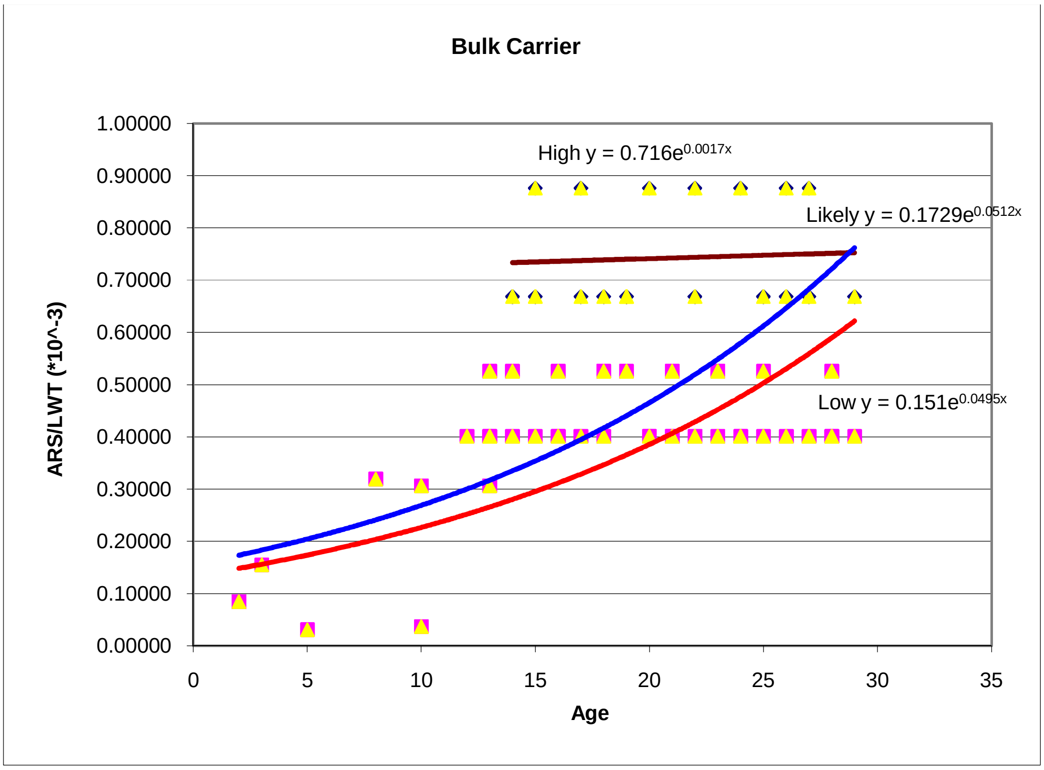

Figure5.13 Regressions for bulk carriers with respect to "steel replacement/lightweight vs. age"

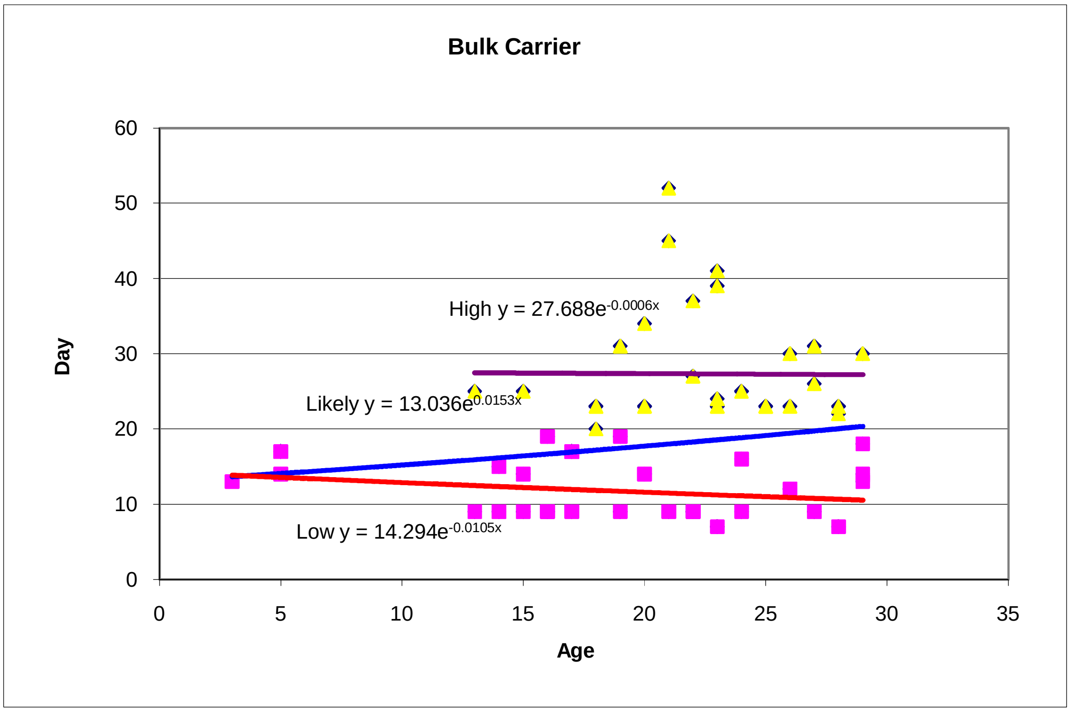

Figure 5.14 Regressions for bulk carriers with respect to “unavailability vs. age”

As Figure 5.14 clearly indicates unavailability depends on the maintenance strategy.

<u>Tanker</u>

Regression analyses are performed for steel repairs and unavailability times and for these analyses dry docking data are used. Two approaches are used in order to predict the amount of steel replacement and unavailability times; approximation based on expert judgment and approximation using confidence level.

In expert oriented approximation, of the steel replacement is calculated using the repair data of 22 different tanker vessels as provided in Table 5.4. The population of unavailability is calculated using 41 tanker vessel data and average unavailability value is found to be 38 days.

##	Ship type	Survey period	Age	LWT	Steel repair (kgs)	ARS/LWT (*10^-3)
1	Tanker	2nd Sp.	10	16,327	5,000	0.3062
2	Tanker	2nd Int.	13	16,327	5,000	0.3062
3	Tanker	Annual	2	23,650	2,000	0.0846
4	Tanker	1st Int.	3	19,346	3,000	0.1551
5	Tanker	1st Sp.	5	16,327	500	0.0306
6	Tanker	1st Int.	8	16,327	5,210	0.3191
7	Tanker	2nd Sp	10	16,327	600	0.0367
8	Tanker	4th Int.	23	13,939	145,000	10.4023
9	Tanker	4th Int.	22	14,251	381,000	26.7350
10	Tanker	4th Int.	23	14,118	135,000	9.5622
11	Tanker	4th Int.	22	13,889	400,000	28.7993
12	Tanker	4th Int.	23	13,850	202,000	14.5846
13	Pr. Tanker	3rd Sp	15	11,569	50,000	4.3219
14	Pr. Tanker	3rd Sp	15	11,569	50,000	4.3219
15	Pr. Tanker	3rd Sp	15	11,580	30,000	2.5907
16	Pr. Tanker	3rd Sp	15	11,600	40,000	3.4483
17	Tanker	3rd Sp	15	22,786	900,000	39.4979
18	Tanker	3rd Sp	15	22,786	300,000	13.1660
19	Tanker	3rd Sp	15	22,786	2,000,000	87.7732
20	Tanker	3rd Sp	14	22,786	600,000	26.3320
21	Ch. Tanker	Drydock	31	2,875	20,670	0.1391
22	Tanker	Drydock	12	923	259	3.5641

Table 5.4 22 points used in the population of steel replacement (for expert oriented approximation)

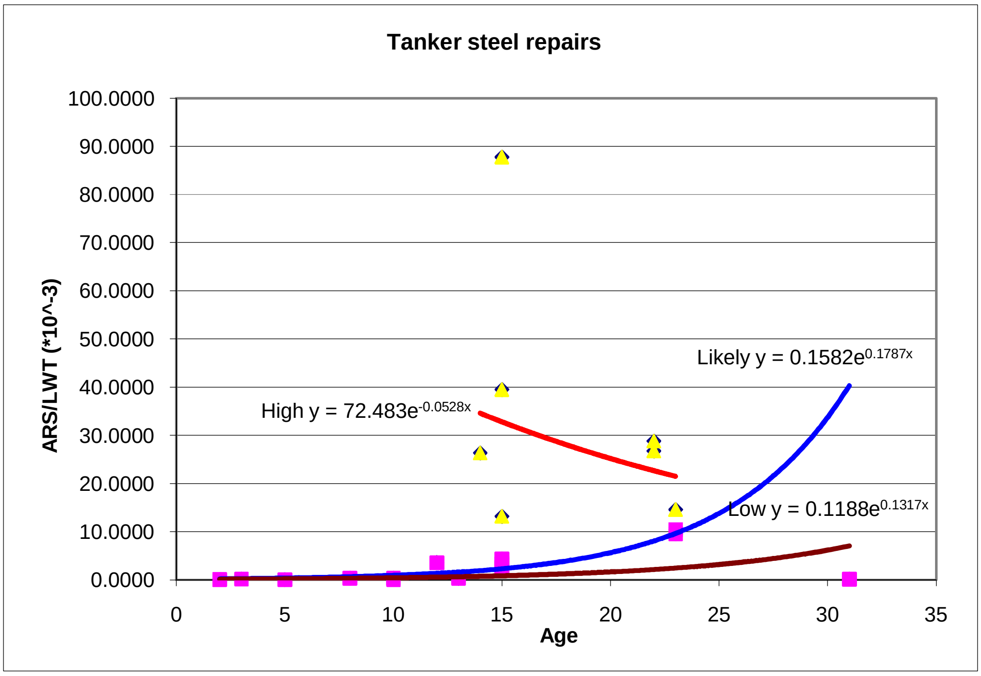

Figure 5.15 Regressions for Tankers with respect to “steel replacement/lightweight vs. age” (for expert oriented approximation)

##	Ship type	Survey period	Age	Unavailability time (days)
1	Pr. Tanker	Annual	3	24
2	Pr. Tanker	Annual	4	13
3	Pr. Tanker	1st Sp.	5	42
4	Pr. Tanker	1st Int.	8	25
5	Pr. Tanker	2nd Sp.	10	37
6	Pr. Tanker	2nd Int.	13	31
7	Pr. Tanker	3rd Sp.	15	44
8	Pr. Tanker	3rd Int.	18	51
9	Pr. Tanker	4th Sp.	19	7
10	Tanker	Annual	3	18
11	Tanker	1st Sp.	6	17
12	Tanker	1st Int.	8	25
13	Tanker	2nd Sp.	10	21
14	Tanker	2nd Int.	13	30
15	Tanker	2nd Sp.	10	20
16	Tanker	Annual	2	16
17	Tanker	Annual	1	14
18	Tanker	1st Int.	3	14
19	Tanker	2nd Int.	3	23
20	Tanker	Annual	1	11
21	Tanker	Annual	3	16
22	Tanker	1st Sp.	5	18
23	Tanker	1st Int.	8	41
24	Tanker	Repair	9	5
25	Tanker	Repair	10	16
26	Tanker	2nd Sp	10	20
27	Tanker	4th Int.	23	34
28	Tanker	4th Int.	22	50
29	Tanker	4th Int.	23	33
30	Tanker	4th Int.	22	67
31	Tanker	4th Int.	23	43
32	Pr. Tanker	3rd Sp	15	37
33	Pr. Tanker	3rd Sp	15	43
34	Pr. Tanker	3rd Sp	15	52
35	Pr. Tanker	3rd Sp	15	41
36	Tanker	3rd Sp	15	180
37	Tanker	3rd Sp	15	68
38	Tanker	3rd Sp	15	149
39	Tanker	3rd Sp	14	167
40	Ch. Tanker	Drydock	31	6
41	Tanker	Drydock	12	1

Table 5.5 41 points used in the population of unavailability (for expert oriented approximation)

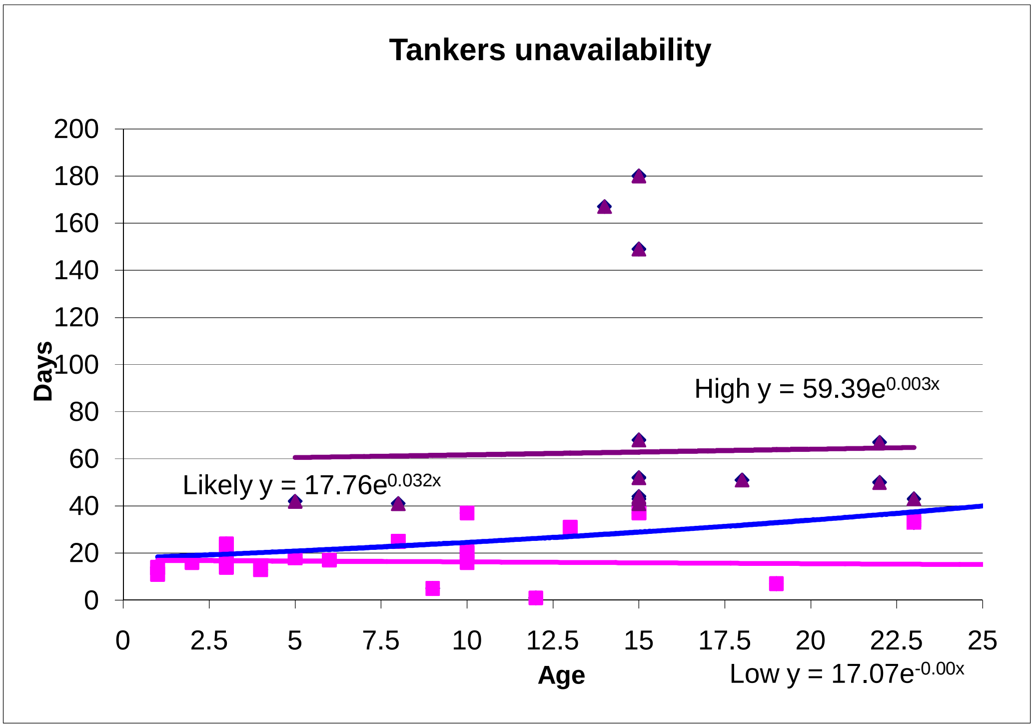

Figure 5.16 Regressions for Tankers with respect to "unavailability vs. age" (for expert oriented approximation)

According to Figure5.16 unavailability of the tanker is increasing by the age. Minimum unavailability value is under 10 days and maximum unavailability value is more than 180 days. This maximum unavailability value can be due to special circumstances like rebuilding the tanker due to the new rules such as changing the hull form from single skin to double skin.

Normally ship does not need major steel renewals until the age of 10. However there is some unavailability data for ships less than 10 years of age and even less than 5 years of age. However, steel replacement for less than 10 years vessel is scarce. If the ship operator applies preventive maintenance, these unavailability data are normal. However ship operator who has a small fleet or just one ship does not apply preventive maintenance. These ship operators prefer to apply corrective maintenance. According to the experts, these ships should not need any dry docking if they are under 5 years of age. This may happen due to poor quality design and production as well as machinery, propeller and shaft failure.

The average tanker unavailability is varying between 10 and 40 days.

The regression model using the confidence level oriented approximation gives an exponential line of specific predicted steel replacement amount based on years.

##	x	y	y' = mean	(y-y')	(y-y')2	y'+ CI	y'-CI
1	10	0.3062	0.489	-0.18	0.033	9.361	0.000
2	13	0.3062	1.124	-0.82	0.668	9.995	0.000
3	2	0.0846	0.053	0.03	0.001	0.000	0.000
4	3	0.1551	0.070	0.08	0.007	0.000	0.000
5	5	0.0306	0.122	-0.09	0.008	0.000	0.000
6	8	0.3191	0.281	0.04	0.001	9.153	0.000
7	10	0.0367	0.489	-0.45	0.205	9.361	0.000
8	23	10.4023	17.961	-7.56	57.129	26.832	9.089
9	23	9.5622	17.961	-8.40	70.534	26.832	9.089
10	23	14.5846	17.961	-3.38	11.398	26.832	9.089
11	15	4.3219	1.956	2.37	5.598	10.828	0.000
12	15	4.3219	1.956	2.37	5.598	10.828	0.000
13	15	2.5907	1.956	0.63	0.403	10.828	0.000
14	15	3.4483	1.956	1.49	2.227	10.828	0.000
15	12	3.5641	0.852	2.71	7.358	9.723	0.000
16	15	13.1660	1.956	11.21	125.667	10.828	0.000
		sum	67.14	0.06	286.84		
		average	4.196	0.004	17.93		
		st error	4.53				
	95% C.I.	8.872					

Table 5.6 16 points used in the population of steel replacement (for confidence level oriented approximation)

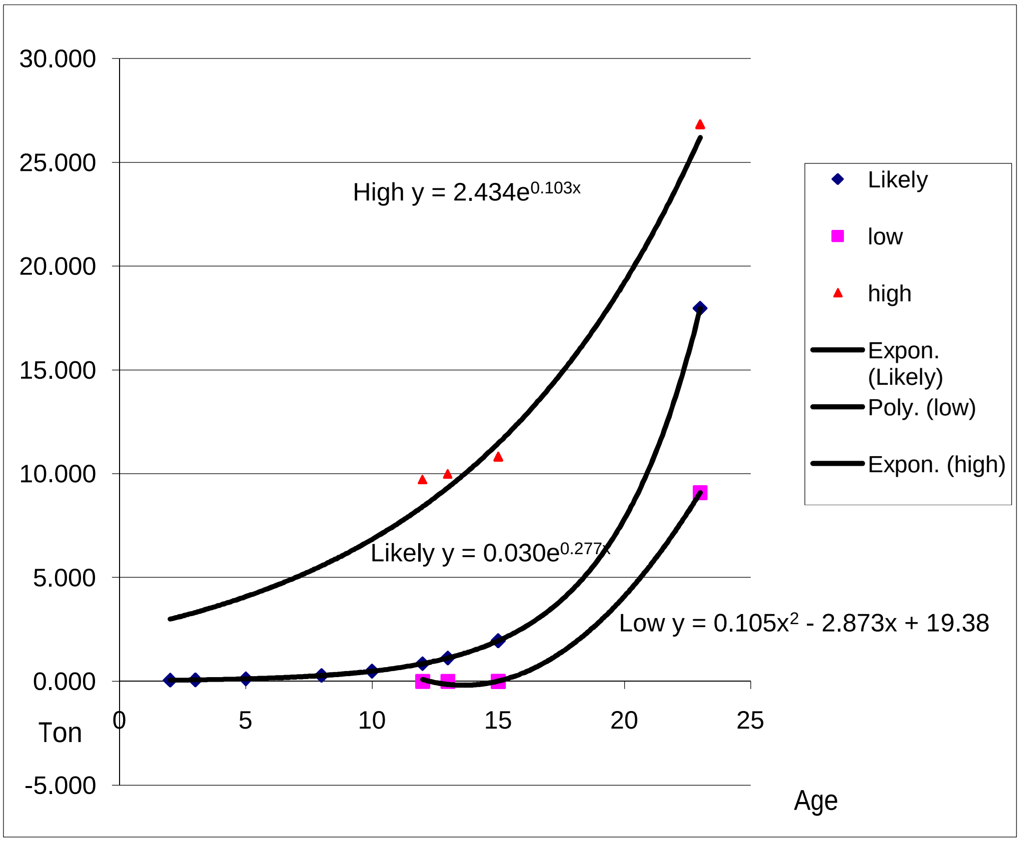

Figure 5.17 Regressions for Tankers with respect to "steel replacement vs. age" (for confidence level oriented approximation)

According to Figure5.17, amount of steel replacement increases with the increasing age. For low replaced steel amount, the increase starts from at the age of 15. Likely amount of steel replacement starts from the age of 10 and high amount of steel replacement it starts from at the age of 5.

##	Age	Unavailability time (days)	y'	y-y'	(y-y')2	y'+ CI	y'-CI
1	3	24	18.88	5.12	26.22	37.29	0.47
2	4	13	20.38	-7.38	54.45	38.79	1.97
3	5	42	21.88	20.12	404.87	40.29	3.47
4	8	25	26.38	-1.38	1.89	44.79	7.97
5	10	37	29.38	7.63	58.14	47.79	10.96
6	13	31	33.87	-2.87	8.25	52.28	15.46
7	15	44	36.87	7.13	50.82	55.28	18.46
8	18	51	41.37	9.63	92.75	59.78	22.96
9	3	18	18.88	-0.88	0.77	37.29	0.47
10	6	17	23.38	-6.38	40.68	41.79	4.97
11	8	25	26.38	-1.38	1.89	44.79	7.97
12	10	21	29.38	-8.38	70.14	47.79	10.96
13	13	30	33.87	-3.87	15.00	52.28	15.46
14	10	20	29.38	-9.38	87.89	47.79	10.96
15	2	16	17.38	-1.38	1.91	35.79	-1.03
16	1	14	15.88	-1.88	3.54	34.29	-2.53
17	3	14	18.88	-4.88	23.81	37.29	0.47
18	3	23	18.88	4.12	16.98	37.29	0.47
19	3	16	18.88	-2.88	8.29	37.29	0.47
20	5	18	21.88	-3.88	15.04	40.29	3.47
21	8	41	26.38	14.62	213.85	44.79	7.97
22	10	16	29.38	-13.38	178.89	47.79	10.96
23	10	20	29.38	-9.38	87.89	47.79	10.96
24	23	34	48.87	-14.87	220.99	67.28	30.46
25	22	50	47.37	2.63	6.93	65.78	28.96
26	23	33	48.87	-15.87	251.73	67.28	30.46
27	22	67	47.37	19.63	385.47	65.78	28.96
28	23	43	48.87	-5.87	34.41	67.28	30.46
29	15	37	36.87	0.13	0.02	55.28	18.46
30	15	43	36.87	6.13	37.56	55.28	18.46
31	15	52	36.87	15.13	228.87	55.28	18.46
32	15	41	36.87	4.13	17.04	55.28	18.46
	sum				2,647.00		
	Average	31	30.50	0.001			
		st error	9.39				
	95% C.I.	18.411					

Table 5.7 32 points used in the population of unavailability (for confidence level oriented approximation)

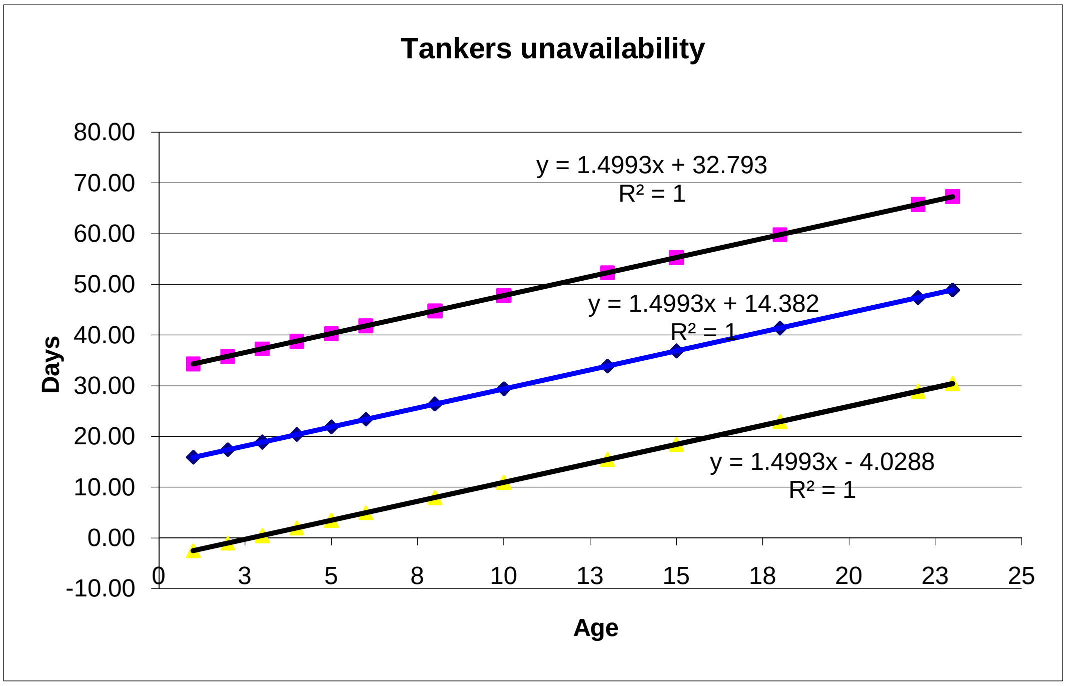

Figure 5.18 Regressions for Tankers with respect to "unavailability vs. age" (for confidence level oriented approximation)

According to unavailability for different ship types, tanker vessel has the biggest unavailability problem due to the maintenance and repair (Figure5.18). The unavailability value is increasing more by the age compared to the bulk carriers and general cargo vessels.

The steel replacement values given in Figure5.19, Figure5.20 and Figure5.21 for different ship types show that tanker and general cargo vessel have the most steel replacement work. Steel replacement for tanker vessel is increases by the age faster than the other ship types. Well known corrosion problem with tanker vessel can be referred to as the most reason.

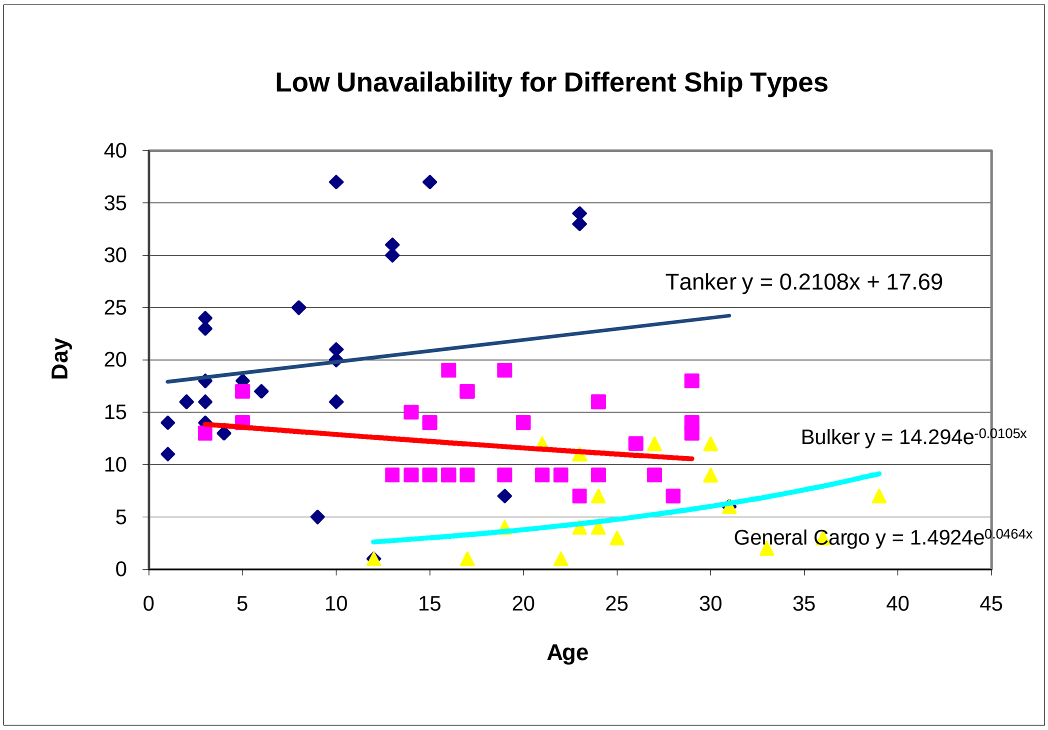

Figure 5.19 Regressions for different ship types with respect to “low unavailability vs. age”

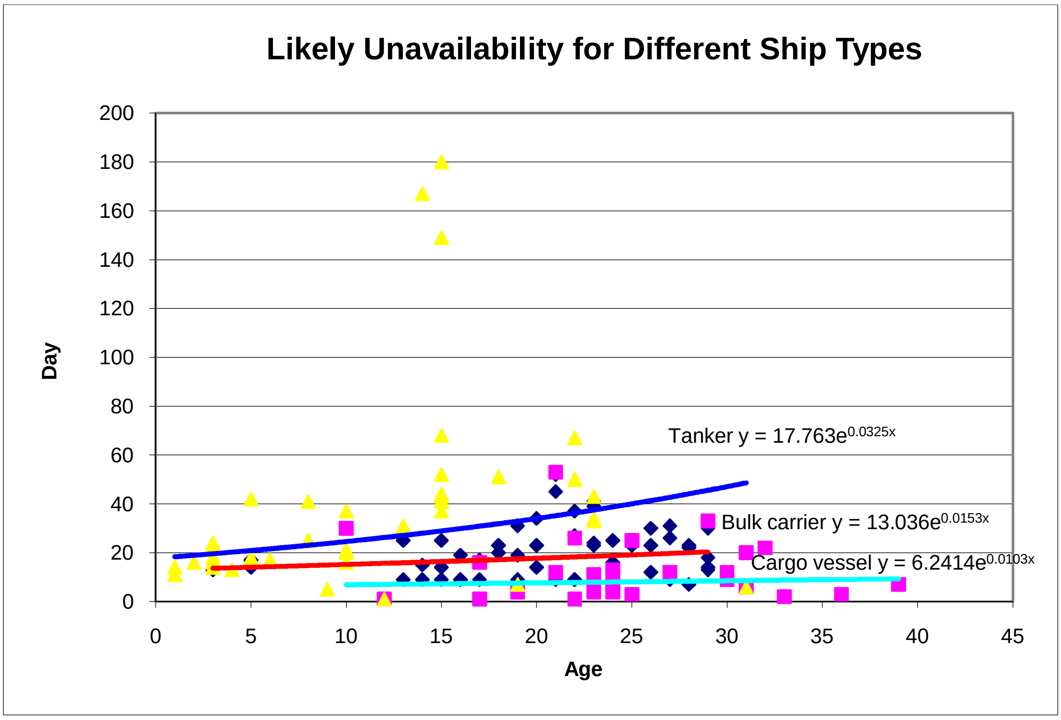

Figure 5.20 Regressions for different ship types with respect to “likely unavailability vs. age”

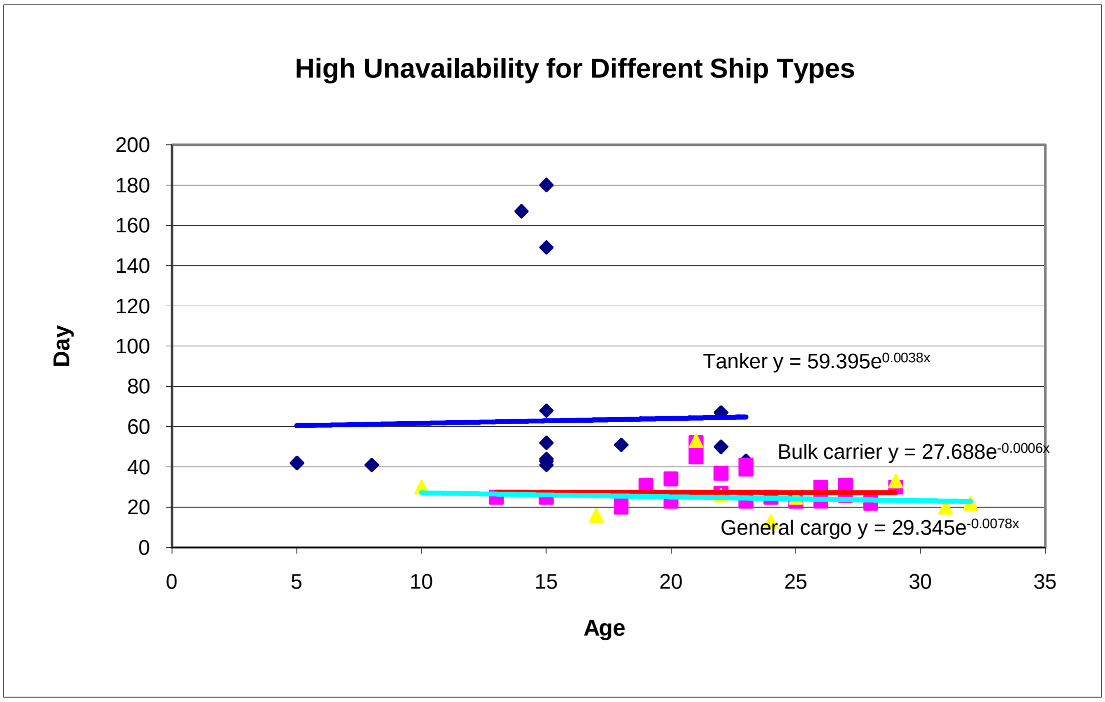

Figure 5.21 Regressions for different ship types with respect to "high unavailability vs. age"

According to unavailability trends for different ship types graphic tanker vessel has the highest unavailability time in dry dock. The reason for high unavailability data can be because of the high steel replacement amount. This is mainly caused by corrosion. Repair and maintenance activity for tanker requires cargo areas needs to be cleaned carefully at first instance, therefore this cleaning activity also cause some delay in dry dock. Bulk carriers have the second highest unavailability rate due to the type of cargo.

<u>Unavailability & Steel Replacement Prediction</u>

Based on the established relationships for various vessels, the unavailability for different ship types can be estimated using the following equations.

Tanker;

Tanker Low Unavailability (Day)	$= 0.2108\ Age + 17.69$	(14)
Tanker Likely Unavailability (Day)	$= 17.763e^{0.0325*Age}$	(15)
Tanker High Unavailability (Day)	$= 59.395e^{-0.0038*Age}$	(16)

Bulk Carrier;

Bulk Carrier Low Unavailability (Day)	$= 14.294e^{-0.0105*Age}$	(17)
Bulk Carrier Likely Unavailability (Day)	$= 13.036e^{0.0153*Age}$	(18)
Bulk Carrier High Unavailability (Day)	$= 27.688e^{-0.0006*Age}$	(19)

General Cargo Vessel;

General Cargo Low Vessel (Day)	$= 1.4924e^{-0.0464*Age}$	(20)
General Cargo Likely Vessel (Day)	$= 6.2414e^{0.0103*Age}$	(21)
General Cargo High Vessel (Day)	$= 29.345e^{-0.0078*Age}$	(22)

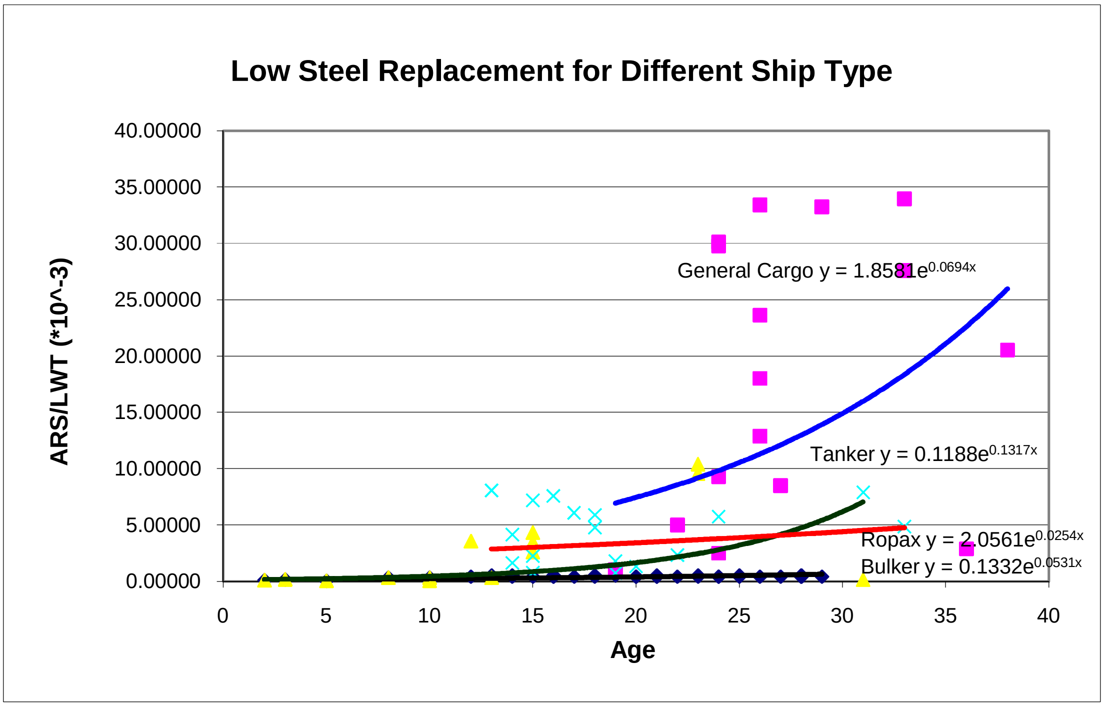

Figure 5.22 Regressions for different ship types with respect to “low steel replacement vs. Age”

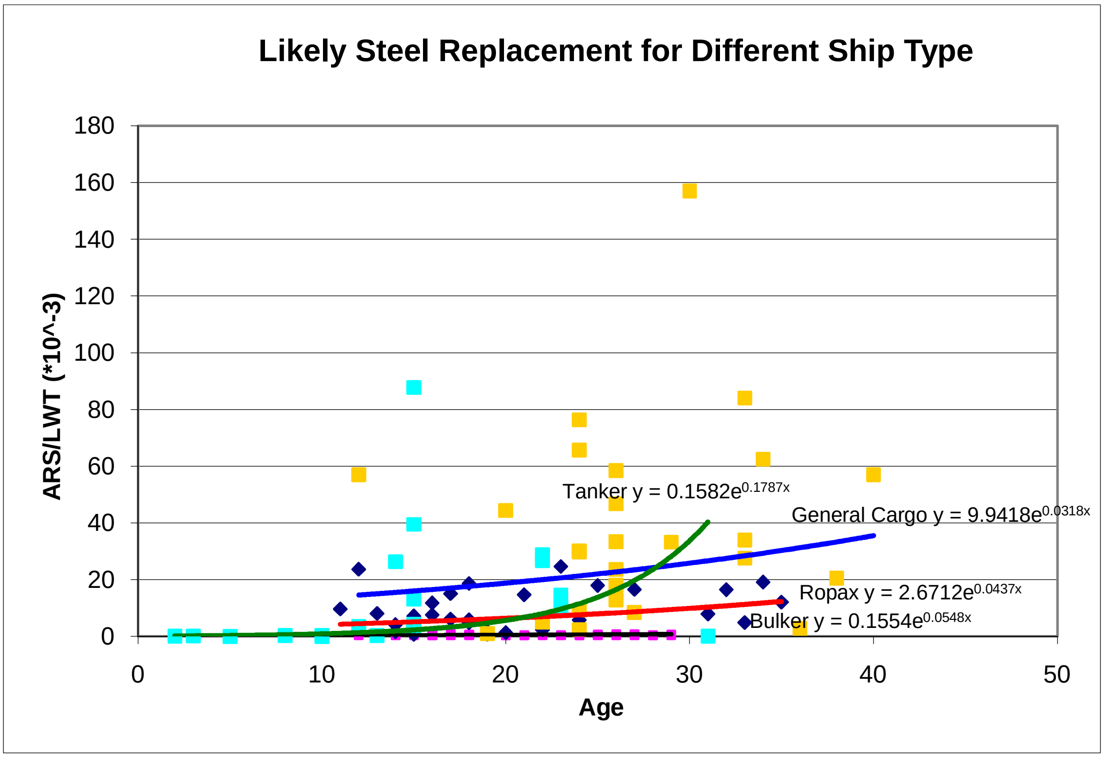

Figure 5.23 Regressions for different ship types with respect to "likely steel replacement vs. Age"

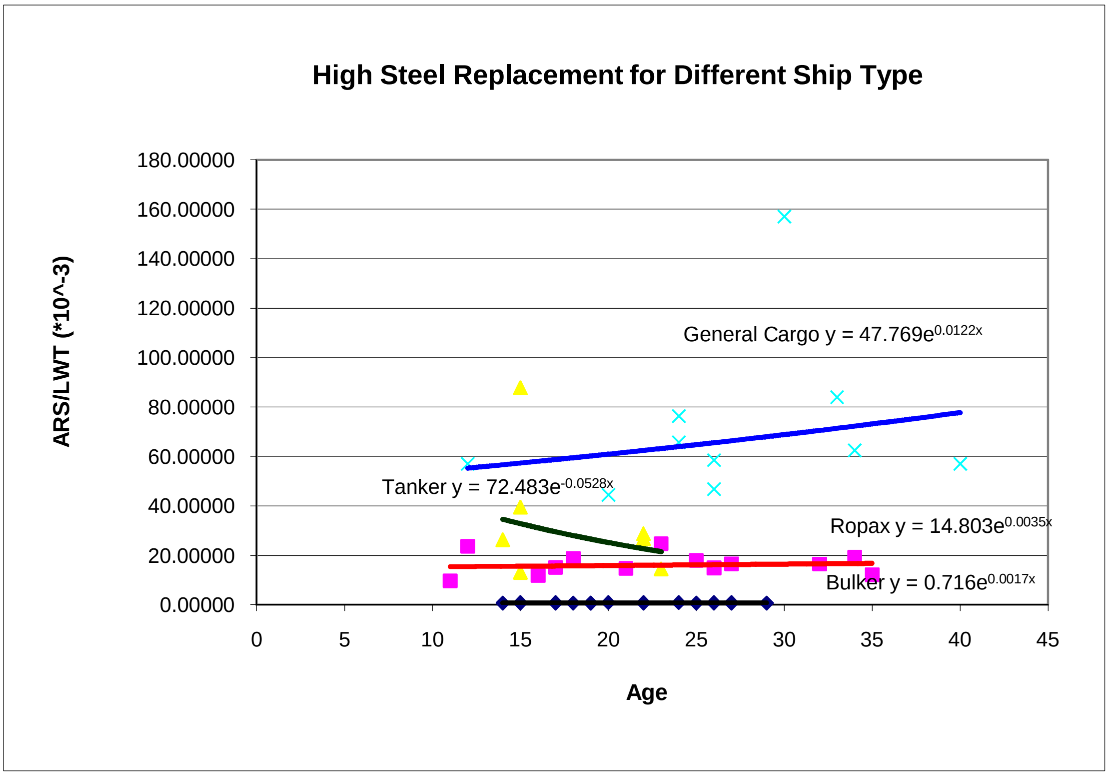

Figure 5.24 Regressions for different ship types with respect to "high steel replacement vs. Age"

Based on low steel replacement (Figure5.22 for different ships), general cargo vessel has the highest ARS/LWT value followed by tanker and ropax vessel. The effect of the age for low steel replacement ARS/LWT for general cargo vessel is the highest as indicated in Figure5.22.

Estimation of steel replacement as function of DWT & Age can be calculated using the following equations.

Tanker;

$$\text{Tanker Low ARS/LWT } (*10\text{^}-3) = 0.1188e^{0.1717*Age} \quad (23)$$

$$\text{Tanker Likely ARS/LWT } (*10\text{^}-3) = 0.1582e^{0.1787*Age} \quad (24)$$

$$\text{Tanker High ARS/LWT } (*10\text{^}-3) = 72.483e^{-0.0528*Age} \quad (25)$$

General Cargo Vessel;

$$\text{General Cargo Low ARS/LWT } (*10\text{^}-3) = 1.8581e^{0.0694*Age} \quad (26)$$

$$\text{General Cargo Likely ARS/LWT } (*10\text{^}-3) = 9.9418e^{0.0318*Age} \quad (27)$$

$$\text{General Cargo High ARS/LWT } (*10\text{^}-3) = 47.769e^{0.0122*Age} \quad (28)$$

Ropax;

$$\text{Ropax Low ARS/LWT } (*10\text{^}-3) = 2.0561e^{0.0254*Age} \quad (29)$$

$$\text{Ropax Likely ARS/LWT } (*10\text{^}-3) = 2.6712e^{0.0437*Age} \quad (30)$$

$$\text{Ropax High ARS/LWT } (*10\text{^}-3) = 14.803e^{0.0035*Age} \quad (31)$$

Bulker;

$$Bulker\ Low\ ARS/LWT\ (*10^{\wedge}\text{-}3) = 0.1332e^{0.0531*Age} \quad (32)$$

$$Bulker\ Likely\ ARS/LWT\ (*10^{\wedge}\text{-}3) = 0.1554e^{0.0548*Age} \quad (33)$$

$$Bulker\ High\ ARS/LWT\ (*10^{\wedge}\text{-}3) = 0.716e^{0.0017Age} \quad (34)$$

The equations for likely steel replacement rates for different ship types can be upgraded using the relation between DWT & LWT. So in state of lightweight value deadweight value can be used to calculate the steel replacement rates. As an example, formulas given below will be able to predict likely replaced steel by using DWT.

Ropax;

If the equation (9) is introduced in the equation (30), and after re arranging the formula, ARS can be estimated using the following formula;

$$Ropax\ Likely\ ARS/\ (1.6206\ DWT + 2218.9)\ (*10^{\wedge}\text{-}3) = 2.6712e^{0.0437*Age}$$

And if the formula is re arranged,

$$Ropax\ Likely\ ARS = (1.6206\ DWT + 2218.9)\ (*10^{\wedge}\text{-}3)*2.6712e^{0.0437*Age} \quad (35)$$

Bulker;

If the equation (11) is introduced in the equation (33), and after re arranging the formula, ARS can be estimated using the following formula;

$$Bulker\ Likely\ ARS/5906e^{8E\text{-}06DWT}\ (*10^{\wedge}\text{-}3) = 0.1554e^{0.0548*Age}$$

And if the formula is re arranged,

$$Bulker\ Likely\ ARS = 5906e^{8E\text{-}06DWT}\ (*10^{\wedge}\text{-}3)*\ 0.1554e^{0.0548*Age} \quad (36)$$

Tanker;

If the equation (12) is introduced in the equation (24), and after re arranging the formula, ARS can be estimated using the following formula;

$$Tanker\ Likely\ ARS/\ (0.1819\ DWT + 2230.9)\ (*10^{\wedge}-3) = 0.1582e^{0.1787*Age}$$

And if the formula is re arranged,

$$Tanker\ Likely\ ARS = (0.1819\ DWT + 2230.9)\ (*10^{\wedge}-3)*\ 0.1582e^{0.1787*Age} \quad (37)$$

General Cargo Vessel;

If the equation (8) is introduced in the equation (27), and after re arranging the formula, ARS can be estimated using the following formula;

$$General\ Cargo\ Likely\ ARS/\ (4729.9(lnDWT)\ 37912)\ (*10^{\wedge}-3) = 9.9418e^{0.0318*Age}$$

And if the formula is re arranged,

$$General\ Cargo\ Likely\ ARS = (4729.9(lnDWT)\ 37912)\ (*10^{\wedge}-3)*\ 9.9418e^{0.0318*Age} \quad (38)$$

5.2 Reliability Analyses

Reliability analyses of hull structure based on hull repair & maintenance data are carried out by fault tree analysis. The main aim is to identify the most critical areas in hull structure so that necessary action can be taken to improve it. Fault tree analysis was introduced in 1962 at Bell Labs firstly and then fault tree analysis has become very popular in various sectors like chemical and railway industry for the improvement of vehicle design and software reliability [49].

Allowing the examination of multiple failures is an important characteristic of the fault tree analysis. Fault tree analysis is a deductive or backwards method which uses `what can cause this approach` to identify relationship leading to a specific system failure [50].

Fault tree analysis is a procedure for determining the various combinations of software and hardware failure as well as human errors which can result in the occurrence of a specified undesired event at the system level. This undesired event to evaluate is referred to as the top event. All the software and hardware failures and human errors which can lead to the occurrence of the top event are referred to as events. Gates are known as logic operators that determine how events are generated. Various symbols are used to represent events and gates in the construction of a fault tree [7].

In fault trees gates and event types as fault tree building blocks are used in structure of static and dynamic fault trees [7]. Most of the gates are static gates therefore there is no specific description for them and dynamic gates are indicated in the definitions with discussion.

Basic event; basic events represent the lowest level in a fault tree. Basic events can include software and hardware failures as well as human errors and system failures. Basic events are the most common primary events in fault tree analysis.

Undeveloped event; it is similar to a basic event, however undeveloped event is shown as a different symbol to signify that it could be developed further but it has not been done so far in the analysis. Undeveloped events are used if further resolution of that event does not improve the understanding of the problem, or if further resolution is not necessary for proper evaluation of the fault tree.

Repeated basic event; it means that the event initiates more than one upper level event with the same input data.

Spare event; it is used to specify spares in dynamic fault trees. Spare event is similar to basic event in functionality but spare event allows only rates as inputs.

House event; it is possible to turn on and off the house event. When the house event is turned on (true), that event is presumed to have occurred and the probability of that event is set to 1. When the house event is turned off (false), it is presumed not to have occurred and the probability is set to 0. House event is also referred to as trigger events and switching events.

AND gate; it is used to indicate that the output occurs if and only if all the input events occur. The output of an AND gate can be top event or any intermediate event. The input events can be basic events, intermediate events that outputs of other gates, or a combination of both.

OR gate; an OR gate is used to indicate that the output occurs if and only if at least one of the input events occur. The output of an OR gate can be top event or any intermediate event. The input events can be basic events, intermediate events, or a combination of both. At least two inputs needed for an OR gate.

Voting (m/n) gate; it is used to indicate that the output occurs if and only if m out of the n input events occurs. The m input event does not need to occur simultaneously. The output occurs when at least m input events occur. When m equal to 1, the Voting gate behaves like an OR gate. The output of a Voting gate can be top event or any intermediate event. The input events can be basic events, or a combination of both.

Exclusive OR gate (XOR); it is used to indicate that the output occurs if and only if one of the two input events occurs and the other input event does not occur. The output of a XOR gate can be top event or any intermediate event. The input events can be basic events, intermediate events, or a combination of both. A XOR gate has only two inputs.

NOT gate; it is used to indicate that the output occurs when the input event does not occur. The presence of a NOT gate gives rise to non-coherent trees, where the non-occurrence of an event causes the top event to occur. NOT gate allows only one input.

NAND gate; it functions like a combination of an AND gate and a NOT gate. The NAND gate is used o indicate that the output occurs when at least one of the input events is absent. The output of a NAND gate can be top event or any intermediate event. The input events can be basic events, intermediate events, or a combination of both.

NOR gate; it functions like a combination of an OR gate and a NOT gate. The NOR gate is used to indicate that the output occurs when all the input events are absent. The output of a NOR gate can be top event or any intermediate event. The input events can be basic events, intermediate events, or a combination of both.

INHIBIT gate; it is used to indicate that the output occurs when the input events occur and the input condition is satisfied. The output of an AND gate can be top event or any intermediate event. The input events can be basic events, intermediate events, or a combination of both.

SPARE gate; it is used to model the behaviour of spaces in the system. It is used to indicate that the output occurs if and only if all input spare events occur. All inputs of a SPARE gate are SPARE events. A SPARE gate can have multiple inputs. The SPARE gate is a dynamic gate that means the temporal order of the occurrence of events is important to analyse this gate.

FUNCTIONAL DEPENDENCY gate (FDEP); it is used to indicate that all dependent basic events are forced to occur whenever the trigger event occurs. The separate occurrence of any of the dependent basic events has no effect on the trigger event. The FDEP gate has one or more dependent events and just one trigger event. The FDEP gate is a dynamic gate.

SEQUENCE-ENFORCING gate (SEQ); it forces events to occur in a particular order. The input events are constrained to occur in the left-to-right order in which they appear under the gate. The SEQ gate is used to indicate that the output occurs if and only if all input events occur, when the input events are constrained to occur in a particular order. The SEQ gate is a dynamic gate.

PRIORITY AND gate (PAND); it is used to indicate that the output occurs if and only if all input events occur in a particular order. The PAND gate is a dynamic gate.

TRANSFER gate; it is a symbol used to link logic in separate areas of a fault tree. There are two basic uses of TRANSFER gate, first the fault tree may not fit on a single sheet of a paper and second the same fault tree logic may be used in different places in a fault tree.

As it is mentioned in critical review part, it is possible to calculate the results for reliability, availability, unreliability, unavailability, failure frequency, number of failures, and cut set and importance measures by using fault tree analysis.

Availability and Criticality

The reliability term can be used to cover the reliability, availability, maintainability as well as durability, or in the particular sense, it means the probability of success as opposite the term risk. Also reliability is described as an ability of an item to perform a required function, under given environmental and operational condition for a stated period.

Availability is defined as the probability which an item is available for use when required [3].

The criticality analysis is a way of determining the significance of individual failure modes, and prioritising the failures for the correct action.

Criticality of failure occurrence is ranked in 5 levels. Level 1 has 0 occurrence rate and failure occurrence is unlikely (unreasonable to wait this failure mode to occur). Level 2 has 1/10,000 occurrence rate and failure occurrence is isolated (based on a similar designs having low number of failures). Level 3 has 1/1,000 occurrence rate and failure occurrence is sporadic (based on similar designs that have experienced occasional failures). Level 4 has 1/100 occurrence rate and failure occurrence is conceivable (based on similar designs that have caused problems). Level 5 has 1/10 occurrence rate and failure occurrence is recurrent (certain that failure will ensue) [48].

According to failure types fault tree diagram can be developed. For structural failure analysis, gates and event are used to develop the fault tree diagram. For structural failure OR gates are used as a gate type in fault tree diagram.

In fault tree diagram basic events are used as events. It is possible to enter data like identifier of the events and description of the events for basic events.

Calculation of failure rates is based on MTTF (Mean Time to Fail) and MTBF (Mean Time between Failures) calculations. MTTF represents the time period from the beginning of the life to first failure occurred. MTBF represents the time period between the two failures.

Failure Rate λ,

$$MTTF = 1 / \lambda \quad or \quad MTBF = 1 / \lambda \qquad (39)$$

MTTF and MTBF,

$$MTTF = 1 / \text{Mean Time to Failure in hours} \qquad (40)$$

$$MTBF = 1 / \text{Mean Time between Failures in hours} \qquad (41)$$

Application of Fault Tree to Identify Critical Areas of Hull Structure

For chemical tanker, ropax and general cargo vessel fault tree diagrams are developed separately using the hull structural failure data.

For the construction of fault tree, ropax vessel is used as a top gate description which is an OR gate. Then stern, cargo, bow and non available descriptions are used for second level OR gates descriptions. Under the stern OR gate, door/ramp, engine room, propellers shaft area, rudder area, sponson, steering gear room, transom are used as an OR gate.

Under the cargo OR gate, ballast, bilge keel, bottom shell, cargo winch, deck, garage deck, keel, longitudinal, main deck, sea chest, side shell, tank, transverse and void spaces are used as an OR gate.

Under the bow or gate bow visor and bulbous are used as an OR gate. For basic events buckling, crack/fracture and indent/deformation descriptions are used and for logical conditions for gates and events are entered as normal. There are three different types of logical conditions these are true false and normal and for each gates and events logical conditions are required to calculate the failure rate. For basic failure types such as hull structural failures logical condition should be normal. Parameter definition part for events is user defined and input type for events is failure with repair.

In case of chemical tanker, chemical tanker structure is used as a top OR gate description. Under the top gate transom, rudderstock, propeller, machine, deck, forecastle, bulb, hull, cargo tank, slope tank, wing tank, peak tank, oil tank, double bottom tank descriptions are used as a OR gate descriptions.

For event descriptions buckling, indent/deformation and cracks, fractures are used. Buckling, crack/fracture and indent/deformation descriptions are defined as basic events. For logical conditions for gates and events are normal. Parameter definition part for events is user defined and input type for events is failure with repair.

For general cargo vessel top OR gate description general cargo vessel is used and under general cargo vessel OR gate, aft peak tank, ballast, brackets, bulb, bulkhead, cargo holds, centre girder, chain locker, chain room, coamings, cross deck, double bottom, e.r.sludge tank inserts, engine room, floor insert, fore castle deck, fore peak deck, fore peak tank, fresh water tank, fwd. deck insert, girder, hatch beam plates, hatch cover railway, hatch cover, hold bulkhead, hopper plates, inner bottom plate, inner side inserts, main deck, menhol, paint room inserts, parampet, pipe guard, poop deck plates, pump room inserts, shell plate, side girder starboard, stringer, superstructure, tank top, trim tank, wheelhouse deck, wing tank descriptions are used as events descriptions.

Logical condition of the gates and events are assumed as normal. Parameter definition for events is user defined. Input type for events is failure rate/MTBF.

5.2.1 Ropax Vessel Reliability Analysis

According to classification society data, hull structure failures are classified in three categories; buckling, crack and fracture, indent and deform.

For reliability calculations of ropax vessel, assumption is made that all the failures are occurring for the first time.

Failure rate calculations are done by failure divided operational time or life time. Life time calculations are made in hours. So the failure rate is calculated in hours.

Using the hours based calculations; specific hours reliability can be calculated.

Failures for Ropax vessel structure is given in table5.8, which includes the records from the beginning of 1970 until 2006. 213 records of structural problems are recorded for 85 different ships (Table5.8). It needs to be emphasised that these failures are not identifiable as these are not given as ship separate failures.

Number of defects	Defect Type							
Position	Buckling		Crack/Fracture		Indent/Deformation		Total	
Undefined	**1**	*13%*	**1**	*1%*	**2**	*2%*	**4**	*2%*
Ballast tank			**5**	*6%*	**1**	*1%*	**6**	*3%*
Bilge keel					**2**	*2%*	**2**	*1%*
Bottom shell			**4**	*5%*	**7**	*6%*	**11**	*5%*
Bow visor	**1**	*13%*	**8**	*10%*	**8**	*7%*	**17**	*8%*
Bulbous			**3**	*4%*	**4**	*3%*	**7**	*3%*
Cargo winch			**1**	*1%*			**1**	*0%*
Deck	**2**	*25%*	**6**	*7%*	**4**	*3%*	**12**	*6%*
Door/ramp			**13**	*16%*	**4**	*3%*	**17**	*8%*
Engine room			**4**	*5%*			**4**	*2%*
Garage deck	**1**	*13%*	**1**	*1%*	**3**	*2%*	**5**	*2%*
Keel					**4**	*3%*	**4**	*2%*
Longitudinal					**2**	*2%*	**2**	*1%*
Main deck			**4**	*5%*	**1**	*1%*	**5**	*2%*
Propellershat area			**1**	*1%*			**1**	*0%*
Rudder area			**5**	*6%*			**5**	*2%*
Sea chest			**1**	*1%*		*0%*	**1**	*0%*
Side shell	**2**	*25%*	**11**	*13%*	**56**	*46%*	**69**	*32%*
Sponson			**2**	*2%*	**2**	*2%*	**4**	*2%*
Steering gear room					**1**	*1%*	**1**	*0%*
Tank	**1**	*13%*	**5**	*6%*	**3**	*2%*	**9**	*4%*
Transom					**4**	*3%*	**4**	*2%*
Transverse			**7**	*8%*	**14**	*11%*	**21**	*10%*
Void space			**1**	*1%*			**1**	*0%*
Total	**8**	*100 %*	**83**	*100 %*	**122**	*100 %*	**213**	*100 %*

Table5.8 Ropax vessel structural failures

In the ro-ro database 8 buckling failures are listed. 1 in bow visor, 2 in deck, 1 in garage deck keel, 2 in side shell, 1 in tank while location of 1 buckling failure is unknown. Deck and side shell are the highest percentage with 25% failure rate.

83 crack and fracture failures are observed for 85 ropax vessels. Crack and fracture failures are listed in terms of location; 5 in ballast tank, 4 in bottom shell, 8 in bow visor, 3 in

bulbous, 1 in cargo winch, 6 in deck, 13 in door/ramp, 4 in engine room, 1 in garage deck keel, 4 in main deck, 1 in propeller and shaft area, 5 in rudder area, 1 in sea chest, 11 in side shell, 2 in sponson, 5 in tank, 7 in transverse and 1 in void space while location of 1 failure is unknown. Door/ramp has the highest percentage of the crack and fracture observed rate with %16. Then side shell is following it with 13%.

122 indent/deformation failures are observed for ropax vessels. 2 indent/deformation failure are in unknown position, 1 in ballast tank, 2 in bilge keel, 7 in bottom shell, 8 in bow visor, 4 in bulbous, 4 in deck, 4 in door/ramp, 3 in garage deck, 4 in keel, 2 in longitudinal, 1 in main deck, 56 in side shell, 2 in sponson, 1 in gear room, 3 in tank, 4 in transom and 14 in transverse. Side shell has the highest percentage of the observed indent/deformation failures with %46 and transverse is following it with 11%.

Buckling is the least seen failure in Ropax structure comparing with the other failures. It is only seen in cargo winch deck and side shell.

Cracks and fractures are generally occurred in structure and the numbers of these failures are high. Cracks and failures are mostly seen in door/ramp and side shell.

Indent and deformation is the most observed failures with ropax vessels. More than half of the failures are indent and deformation failures. Bow visor, transverse and side shell are the main areas which the indent and deformation occurred. Every kind of failures observed in this part and indent and deformation failure rate is too high for this part.

In total 32% of the all failures are observed in side shell area for ropax vessel. Ropax vessels are generally operating in short distance. Moreover ropax vessels are visiting ports every day and some ropax vessels visit the port 3-4 times a day. During all port visits, side shell is in contact with port and sometimes with other vessels and some of these contacts have higher impacts on the side shell. In every contact side shell is affected and may result in buckling, crack/fracture and especially indent/deformation which are observed from the database.

Fault tree diagram for Ropax vessel

Fault tree diagram for Ropax vessel is developed using Or gates and basic events and failure rate values are assigned to basic events using the database. No value entered to gates. Basic events for this diagram are cracks and fractures, indent and deformation as well as buckling.

As a first step, Or gates are divided into four categories which are stern, cargo, bow and N/A. Stern is also divided into seven Or gates which are door/ramp, engine room, propellers shaft area, rudder area, sponson, steering gear room and transom. Cargo Or gates are divided into fourteen Or gates which are ballast, bilge keel, bottom shell, cargo winches, deck, garage deck, keel, longitudinal, main deck, sea chest, side shell, tank, transverse and void space. Bow Or gate is divided into two sub categories which are bow visor and bulbous (Figures5.25, 5.26, 5.27, 5.28, 5.29, 5.30, 5.31 and 5.32).

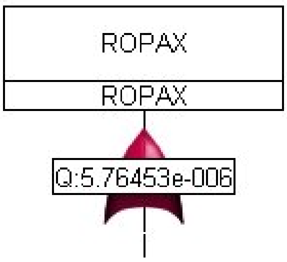

Figure5.25 An example of Or gate

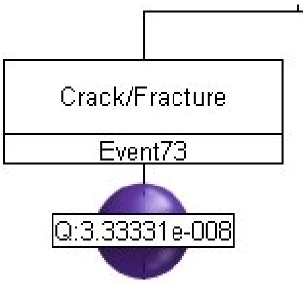

Figure5.26 An example of basic event

With fault tree analysis criticality, availability, reliability, unavailability and unreliability values are calculated and are shown in Table5.9.

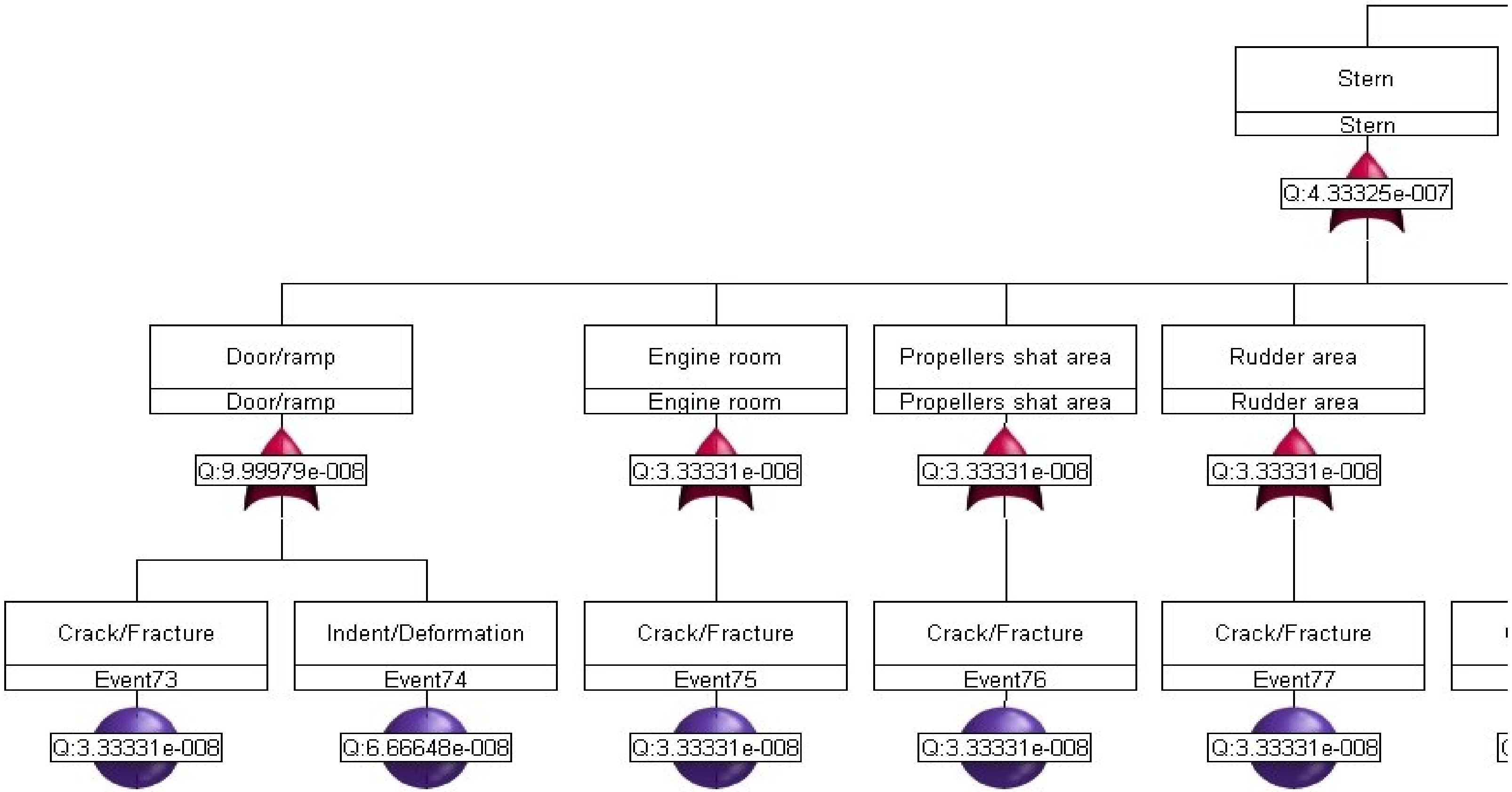

Figure5.26 Ropax vessel fault tree diagram part I

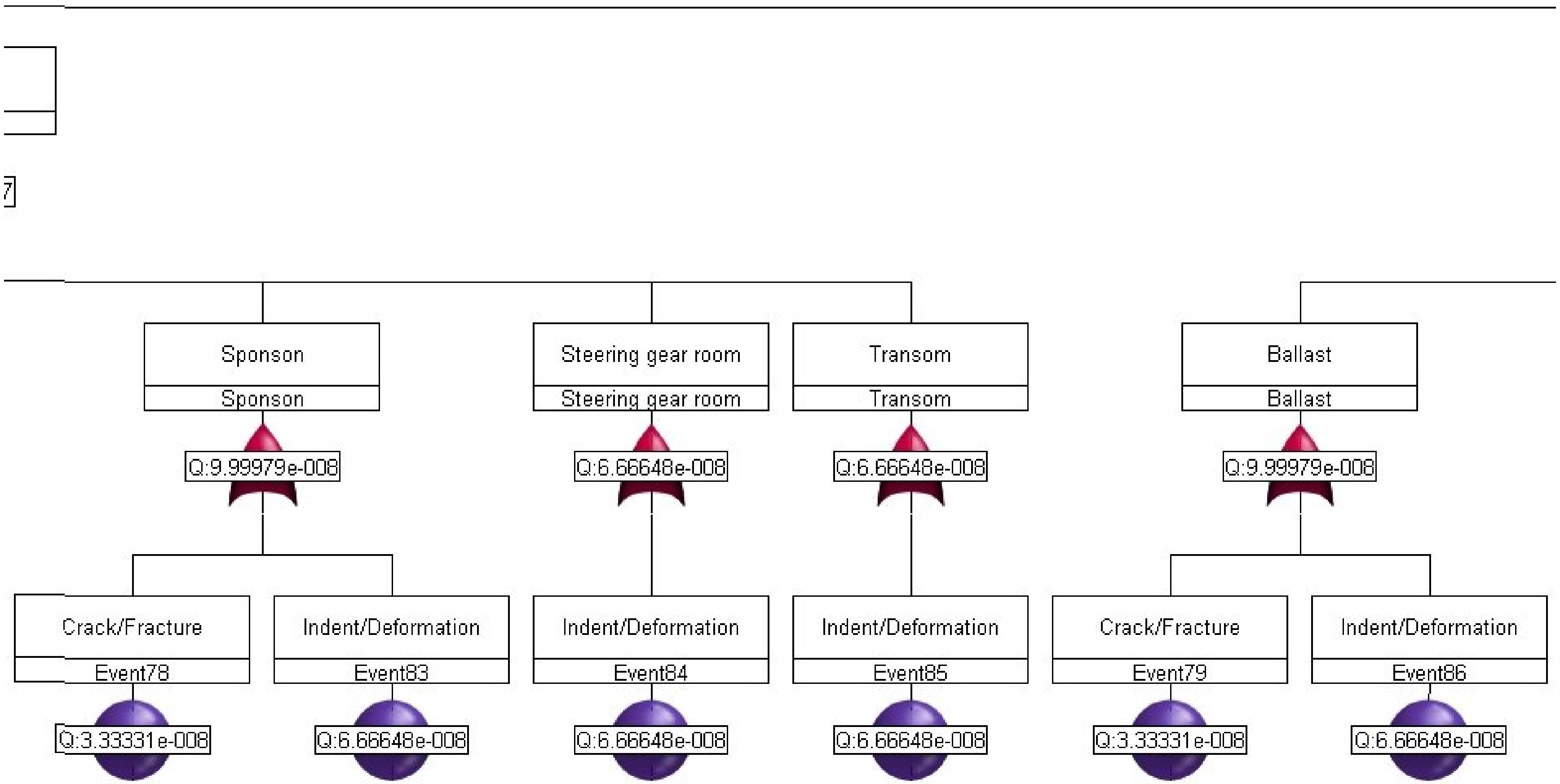

Figure5.27 Ropax vessel fault tree diagram part II

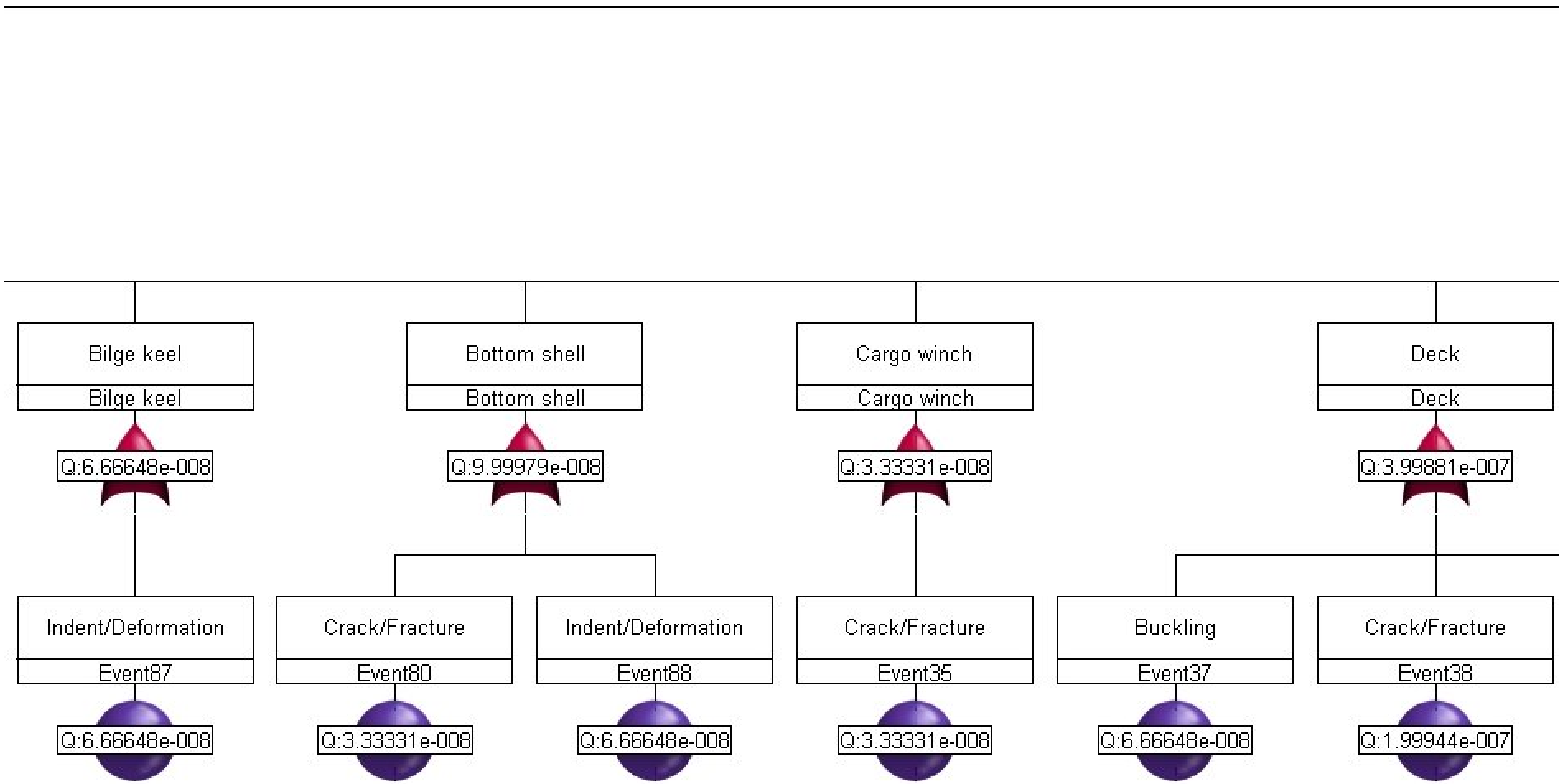

Figure5.28 Ropax vessel fault tree diagram part III

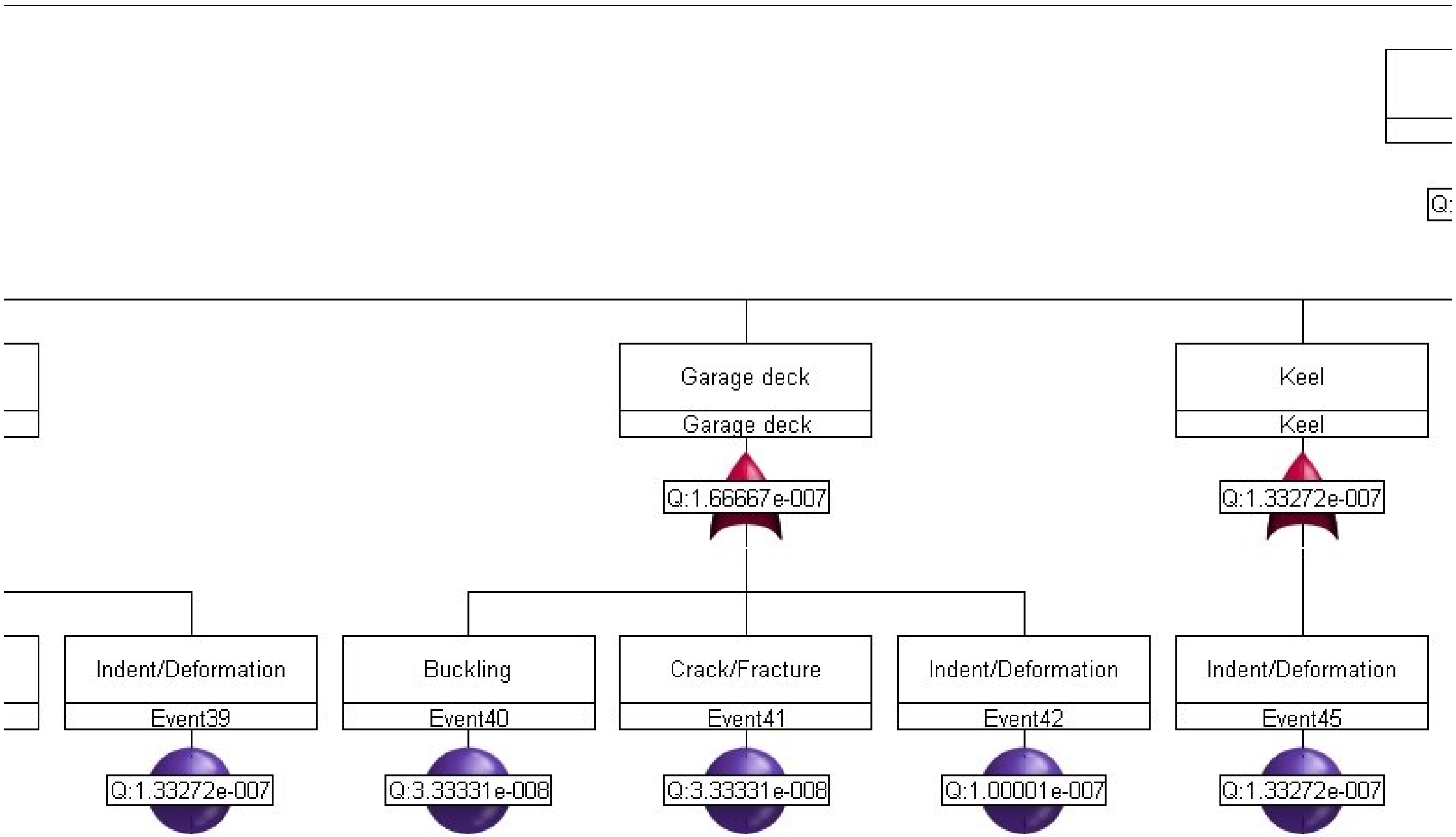

Figure5.29 Ropax vessel fault tree diagram part IV

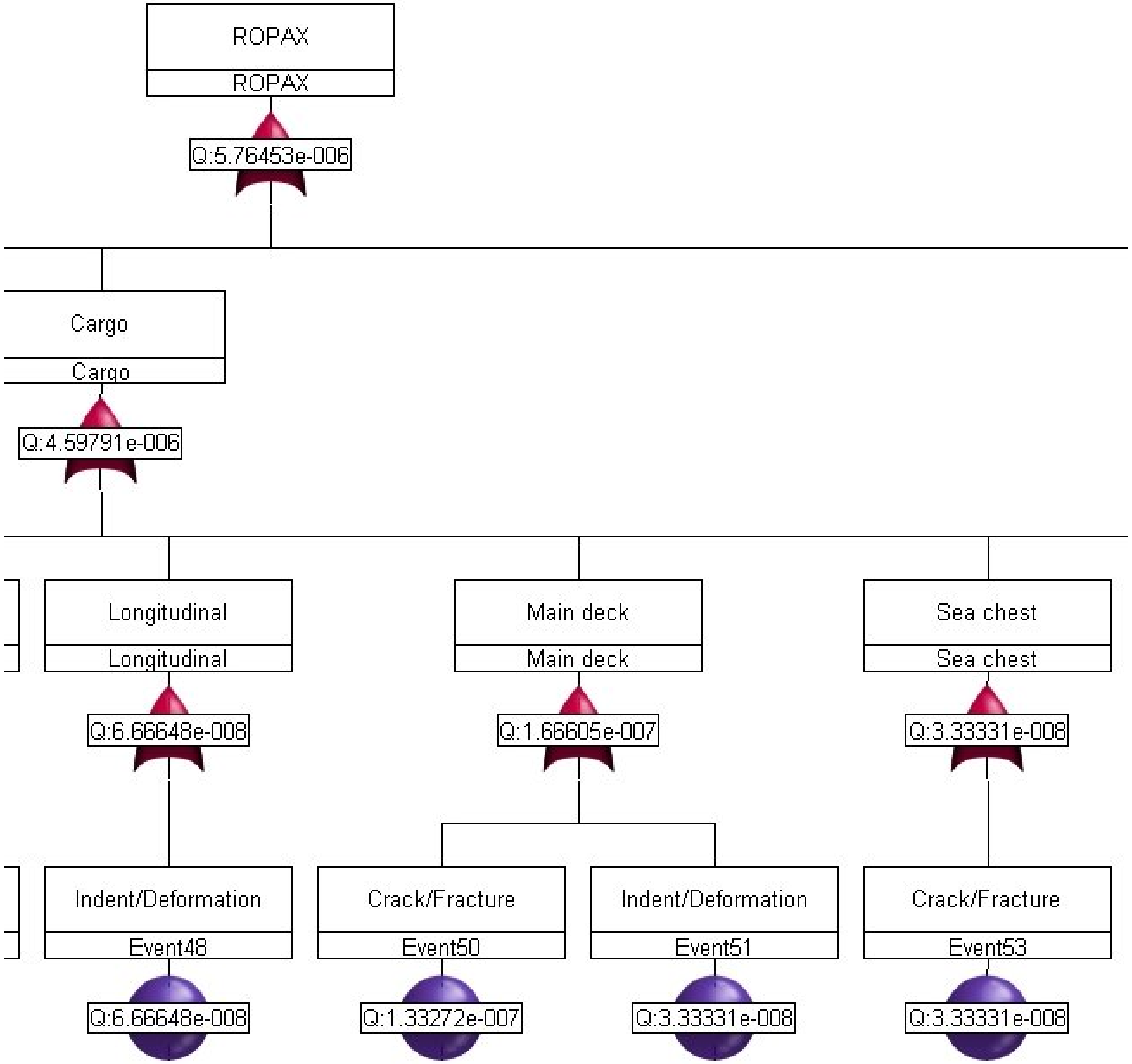

Figure5.30 Ropax vessel fault tree diagram part V

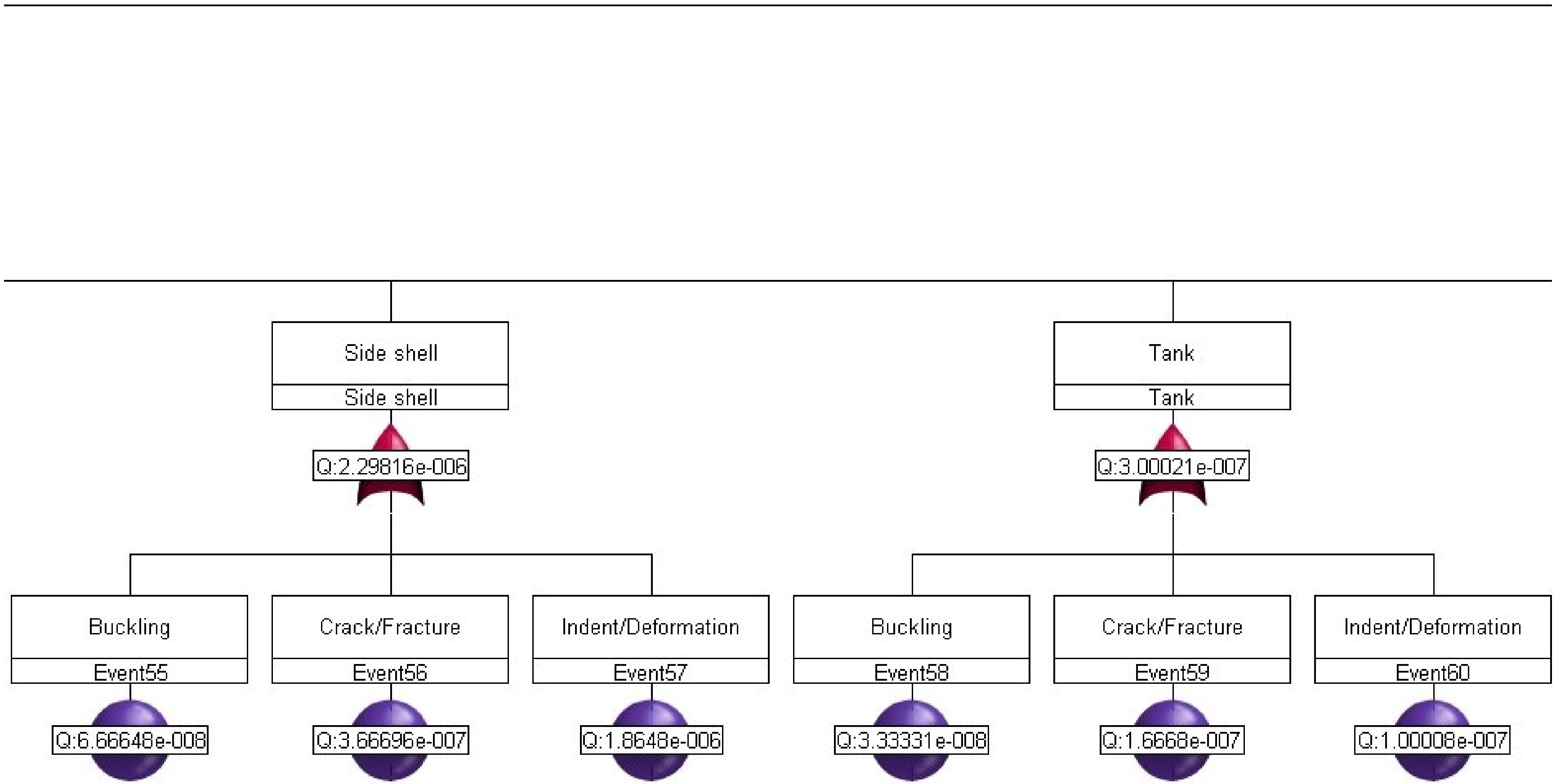

Figure5.31 Ropax vessel fault tree diagram part VI

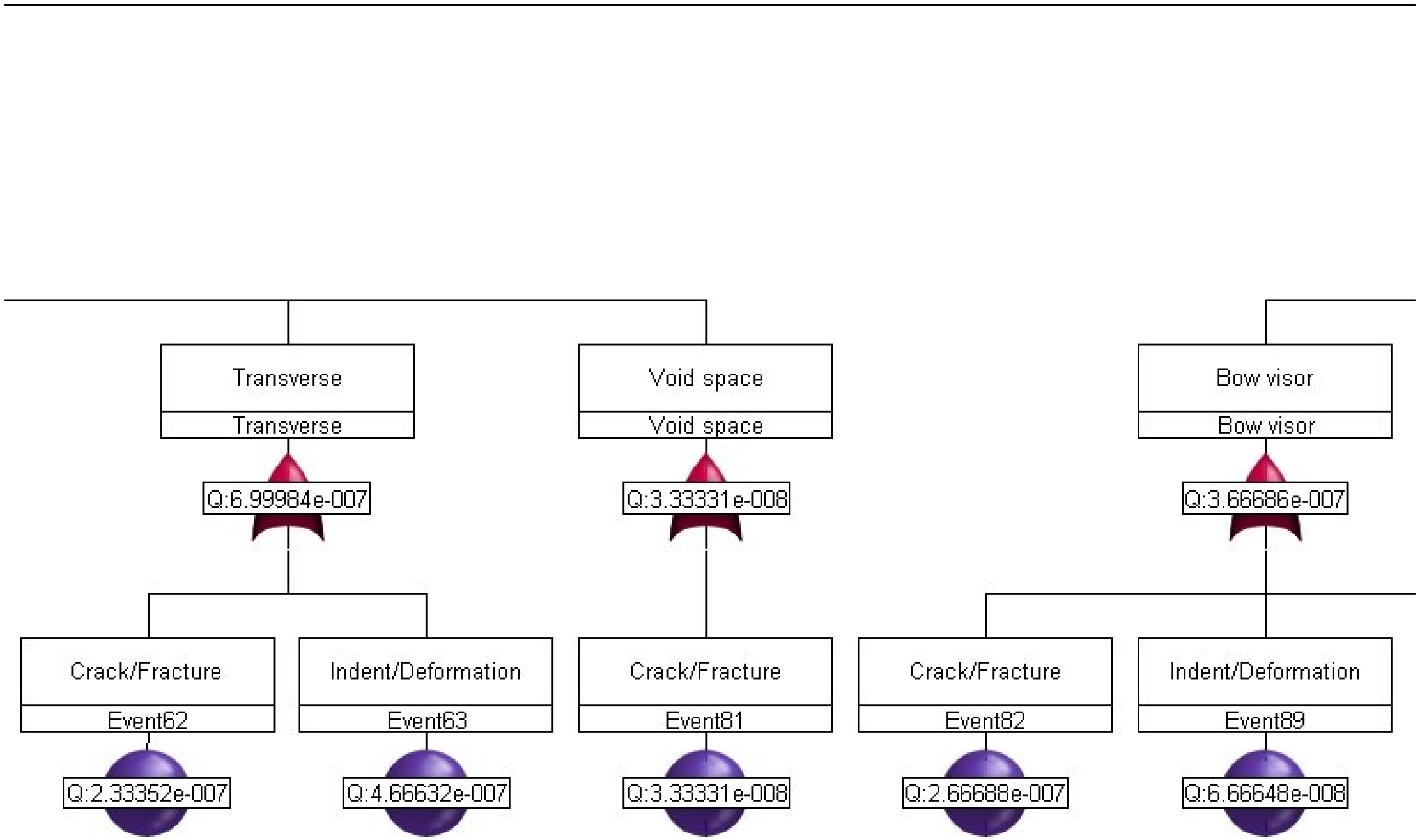

Figure5.32 Ropax vessel fault tree diagram part VII

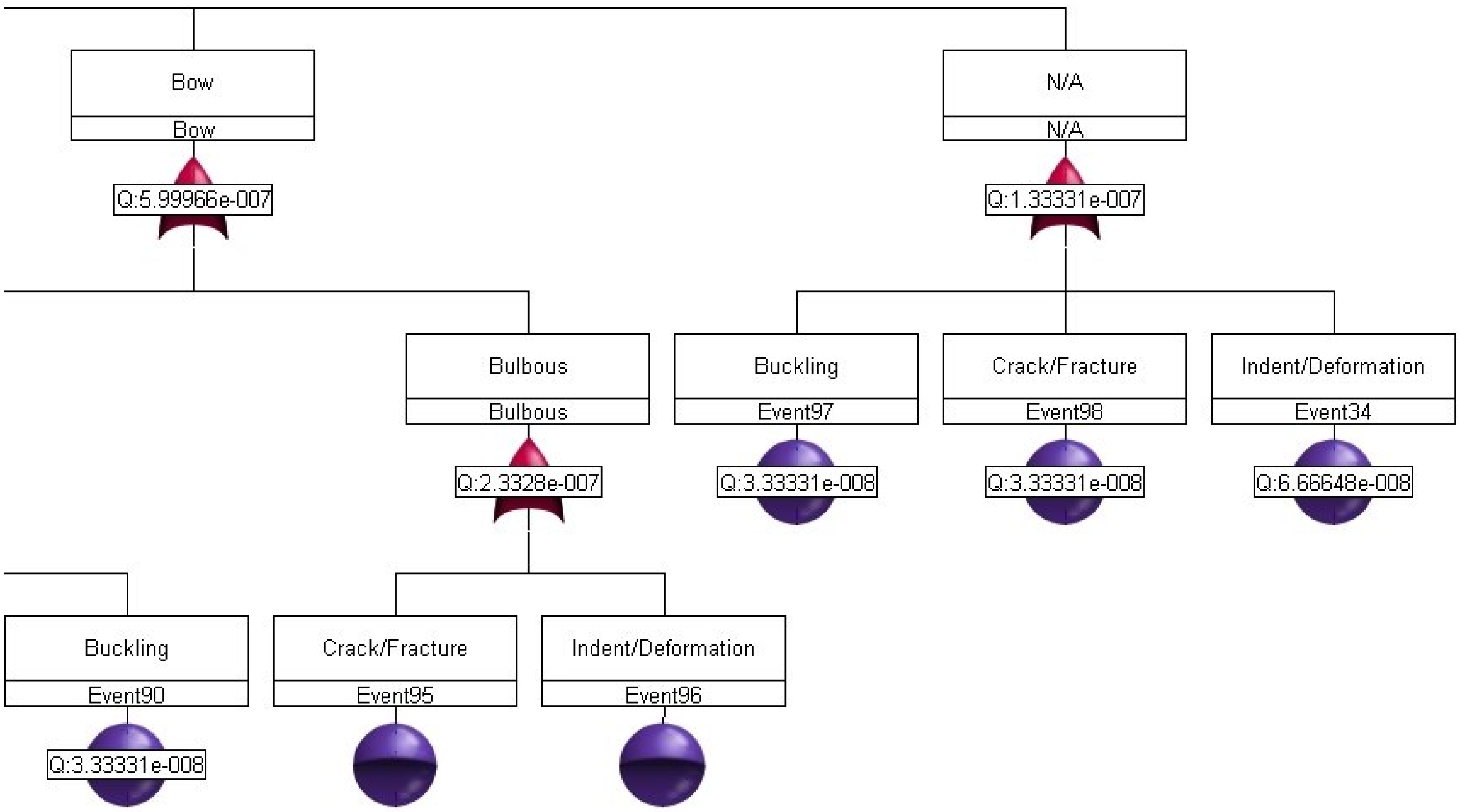

Figure5.33 Ropax vessel fault tree diagram part VIII

Comment1	Identifier	Criticality	Availability	Reliability	Unavailability	Unreliability
ROPAX	Gate1		0.9999929	0.99787091	0.0000071	0.00212909
Stern	Gate25		0.9999988	0.99964007	0.0000012	0.00035993
Door/ramp	Gate28		0.99999943	0.99983003	0.00000057	0.00016997
Crack/Fracture	Event5	0.011565	0.99999957	0.99987001	0.00000043	0.00012999
Indent/Deformation	Event6	0.005782	0.99999987	0.99996002	0.00000013	0.00003998
Engine room	Gate29		0.99999987	0.99996002	0.00000013	0.00003998
Crack/Fracture	Event8	0.005782	0.99999987	0.99996002	0.00000013	0.00003998
Propellers shat area	Gate30		0.99999997	0.99999	0.00000003	0.00001
Crack/Fracture	Event11	0.005782	0.99999997	0.99999	0.00000003	0.00001
Rudder area	Gate31		0.99999983	0.99995	0.00000017	0.00005
Crack/Fracture	Event14	0.005782	0.99999983	0.99995	0.00000017	0.00005
Sponson	Gate32		0.99999987	0.99996	0.00000013	0.00004
Crack/Fracture	Event17	0.005782	0.99999993	0.99998	0.00000007	0.00002
Indent/Deformation	Event18	0.011565	0.99999993	0.99998	0.00000007	0.00002
Steering gear room	Gate33		0.99999997	0.99999	0.00000003	0.00001
Indent/Deformation	Event21	0.011565	0.99999997	0.99999	0.00000003	0.00001
Transom	Gate34		0.99999987	0.99996002	0.00000013	0.00003998
Indent/Deformation	Event24	0.011565	0.99999987	0.99996002	0.00000013	0.00003998
Cargo	Gate26		0.99999504	0.99851083	0.00000496	0.00148917
Ballast	Gate35		0.9999998	0.99994	0.0000002	0.00006
Crack/Fracture	Event26	0.005782	0.99999983	0.99995	0.00000017	0.00005
Indent/Deformation	Event27	0.011565	0.99999997	0.99999	0.00000003	0.00001
Bilge keel	Gate36		0.99999993	0.99998	0.00000007	0.00002
Indent/Deformation	Event30	0.011565	0.99999993	0.99998	0.00000007	0.00002
Bottom shell	Gate37		0.99999963	0.99989002	0.00000037	0.00010998
Crack/Fracture	Event32	0.005782	0.99999987	0.99996002	0.00000013	0.00003998
Indent/Deformation	Event33	0.011565	0.99999977	0.99993	0.00000023	0.00007
Cargo winch	Gate38		0.99999997	0.99999	0.00000003	0.00001
Crack/Fracture	Event35	0.005782	0.99999997	0.99999	0.00000003	0.00001
Deck	Gate39		0.9999996	0.99988004	0.0000004	0.00011996
Buckling	Event37	0.023119	0.99999993	0.99998	0.00000007	0.00002
Crack/Fracture	Event38	0.034685	0.9999998	0.99994002	0.0000002	0.00005998
Indent/Deformation	Event39	0.011565	0.99999987	0.99996002	0.00000013	0.00003998
Garage deck	Gate40		0.99999983	0.99995	0.00000017	0.00005
Buckling	Event40	0.017348	0.99999997	0.99999	0.00000003	0.00001
Crack/Fracture	Event41	0.005782	0.99999997	0.99999	0.00000003	0.00001
Indent/Deformation	Event42	0.005782	0.9999999	0.99997	0.0000001	0.00003
Keel	Gate41		0.99999987	0.99996002	0.00000013	0.00003998
Indent/Deformation	Event45	0.023119	0.99999987	0.99996002	0.00000013	0.00003998
Longitudinal	Gate42		0.99999993	0.99998	0.00000007	0.00002
Indent/Deformation	Event48	0.011565	0.99999993	0.99998	0.00000007	0.00002
Main deck	Gate43		0.99999983	0.99995002	0.00000017	0.00004998
Crack/Fracture	Event50	0.005782	0.99999987	0.99996002	0.00000013	0.00003998
Indent/Deformation	Event51	0.023119	0.99999997	0.99999	0.00000003	0.00001
Sea chest	Gate44		0.99999997	0.99999	0.00000003	0.00001

Crack/Fracture	Event53	0.005782	0.99999997	0.99999	0.00000003	0.00001
Side shell	Gate45		0.9999977	0.99931071	0.0000023	0.00068929
Buckling	Event55	0.323495	0.99999993	0.99998	0.00000007	0.00002
Crack/Fracture	Event56	0.063612	0.99999963	0.99989	0.00000037	0.00011
Indent/Deformation	Event57	0.011565	0.99999814	0.99944072	0.00000186	0.00055928
Tank	Gate46		0.9999997	0.99991	0.0000003	0.00009
Buckling	Event58	0.005782	0.99999997	0.99999	0.00000003	0.00001
Crack/Fracture	Event59	0.028915	0.99999983	0.99995	0.00000017	0.00005
Indent/Deformation	Event60	0.017349	0.9999999	0.99997	0.0000001	0.00003
Transverse	Gate47		0.9999993	0.99979002	0.0000007	0.00020998
Crack/Fracture	Event62	0.080949	0.99999977	0.99993	0.00000023	0.00007
Indent/Deformation	Event63	0.040481	0.99999953	0.99986002	0.00000047	0.00013998
Void space	Gate48		0.99999997	0.99999	0.00000003	0.00001
Crack/Fracture	Event65	0.005782	0.99999997	0.99999	0.00000003	0.00001
Bow	Gate27		0.9999992	0.99976001	0.0000008	0.00023999
Bow visor	Gate49	0.046264	0.99999943	0.99983	0.00000057	0.00017
Buckling	Event67	0.011565	0.99999997	0.99999	0.00000003	0.00001
Crack/Fracture	Event68	0.005782	0.99999973	0.99992	0.00000027	0.00008
Indent/Deformation	Event69		0.99999973	0.99992	0.00000027	0.00008
Bulbous	Gate50		0.99999977	0.99993002	0.00000023	0.00006998
Crack/Fracture	Event71	0.023119	0.9999999	0.99997	0.0000001	0.00003
Indent/Deformation	Event72	0.017349	0.99999987	0.99996002	0.00000013	0.00003998
N/A	Gate51		0.99999987	0.99996	0.00000013	0.00004
Buckling	Event1	0.005782	0.99999997	0.99999	0.00000003	0.00001
Crack/Fracture	Event2	0.005782	0.99999997	0.99999	0.00000003	0.00001
Indent/Deformation	Event3	0.011565	0.99999993	0.99998	0.00000007	0.00002

Table5.9 Fault tree reliability analysis results for Ropax vessel

According to reliability analysis of ropax vessels, cargo area has the lowest reliability value, which is followed by side shell. Stern, door/ramp, engine room, propellers shaft area, rudder area, sponson, steering gear room, transom, ballast, bilge keel, bottom shell, cargo winch, garage deck, keel, longitudinal, main deck, sea chest, side shell, transverse, void space, bow visor and bulbous have reliability values between 0.9995 to 1 which is reasonable. These areas are more reliable than cargo area and side shell. However the reliability values for ropax vessel are more than 0.99 which is a good value for reliability and it is over the standard reliability values.

The reason for high reliability of Ropax vessel can be due to the limited failures during the life time of the vessel which may be related to the annual dry dock and maintenance activities accidents and production failures for Ropax hull structure are not common. Moreover there are not much electronic devices or machines which are causes failures for hull structure. Therefore the reliability analysis results are high.

Increasing the overall structural reliability of the Ropax vessel is directly related to increasing the reliability of cargo area and the side shell.

Ropax Criticality Analysis and Criticality Table

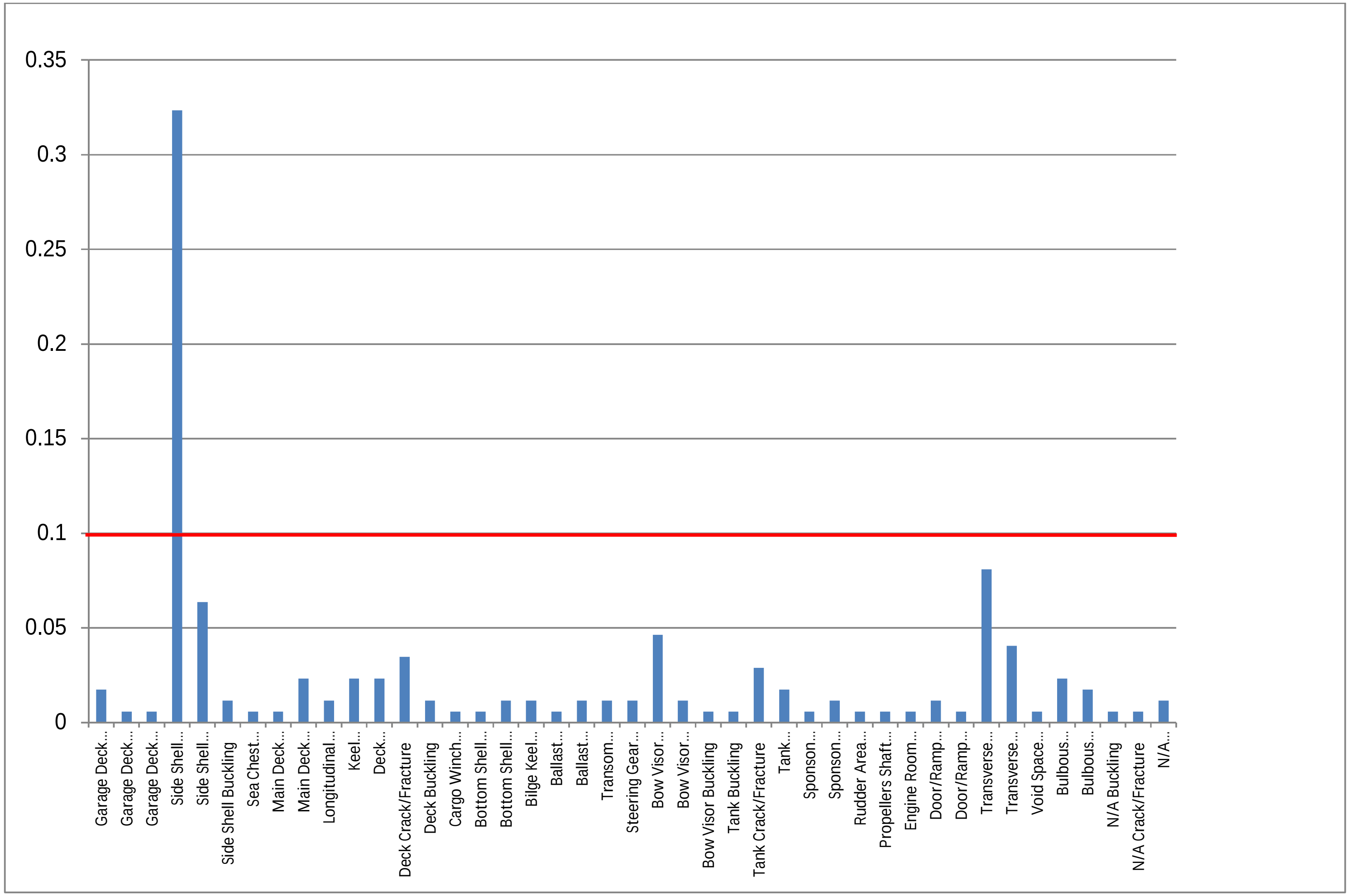

Figure5.35 Ropax criticality analysis

According to criticality analysis for ropax vessel, side shell part and transverse members are the most critical parts. Bow visor and deck are the other critical parts for Ropax vessel. Although the criticality value for some parts of the vessel is high, it is not affecting the operational availability of vessel. However in the dry docking period most of the steel replacement work is carried out on these parts.

Garage deck is the one of the critical parts of ropax where indent and deformation is the most observed failure. In this part cracks and fractures and buckling failures are also observed. Due to the loading and discharging activities garage deck can easily be worn out or damaged. This is directly related to typical operational activities (loading/unloading) of Ropax vessels. Therefore the failure rate is high for this area. However such failures do not affect the availability of Ropax vessels.

Due to the ship being in contact with port or other ships in regular frequency, side shell has the highest criticality with ropax vessel. Most common damages are fractures, buckling and cracks.

Although crack and fracture, indent and deformation are observed, there is no buckling failure for bottom shell. The number of the indent and deformation is more than crack and fracture.

In tank area, generally crack and fracture, buckling, indent and deformation are observed. The number of the crack and fracture is the highest observed failure in tanks while buckling is very low.

Although indent and deformation, crack and fracture are observed in transverse members, there is no buckling observed with transverse members. Due to the number of indent and deformation transverse member is identified as one of the most critical members.

Overall observation;

Although, there are high number of cracks, fractures, indents and deformation overall structural condition of ropax vessels are very good and these failures do not affect Ropax vessels reliability and availability. This may be due to the annual inspections required by regulations and involvement of passengers.

5.2.2 Chemical Tanker Reliability Analysis

Based on data from classification society, chemical tanker failures are listed in three category; buckling, indent and deformation, and cracks and fractures. Structural reliability analysis for chemical tanker is done using time based failure rate analysis. Failure rate are calculated as MTTF and MTBF. Numbers of the failures for specific areas are divided into time and time calculations are made in hours.

Cargo tanks are the one of the most critical areas for the chemical tanker. Due to nature of cargo, coating of the structure can be damaged easily. Especially epoxy coating can easily be affected by the cargo. Generally stainless steel, epoxy coating and zinc silicate materials are used for cargo areas. There are also some advanced coatings materials which are developed for chemical tanker coating such as polymer coatings. Each coating materials have advantages and disadvantages and each tank should be coated, specific to the type of cargo that it will carry.

Cleaning the cargo hold after the voyage is important for chemical tanker. Stainless steel coating is suitable for every cargo types and it is easy to clean. However it is four times more expensive than the epoxy coating. Epoxy coating is cheap but it is not suitable for every cargo types. Small pieces from the coating can easily mix with cargo due to the deformation and it may affect the quality of the cargos as well as causing corrosion.

Using stainless steel for coating is growing, there are some mix coating examples. Figure 5.36 which are collected from Jotankers shipping company website (28) is an example of a mix coating tank arrangement.

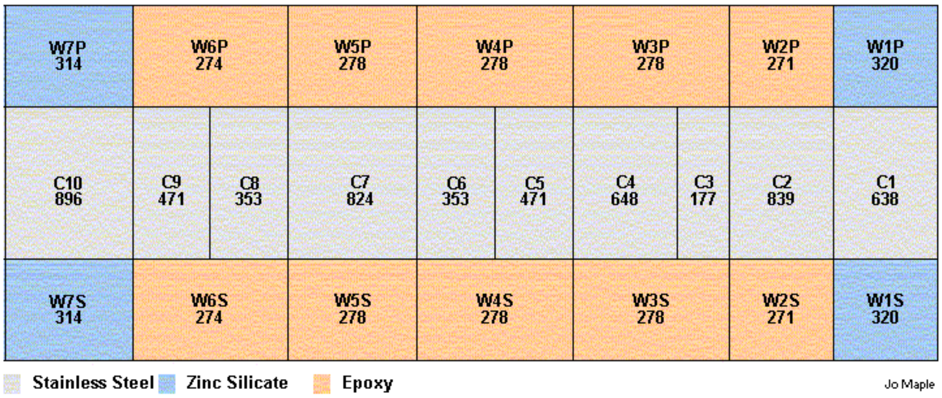

Figure5.36 An example of tank arrangement and tank coating of chemical tanker [28]

Structural failures are mostly observed in cargo areas of chemical tankers. One of the reasons for structural failure is cargo absorbing. Chemical tankers are able to carry various cargos which include acids. Therefore during the voyage cargo areas are affected by the cargo. Also after the discharging cargo these affect is continuing. Some cargo can be absorbed by cargo area and if the cargo area is not cleaned well, deformations in this area observed shortly.

Chemical tanker failure data is presented in Table5.10 which deals with 77 chemical tankers in the time period from 1998 until 2006 listing 134 different defects. Unfortunately we do not have the details of ships age and which ship had how many defects.

	General Defects			
Defected System	Buckling	Indent/Deformation	Cracks/Fractures	Total
Transom	1	2	1	4
Rudderstock		1	2	3
iPropeller		0	1	1
Machine		4	4	8
Deck	2	1	8	11
Forecastle		1	0	1
Bulb		4	1	5
Hull	2	24	10	36
Cargo Tank	2	3	25	30
Slope tank	2	0	2	4
Wing Tank	5	13	5	23
Peak Tank		1	1	2
Oil tank		0	1	1
Double Bottom Tank		2	3	5
Total	14	56	64	134

Table5.10 Chemical tanker failure data

Fault tree diagram for Chemical Tanker

Fault tree diagram for chemical tanker is developed using Or gates and basic events. Failure rates are assigned to basic events, which are listed as indent and deformation, crack and fracture and buckling. For chemical tanker structure, Or gate is developed by fourteen Or gates which are transom, rudderstock, propeller, machine, deck, forecastle, bulb, hull, cargo tank, slope tank, wing tank, peak tank, oil tank and double bottom tank.

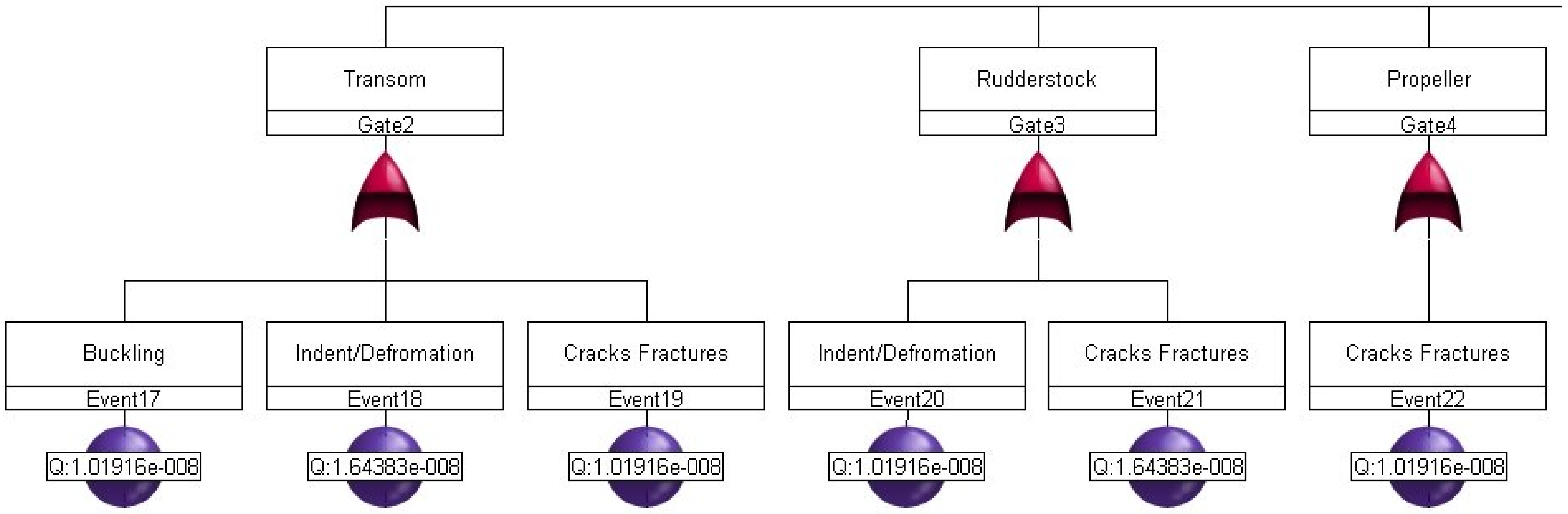

Figure5.37 Chemical tanker fault tree diagram part I

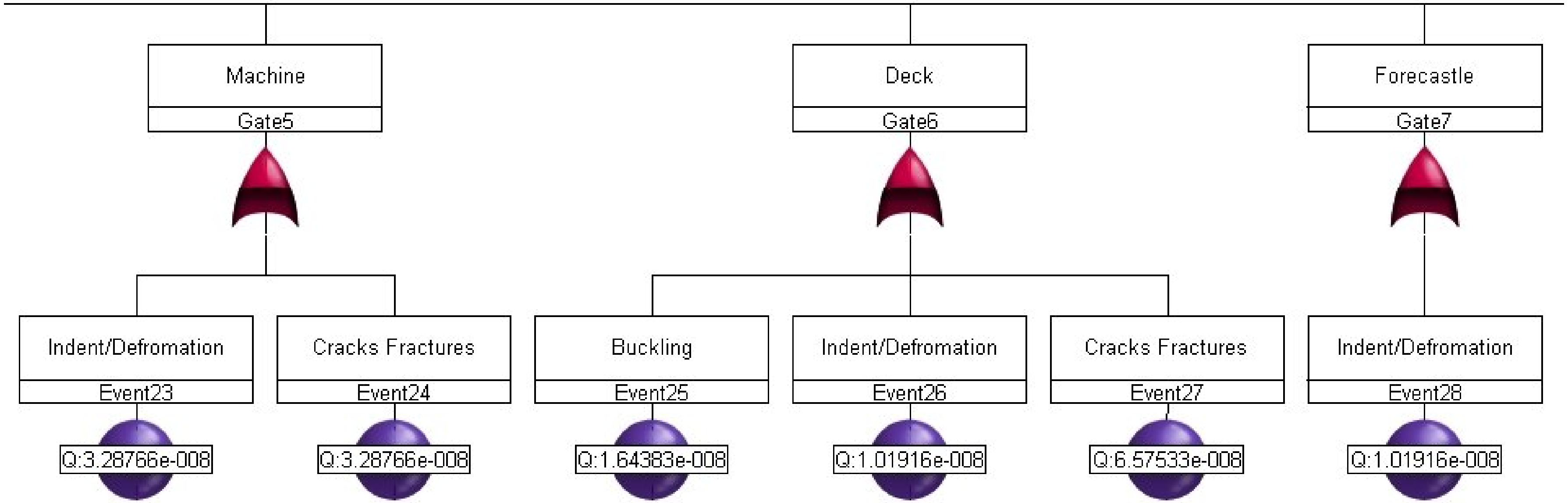

Figure5.38 Chemical tanker fault tree diagram part II

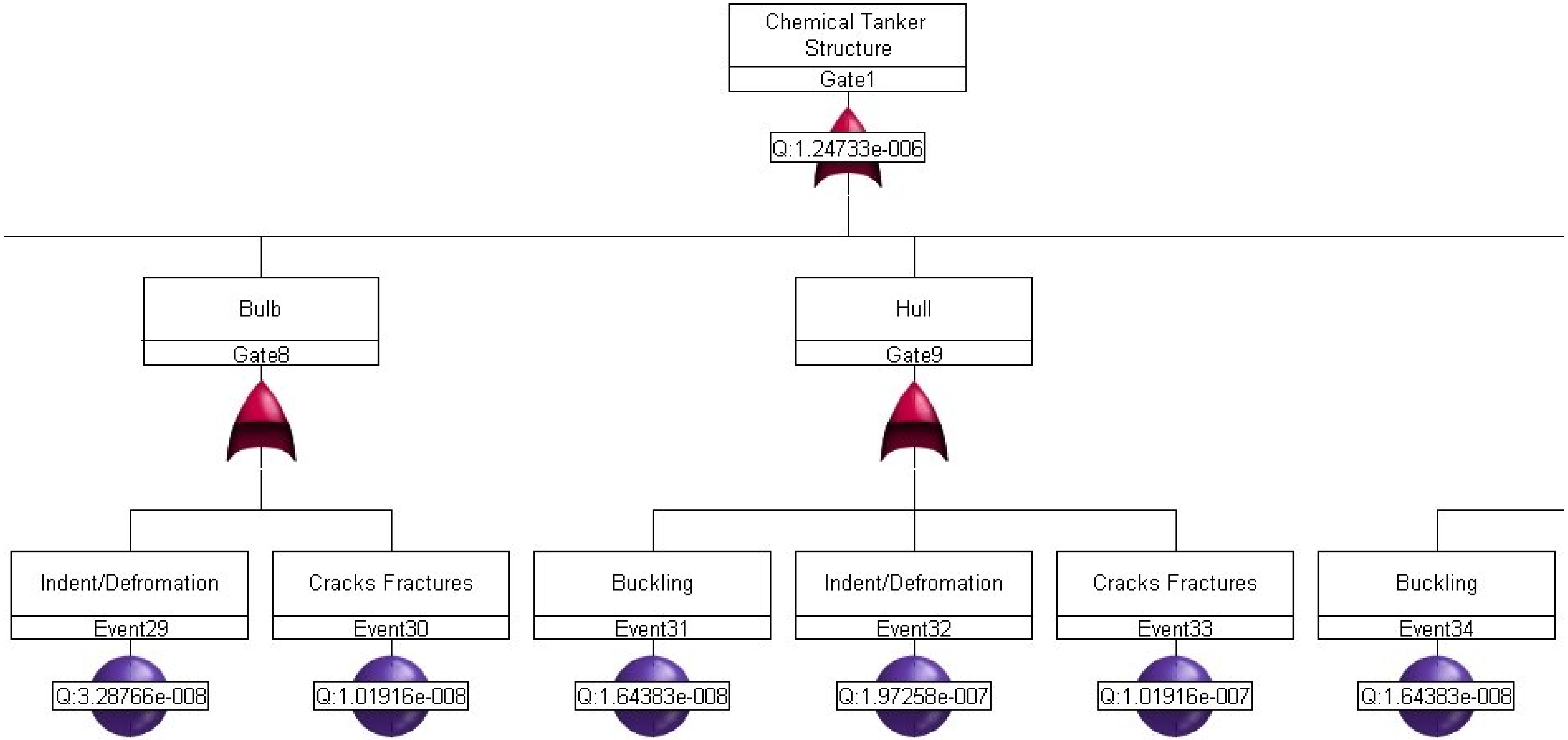

Figure5.39 Chemical tanker fault tree diagram part III

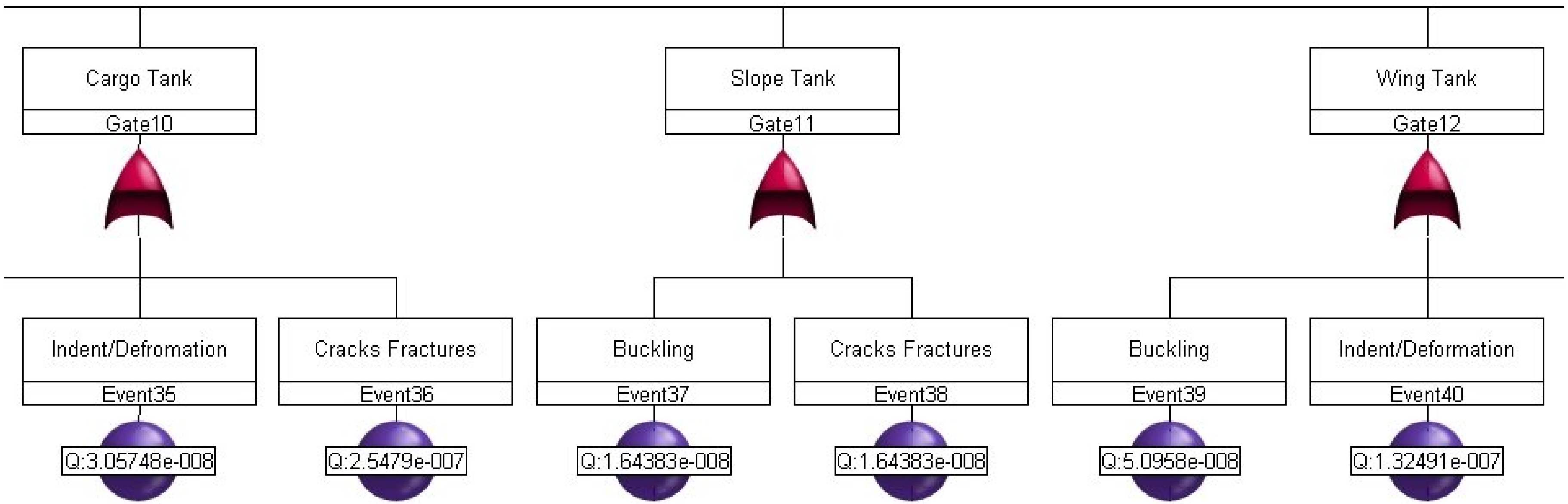

Figure5.40 Chemical tanker fault tree diagram part VI

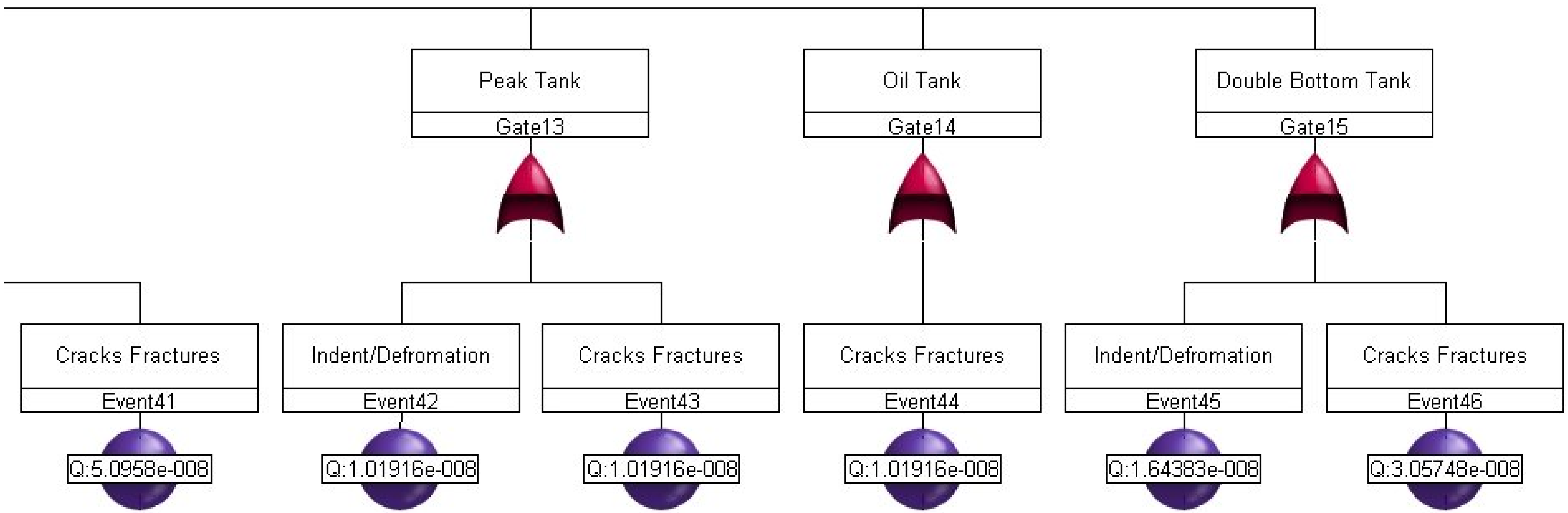

Figure5.41 Chemical tanker fault tree diagram part V

Comment1	Identifier	Criticality	Availability	Reliability	Unavailability	Unreliability
Chemical Tanker	Gate1		0.99999875	0.99962587	0.00000125	0.00037413
Transom	Gate2					
Buckling	Event17	0.008171	0.99999999	0.99999694	0.00000001	0.00000306
Indent/Defromation	Event18	0.013179	0.99999998	0.99999507	0.00000002	0.00000493
Cracks Fractures	Event19	0.008171	0.99999999	0.99999694	0.00000001	0.00000306
Rudderstock	Gate3					
Indent/Defromation	Event20	0.008171	0.99999999	0.99999694	0.00000001	0.00000306
Cracks Fractures	Event21	0.013179	0.99999998	0.99999507	0.00000002	0.00000493
Propeller	Gate4					
Cracks Fractures	Event22	0.008171	0.99999999	0.99999694	0.00000001	0.00000306
Machine	Gate5					
Indent/Defromation	Event23	0.026358	0.99999997	0.99999014	0.00000003	0.00000986
Cracks Fractures	Event24	0.026358	0.99999997	0.99999014	0.00000003	0.00000986
Deck	Gate6					
Buckling	Event25	0.013179	0.99999998	0.99999507	0.00000002	0.00000493
Indent/Defromation	Event26	0.008171	0.99999999	0.99999694	0.00000001	0.00000306
Cracks Fractures	Event27	0.052715	0.99999993	0.99998027	0.00000007	0.00001973
Forecastle	Gate7					
Indent/Defromation	Event28	0.008171	0.99999999	0.99999694	0.00000001	0.00000306
Bulb	Gate8					
Indent/Defromation	Event29	0.026358	0.99999997	0.99999014	0.00000003	0.00000986
Cracks Fractures	Event30	0.008171	0.99999999	0.99999694	0.00000001	0.00000306
Hull	Gate9					
Buckling	Event31	0.013179	0.99999998	0.99999507	0.00000002	0.00000493
Indent/Defromation	Event32	0.158145	0.9999998	0.99994082	0.0000002	0.00005918
Cracks Fractures	Event33	0.081708	0.9999999	0.99996943	0.0000001	0.00003057
Cargo Tank	Gate10					
Buckling	Event34	0.013179	0.99999998	0.99999507	0.00000002	0.00000493
Indent/Defromation	Event35	0.024512	0.99999997	0.99999083	0.00000003	0.00000917
Cracks Fractures	Event36	0.204269	0.99999975	0.99992357	0.00000025	0.00007643
Slope Tank	Gate11					
Buckling	Event37	0.013179	0.99999998	0.99999507	0.00000002	0.00000493
Cracks Fractures	Event38	0.013179	0.99999998	0.99999507	0.00000002	0.00000493
Wing Tank	Gate12					
Buckling	Event39	0.040854	0.99999995	0.99998471	0.00000005	0.00001529
Indent/Deformation	Event40	0.10622	0.99999987	0.99996025	0.00000013	0.00003975
Cracks Fractures	Event41	0.040854	0.99999995	0.99998471	0.00000005	0.00001529
Peak Tank	Gate13					
Indent/Defromation	Event42	0.008171	0.99999999	0.99999694	0.00000001	0.00000306
Cracks Fractures	Event43	0.008171	0.99999999	0.99999694	0.00000001	0.00000306
Oil Tank	Gate14					
Cracks Fractures	Event44	0.008171	0.99999999	0.99999694	0.00000001	0.00000306
Double Bottom Tank	Gate15					
Indent/Defromation	Event45	0.013179	0.99999998	0.99999507	0.00000002	0.00000493
Cracks Fractures	Event46	0.024512	0.99999997	0.99999083	0.00000003	0.00000917

Table5.11 Fault tree reliability analysis results for chemical tanker

Chemical Tanker Criticality Analysis and Criticality Table

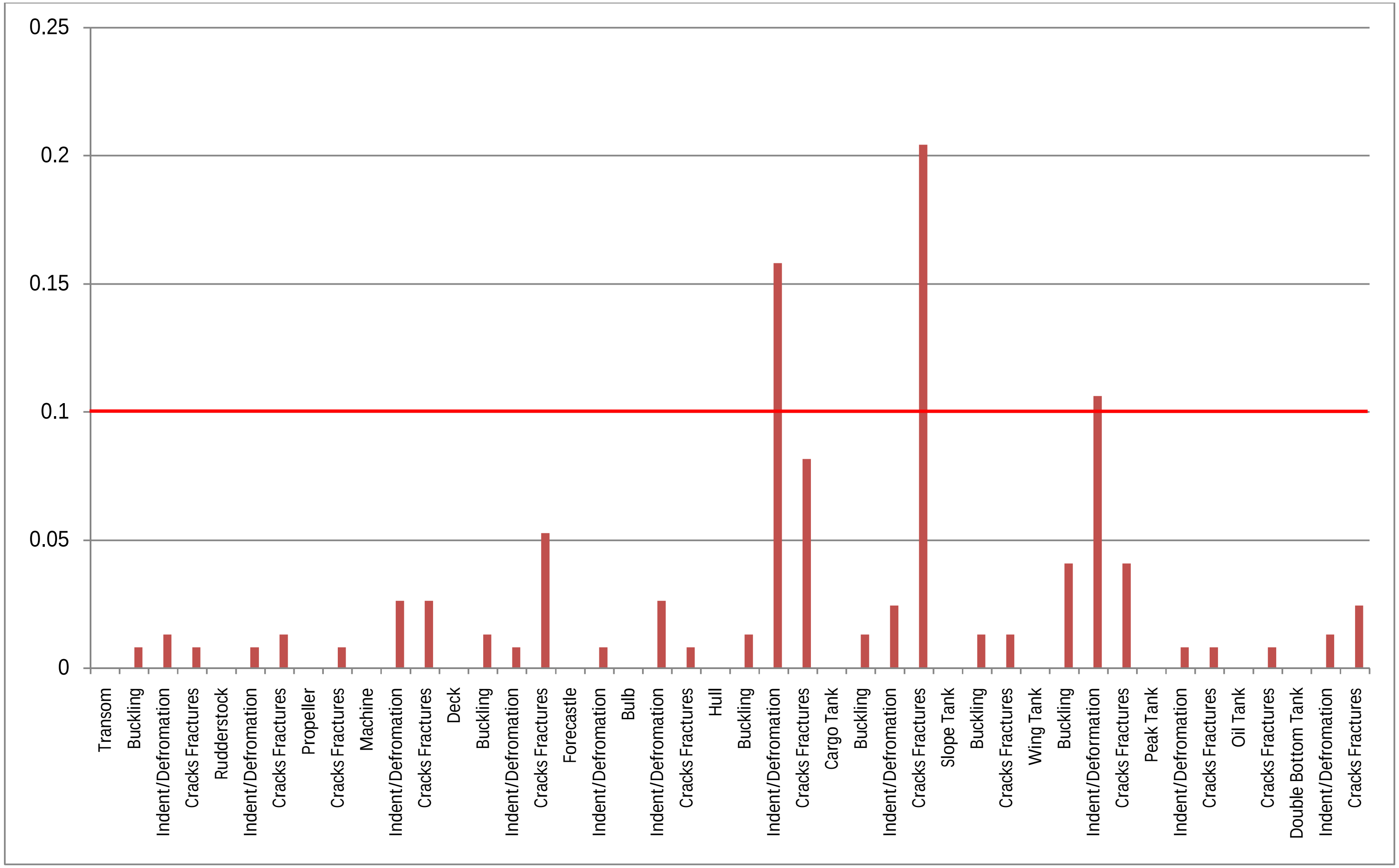

Figure5.42 Chemical tanker criticality analysis

According to chemical tanker criticality calculations, most critical parts of chemical tankers are hull and cargo tanks, while wing tanks and deck are identified as the second most critical parts.

In cargo tanks buckling, indent and deformations, cracks and fractures are observed and cracks and fractures are the most occurred failures in cargo tanks of chemical tanker structure. Chemical tankers are carrying various type of cargo. It is very important to protect cargo tanks by cleaning of the tanks properly after discharging is completed. Bad cleaning can cause of worn out and corrosion, therefore high number of failure can be observed in this area.

In hull, buckling, indent and deformations, cracks and fractures are observed and hull indent and deformations are the most observed failures for hull.

Wing tanks are the other critical part for chemical tankers, as buckling, indent and fractures, cracks and fractures are observed in wing tanks. Indent and deformations are the most observed failures in wing tanks.

Deck is the other critical part of the chemical tankers, where buckling, indent and deformations, cracks and fractures are observed, while cracks and fractures are the most observed failure on deck area.

Indent and deformations, cracks and fractures are observed but no buckling in bulb area. Indent and deformations are the most observed failures.

Cargo tank area is the most critical part chemical tanker.

5.2.3 General Cargo Vessel Reliability Analysis

Using the repair and maintenance data for 35 different general cargo vessels from Turkish shipyard, reliability analysis is carried out. The vessels are handy size general cargo vessels between 2000 dwt to 7000 dwt. Most of them are under Turkish flag. There are some other flags as well. Malta, Russia, Romania, Bulgaria and Ukraine are the some examples of the other flags. The vessels are working around Black Sea, Sea of Marmara, Aegean Sea and Mediterranean Sea. Some of the vessels, mostly Russians, are operating in rivers as well.

The age of the vessels are varying between 15 and 35. Most of the ships are over 25 years of age. There is one ship which is 47 years old in the shipyard as Turkish owner just bought from Greek operator which needs plenty steel work.

There is an annual survey for general cargo vessels, which normally does not need dry docking. Every two and half year period there is an intermediate survey which needs dry docking and every 5 years special survey or class renewed survey. Which also needs dry docking.

The ships in this study are working with different classification societies which are ABS class and BV class, and some ships are in TL class. There are some other classification societies but number of ships under them is lower.

These vessels are generally owned by families which have just one or two ships. Therefore operators want their vessels in operation all the time. As a result operators put pressure on shipyard and ship crew to finish the repair work as soon as possible and with lower repair cost. Furthermore operators are staying in shipyard during the repair time to have the direct control of the repair work in shipyard. Operators, which are Turkish, generally control the repair work by themselves. Other operators who work with inspectors generally prefer the Turkish speaker inspectors to control the repair work in shipyard.

One of the most observed steel renewed area with cargo ship is cargo hold area. There are lot of reasons for steel replacement in cargo hold. During the cargo loading, cargo can be released from height by the winches so cargo crashes on to cargo hold area and make damages on it. Moreover during the cargo discharging, sometimes forklifts are used in the cargo hold area. Forklifts can hit the cargo hold area or even just using forklift without any crash can damage the bottom area by it tyres. Forklift causes damage to ground coating. Also during the repair period in ship yard cargo holds can easily be damaged by workers as well. The workers with low attention can easily drop tool and damage bottom area or during the cleaning of the cargo hold lifting the rubbish or old steels with winches can be another reason for the damage. The rubbish or old steels can fall down during the lifting because of poor fastening.

Figure5.43 Lifting activity

Other reason for steel replacement in cargo hold is bad coating. Protection of steel thickness from corrosion is directly related to good coating. In the dry docking period generally operator applies good coating and shipyard cleans the surface properly. However during the operations, it is very difficult to clean the surface properly. Cleaning done by crew and crew does it with hammers and it is not cleaned properly. There are some gaps occurred between the surface and coating and water and air can easily enter to this gaps and causes corrosion.

The next most steel replacement area is shell plate. Because of corrosion the thickness of the shell plate can easily decrease and should be replaced. They are generally large size plates so the weight of steel replacement. Bad coating or damage to coating is one of the reasons for corrosion. Other reason is that there is no zinc on the plate or zincs are not working properly.

During anchoring to port, shell plate can hit the port side and can cause damage to the shell plate. Also tug used for anchoring causes similar damage to shell plate.

In general, operators would like to pay as little as possible for maintenance & repair work and naturally where possible prefer small piece of plate to be renewed. Although operators would like to change the only critical steel work rather than advised amount, this requires more welding which causes more deformation. As a result more steel work is affected and more steel is required to be replaced in the life cycle period of the ship. If the operator agrees the make the advised repair work, large plate of steel will be replaced by less welding and this area will not need any repair work for a long time unless there is an accident. However the operator decides to repair the just critical area with small botch. This naturally lead to the repair of those areas during next dry docking results in more welding of plate.

Fault tree diagram for General Cargo Vessel

Similar to other ships reliability analysis for general cargo vessel is done using the fault tree analysis which is formed by Or gates and basic events. Failure rate is calculated by using steel replacement data. Which are based on time and operational hours.

The failure rates are calculated according to replaced steel amount in kilo and analysis are made based on 30 years of ship life cycle. In order to calculate the failure rate, each part of the vessel replaced steel amount is divided by total operational life of the ship. It is also assumed that for operational time per year roughly 350 days. Failure rate is calculated as;

$$FR = RSA/30*350*24*SN \qquad (42)$$

Where ;

FR	Failure Rate
RSA	Replaced Steel Amount (kg)
30	Life Time (year)
350	Average Available Days (per year)
24	Hour
SN	Ship Number

Then calculated failure rates for cargo ship are given in Table5.12.

	STEEL REPAIR WORK	AMOUNT(KG)	FAILURE RATE
1	AFT PEAK TANK	16926.996	0.001919161
2	BALLAST	3607.498	0.000409013
3	BRACKET	920.22	0.000104333
4	BULB	4899.783	0.000555531
5	BULKHEAD	32952.612	0.003736124
6	CARGO HOLDS	30343.10995	0.003440262
7	CENTER GIRDER	917	0.000104018
8	CHAIN LOCKER	15590.62912	0.001767645
9	CHAIN ROOM	73017	0.008278588
10	COAMINGS	48900.285	0.00554425
11	CROSS DECK	5336.46	0.000605041
12	DOUBLE BOTTOM	79220.04427	0.008981864
13	E.R. SLUDGE TANK INSERTS	18343.54	0.002079767
14	ENGINE ROOM	29962.79	0.003397142
15	FLOOR INSERT	18865.40	0.002138934
16	FORE CASTLE DECK	11327.2	0.001284263
17	FORE PEAK DECK	81577.767	0.00924918
18	FORE PEAK TANK	170291.7878	0.019307459
19	FRAME INSERT	244459.9239	0.027716545
20	FRESH WATER TANK	16174.32	0.001833823
21	FWD. DECK INSERT	12291	0.001393537
22	GIRDER	25561	0.002898073
23	HATCH BEAM PLATES	1765	0.000200097
24	HATCH COVER RAIL WAY	782	0.0000887
25	HATCH COVER	6975.2592	0.000790846
26	HOLD BULKHEAD	365.427	4.14316E-05
27	HOPPER PLATES	55	6.23583E-06
28	INNER BOTTOM PLATE	49002	0.005555797
29	INNER SIDE INSERTS	259	2.93619E-05
30	MAIN DECK	154289.1722	0.017493103
31	MENHOL	9765.483	0.001107198
32	PAINT ROOM INSERTS	2058.00	0.000233333
33	PARAMPET	8226.9753	0.000932764
34	PIPE GUARD * 6	186.08	2.10975E-05
35	POOP DECK PLATES	7087.71	0.000803595
36	PUMP ROOM INSERTS	6546.54	0.000742238
37	SHELL PLATE	404073.10	0.045813277
38	SIDE GIRDER STB.	1008	0.000114286
39	STRINGER	39639.8436	0.004494313
40	SUPERSTRUCTURE	1787.84	0.000202703
41	TANK TOP	67857.8807	0.007693637
42	TRIM TANK	141310.54	0.016021603
43	WHEELHOUSE DECK	10924	0.001238549
44	WING TANK A (PORT)	8215	0.000931406

Table5.12 General cargo vessels failure data

Basic events are developed using steel replacement data which can be listed as aft peak tank, ballast tank, bracket, bulb, bulkhead, cargo holds, centre girder, chain locker, chain room, coamings, cross deck, double bottom, sludge tank inserts, engine room, floor insert, fore castle deck, fore pick deck, fore pick tank, frame insert, fresh water tank, deck insert, girder, hatch beam plates, hatch cover rail way, hatch cover, hold bulkhead, hopper plates, inner bottom plate, inner side inserts, main deck, menhol, paint room inserts, parampet, pipe guard, poop deck plates, pump room inserts, shell plate, side girder, stringer, superstructure, tank top, trim tank, wheelhouse deck and wing tank. The developed fault tree for general cargo ship is provided in Figures5.44-5.51.

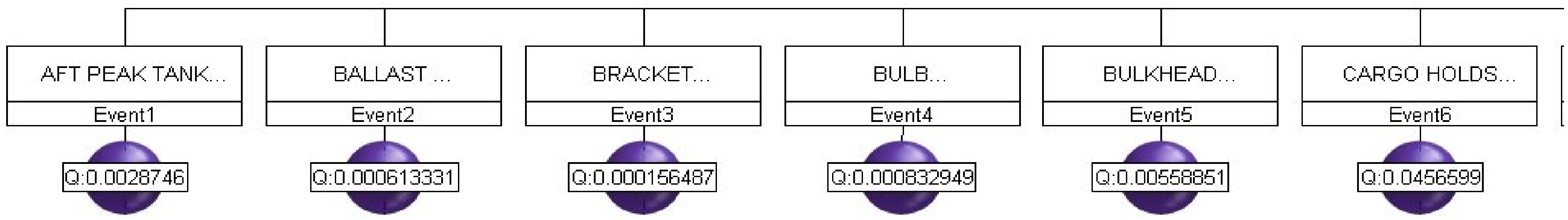

Figure5.44 Fault tree diagram for general cargo vessel part I

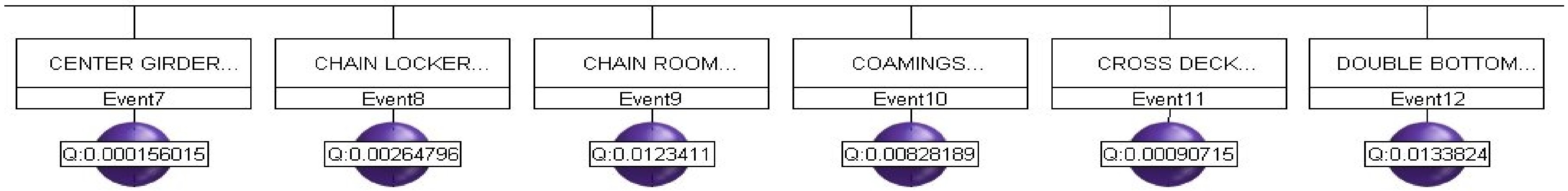

Figure5.45 Fault tree diagram for general cargo vessel part II

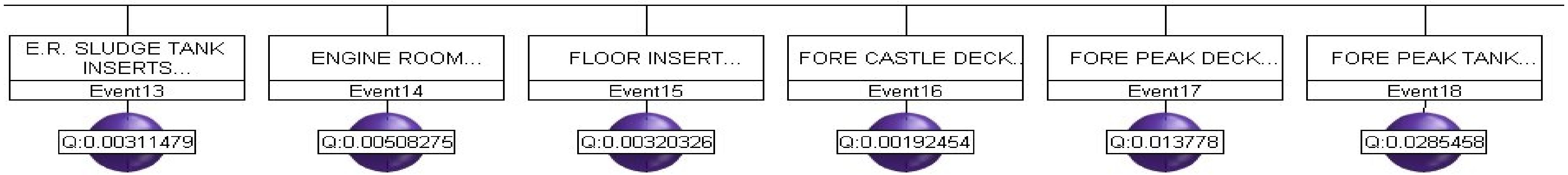

Figure5.46 Fault tree diagram for general cargo vessel part III

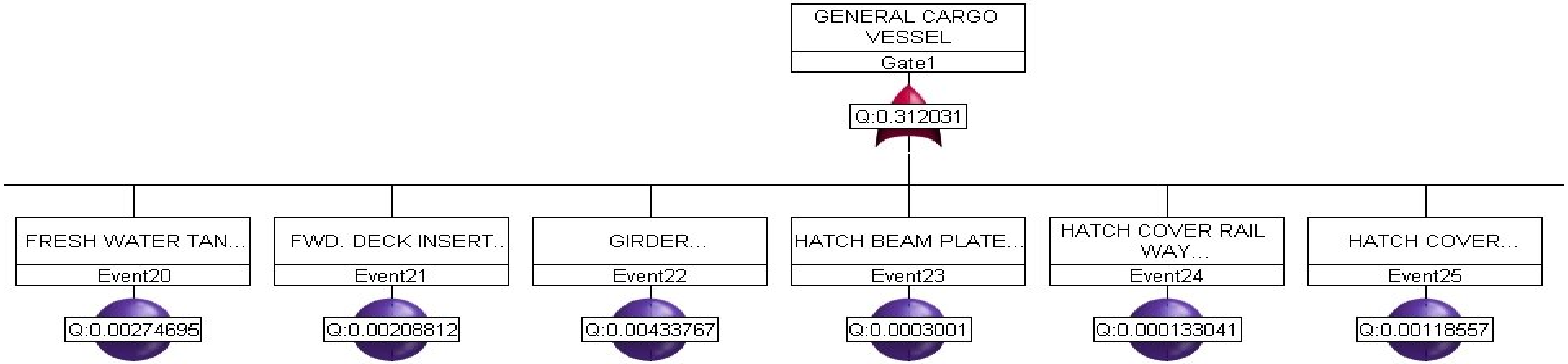

Figure5.47 Fault tree diagram for general cargo vessel part IV

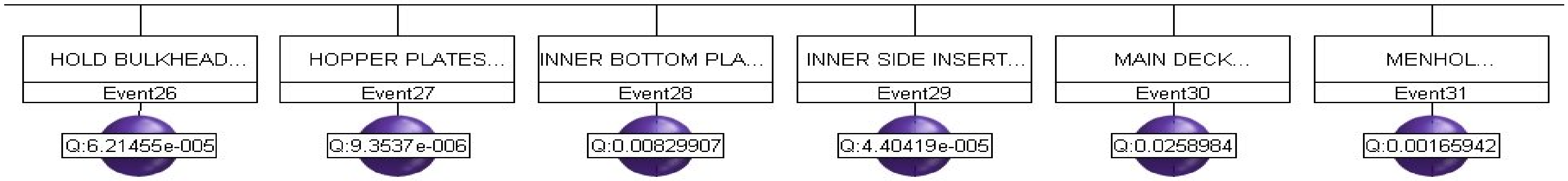

Figure5.48 Fault tree diagram for general cargo vessel part V

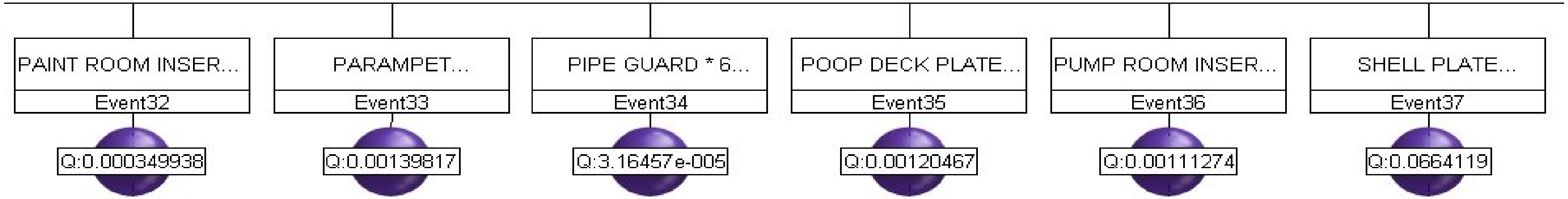

Figure5.49 Fault tree diagram for general cargo vessel part VI

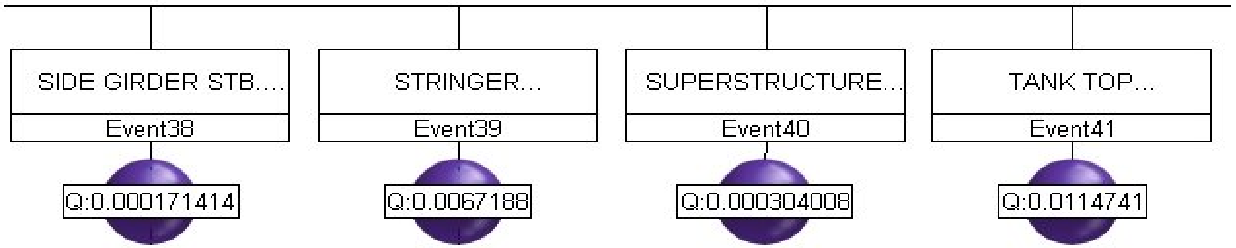

Figure5.50 Fault tree diagram for general cargo vessel part VII

Figure5.51 Fault tree diagram for general cargo vessel part VIII

Fault tree reliability analysis results for General Cargo Vessel

Comment1	Identifier	Criticality	Availability	Reliability	Unavailability	Unreliability
GENERAL CARGO VESSEL	Gate1		0.999788702	0.999788702	0.000211298	0.000211298
AFT PEAK TANK	Event1	0.009213	0.999998081	0.999998081	1.9192E-06	1.9192E-06
BALLAST	Event2	0.001966	0.999999591	0.999999591	0.000000409	0.000000409
BRACKET	Event3	0.00502	0.999999896	0.999999896	1.043E-07	1.043E-07
BULB	Event4	0.002669	0.999999445	0.999999445	5.555E-07	5.555E-07
BULKHEAD	Event5	0.01791	0.999996264	0.999996264	3.7361E-06	3.7361E-06
CARGO HOLDS	Event6	0.146331	0.999968844	0.999968844	3.11563E-05	3.11563E-05
CENTER GIRDER	Event7	0.0005	0.999999896	0.999999896	0.000000104	0.000000104
CHAIN LOCKER	Event8	0.008486	0.999998232	0.999998232	1.7676E-06	1.7676E-06
CHAIN ROOM	Event9	0.039551	0.999991721	0.999991721	8.2786E-06	8.2786E-06
COAMINGS	Event10	0.026542	0.999994456	0.999994456	5.5442E-06	5.5442E-06
CROSS DECK	Event11	0.002907	0.999999395	0.999999395	0.000000605	0.000000605
DOUBLE BOTTOM	Event12	0.042888	0.999991018	0.999991018	8.9818E-06	8.9818E-06
E.R. SLUDGE TANK INSERTS	Event13	0.009982	0.99999792	0.99999792	2.0798E-06	2.0798E-06
ENGINE ROOM	Event14	0.016289	0.999996603	0.999996603	3.3971E-06	3.3971E-06
FLOOR INSERT	Event15	0.010266	0.999997861	0.999997861	2.1389E-06	2.1389E-06
FORE CASTLE DECK	Event16	0.006168	0.999998716	0.999998716	1.2843E-06	1.2843E-06
FORE PEAK DECK	Event17	0.044156	0.999990751	0.999990751	9.2491E-06	9.2491E-06
FORE PEAK TANK	Event18	0.091484	0.999980693	0.999980693	1.93073E-05	1.93073E-05
FRESH WATER TANK	Event20	0.008803	0.999998166	0.999998166	1.8338E-06	1.8338E-06
FWD. DECK INSERT	Event21	0.006692	0.999998607	0.999998607	1.3935E-06	1.3935E-06
GIRDER	Event22	0.013901	0.999997102	0.999997102	2.8981E-06	2.8981E-06
HATCH BEAM PLATES	Event23	0.000962	0.9999998	0.9999998	2.001E-07	2.001E-07

HATCH COVER RAIL WAY	Event24	0.000426	0.999999911	0.999999911	8.87E-08	8.87E-08
HATCH COVER	Event25	0.0038	0.999999209	0.999999209	7.908E-07	7.908E-07
HOLD BULKHEAD	Event26	0.000199	0.999999959	0.999999959	4.14E-08	4.14E-08
HOPPER PLATES	Event27	0.00003	0.999999994	0.999999994	6.2E-09	6.2E-09
INNER BOTTOM PLATE	Event28	0.026597	0.999994444	0.999994444	5.5558E-06	5.5558E-06
INNER SIDE INSERTS	Event29	0.000141	0.999999971	0.999999971	2.94E-08	2.94E-08
MAIN DECK	Event30	0.082999	0.999982507	0.999982507	1.74929E-05	1.74929E-05
MENHOL	Event31	0.005318	0.999998893	0.999998893	1.1072E-06	1.1072E-06
PAINT ROOM INSERTS	Event32	0.001121	0.999999767	0.999999767	2.333E-07	2.333E-07
PARAMPET	Event33	0.004481	0.999999067	0.999999067	9.328E-07	9.328E-07
PIPE GUARD * 6	Event34	0.000101	0.999999979	0.999999979	2.11E-08	2.11E-08
POOP DECK PLATES	Event35	0.003861	0.999999196	0.999999196	8.036E-07	8.036E-07
PUMP ROOM INSERTS	Event36	0.003566	0.999999258	0.999999258	7.422E-07	7.422E-07
SHELL PLATE	Event37	0.212837	0.999954188	0.999954188	4.58122E-05	4.58122E-05
SIDE GIRDER STB.	Event38	0.000549	0.999999886	0.999999886	1.143E-07	1.143E-07
STRINGER	Event39	0.021532	0.999995506	0.999995506	4.4943E-06	4.4943E-06
SUPERSTRUCTURE	Event40	0.000974	0.999999797	0.999999797	2.027E-07	2.027E-07
TANK TOP	Event41	0.036772	0.999992306	0.999992306	7.6936E-06	7.6936E-06
TRIM TANK	Event42	0.076101	0.999983979	0.999983979	1.60215E-05	1.60215E-05
WHEELHOUSE DECK	Event43	0.005948	0.999998762	0.999998762	1.2385E-06	1.2385E-06
WING TANK A (PORT)	Event44	0.004474	0.999999069	0.999999069	9.314E-07	9.314E-07

Table5.13 Fault tree reliability analysis results for general cargo vessel

According to reliability analysis for general cargo vessels, shell plate and cargo holds areas have the lowest reliability (Table5.13). Fore peak tank and main deck have the next lowest reliability values. Reliability values for general cargo vessels are varying between 0.99995 and 1 while average value is 0.999788, which is a quite high reliability value. This demonstrates that although there are local damages, these damages and failures do not decrease the reliability of the structure and the overall reliability of general cargo vessels.

General Cargo Vessel Criticality Analysis and Criticality Table

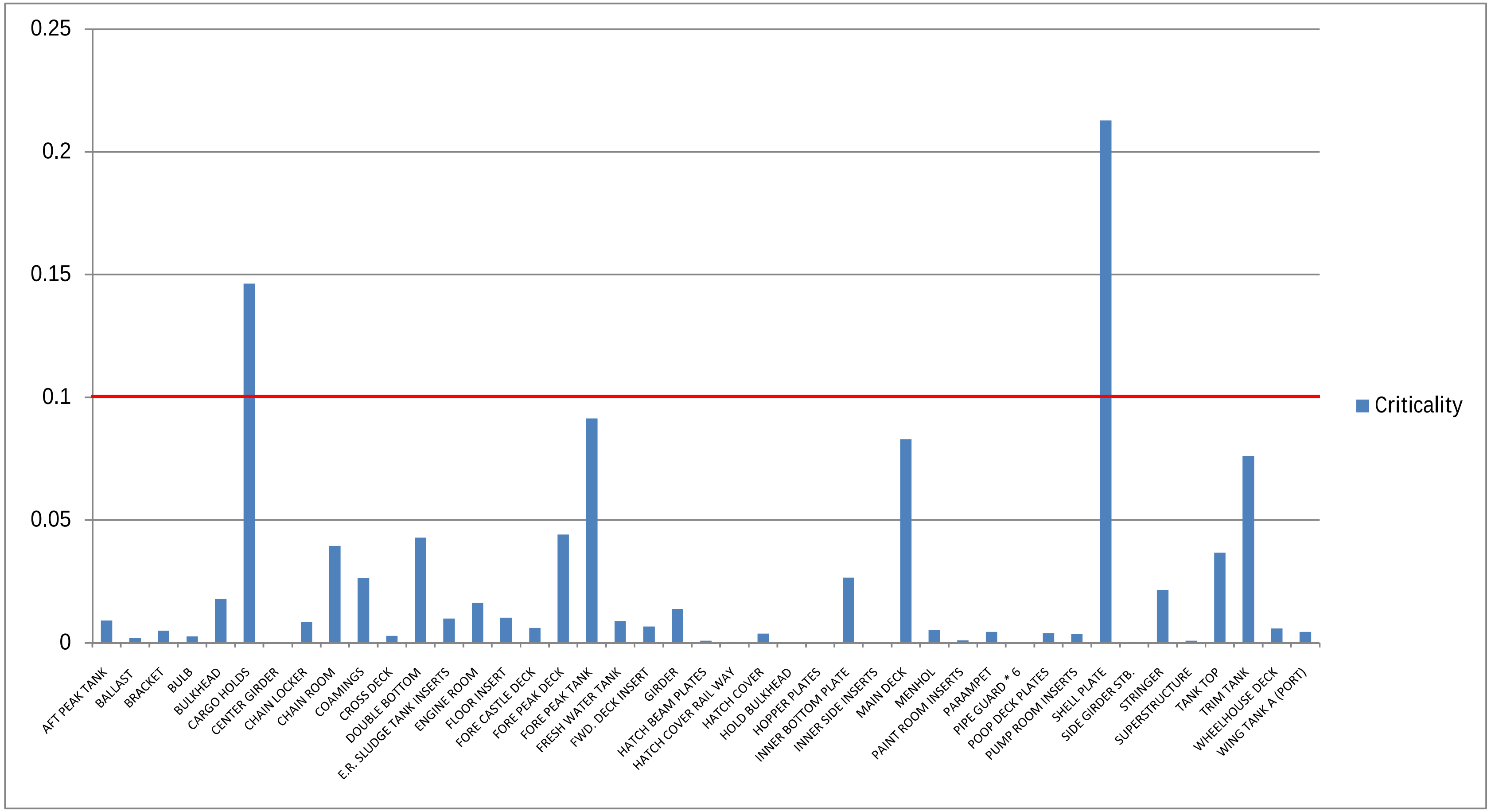

Figure5.52 General cargo vessel criticality analysis

Criticality analysis of general cargo vessels shows that the most critical parts are shell plate and cargo holds (Figure5.52). Shell plate has the highest critical value which is more than 0.2 and this is followed by cargo holds shell plate with a value over 0.1. Fore peak tank, main deck, trim tank are the other high critical areas for which the critical values are higher than 0.05. Chain room, coamings, double bottom, fore peak deck, inner bottom plate and tank top are under 0.05. Aft peak, ballast, bulb, bulkhead, centre girder, chain locker, cross deck, sludge tank, engine room, fore castle deck, fresh water tank, girder, hatch beam plates, hatch cover railway, poop deck, pump room, paint room, superstructure, wheelhouse deck and wing tank areas are the other areas where failures are observed.

Summary:

In chapter 5, data collected from repair yard, ship operators and classification society are analysed by using fault tree analysis and regression analysis.

Regression analyses are carried out for general cargo vessel, tanker, bulker and ropax vessel. According to these analyses the unavailability time due to dry docking and the replaced steel amount are formulated as function of ship type and age. Tanker vessels have the highest unavailability time compared to the other ships and general cargo vessels have the highest steel replacement.

Fault tree analyses are carried out for ropax vessel, general cargo vessel and chemical tanker. Reliability, availability and criticality values are calculated from these analyses and results clearly demonstrate the very high hull structural reliability for these type vessels. The critical parts for each vessel types can be listed as shell plate for ropax, cargo tanks for chemical tanker and shell plate and cargo holds for general cargo vessel.

Fault tree analyses show the critical parts of the each vessel. Due to these analyses in improvement of reliability of these parts in design and production stage or during the operation stage will bring more reliable hull structure and less maintenance and repair work and cost. Fault tree analyses results can be used to improve the reliability of each vessel which will bring more saving in operation cost and less maintenance and repair work.

CHAPTER 6 RUNNING COST MODEL

6.1 Running Cost Model

Running cost model is developed by taking into account the detailed repair and maintenance cost, which change according to type, age, size, classification society, and flag of vessel. It is possible to expand the model by bringing maintenance strategy into the model.

As size of the ship is one of the most important parameters for maintenance cost calculation, the running cost model calculations are performed also based on size of the vessels. The biggest cost value of maintenance and repair is steel replacement and steel replacement cost calculated according to age and size of the vessel. As proven in chapter 5 there is a direct relationship between the light weight and replaced steel amount, and during the field study at shipyard, it was found out that in general, operators do not have any idea about the light weight of the vessel. Therefore as a first step DWT and Light weight relationship for different types of ships are established. These calculations are made based on the existing vessels with lightweight information.

From existing ships, DWT and light weight data are collected and the relation between DWT and lightweight is established for general cargo vessel, ferry, ro-ro, bulker, tanker and chemical tanker. By using this relation, it is possible to calculate the light weight of the vessel if DWT of the vessel is known.

The running cost model is developed by using the relation between lightweight of the ship and maintenance and repair cost. The general ship related information used in the model is listed in Table 6.1.

Length o.a. (m)
Length b.p. (m)
Breadth mld. (m)
Max. draught (m)
GRT (ton)
NRT (ton)
DWT (ton)
LWT (ton)
Escalation Rate
Discount Rate
Original lightweight (ton)
Original Displacement (ton)
Original DWT (ton)
New lightweight (ton)
Var (lightweight) (ton)
New Displacement (ton)
New DWT (ton)
V design speed (knot)

Table6.1 General information table for vessels

The running cost model make also use of the following information;

- Amount of repaired steel
- Total area of coating
- Cost of unavailability
- Earning of dismantling

Amount of repaired steel cost is calculated based on unit price of steel replacement per kg. This value changes according to shipyard, country, class and flag. Coating cost is calculated based on total area of coating per square meter and price of coating paint per kg. This value also changes according to shipyard, country, coating quality and coating company. Cost of unavailability is calculated as well. Cost of unavailability is calculated based on number of days in dry dock and cost of one day downtime.

In Table 6.2 amount of repaired steel, total area of coating and cost of unavailability are presented with their abbreviations. As it is indicated in Table 6.2 some of the values are variable and some of them constant. Unit price of steel replacement/kg and price of coating is constant. Amount of repaired steel, total area of coating, days in dry dock and cost of one day downtime are variable parameters.

Cost Elements	Abbreviation of Cost Elements	Type	Function of
Amount of repaired steel	ARS	Variable	Lightweight
Unit Price of steel replacement / kg	Prstrp	Constant	
Cost of steel replacement	COSR @ current prices		
	Escalated COSR		
	Discounted COSR		
	COSR		
total area of coating (m^2)	TAC	Variable	ARS
Price of coating	PrCOA	Constant	
Coating	COA @ current prices		
	Escalated COA		
	Discounted COA		
	COA		
Days in dry dock	Ddock	Variable	Year
Cost of one day downtime (unavailability)	CDDT	Variable	Revenue
Cost of unavailability	CUNA @ current prices		
	Escalated CUNA		
	Discounted CUNA		
Cost of unavailability	CUNA		
	CODO - NPV		

Table6.2 Running cost model part I

The Cost of Steel Replacement

According to interviews carried out with ship repair yards and operators, steel replacement is very rare before 10 years of age. Steel replacement usually takes place every 2.5 years following the intermediate and special surveys.

Common practice with regards to calculating cost of steel replacement is given in unit price per kg (Pr_{strp}) depending on the location of the yard where the replacement is taken place. For example, In China, this figure is 1.6 - 1.7 $ per kg regardless of the ship's zone, 5 - 6 € per kg in Greece, 3 – 4 $ per kg in Turkey, all including labour and material costs and excluding coating costs. In general these steel processing prices include material, workmanship, lighting, ventilation, and hanging staging included but excludes staging, tank cleaning, testing the tanks and access work. Coating is also a separate job.

The cost of steel replacement, COSR, is calculated by using the following formula:

$$COSR = ARS \times 1{,}000 \times Pr_{strp} \quad (43)$$

Based on the Tanker data, ARS is calculated by using the following regression formula:

$$ARS = \text{Lightweight (tonnes)} \times 0.1451 \times (e)^{0.1814 \times (age)} / 1{,}000 \quad (44)$$

Based on the data of passenger vessels, ARS is calculated by using the following regression formula:

$$ARS = \text{Lightweight (tonnes)} \times 11.545 \times (e)^{0.0742 \times (age)} / 1{,}000 \quad (45)$$

Where

Symbol	Description	Unit
COSR	The cost of steel replacement	€
ARS	The amount of replaced steel	Tonnes
Pr_{strp}	The unit price of steel replacement	€/kg

The Cost of Coating

This cost item includes the coating which is carried out for the replaced steel during dry-docking. This cost, COA, is calculated as

$$COA = TAC \times Pr_{COA} \qquad (46)$$

Where

Symbol	Description	Unit
COA	The cost of coating	€
TAC	The total area of coating	m^2
Pr_{COA}	The unit price of coating per m^2, including material and labour	€/ m^2

TAC can be calculated using the following regression

$$TAC = ARS \times 1000 / (8*(\text{Average Thickness})) \qquad (47)$$

The Cost of Unavailability

The main assumption here is that the unavailable days considered in this study are the days spent during dry-docking, D_{dock}, assuming

$$D_{sea} \ (= D_{sea\text{-}ld} + D_{sea\text{-}bal} + D_{port}) + D_{dock} = 365 \qquad (48)$$

Where

Symbol	Description	Unit
D_{dock}	Number of days in shipyard	
D_{port}	Number of days in port	
D_{sea-ld}	Number of days at sea in loaded condition	
$D_{sea-bal}$	Number of days at sea in ballast condition	

The following formula is used for calculating the cost of unavailability (CUNA) per year:

$$CUNA = D_{dock} \times C_{DDT} \qquad (49)$$

Where

C_{DDT} = Cost of one day down-time because of the unavailability of the subject vessel,

D_{dock} = The number of down-time days spent during dry-docking

Finally, the total cost of periodic maintenance is equal to the sum of the cost of steel replacement, the cost of coating and the cost of unavailability as shown below:

$$CODO = COSR + COA + CUNA \qquad (50)$$

Where

Symbol	Description	Unit
COSR	The cost of steel replacement	€
COA	The cost of coating	€
CUNA	The cost of unavailability	€

The bunker cost includes lubrication oil, heavy oil and diesel. Calculation of bunker cost is performed based on engine power, daily fuel oil consumptions (tons), days at sea, price of fuel and number of main engine. Bunker cost changes depending on operational area.

Table 6.3: the parameters of annual cost of fuel for main engine(s) and their types and functions.

Cost Elements	Abbreviation of Cost Elements	Type	Function of
Engine power max	Pmax	Variable	
Specific FOC (gr/KW*h)	SFOCmain	Variable	PB, V, C
% of max speed	Fmean (%)	Constant	
Daily fuel oil consumption (tons)	DFC	Dep. Variable	
Days at sea	Dsea	Variable	Ddock
Price of fuel	Prfuel	Constant	
No of main engines	Nmain	Constant	
Lub oil correction factor	Lubcorr	Constant	
Annual cost of fuel	ACOF @ current prices		
	Escalated ACOF		
	Discounted ACOF		
	ACOF - NPV		

Table6.3 Running cost model part II

This model is developed based on the following assumptions and relations:

Assuming DWT is constant, then when the Lightweight	increase
Displacement	increase
Draught	increase
Resistance	increase
Power of main engine	increase
Daily fuel oil consumption	increase

Table6.4 Parameters for annual cost of fuel for main engine(s) I

Assuming DWT is constant, then when the Lightweight	decrease
Displacement	decrease
Draught	decrease
Resistance	decrease
Power of main engine	decrease
Daily fuel oil consumption	decrease

Table6.5 Parameters for annual cost of fuel for main engine(s) II

Annual cost of fuel for main engine (s), ACOF, is calculated by using the following equations

$$ACOF \text{ (in €)} = D_{sea} \times \text{(Daily fuel consumption in tonnes)} \times Pr_{fuel} \times N_{main} \times Oil_{corr} \quad (51)$$

Daily fuel oil consumption (in tonnes),

$$DFC, = P_{max} \times SFOC_{main} \times 10^{-6} \times F_{mean} \times 10^{-2} \times 24 \quad (52)$$

Where

Symbol	Description	Unit
ACOF	Annual cost of fuel for main engine(s)	€
N_{main}	Number of main engines	
DFC	Daily fuel consumption	Tonnes
Pr_{fuel}	Fuel price	€/ton
P_{max}	Maximum power of main engine	KW
$SFOC_{main}$	Specific fuel oil consumption of main engine	g/kWh
F_{mean}	Reduction factor average speed (percentage of	%

	maximum speed)	
Oil_{corr}	Correction ratio for lubrication oil and diesel oil	1.15
δ	Variation	

Unavailability cost is calculated based on average operating speed/hour, loaded days at sea, Dwt utilization, productivity ton miles of cargo/annum, freight rate euro/ton mile and revenue/annum. Unavailability cost is changing depending on operational area.

Cost Elements	Abbreviation of Cost Elements	Type	Function of
Average operating speed /hour	Stm	Constant	
Loaded days at sea	Dsea-ld	Variable	Ddock
Dwt utilization	DWUtm	Variable	New DWT
Productivity ton miles of cargo/annum	Ptm	Dep. Variable	
Freight rate Euro/ton mile	FRtm	Constant	
Revenue/annum	Rtm @ current prices		
	Escalated Rtm		
	Discounted Rtm		
	Rtm - NPV		

Table6.6 Running cost model part III

This model is developed based on the following assumptions and relations:

Assuming displacement is constant, then when the Lightweight	increase
Deadweight	decrease
Operational earning	decrease

Table6.7 Parameters for revenue per annum I

Assuming displacement is constant, then when the Lightweight	decrease
Deadweight	increase
Operational earning	increase

Table6.7 Parameters for revenue per annum II

The model should be able to assess the variation in earning due to the change in lightweight and deadweight, preferably expressed in revenue per annum.

According to [Stopford 1997], the basic revenue calculation involves two steps: first, determining how much cargo the vessel can carry in the financial period, measured in whatever units are appropriate (tons, ton miles, cubic metres, etc.), and, second, establishing what price or freight rate the owner will receive per unit transported. In more technical terms, the revenue per annum can be viewed as the product of the ship's productivity, measured in ton miles of cargo transported per annum, and the freight rate per ton mile, thus

$$R_{tm} = \quad P_{tm} \quad FR_{tm} \qquad (53)$$

Where

R = revenue per annum

P = Productivity in ton miles of cargo per annum

FR = freight rate per ton mile of cargo transported

t = time period

m = ship type

The analysis of productivity can be carried further by subdividing into its component parts as follows:

$$P_{tm} = 24 \text{ x } S_{tm} \text{ x } (D_{sea\text{-}ld})_{tm} \text{ x } DWU_{tm} \qquad (54)$$

Where

S = average operating speed per hour,

$D_{sea\text{-}ld}$ = loaded days at sea per annum, DWU = deadweight utilization

This definition states that ship productivity, measured in terms of ton miles of cargo transported in year t, is determined by the distance the vessel actually travels in 24 hours, the number of days it spends loaded at sea in a year, and the extent to which it travels with a full deadweight of cargo. By further examination of each of these components a precise definition of productivity can be obtained [4].

Dismantling cost is based on the price of dismantling/ton which changes according to type of ship, condition of ship, age of ship and dismantling country and general trends in shipping.

Cost Elements	Abbreviation of Cost Elements	Type	Function of
Price of dismantling/ton	Prdist	Constant	
Earning of dismantling	EDIS @ current prices		
	Escalated EDIS		
	Discounted EDIS		
	EDIS - NPV		

Table6.9 Running cost model part IV

The dismantling revenue, EDIS, will be the function of the lightweight of the subject vessel, and will be calculated as

$$EDIS = Pr_{dist} \text{ x } lightweight_i \qquad (55)$$

Where

Symbol	Description	Unit
EDIS	The earning of dismantling	€
Prdist	The unit price of dismantling per ton	€/ton

CHAPTER 7 CASE STUDIES

In order to develop better understanding of periodic maintenance cost and it`s effect on running cost, the running cost model developed in previous chapter is used for ropax and tanker vessels. Different maintenance and repair cases are considered in order to investigate how the variation in some parameters affects the maintenance and hence the running cost.

The effect of lightweight on periodic maintenance cost is also considered in this part for tanker and ropax vessel.

Most of the data which are used in the calculations are collected from the ship operators. While the input related to ship repair and maintenance was generated using the relevant formulas developed in Chapter 6.

7.1 Case Study for Running Cost Models

7.1.1 Ropax Vessel

In order to understand the effect of lightweight on repair and maintenance cost and also the effect of well maintained ship and not well maintained ship on running costs, the developed model is implemented for ropax vessel. The original lightweight of the vessel, which is directly given by ship operator, as the 12870, is used in the calculations. In order to observe the effect of lightweight change on repair and maintenance cost, lightweight is varied with 1000 tonnes steps between 9870 & 15870 tonnes for calculation. The calculations are made for 25 years life span; therefore escalation rate and discount rate are also added to this calculation. The escalation rate is considered as 3% and the discount rate is considered as 8% in this study. Developed model was run for three times for different lightweight values which are 9870, 12870 (original lightweight) and 15870 to understand the effect of lightweight on repair and maintenance cost. Also developed model has been run for different replaced steel amounts which is categorised as low (well maintained), likely and high (not well maintained). This will make it possible to compare the effects of well maintained and not well maintained vessel on running cost.

The principal dimensions of the ropax vessel which is used for running model calculations are given in Table7.1.

Principal Dimensions		
Length o.a. (m)	169.4	
Length b.p. (m)	149.8	
Breadth mld. (m)	27.6	
Max. draught (m)	6.35	
GRT (ton)	34384	
NRT (ton)	19862	
DWT (ton)	3690	
LWT (ton)	12870	
Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	12,870	
Original Displacement (in tonnes)	16,560	
Original DWT (in tonnes)	3,690	
New Lightweighti (in tonnes)	12,870	Indep. Variable
Var (lightweight)	0	
New Displacement (in tonnes)	16,560	
New DWT (in tonnes)	3,690	
V design speed (in knots)	21	

Table7.1 General information table for ropax vessel

The deadweight of vessel is 3690 ton which is obtained from ship operator's data and design speed is taken as 21 knot for calculations. Other variables are presented in Table 7.1.

In this model the running cost includes annual cost of fuel oil for main engine(s), revenue, the cost of periodic maintenance and the earning of dismantling which are detailed in Chapter 6.

The periodic maintenance cost is formed by cost of steel replacement, coating/painting and cost of unavailability.

The steel replacement cost is calculated according to amount of steel replacement and unit price of steel replacement as indicated in previous chapter amount of steel replacement is taken into account and by using the equation which are presented as low, likely and high amount of steel replaced. The unit price of steel replacement is 5 Euro / kg for this study which is decided after having a discussion with some European and Turkish shipyards.

Coating cost is calculated according to the total steel area that coating is applied. Cost is calculated as per unit area which is taken as 3 euro per square meter.

Cost of unavailability is calculated based on number of days that ship is not available for hire and daily earning rate.

Annual fuel consumption is calculated by taken the price of oil as 320 euro/ton and maximum engine power is taken as 6550kW*4(number of main engines).

Revenue/per annum is calculated according to passenger capacity, car capacity, average daily passenger fee and average daily car fee. The passenger capacity for this vessel is 2500 and the car capacity is 430. The prices for passenger and car are changing according to the time of the week and time of the year. Weekends are also the specific time period like Christmas time. After considering all this differences the average price for passenger is 40.7 Euro per day and for car is 46 Euro per day. The revenue/annum price is calculated according to these data, which were based on actual ship operations. The number of passenger and the car is calculated constantly against the DWT changes for Ropax vessel.

The earning from dismantling calculated due to dismantling price and ship lightweight. The dismantling value is changing with the type of ship and condition of ship. In this study the dismantling fee is 430 Euro per ton.

For ropax study two scenarios are developed which are calculated with the above data.

Scenario 1(cost) is calculated as;

The cost of periodic maintenance + annual cost of fuel for main engine(s) – the earning of dismantling (56)

Scenario 2(earning) is calculated as;

The cost of periodic maintenance – revenue/annum – the earning of dismantling (57)

For both scenarios original and variant lightweight and steel replacement amount calculations are taken into account.

	LWT	Changes	Scenario 1	Changes	LWT	Scenario 2	Changes
	9870	-23.31%	33,211,178	-2.58%	9870	703,313,237	0.13%
	10870	-15.54%	33,503,906	-1.72%	10870	703,020,510	0.08%
	11870	-7.77%	33,796,633	-0.86%	11870	702,727,782	0.04%
Original	12870	0.00%	34,089,361	0.00%	12870	702,435,055	0.00%
	13870	7.77%	34,382,088	0.86%	13870	702,142,327	-0.04%
	14870	15.54%	34,674,816	1.72%	14870	701,849,600	-0.08%
	15870	23.31%	34,967,543	2.58%	15870	701,556,872	-0.13%

Table7.2 Scenario 1 and scenario 2 tables for ropax vessel

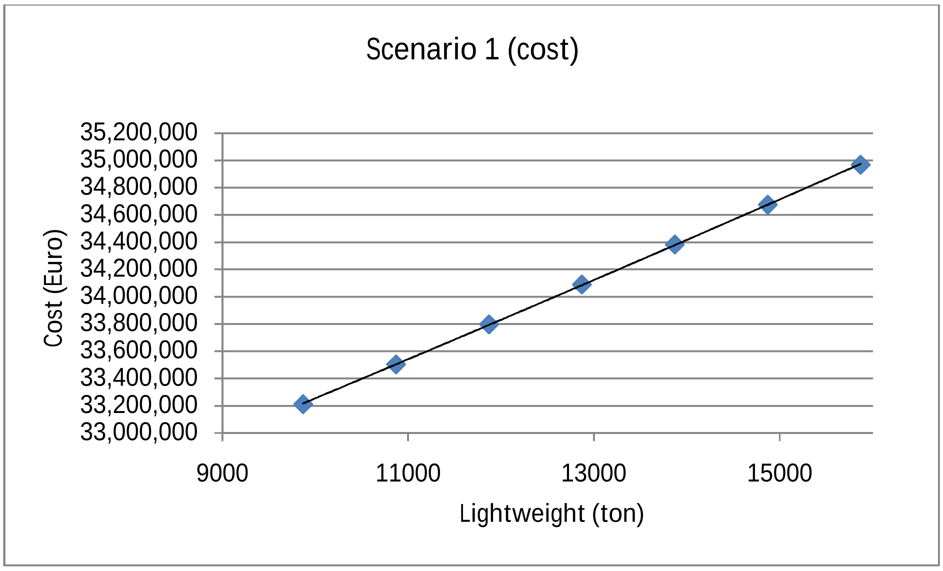

Figure7.1 Scenario 1 for 25 years for ropax vessel with different lightweight

Figure7.1 shows that there is a direct relation between scenario1 (cost) and lightweight of the ship and as lightweight increases causes of running cost increases. The main reason for that lightweight increase causes more steel replacement and therefore spending more time in dry dock. So the operational earning will be decrease due to unavailability time. Figure7.1 also includes the operational earning losses because of the unavailability of the ship.

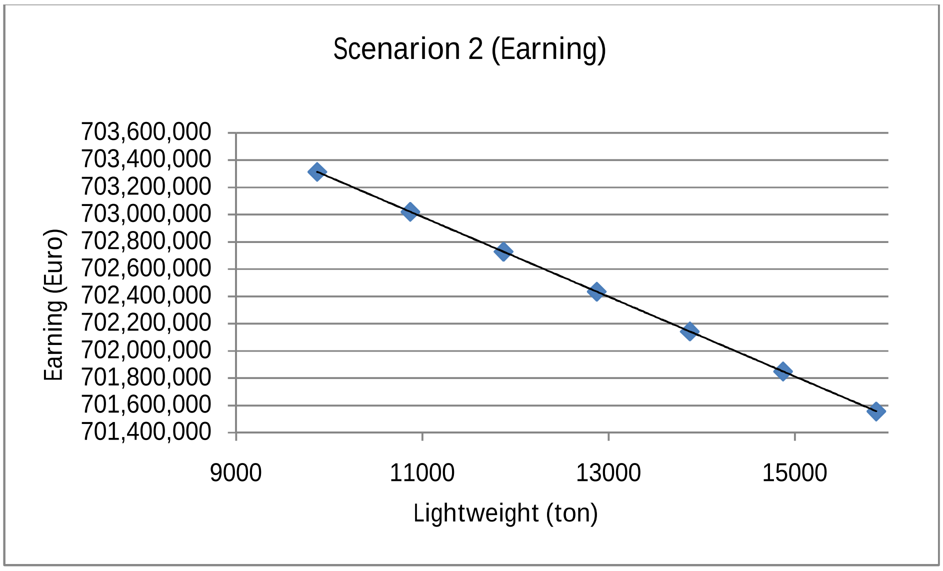

Figure7.2 Scenario 2 for 25 years for ropax vessel with different lightweight

Lightweight has a direct effect on scenario2 (earning) in Figure7.2. The Displacement value is constant for this calculation and deadweight decreases by lightweight increase and periodic maintenance cost increases with lightweight increase, therefore the earning for ropax vessel increases with lightweight decrease.

To understand the importance of well maintained and not well maintained vessels on running cost for ropax vessel, the worst case, the most likely case and the best case scenarios are developed and the calculation are carried out based on the formulas which are developed in data analysis chapter. Steel replacement cost and unavailability are calculated for all three cases. High steel replacement and unavailability time represent the not well maintained and low value represent the well maintained as presented in the Table7.3 for original LWT.

Ropax LWT (9870,12870 and 15870 ton)	Steel Replacement	Unavailability
The worst case	High	High
The most likely case	Likely	Likely
The best case	Low	Low

Table7.3 Ropax vessel cases with different light weight

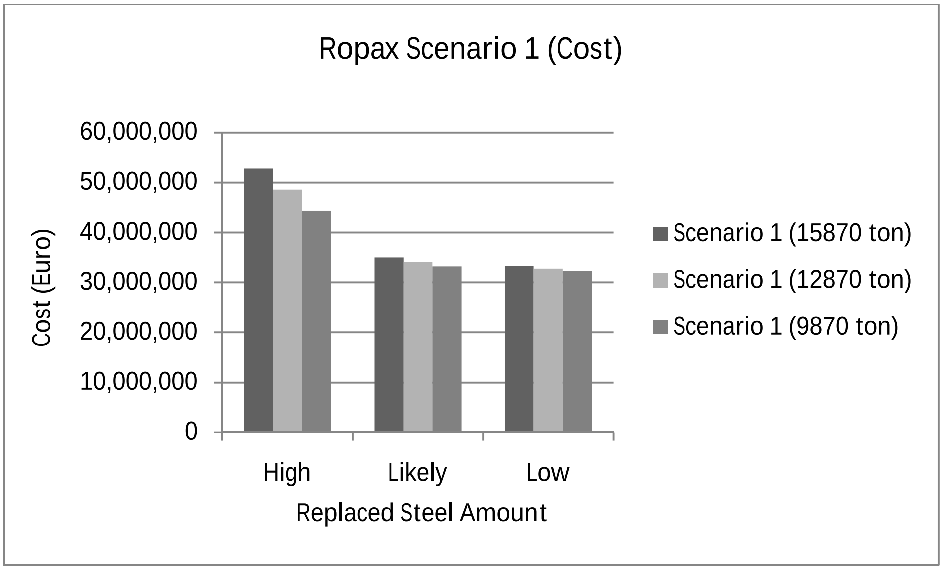

Figure7.3 Ropax vessel scenario 1 due to different lightweights

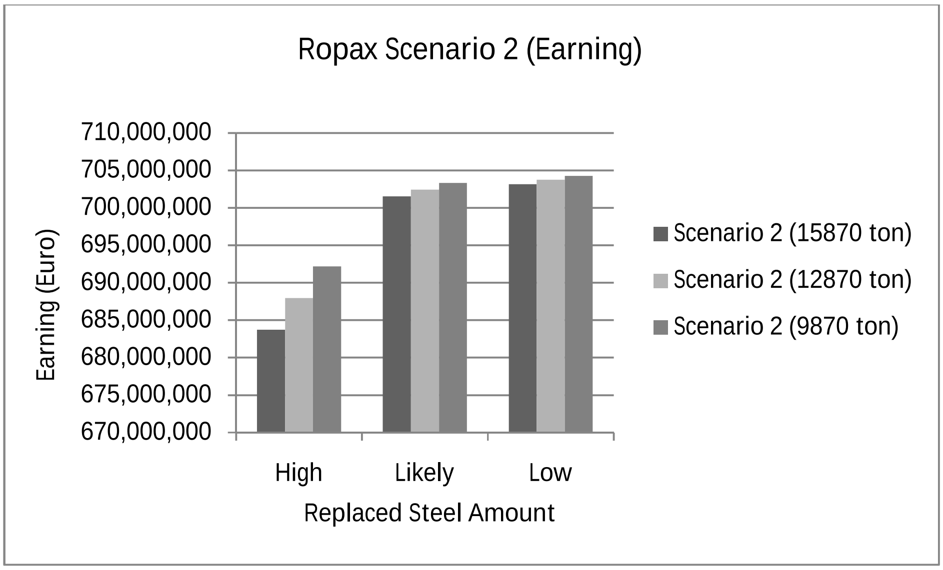

Figure7.4 Ropax vessel scenario 2 due to different lightweights

The Figures 7.3 and 7.4 show that there is a large difference of earning and cost due to the maintenance and repair strategy. Because of the high unavailability time the earning is decreasing and also the cost of the repair work is increasing due to the replaced steel amount.

It can be easily concluded that if a vessel is not maintained well (worst case), earning decrease can be nearly 3% compared to the best case (well maintained vessel).

For the original lightweight calculation with high steel replacement amount, the cost is nearly 50 million euro. For 25 years which is considered as ship life, Scenario1 (cost) calculation with likely steel replacement amount is more than 30 million euro and the lowest cost for scenario1 (cost) which is with low steel replacement amount is just more than 30 million euro too (Figure7.3).

According to lightweight 15870 ton calculations for scenario1 (cost) with high steel replacement amount the cost is more than 50 million euro, for likely case the cost is increasing to 35 million euro and for the low case cost the cost is closer to 30 million euro (Figure7.3).

According to calculations for lightweight of 9870 ton scenario1 (cost) with high amount of steel replacement cost is close to 45 million euro, for likely case cost is more than 33 million euro and for low case cost is 32 million euro (Figure7.3).

According to lightweight 15870 ton calculations for scenario2 (earning) with high steel replacement amount is more than 683 million euro, for likely case it is more than 701 million euro and for the low case 703 million euro (Figure7.4).

According to calculations for lightweight of 9870 ton scenario2 (earning) with high amount of steel replacement is 692 million euro, for likely case cost is more than 703 million euro and for low case 704 million euro (Figure7.4).

The dry docking cost for different lightweights and high, likely and low amount of steel replacements are also calculated. Again original lightweight which is 12870 ton, 9870 ton and 15870 ton lightweight values are used in this calculation. Also high, likely and low replace steel amount is calculated for each lightweights (Table7.4).

Dry Docking Cost	High Repair Work	Likely Repair Work	Low Repair Work
Lwt 9870	22,488,286	11,387,702	10,397,371
Lwt 12870	27,134,897	12,660,275	11,368,931
Lwt 15870	31,781,507	13,932,849	12,340,492

Table7.4 Ropax vessel dry docking cost

Repair cost values for light weight 9870 ton shows that the repair cost with high replaced steel work is more than 20 million euro and with likely repair work it is more than 11 million euro and with low repair work it is more than 10 million euro. There is a huge difference between high and low maintenance work cost. In another word there is a 10 million euro cost difference between well maintained and not well maintained vessel`s repair cost over 25 years period.

The repair work cost for original lightweight shows that the repair work cost increases with lightweight increases. The repair cost with high repair work for original lightweight is 5 million euro more than first vessel which has 9870 to lightweight, 3000 ton lightweight increase causes 5 million euro increase in repair work cost for high amount of steel replacement. The likely and low repair work cost also increase as lightweight increases however it is not as much as high repair work cost (Figure7.5).

Repair cost for 15870 ton lightweight is more than the other ships. The repair work cost with high steel replacement amount is nearly 32 million euro and for likely steel replacement amount it is close to 14 million euro and for low steel replacement amount it is more than 12 million euro.

It should be emphasized that all these lightweight changes are assumed to be based on the required thickness. If one considers the case that increase in lightweight is due to additional thickness to prevent steel replacement. This may create different trends that should be investigated separately.

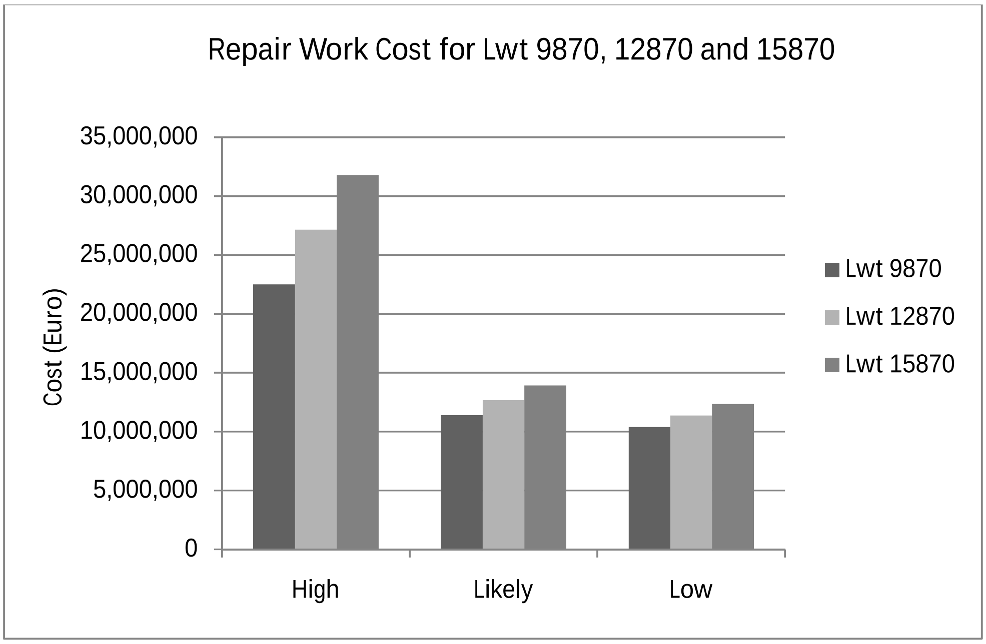

Figure7.5 Repair cost for ropax vessel with different lightweight

Figure7.5 shows that the repair work cost increases as lightweight increases. For high steel replacement amount it is easier to understand this increase. Also there is a big repair work cost difference between well maintained and not well maintained vessels.

In order to understand the effect of various parameters, the relationship between repair work cost, age and LWT are established as presented in Figures 7.6, 7.7 and 7.8. These figures are prepared with accumulative function.

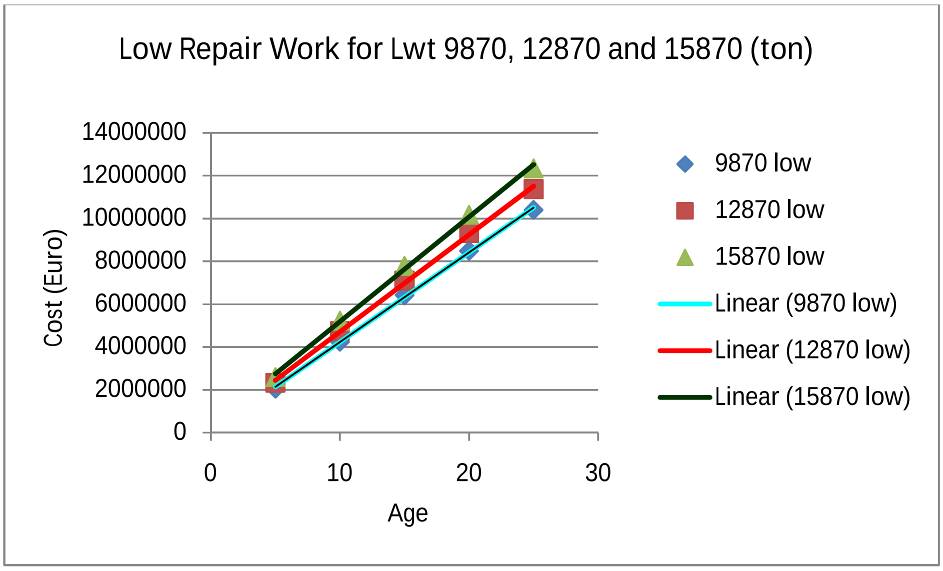

Figure7.6 Low repair work for different lightweight

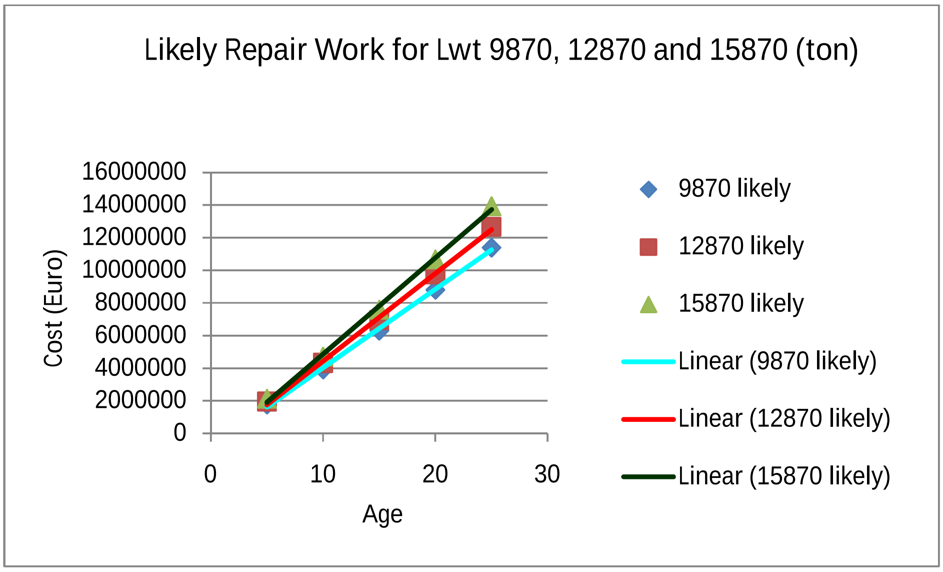

Figure7.7 Likely repair work for different lightweight

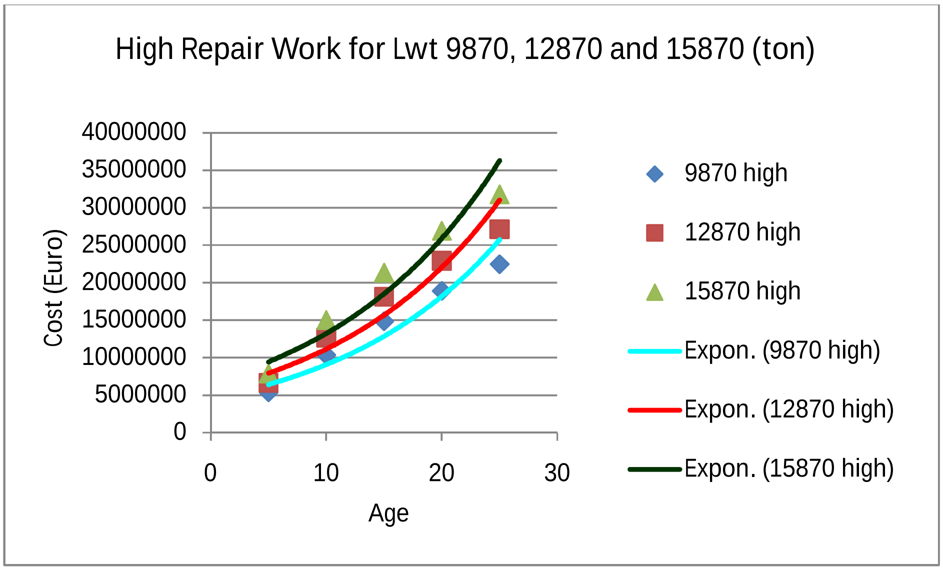

Figure7.8 High repair work for different lightweight

According to Figures 7.6, 7.7 and 7.8 the periodic maintenance cost for different lightweights are changing between 2 million euro and 14 million euro. For likely repair work graphic it is changing between 2 million euro and 16 million euro. For high repair work graphic this value is changing between 5 million euro and 40 million euro depends on the age. There is roughly 25 million euro cost difference between high repair work and low or likely repair works for ropax vessel.

7.1.2 Tanker Vessel

Developed Model A is implemented for tanker vessel as well. The original lightweight of the vessel which is directly given by ship operator, is used for the calculations. The original lightweight of the vessel is 9500 ton. The running cost model run for lightweights 8500, 9000, 9500, 10000, 10500. To see the effect of 1000 ton lightweight changes on repair and maintenance cost below table is prepared according to these calculations. The calculations are made for 25 years which includes escalation rate and discount rate.

The principal dimensions for tanker is in the below table,

Principal Dimensions		
Length o.a. (m)	182.88	
Length b.p. (m)	175.25	
Breadth mld. (m)	32.2	
Max. draught (m)	10.8	
DWT (ton)	32000	
Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	9,500	
Original Displacement (in tonnes)	41,500	
Original DWT (in tonnes)	32,000	
New Lightweighti (in tonnes)	9,500	Indep. Variable
Var (lightweight)	0	
New Displacement (in tonnes)	41,500	
New DWT (in tonnes)	32,000	
V design speed (in knots)	15	

Table7.5 Principal dimensions table for tanker vessel

The deadweight of vessel is 32000 ton which is collected from ship operator's data and design speed is 15 knot for calculations. Other variables are presented in below table.

Amount of steel replacement is calculated using the developed formulas for low, likely and high replaced steel amounts and the unit price of steel replacement is taken as 5 Euro / kg, same as ropax vessel calculation. Also the unit coating price is same as ropax vessel Euro per square meter (3euro/per square meter).

For annul fuel oil consumption the price of oil is taken as 320 euro per ton for this model. The maximum engine power is 11088kW and the vessel has 1 main engine. Daily fuel oil consumption is calculated as 29.9 ton for this vessel.

Revenue/per annum is calculated according to productivity ton miles of cargo/annum. Average operating speed is 14 knot for this calculation and the number of loaded days at sea is 229 days per annum and dwt utilisation is 0.8 and the freight rate Euro /ton mile is 0.005 for molasses cargo type. Productivity is calculated by 24 times average operating speed times loaded day at sea times dwt utilisation times dwt. Revenue/Annum is calculated by productivity ton miles of cargo/annum times freight rate euro /ton miles.

The earning from dismantling calculated using the dismantling price which is 430 Euro per ton and ship lightweight.

From the tanker model two scenarios are developed and calculations are carried out using the above data.

	LWT	Changes	Scenario 1	Changes	LWT	Scenario 2	Changes
	8500	-10.53%	143774254.4	-2.92%	8500	1112178263	3.12%
	9000	-5.26%	145938503.5	-1.46%	9000	1095364672	1.56%
	9250	-2.63%	147020417.5	-0.73%	9250	1086957877	0.78%
Original	9500	0.00%	148102192.7	0.00%	9500	1078551081	0.00%
	9750	2.63%	149183830.2	0.73%	9750	1070144286	-0.78%
	10000	5.26%	150265331	1.46%	10000	1061737491	-1.56%
	10500	10.53%	152427927.2	2.92%	10500	1044923900	-3.12%

Table7.6 Scenario 1 and scenario 2 table for tanker vessel

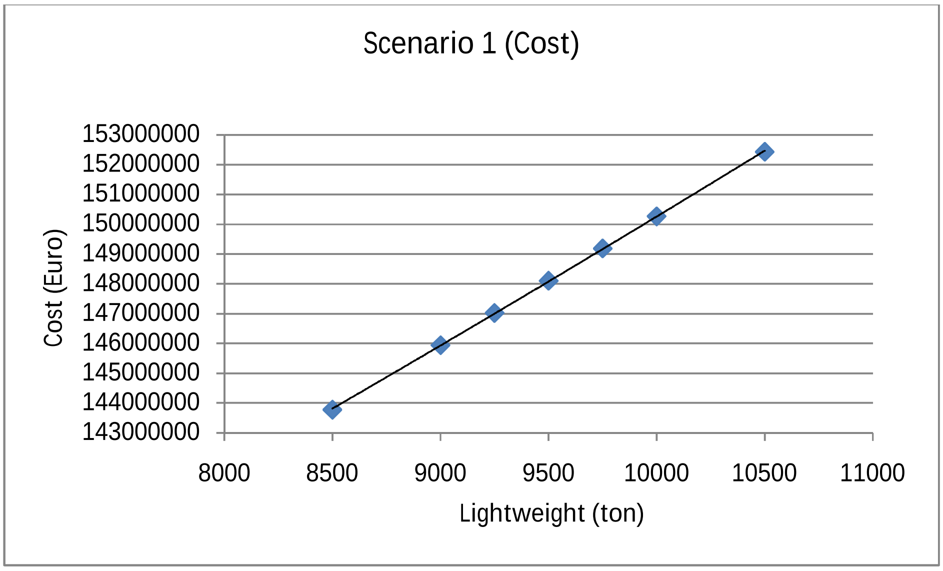

Figure7.9 Scenario 1 for tanker vessel with different lightweight

As it is seen in the Figure7.9, scenario1 (cost) increases as lightweight increase. As in the ropax vessel case, replaced steel increases with lightweight increase. Therefore the cost of periodic maintenance increases.

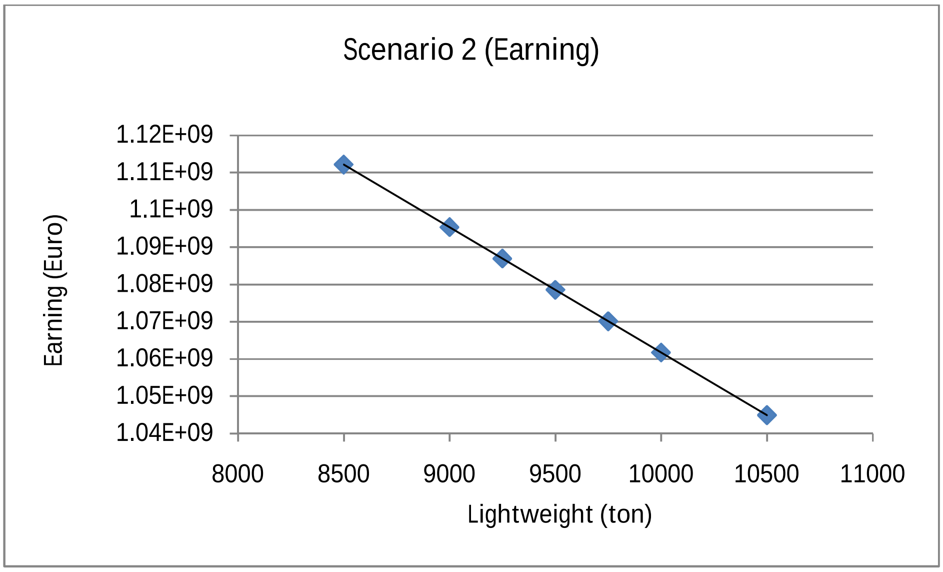

Figure7.10 Scenario 2 for tanker vessel with different lightweight

Earning decreases as lightweight increase in Figure7.10. As it is indicated in chapter 6 displacement is constant and deadweight is increasing as lightweight decrease. Therefore the deadweight and the operational earning are increasing as lightweight decrease. The periodic maintenance cost is also decreasing as lightweight decrease so it brings more earning.

Calculations are carried out for well maintained and not well maintained cases with different lightweight amounts as well. These calculations show that there is a large difference between running cost well maintained and not well maintained tanker ships.

Tanker LWT (7500, 9500 and 11500 ton)	Steel Replacement	Unavailability
The worst case	High	High
The most likely case	Likely	Likely
The best case	Low	Low

Table7.7 Tanker vessel cases

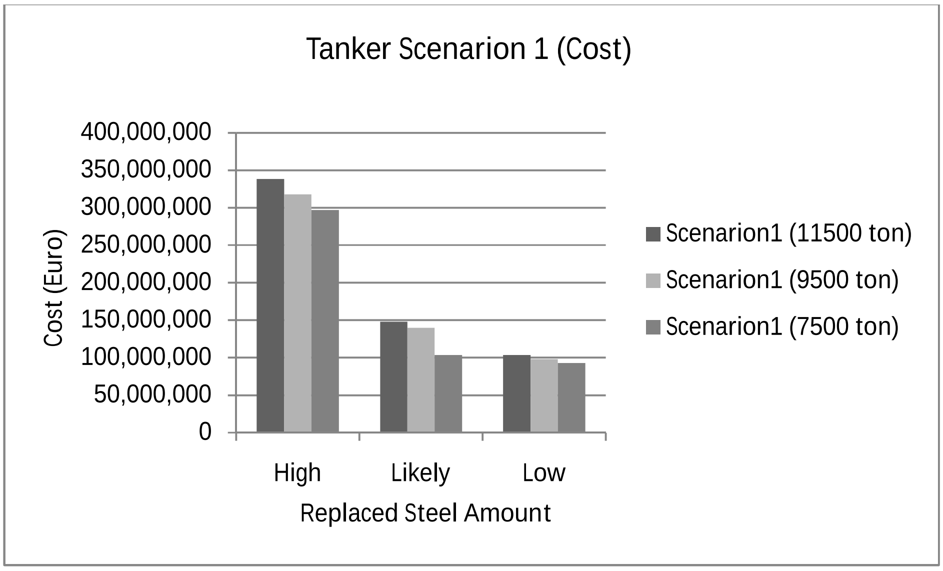

Figure7.11 Tanker vessel scenario 1 due to different lightweights

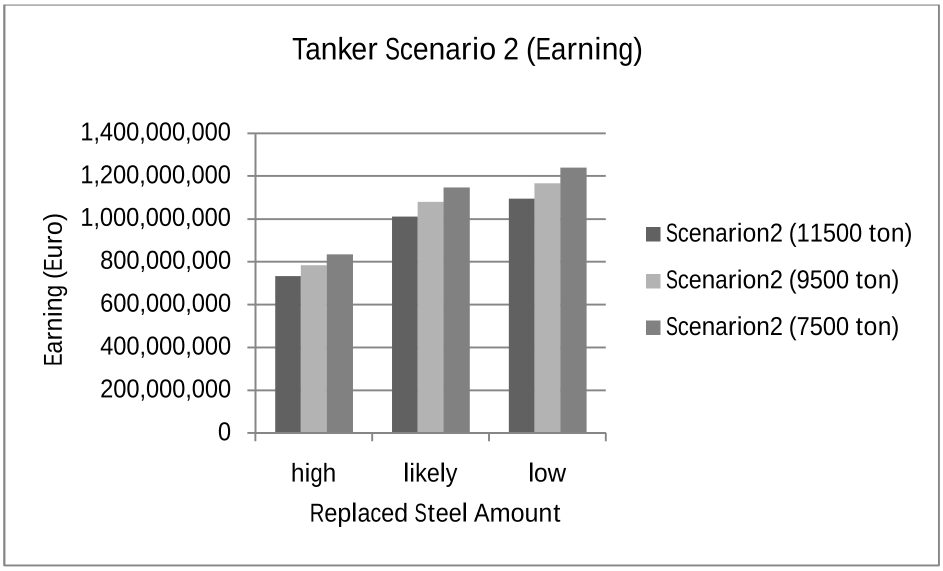

Figure7.12 Tanker vessel scenario 2 due to different lightweights

According to 9500 ton lightweight scenario 1 (cost) for high steel replacement case is nearly 317 million euro for over 25 years and for likely steel replacement it is nearly 140 million euro while for low steel replacement it is nearly 98 million euro (Figure 7.11).

The earning for vessel with 9500 ton lightweight for high steel replacement case cost is close to 784 million euro and for likely steel replacement it is nearly 1.078 billion euro while for low steel replacement amount it is close to 1.166 billion euro (Figure 7.12).

It can be easily concluded that if a vessel is not maintained well (worst case), cost increase can be more than 200% compared to the best case (well maintained vessel) for cost. Similarly, the same can be concluded for earning element with the figure decreasing almost 40%.

According to 11500 ton lightweight scenario 1 (cost) for high steel replacement case is nearly 338 million euro and for likely steel replacement amount it is nearly 148 million euro while for low steel replacement amount it is more than 100 million euro (Figure 7.11).

The earning for vessel with 11500 ton lightweight for high steel replacement amount is close to 733 million euro and for likely steel replacement it is more than 1.01 billion euro and for low steel replacement amount it is more than to 1.09 billion euro (Figure 7.12).

According to 7500 ton lightweight scenario 1, cost for high steel replacement case is more than 297 million euro and for likely steel replacement it is nearly 108 million euro while for low steel replacement it is more than 90 million euro (Figure 7.11).

The earning for vessel with 7500 ton lightweight with high steel replacement is close to 833 million euro and for likely steel replacement it is more than 1.1 billion euro while for low steel replacement it is more than 1.2 million euro (Figure 7.12).

To explain the effects of lightweight and maintenance strategy on dry docking cost Table7.8 is prepared based on the model results.

Dry Docking Cost	High Repair Work	Likely Repair Work	Low Repair Work
Lwt 7500	18,855,389	5,976,398	3,527,537
Lwt 9500	20,765,188	6,163,946	3,607,638
Lwt 11500	22,674,988	6,351,493	3,687,739

Table7.8 Dry docking cost for tanker vessel

Table7.8 shows that the repair cost for high steel replacement for 7500 ton light weight is more than 18 million euro repair cost for likely steel replacement cost is nearly 6 million euro and for low steel replacement amount it is more than 3.5 million euro. All these calculations are made based on 25 years ship life.

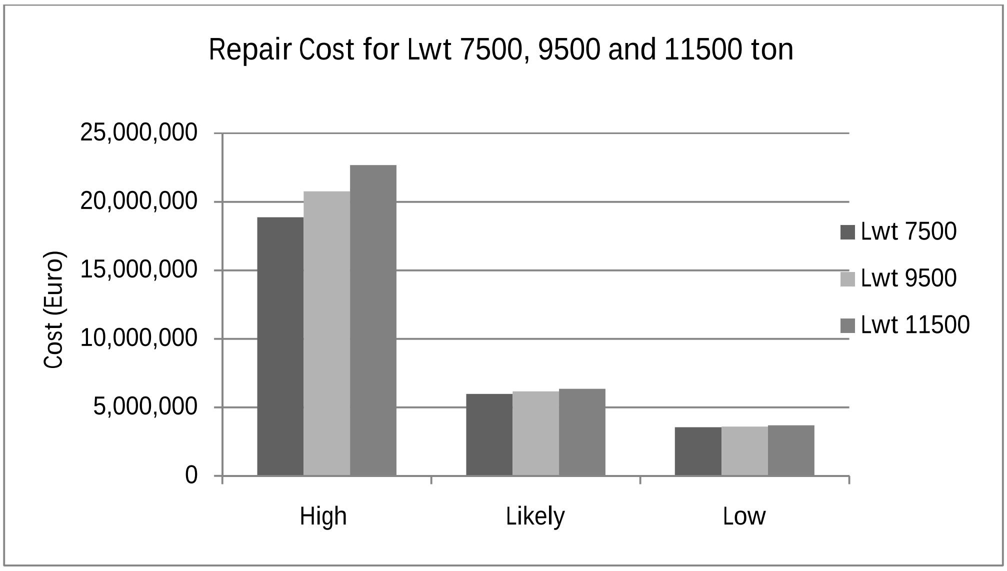

Figure7.13 Repair cost for tanker vessel with different lightweight

The increase in lightweight causes more repair cost. Nearly 2 million euro cost difference between 7500 ton and 9500 ton lightweight for high steel replacement amount. The amount decreases as the steel replacement amount decreases (Figure7.13).

The increase between lightweights 9500 ton and 11500 ton is nearly same. The light weight has an effect on repair work cost. The main effect is due to 4000 ton of light weight change cost change maximum 4 million euro however, due to the maintenance strategy the difference between well maintained & not well maintained ships is 19 million euro for 11500 light weight (Figure7.13).

Figures 7.14, 7.15 and 7.16 show the accumulated repair work cost with different lightweight values and different steel replacement amount for varying years.

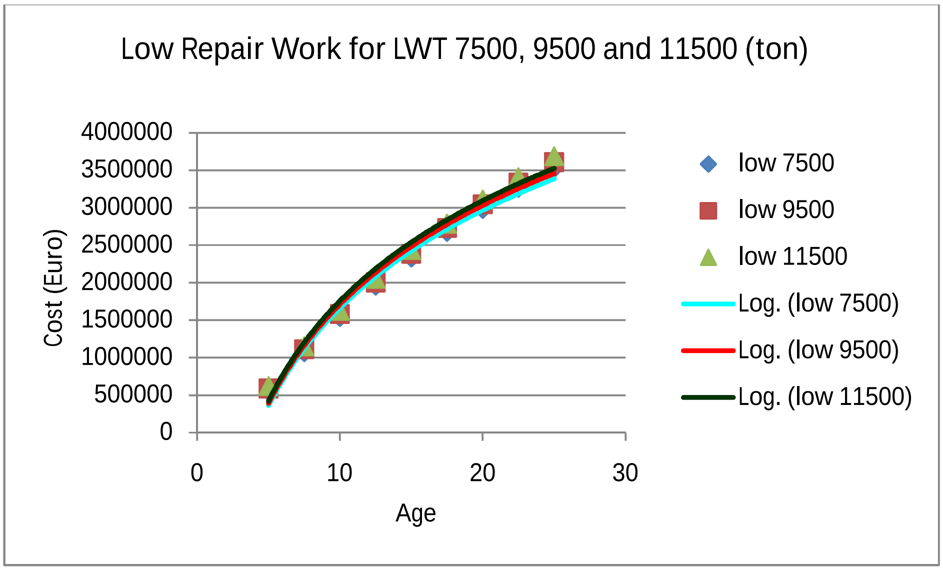

Figure7.14 Low repair work for different lightweight

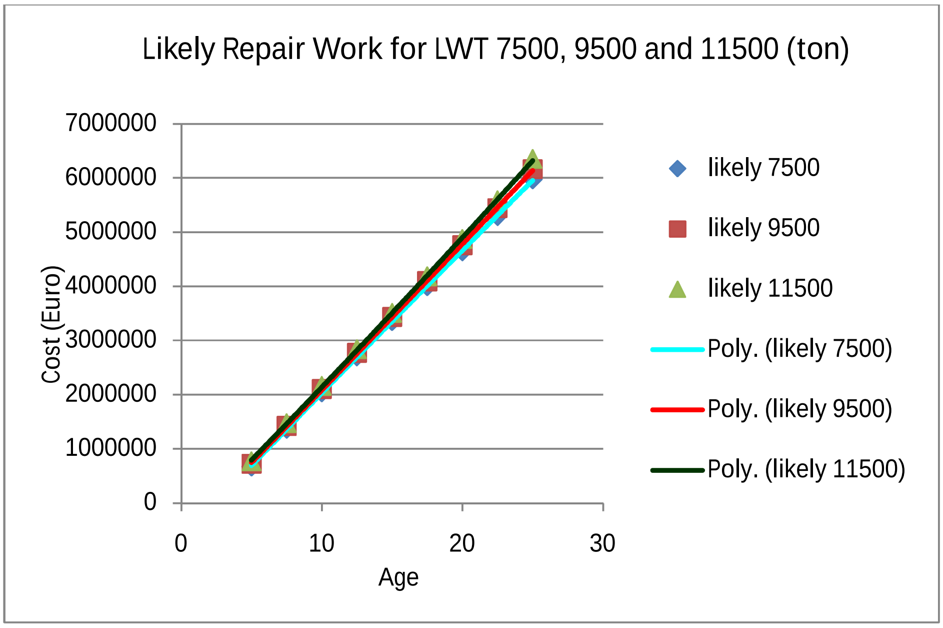

Figure7.15 Likely repair work for different lightweight

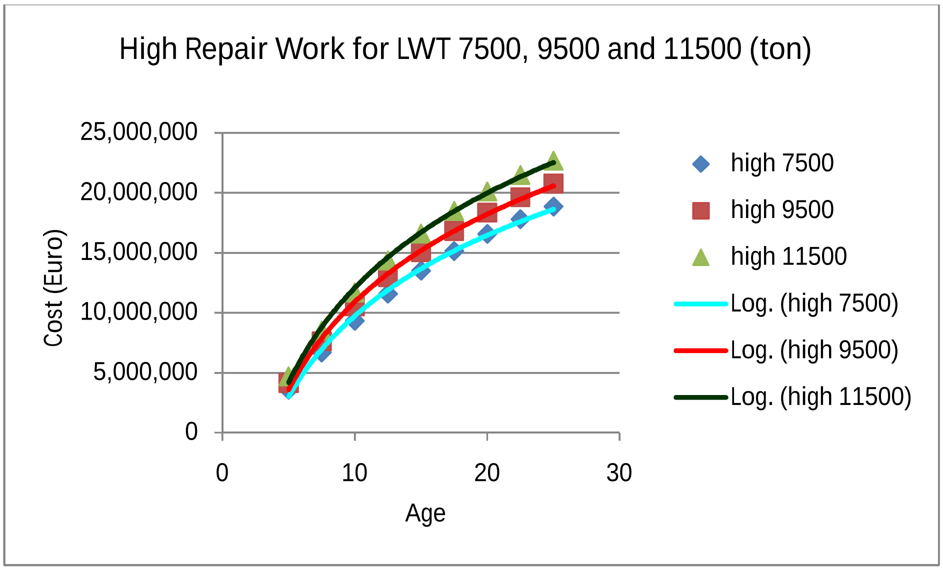

Figure7.16 High repair work for different lightweight

According to study for low repair work case (Figure 7.14), the periodic maintenance cost for different lightweights are changing between 1 million euro and 4.5 million euro. For likely repair work (Figure 7.15) it is changing between 1 million euro and 8 million euro. For high repair work (Figure 7.16) graphic this value is changing between 5 million euro and 30 million euro. In early stages the repair cost difference is not as much as end of the life cycle however there is roughly 25 million euro cost difference between high repair work and low repair work for tanker vessel.

The results for both types of vessels show the importance of maintenance and repair strategies on running cost of the vessel. There is a large difference between well maintained and not well maintained vessel`s repair and maintenance cost. However main cost is due to the unavailability of the vessels. The repair cost for ropax vessel for 25 years changes from 31.8 million euro to 12.3 million euro. And for tanker the repair cost for 25 years changes from 22.6 million euro to 3.6 million euro. However the unavailability time for these vessels changes from 80 days to 10 days due to the repair and maintenance activities. The largest repair and maintenance cost effect on the running cost of the vessel is due to the operational unavailability of the vessel.

CHAPTER 8 DISCUSSION AND FUTURE WORK

Maintenance and repair of ships is one of the key components of ship's running costs that affect the ship's operation in terms of overall running costs, reliability as well as availability. While the maintenance and repair may add up to 15-25% of ship's overall running costs, improving ship's maintenance and strategy not only reduces the cost but increases the ship's availability for hire as well as operational life of the ship.

In this thesis attempt was made to investigate the maintenance and repair aspect of ship operation and a running cost model was developed. The author of the thesis spent 1 month in a ship repair yard to understand the way the ship repair business is handled while collecting the maintenance and repair data of various ships with an aim of developing criticality analysis. By utilising the data collected from shipyards, operators as well as classification societies, reliability of the ships was examined. Running cost model was modelled with a focus on maintenance and repair cost and applied on different types of vessels.

This thesis should be seen as an attempt to introduce the ship maintenance and repair field, which is a vast area that requires significant amount of work to improve. The experience gained and results produced during this study are discussed in this chapter while recommendation for future work and concluding remarks are presented.

8.1 Discussion

Current Practice of Shipping Companies

Current machinery and hull structure maintenance/repair of a ship is regularly performed on a time scheduled base. The maintenance program is scheduled by the equipment manufacturer based on working hours of equipment/machinery. Classification society rules impose periodical and systematic inspection on a yearly based procedure to survey the status/health of machinery as well as hull structure.

International Safety Management (ISM) Code introduced the obligation to submit the recorded planned maintenance document that is essential on board for safety. However the effectiveness of such systems which are based on the scheduling of these activities has been low compared to the original expectations.

Due to the average daily running cost of a vessel and loss of hire income, taking a vessel out of service into dry dock for either surveys or maintenance is an unwelcome activity for ship operator.

The maintenance and repair work in the shipyard starts following the survey reports and work order. The survey takes average 2-3 days to complete and this average time may increase depending on the workload of the ship repair yard. Ship operators ideally want to minimise the amount of time which their vessels spend in dry dock. The impact of dry docking on the operators could be decreased if:

- some of surveys are performed while the vessel is in service,
- the steel replacement is carried out based on accurate hull strength calculations rather than plate thickness falling below a minimum level that is required by classification societies.
- the schedule of maintenance is planned in accordance with the ships' work schedule (e.g. ensuring surveys or maintenance is carried out when the hire rate of the vessel is lowest or less busy period: this might be seasonal).

Collection of Ship Repair and Maintenance Data

During this study it was experienced that collecting ship repair and maintenance data for analysis and for developing running cost model was very difficult due to the unavailability of useful data

In order to collect data one month long field study was carried out by the author in ship repair yard while visits to classification societies and ship operators were executed..

The experience that the author had during his one month field study with regards to data collection can be summarised as:

- Although large companies have extensive data base with regards to repair and maintenance of the ships, it is extremely difficult to access to their database. This is due to the fact that they treat operational data as very sensitive and therefore they are not willing to share it. This happens in a limited way if personal connection can be established with company and their trust is earned. Data collected from large companies and classification societies is not perfect but more complete, better formatted and easy to understand.

- Small companies, which are run generally by families, are more open to sharing their data and experience. However, in general data from small companies are not very useful as it is neither complete nor it has the repair history. This leads to major effort of putting the data in a useful format.

- Regardless of the company size, exception of a few companies, it is extremely difficult to obtain history of maintenance and repair for one specific ship. This was an unwelcoming surprise for the author as the time based maintenance and repair record is the most essential aspects of the data to identify the critical regions of the ship and critical components. Without the repair history, it is very difficult to develop a repair and maintenance strategy as a function of ship's age.

- The maintenance and repair database that author developed has more than 300 points but only two ships have more than two consecutive drydocking/repair data. In order to make efficient utilisation of data. quantity of the data is important. As the collected data are for different ship types and size, after categorizing the collected data for specific ship type and ship size the size of useful data decreases to smaller number.

- It was felt that companies are not fully utilising their past experience related to maintenance and repair. Such data, if utilised, would provide valuable information to develop a efficient plan and take measures to reduce the maintenance and repair cost of any ship.

- On the other hand ship repair yards do not utilise such data to enhance their repair and maintenance activity to build long term customer relation. Even if the customer comes back to same shipyard, shipyard is not storing the previous repair/maintenance book of the same ship.
- It may be very useful if guidelines are prepared on how to collect and store the data as well as potential benefits of collecting the data such as cost reduction, improved reliability and availability. This would certainly help toward cultural changes that shipping companies may need to go through.

Existing Onboard Ship Management Software

There are some existing ship management software, which also include maintenance and repair cost and offers a range of services to the ship operators. The services tend to revolve around a number of areas which are presented in Table 8.1 :

- Planned Maintenance System (PMS).
- Purchasing
- Budget
- Accounts
- Vessel Operations
- Crew Management
- Safety

SOFTWARE	PMS	PURCHASING	VESSEL OPERATION	CREW MAN.	SAFETY	BUDGET	ACCOUNT
ABS-NS	X	X	X	X	X	X	X
ADONIS				X			
AVECS	X	X		X	X		
BASS	X	X	X	X	X	X	X
CODIE	X	X			X		
CONSULTAS	X	X	X	X	X	X	X
DANAOS	X	X	X	X	X	X	X
IFS	X	X					
LOGIMATIC	X	X					
MANPOWER SOFTWARE				X			
MARINE SOFTWARE	X	X			X		
MESPAS	X	X					
MRO SOFTWARE	X	X					
ONSOFT	X	X		X			
SATPOOL	X						
SES	X	X	X	X	X	X	X
SHINET	X	X	X	X	X	X	X
STAR	X	X	X	X	X	X	X
TELEDATA	X	X	X	X	X	X	X
TERO MARINE	X	X	X	X	X	X	X
ULYSSES SYSTEMS	X	X	X	X	X		
VECTOR MARITIME	X	X	X	X	X	X	X
XANTIC (AMOS)	X	X	X	X			
V-BRIDGE	X	X	X				

Table 8.1 Available software and their functions ((X) represents availability of the function) [2]

Only a few softwares are able to provide full range of activities. The most of the software focus on Planned Maintenance System (PMS) and Purchasing. Typically, the PMS is planning, recording and reporting maintenance work to purchase, monitor and record delivery of spares and on-board inventory. The aim of the system is to manage planned maintenance and the overall budgeting of maintenance and running costs.

In this case, some softwares are combining the PMS with Purchasing, Vessel Operation, Crew Management, Safety, Budget and Account. DANAOS is one of these systems which combines PMS system with other systems including budgeting, planning, classification society issues, dry docking, spare parts and ship's follow up. V-BRIDGE is a similar system, which provides an interactive content management solution of a ship's functions for through life support of electromechanical systems.

However, none of the software is geared towards dealing with maintenance and repair recordings, analysis and decision support to assist ship operator to take the necessary actions to improve the system's reliability. Considering the existing structure of such PMS software, integrating the collection of maintenance and repair data together with reliability analysis on the back of PMS software would immensely improve the benefits of PMS software.

As it is presented in Figure 8.1; existing systems located inside the ellipsoid should be improved by implementing training to the workers, communication with the shipyard during the purchasing, implementing criticality analysis during the ship operation, adopting common working platform, cost effective inspection techniques and decision support system. Although it requires big effort to develop these additional features, these improvements will definitely bring more effective and efficient ship operation while saving significant amount of money and time.

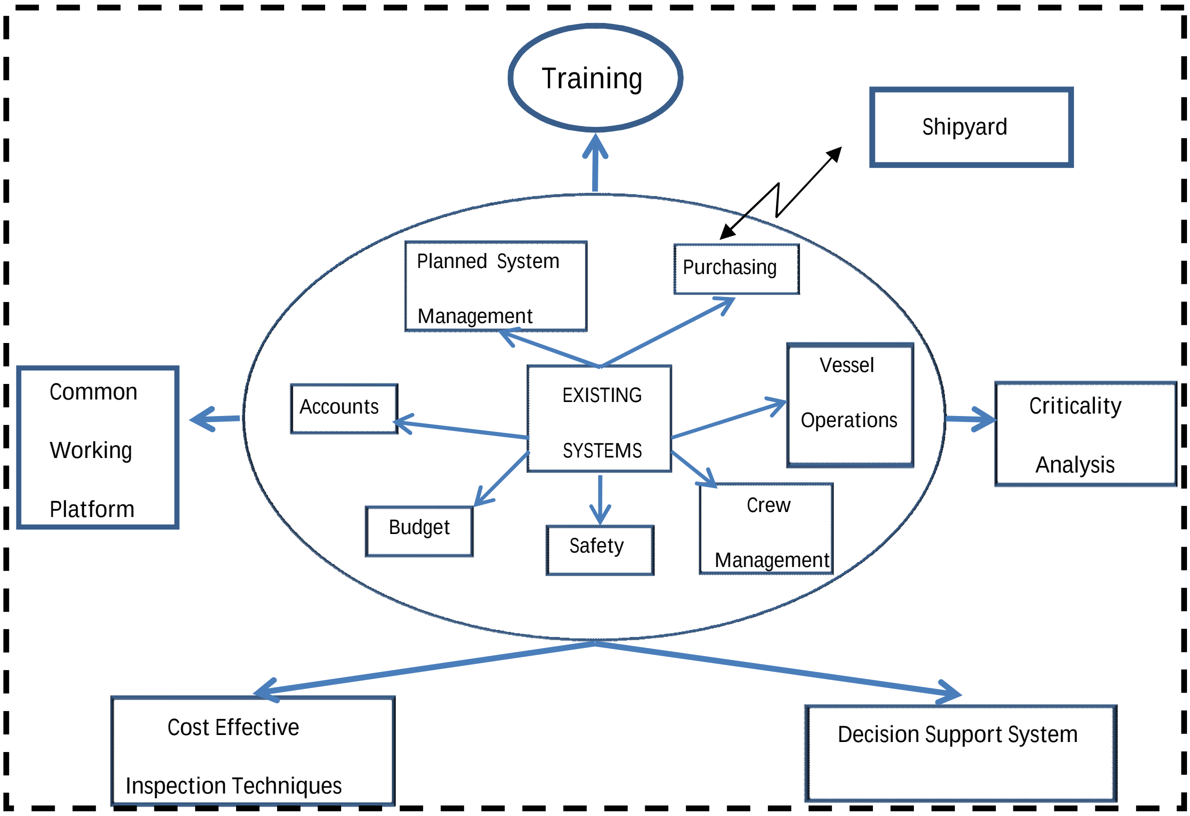

Figure 8.1 improvements and implementations

Findings From Analysis of Repair And Maintenance Data.

This thesis focused on the maintenance and Repair of hull structure. The first step for case study is to identify the critical parts and areas for hull structure. For this purpose reliability analysis are carried out for different ship types. There are some popular reliability analysis methods like reliability block diagram, reliability prediction method, fault tree and failure mode effect analysis. Due to the required data type and demonstrated results fault tree analysis appears to be more suitable than the other methods. Therefore fault tree analyses for different ship types are carried out. It is also easy to build the ship hull structure diagram with fault tree than the other reliability analyses methods.

Using the Reliability analysis critical parts for each vessel types are identified as *shell plate* for ropax vessel, *cargo tanks* for chemical tanker and *shell plate and cargo holds* for general cargo vessel.

General Cargo Vessel: According to criticality analysis of general cargo vessels the most critical part is shell plate and cargo holds. Shell plate has the highest criticality value which is more than 0.2 while cargo hold shell plate has a criticality value of over 0.1. Criticality occurrence of these parts is level 5 which is highest level (failure occurrence is recurrent). Fore peak tank, main deck, trim tank are the other high critical areas for which the criticality values are higher than 0.05 which is level 4 (failure occurrence is conceivable). Chain room, coamings, double bottom, fore peak deck, inner bottom plate and tank top are under 0.05.

According to reliability analysis for general cargo vessels, shell plate and cargo holds areas have the lowest reliability. Fore peak tank and main deck have the next lowest reliability values. However, despite some critical local items, reliability values for general cargo vessels vary 0.99995 and 1 which is a quite high reliability value. Overall reliability of cargo vessel is 0.999788 which is a very high value.

Chemical Tankers: Based on criticality calculations, the most critical parts of chemical tankers are the cargo tanks with criticality value of 0.204269 (level 5) and the hull with criticality value of 0.158145 (level 5). Wing tanks with criticality value of 0.10622 and deck with criticality value of 0.052715 are identified as the next critical parts.

The reliability analysis indicated that overall reliability of chemical tanker is more than 0.99 and it is an acceptable value. Chemical tankers are carrying various type of cargo. It is very important to protect cargo tanks by cleaning of the tanks properly after discharging is completed. Bad cleaning can wear out the plates, and therefore high number of failure can be observed in this area. In hull, buckling, indent and deformations, cracks and fractures are observed and hull indent and deformations are the most observed failures for hull.

Ropax Vessels: According to criticality analysis for Ropax vessel, side shell and transverse members are identified as the most critical parts, while bow visor and deck are identified as other critical parts for Ropax vessel. Garage deck is the one of the critical parts of Ropax where indent and deformation is the most observed structural damages. In this part cracks and fractures and buckling failures are also observed. Due to the loading and discharging activities garage deck can be easily worn out or damaged. This is directly related to typical operational activities (loading/unloading) of Ropax vessels. Therefore the failure rate is high for this area. Due to the ship being in contact with port or other ships in regular frequency, side shell has the highest criticality with Ropax vessel. Most common damages are fractures, buckling and cracks.

According to reliability analysis of ropax vessels, cargo area has the lowest reliability value, which is followed by side shell. However the overall reliability values for ropax vessel are more than 0.995 which is a good value for reliability and it is over the standard reliability values. This means, local criticalities do not affect the overall reliability of Ropax vessels.

Maintenance& Repair Process: Relation Between shipyard and Operator.

There is a big communication gap between ship operators, shipyard and sub constructor company. By improving the communication and process it is possible to minimize the delay in repair yard and increasing the operational availability of ship.

The process starts 5-6 months before the dry docking time. The ship operators send their engineers to control the ship and make the marking for steel replacement. At this stage engineer does not want to mark a lot of steel work as he does not want to make ship operator angry. If the engineer marks a lot of steel work then ship operator try to find someone else to avoid marking of more steel work. After finishing the marking, ship operators based on the marking, get the price from the shipyard and the available date for dry docking. However, during the inspection at shipyard, the marked steel replacement in majority of the cases are significantly higher and this is not accepted by the operator leading to delays with the repair.

Classification society, shipyard and ship operator need to work together at this stage and make the marking together to solve the marking problem. So the conflict between the repair work and cost between shipyard and ship operators can easily be resolved. Moreover this will give shipyard opportunity for better preparation as the shipyard knows exact nature of steel work to be carried out 5-6 months before the dry docking time. So it is very easy for the shipyard to order the steel and the other things from the supplier and also it is possible to make all the preparations in advance. Preparing the frames, lamas, brackets etc. in advance is possible and just before the dry docking time it is also possible to put these parts near the cradle which the ship is going to be dry docked. And because the shipyard engineer is familiar with the ship and the work in advance, it is going to provide more quality work and less dry docking time.

However, ship operators want their ship to be dry docked when they want. Generally ship operators do not care whether the ship yard is really available or not for the particular time when his ship is to be dry docked. Ship operators get the time by insisting on ship yard so; although ship yard is not available, ship yard makes the date available on which ship operators insist on. It is also possible that although the ship yard is not available in this date, ship yard gives the date which ship operator wants as ship yard does not want to lose the customer. In both condition ship operator will not be happy, as because of the limited time the quality of the work will be low and work will not be completed in time. This stage problem can be easily solved with good communication between ship yard and ship operator.

Shipyards use sub constructors and shipyards work with combination of different sub constructors. The communication gap between these sub constructors affect the work quality as sometimes it can even cause rework. This problem can easily be handled by arranging small regular meetings between the sub constructors and ship yard to plan the work. And also these meetings can be more effective if classification society and supplier can join these meetings.

This requires the development of a good strategy by shipyards and unfortunately most of the small repair yards they do not have a strategic repair plan or well thought repair plan.

Running Cost Model and Results:

Running cost model is developed using operational, repair and maintenance data. The quality and the quantity of the collected data affect the results. The developed model includes only one or two maintenance and repair data for each ship. In order to get more sensitive results the maintenance and repair history is needed for each ship. Due to the shipyards or ship operator's management policy, the maintenance and repair history is not saved. Although the author made a field study to collect the related data from shipyard, only one or two maintenance and repair work data are collected for each ship.

Although, the quality of the data is less than desirable the developed model provide us a good basis for comparative analysis and a solid basis for further development if and when more and better quality data is available.

By running the developed cost model it was possible to see the difference between the well maintained and not well maintained ships. However as the author mentioned earlier maintenance and repair works are just including the hull structural work. The results g an give an idea about the difference of well maintained and not well maintained ship however it is not going to be the exact value without including all maintenance and repair cost. Although running cost for machinery/equipment is extremely important, running cost for Machinery is not included in this study and it is suggested that this should be included in the running cost model.

Balance between maintenance expenses, reliability and running cost is very important. Reliability of hull structure increases with investment, however it is important to determine what work is worth doing and when, and also by criticality analysis clear understanding is needed of which system do what, and what happens if the balance between maintenance expenses, reliability and running cost is not achieved.

Condition monitoring can be the way forward to improve the maintenance and repair of ships. Currently, condition monitoring system is widely used only on the main engines and vibration measurements for specific parts such as shafts etc. It is possible to improve and implement the condition monitoring approach in as a Criticality Based approach in various areas of the ship cost effectively with an aim of early identification and rectification of the problems.

The important thing is that not only learning what the new techniques are but to decide which of them are worthwhile implementing.

Results clearly demonstrate the effect of lightship on the running cost of the ship. Based on the data it is established that as the lightship increases the repair/steel replacement cost increases. However, it has to be emphasised that , in the model, conventional ship design corrosion margins are taken into account according to the Class requirements. However, as some ship owners suggested, appropriate corrosion margin can be taken into account during the design stage to avoid/reduce the steel repair or replacement.

The effect of lightweight changes on maintenance and repair work analysis is carried out without taken into account the corrosion effect in a proper way. The current model indicates that as the lightweight increases, the steel repair and replacement cost will increase. This is contradicting to shipowners' idea that with higher corrosion margin the repair cost should decrease.

Although the corrosion is an important factor for maintenance and repair work, due to lack of data it is not possible to consider corrosion factor in running cost model. Including corrosion factor in running cost model is also very important for more sensitive and reliable result and should be very important future study.

The results also indicated that significant repair cost differences may exist between well repair and not well repaired ships. This is a crucial point to well establish so that ship operators can be presented with hard evidence on benefits of adopting good maintenance/repair strategy.

8.2 Future recommendations

- Data collection is the most difficult part of this study. Ship operators, ship yards and classification societies are not happy to share their data base. In this study contact with shipyard, classification society and ship operators are made as due to the personal relationship, it was possible to collect the ship maintenance and repair data collected. However, in order to develop an efficient approach to reduce the operation cost, access to maintenance and repair data is crucial and future studies should include developing a strategy on how to help the ship operators to utilize/share the data without revealing sensitive company data.

- The format of the collected data is not standard. Therefore putting all the data in same format and trying to understand what the data means takes a big effort. Even in the shipyard, engineers have their own format. Standardizing the format of data collection will bring more time saving and better utilization.

- Collecting repair history of ship with same size and type as well as developing the model according to these data is important to achieve more sensitive results.

- Corrosion model should be taken into account appropriately so that alternative design ideas can be investigated accurately.

  In developing running cost model corrosion factor is not included for lightweight changes. The effect of lightweight changes is on maintenance and repair work analysis is carried out due to no corrosion. Although the corrosion is an important factor for maintenance and repair work, due to lack of data it is not possible to consider corrosion factor in running cost model. Including corrosion factor to running cost model is also very important for more sensitive and reliable result.

In this model increase of steel thickness brings more repair and maintenance work in other word with thinner steel the repair and maintenance work is less. However if the study included the corrosion factor the increase of the steel thickness will not bring the same repair and maintenance work. Moreover due to the corrosion the thinner steel will need more repair work. To get more efficient numbers corrosion should be included to this study.

- Running cost modeling will be complete only if the running cost for engine and onboard equipments are taken into account.
- As suggested in discussions, ship operators should be assisted technically so that they make their ship operation more efficient and more reliable. This can only be done by developing the real time maintenance and repair data recording, performing real time reliability and criticality analysis, to identify the critical items and developing decision support system to assist the ship operator to make a decision when and what action to take. Finally these developments should be integrated with PSM software.

CHAPTER 9: CONCLUSION

This thesis can be seen as a starting point towards developing a comprehensive life cycle ship operation strategy focusing on the running cost including repair and maintenance. To reach this ultimate aim, there are many issues to be addressed but this needs to be done systematically and step by step. Based on the study carried out in this thesis following concluding remarks can be listed.

- Maintenance and repair has an important role for operational availability of ship. Generally ship operators do not want to spend time on dry dock, and it is mainly done to comply with classification society rules. Operators want their ship on operation as soon as possible and therefore they are reluctant to perform repair works which are advised by classification society. They just want to do the compulsory repair and maintenance works.
- Maintenance and repair strategies are changing according to type of ship, age of ship and company policies. Small companies with one or two vessels do not generally have a good maintenance strategy. These companies apply corrective maintenance in other word break down maintenance. These companies only do what classification societies demand in order not to lose the class certificate. Operators with big fleet are more advanced about applying maintenance strategies. Especially passenger vessel operators are very strict with maintenance issue. These operators are making their plans for now and future. Preventive maintenance, corrective maintenance, condition monitoring are applied by these operators.
- Generally dry docking period starts after ten years of age. There are some exceptional situations which are mostly due to wrong design and production implementation.
- Reliability analysis based on the data identified the critical parts of the each ship types. Improving these critical parts in design and production stage will bring more saving for maintenance and repair cost. Moreover availability of ship will be increased. Applying preventive maintenance policy and condition monitoring rather than corrective maintenance can bring more money and time saving.

- Study with regards to the unavailability and steel replacement for same type of ship is showed that there is a big difference between well maintained and not well maintained vessels. The effect of this difference on running cost is significant to pay attention
- According to reliability analysis mostly observed structural failures for Ropax vessel are indent and deformation. Especially side shell is the most critical part for the Ropax vessels. According to chemical tanker criticality calculations most critical parts are hull and cargo tanks. Wing tanks and deck are the second critical parts. Criticality analysis of general cargo vessels shows that the most critical part is shell plate and cargo holds.
- To improve the maintenance and repair strategy, it is important to take advantage of previous data and utilise them in company’s maintenance and repair strategy. This can be done by combining automated reliability and analysis and PSM software together with Decision support system.

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List of Appendices

Ropax running cost model with high repair work amount (9870 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	12,870	
Original Displacement (in tonnes)	16,560	
Original DWT (in tonnes)	3,690	
New Lightweighti (in tonnes)	9,870	Indep. Variable
Var (lightweight)	-3,000	
New Displacement (in tonnes)	13,560	
New DWT (in tonnes)	690	
V design speed (in knots)	21	

		Type						
			NPV	Age	Age	Age	Age	Age
MODEL 2				5	10	15	20	25
Amount of repaired steel	ARS	Dep. Variable						
Unit Price of steel replaement / kg	Prstrp	Constant		1,059.6	1,129.0	1,203.1	1,281.9	1,366.0
Cost of steel replacement	COSR @ current prices	Dep. Variable		5.0	5.0	5.0	5.0	5.0
	Escalated COSR			5,297,940	5,645,233	6,015,292	6,409,610	6,829,775
	Discounted COSR			6,141,765	7,586,721	9,371,629	11,576,468	14,300,033
	COSR			4,179,982	3,514,120	2,954,328	2,483,710	2,088,061
			15,220,201					
total area of coating (m^2)	TAC	Dep. Variable						
Price of coating	PrCOA	Constant		7,791.1	8,301.8	8,846.0	9,425.9	10,043.8
Coating	COA @ current prices	Dep. Variable		3.0	3.0	3.0	3.0	3.0
	Escalated COA			23,373.3	24,905.4	26,538.1	28,277.7	30,131.4
	Discounted COA			27,096.0	33,470.8	41,345.4	51,072.7	63,088.4

_	COA			18,441.1	15,503.5	13,033.8	10,957.5	9,212.0
			67,148					
Days in drydock	Ddock	Dep. Variable						
				12	19	26	33	40
Cost of unavailability	CUNA @ current prices	Dep. Variable						
	Escalated CUNA			1,477,086	2,320,823	3,164,560	4,008,297	4,852,034
	Discounted CUNA			1,712,347	3,118,992	4,930,281	7,239,430	10,159,081
Cost of unavailability	CUNA			1,165,395	1,444,697	1,554,230	1,553,207	1,483,408
	CODO - NPV	Dep. Variable	7,200,936					
			22,488,286					
MODEL 3								
Engine power max	Pmax	Dep. Variable						
Specific FOC (gr/KW*h)	SFOCmain	Constant		6,550	6,550	6,550	6,550	6,550
% of max speed	Fmean (%)	Constant		125	125	125	125	125
Daily fuel oil consumption (tons)	DFC	Dep. Variable		90	90	90	90	90
Days at sea	Dsea	Dep. Variable		17.7	17.7	17.7	17.7	17.7
Price of fuel	Prfuel	Constant		353	346	339	332	325
No of main engines	Nmain	Constant		320	320	320	320	320
Lub & Diesel oil correction factor	Oilcorr	Constant		4	4	4	4	4
Annual cost of fuel	ACOF @ current prices			1.15	1.15	1.15	1.15	1.15
	Escalated ACOF			9,185,062	9,004,137	8,823,212	8,642,288	8,461,363
	Discounted ACOF			10,648,004	12,100,807	13,746,277	15,608,933	17,716,215
	ACOF - NPV			7,246,852	5,605,015	4,333,400	3,348,869	2,586,885
			23,121,021					
MODEL 4								
Passenger capacity		Constant						
Car capacity		Constant		2500	2500	2500	2500	2500

Average daily passenger fee				430	430	430	430	430
Average daily car fee				40.7	40.7	40.7	40.7	40.7
				46	46	46	46	46
Revenue/annum	Rtm @ current prices	Dep. Variable						
	Escalated Rtm		7,077,855	35,389,275	70,778,550	106,167,825	141,557,100	176,946,375
	Discounted Rtm		8,205,174	41,025,869	82,051,738	123,077,607	164,103,476	205,129,345
	Rtm - NPV		9,512,045	47,560,226	95,120,453	142,680,679	190,240,905	237,801,132
			713,403,395	3,567,016,974	7,134,033,949	10,701,050,923	14,268,067,898	17,835,084,872
MODEL 5								
Price of dismantling/ton	Prdist	Constant						
Earning of dismantling	EDIS @ current prices	Dep. Variable						430
	Escalated EDIS							4244100
	Discounted EDIS							8,886,203
	EDIS - NPV							1,297,545
			1,297,545					
SCENARIO 1	**-**							
SCENARIO 2	**-**		**44,311,762**					
			- 692,212,654					

Ropax running cost model with high repair work amount (12870 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	12,870	
Original Displacement (in tonnes)	16,560	
Original DWT (in tonnes)	3,690	
New Lightweighti (in tonnes)	12,870	Indep. Variable
Var (lightweight)	0	
New Displacement (in tonnes)	16,560	
New DWT (in tonnes)	3,690	
V design speed (in knots)	21	

		Type						
			NPV	Age	Age	Age	Age	Age
MODEL 2				5	10	15	20	25
Amount of repaired steel	ARS	Dep. Variable						
Unit Price of steel replaement / kg	Prstrp	Constant		1,381.7	1,472.2	1,568.7	1,671.6	1,781.1
Cost of steel replacement	COSR @ current prices	Dep. Variable		5.0	5.0	5.0	5.0	5.0
	Escalated COSR			6,908,256	7,361,110	7,843,649	8,357,819	8,905,695
	Discounted COSR			8,008,563	9,892,716	12,220,149	15,095,151	18,646,547
	COSR			5,450,493	4,582,242	3,852,301	3,238,638	2,722,730
			19,846,403					
total area of coating (m^2)	TAC	Dep. Variable						
Price of coating	PrCOA	Constant		10,159.2	10,825.2	11,534.8	12,290.9	13,096.6
Coating	COA @ current prices	Dep. Variable		3.0	3.0	3.0	3.0	3.0
	Escalated COA			30,477.6	32,475.5	34,604.3	36,872.7	39,289.8
	Discounted COA			35,331.9	43,644.3	53,912.4	66,596.3	82,264.2
	COA			24,046.3	20,215.8	16,995.4	14,288.1	12,012.0

			87,558					
Days in drydock	Ddock	Dep. Variable						
				12	19	26	33	40
Cost of unavailability	CUNA @ current prices	Dep. Variable						
	Escalated CUNA			1,477,086	2,320,823	3,164,560	4,008,297	4,852,034
	Discounted CUNA			1,712,347	3,118,992	4,930,281	7,239,430	10,159,081
Cost of unavailability	CUNA			1,165,395	1,444,697	1,554,230	1,553,207	1,483,408
	CODO - NPV	Dep. Variable	7,200,936					
			27,134,897					
MODEL 3								
Engine power max	Pmax	Dep. Variable						
Specific FOC (gr/KW*h)	SFOCmain	Constant		6,550	6,550	6,550	6,550	6,550
% of max speed	Fmean (%)	Constant		125	125	125	125	125
Daily fuel oil consumption (tons)	DFC	Dep. Variable		90	90	90	90	90
Days at sea	Dsea	Dep. Variable		17.7	17.7	17.7	17.7	17.7
Price of fuel	Prfuel	Constant		353	346	339	332	325
No of main engines	Nmain	Constant		320	320	320	320	320
Lub & Diesel oil correction factor	Oilcorr	Constant		4	4	4	4	4
Annual cost of fuel	ACOF @ current prices			1.15	1.15	1.15	1.15	1.15
	Escalated ACOF			9,185,062	9,004,137	8,823,212	8,642,288	8,461,363
	Discounted ACOF			10,648,004	12,100,807	13,746,277	15,608,933	17,716,215
	ACOF - NPV			7,246,852	5,605,015	4,333,400	3,348,869	2,586,885
			23,121,021					
MODEL 4								
Passenger capacity		Constant						
Car capacity		Constant		2500	2500	2500	2500	2500
Average daily passenger				430	430	430	430	430

fee								
Average daily car fee				40.7	40.7	40.7	40.7	40.7
				46	46	46	46	46
Revenue/annum	Rtm @ current prices	Dep. Variable						
	Escalated Rtm		7,077,855	35,389,275	70,778,550	106,167,825	141,557,100	176,946,375
	Discounted Rtm		8,205,174	41,025,869	82,051,738	123,077,607	164,103,476	205,129,345
	Rtm - NPV		9,512,045	47,560,226	95,120,453	142,680,679	190,240,905	237,801,132
			713,403,395	3,567,016,974	7,134,033,949	10,701,050,923	14,268,067,898	17,835,084,872
MODEL 5								
Price of dismantling/ton	Prdist	Constant						
Earning of dismantling	EDIS @ current prices	Dep. Variable						430
	Escalated EDIS							5534100
	Discounted EDIS							11,587,176
	EDIS - NPV							1,691,935
			1,691,935					
SCENARIO 1	-							
SCENARIO 2	-		**48,563,982**					
			-687,960,434					

Ropax running cost model with high repair work amount (15870 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	12,870	
Original Displacement (in tonnes)	16,560	
Original DWT (in tonnes)	3,690	
New Lightweighti (in tonnes)	15,870	Indep. Variable
Var (lightweight)	3,000	
New Displacement (in tonnes)	19,560	
New DWT (in tonnes)	6,690	
V design speed (in knots)	21	

		Type						
			NPV	Age	Age	Age	Age	Age
MODEL 2				5	10	15	20	25
Amount of repaired steel	ARS	Dep. Variable						
Unit Price of steel replaement / kg	Prstrp	Constant		1,703.7	1,815.4	1,934.4	2,061.2	2,196.3
Cost of steel replacement	COSR @ current prices	Dep. Variable		5.0	5.0	5.0	5.0	5.0
	Escalated COSR			8,518,573	9,076,986	9,672,005	10,306,029	10,981,614
	Discounted COSR			9,875,360	12,198,710	15,068,668	18,613,834	22,993,062
	COSR			6,721,004	5,650,363	4,750,273	3,993,565	3,357,399
			24,472,604					
total area of coating (m^2)	TAC	Dep. Variable						
Price of coating	PrCOA	Constant		12,527.3	13,348.5	14,223.5	15,155.9	16,149.4
Coating	COA @ current prices	Dep. Variable		3.0	3.0	3.0	3.0	3.0
	Escalated COA			37,581.9	40,045.5	42,670.6	45,467.8	48,448.3
	Discounted COA			43,567.8	53,817.8	66,479.4	82,119.9	101,440.0

_	COA			29,651.5	24,928.1	20,957.1	17,618.7	14,812.1
			107,967					
Days in drydock	Ddock	Dep. Variable						
				12	19	26	33	40
Cost of unavailability	CUNA @ current prices	Dep. Variable						
	Escalated CUNA			1,477,086	2,320,823	3,164,560	4,008,297	4,852,034
	Discounted CUNA			1,712,347	3,118,992	4,930,281	7,239,430	10,159,081
Cost of unavailability	CUNA			1,165,395	1,444,697	1,554,230	1,553,207	1,483,408
	CODO - NPV	Dep. Variable	7,200,936					
			31,781,507					
MODEL 3								
Engine power max	Pmax	Dep. Variable						
Specific FOC (gr/KW*h)	SFOCmain	Constant		6,550	6,550	6,550	6,550	6,550
% of max speed	Fmean (%)	Constant		125	125	125	125	125
Daily fuel oil consumption (tons)	DFC	Dep. Variable		90	90	90	90	90
Days at sea	Dsea	Dep. Variable		17.7	17.7	17.7	17.7	17.7
Price of fuel	Prfuel	Constant		353	346	339	332	325
No of main engines	Nmain	Constant		320	320	320	320	320
Lub & Diesel oil correction factor	Oilcorr	Constant		4	4	4	4	4
Annual cost of fuel	ACOF @ current prices			1.15	1.15	1.15	1.15	1.15
	Escalated ACOF			9,185,062	9,004,137	8,823,212	8,642,288	8,461,363
	Discounted ACOF			10,648,004	12,100,807	13,746,277	15,608,933	17,716,215
	ACOF - NPV			7,246,852	5,605,015	4,333,400	3,348,869	2,586,885
			23,121,021					
MODEL 4								
Passenger capacity		Constant						
Car capacity		Constant		2500	2500	2500	2500	2500

Average daily passenger fee				430	430	430	430	430
Average daily car fee				40.7	40.7	40.7	40.7	40.7
				46	46	46	46	46
Revenue/annum	Rtm @ current prices	Dep. Variable						
	Escalated Rtm		7,077,855	35,389,275	70,778,550	106,167,825	141,557,100	176,946,375
	Discounted Rtm		8,205,174	41,025,869	82,051,738	123,077,607	164,103,476	205,129,345
	Rtm - NPV		9,512,045	47,560,226	95,120,453	142,680,679	190,240,905	237,801,132
			713,403,395	3,567,016,974	7,134,033,949	10,701,050,923	14,268,067,898	17,835,084,872
MODEL 5								
Price of dismantling/ton	Prdist	Constant						
Earning of dismantling	EDIS @ current prices	Dep. Variable						430
	Escalated EDIS							6824100
	Discounted EDIS							14,288,150
	EDIS - NPV							2,086,326
			2,086,326					
SCENARIO 1	**-**							
SCENARIO 2	**-**		**52,816,202**					
			- 683,708,213					

Ropax running cost model with likely repair work amount (9870 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	12870	
Original Displacement (in tonnes)	13560	
Original DWT (in tonnes)	3690	
New Lightweighti (in tonnes)	9870	Indep. Variable
Var (lightweight)	-3000	
New Displacement (in tonnes)	10560	
New DWT (in tonnes)	690	
V design speed (in knots)	21	

		Type						
			NPV	Age	Age	Age	Age	Age
MODEL 2				5	10	15	20	25
Amount of repaired steel	ARS	Dep. Variable						
Unit Price of steel replaement / kg	Prstrp	Constant		153.6360842	225.8896817	332.1234629	488.3179867	717.9693179
Cost of steel replacement	COSR @ current prices	Dep. Variable		5	5	5	5	5
	Escalated COSR			768180.4212	1129448.409	1660617.314	2441589.933	3589846.589
	Discounted COSR			890531.6466	1517884.216	2587187.667	4409783.009	7516341.56
	COSR			606080.8751	703074.0846	815589.4513	946111.0396	1097520.447
			4168375.898					
total area of coating (m^2)	TAC	Dep. Variable						
Price of coating	PrCOA	Constant		1129.67709	1660.953542	2442.084286	3590.573431	5279.186161
Coating	COA @ current prices	Dep. Variable		3	3	3	3	3
	Escalated COA			3389.03127	4982.860627	7326.252858	10771.72029	15837.55848
	Discounted COA			3928.816088	6696.548012	11414.06324	19454.92504	33160.33041

	COA			2673.886214	3101.797432	3598.188756	4174.019292	4842.001973
			18389.89367					
Days in drydock	Ddock	Dep. Variable						
				12.167	19.117	26.067	33.017	39.967
Cost of unavailability	CUNA @ current prices	Dep. Variable						
	Escalated CUNA			1477085.967	2320822.917	3164559.867	4008296.817	4852033.767
	Discounted CUNA			1712347.467	3118991.932	4930281.161	7239429.913	10159081.22
Cost of unavailability	CUNA			1165394.914	1444696.752	1554230.239	1553206.71	1483407.755
	CODO - NPV	Dep. Variable	7200936.37					
			11387702.16					
MODEL 3								
Engine power max	Pmax	Dep. Variable						
Specific FOC (gr/KW*h)	SFOCmain	Constant		6550	6550	6550	6550	6550
% of max speed	Fmean (%)	Constant		125	125	125	125	125
Daily fuel oil consumption (tons)	DFC	Dep. Variable		90	90	90	90	90
Days at sea	Dsea	Dep. Variable		17.685	17.685	17.685	17.685	17.685
Price of fuel	Prfuel	Constant		352.833	345.883	338.933	331.983	325.033
No of main engines	Nmain	Constant		320	320	320	320	320
Lub & Diesel oil correction factor	Oilcorr	Constant		4	4	4	4	4
Annual cost of fuel	ACOF @ current prices			1.15	1.15	1.15	1.15	1.15
	Escalated ACOF			9185061.563	9004136.939	8823212.315	8642287.691	8461363.067
	Discounted ACOF			10648003.74	12100807.11	13746277.3	15608932.89	17716215.24
	ACOF - NPV			7246852.428	5605015.056	4333399.892	3348868.571	2586884.633
			23121020.58					
MODEL 4								
Passenger capacity		Constant						
Car capacity		Constant		2500	2500	2500	2500	2500

Average daily passenger fee				430	430	430	430	430
Average daily car fee				40.7	40.7	40.7	40.7	40.7
				45.7	45.7	45.7	45.7	45.7
Revenue/annum	Rtm @ current prices	Dep. Variable						
	Escalated Rtm		7077855	35389275	70778550	106167825	141557100	176946375
	Discounted Rtm		8205173.803	41025869.02	82051738.03	123077607	164103476.1	205129345.1
	Rtm - NPV		9512045.265	47560226.33	95120452.65	142680679	190240905.3	237801131.6
			713403394.9	3567016974	7134033949	10701050923	14268067898	17835084872
MODEL 5								
Price of dismantling/ton	Prdist	Constant						
Earning of dismantling	EDIS @ current prices	Dep. Variable						430
	Escalated EDIS							4244100
	Discounted EDIS							8886202.911
	EDIS - NPV							1297544.732
			1297544.732					
SCENARIO 1								
SCENARIO 2			33211178.01					
			-703313237.5					

Ropax running cost model with likely repair work amount (12870 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	12870	
Original Displacement (in tonnes)	16560	
Original DWT (in tonnes)	3690	
New Lightweighti (in tonnes)	12870	Indep. Variable
Var (lightweight)	0	
New Displacement (in tonnes)	16560	
New DWT (in tonnes)	3690	
V design speed (in knots)	21	

		Type						
			NPV	Age	Age	Age	Age	Age
MODEL 2				5	10	15	20	25
Amount of repaired steel	ARS	Dep. Variable						
Unit Price of steel replaement / kg	Prstrp	Constant		200.3339822	294.5491595	433.0728437	636.7429066	936.1970741
Cost of steel replacement	COSR @ current prices	Dep. Variable		5	5	5	5	5
	Escalated COSR			1001669.911	1472745.797	2165364.219	3183714.533	4680985.37
	Discounted COSR			1161209.959	1979247.2	3373566.898	5750142.586	9800943.857
	COSR			790299.9861	916774.4142	1063488.981	1233682.784	1431113.288
			5435359.453					
total area of coating (m^2)	TAC	Dep. Variable						
Price of coating	PrCOA	Constant		1473.043987	2165.802643	3184.359145	4681.933137	6883.802015
Coating	COA @ current prices	Dep. Variable		3	3	3	3	3
	Escalated COA			4419.13196	6497.40793	9553.077435	14045.79941	20651.40605
	Discounted COA			5122.985112	8731.97294	14883.38337	25368.27612	43239.45819

	COA			3486.617586	4044.593004	4691.86315	5442.718166	6313.735095
			23979.527					
Days in drydock	Ddock	Dep. Variable						
				12.167	19.117	26.067	33.017	39.967
Cost of unavailability	CUNA @ current prices	Dep. Variable						
	Escalated CUNA			1477085.967	2320822.917	3164559.867	4008296.817	4852033.767
	Discounted CUNA			1712347.467	3118991.932	4930281.161	7239429.913	10159081.22
Cost of unavailability	CUNA			1165394.914	1444696.752	1554230.239	1553206.71	1483407.755
	CODO - NPV	Dep. Variable	7200936.37					
			12660275.35					
MODEL 3								
Engine power max	Pmax	Dep. Variable						
Specific FOC (gr/KW*h)	SFOCmain	Constant		6550	6550	6550	6550	6550
% of max speed	Fmean (%)	Constant		125	125	125	125	125
Daily fuel oil consumption (tons)	DFC	Dep. Variable		90	90	90	90	90
Days at sea	Dsea	Dep. Variable		17.685	17.685	17.685	17.685	17.685
Price of fuel	Prfuel	Constant		352.833	345.883	338.933	331.983	325.033
No of main engines	Nmain	Constant		320	320	320	320	320
Lub & Diesel oil correction factor	Oilcorr	Constant		4	4	4	4	4
Annual cost of fuel	ACOF @ current prices			1.15	1.15	1.15	1.15	1.15
	Escalated ACOF			9185061.563	9004136.939	8823212.315	8642287.691	8461363.067
	Discounted ACOF			10648003.74	12100807.11	13746277.3	15608932.89	17716215.24
	ACOF - NPV			7246852.428	5605015.056	4333399.892	3348868.571	2586884.633
			23121020.58					
MODEL 4								
Passenger capacity		Constant						
Car capacity		Constant		2500	2500	2500	2500	2500

Average daily passenger fee				430	430	430	430	430
Average daily car fee				40.7	40.7	40.7	40.7	40.7
				45.7	45.7	45.7	45.7	45.7
Revenue/annum	Rtm @ current prices	Dep. Variable						
	Escalated Rtm		7077855	35389275	70778550	106167825	141557100	176946375
	Discounted Rtm		8205173.803	41025869.02	82051738.03	123077607	164103476.1	205129345.1
	Rtm - NPV		9512045.265	47560226.33	95120452.65	142680679	190240905.3	237801131.6
			713403394.9	3567016974	7134033949	10701050923	14268067898	17835084872
MODEL 5								
Price of dismantling/ton	Prdist	Constant						
Earning of dismantling	EDIS @ current prices	Dep. Variable						430
	Escalated EDIS							5534100
	Discounted EDIS							11587176.44
	EDIS - NPV							1691935.228
			1691935.228					
SCENARIO 1								
SCENARIO 2			34089360.7					
			-702435054.8					

Ropax running cost model with likely repair work amount (15870 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	12,870	
Original Displacement (in tonnes)	19,560	
Original DWT (in tonnes)	3,690	
New Lightweighti (in tonnes)	15,870	Indep. Variable
Var (lightweight)	3,000	
New Displacement (in tonnes)	22,560	
New DWT (in tonnes)	6,690	
V design speed (in knots)	21	

		Type						
			NPV	Age	Age	Age	Age	Age
MODEL 2				5	10	15	20	25
Amount of repaired steel	ARS	Dep. Variable						
Unit Price of steel replaement / kg	Prstrp	Constant		247.0	363.2	534.0	785.2	1,154.4
Cost of steel replacement	COSR @ current prices	Dep. Variable		5.0	5.0	5.0	5.0	5.0
	Escalated COSR			1,235,159	1,816,043	2,670,111	3,925,839	5,772,124
	Discounted COSR			1,431,888	2,440,610	4,159,946	7,090,502	12,085,546
	COSR			974,519	1,130,475	1,311,389	1,521,255	1,764,706
			6,702,343					
total area of coating (m^2)	TAC	Dep. Variable						
Price of coating	PrCOA	Constant		1,816.4	2,670.7	3,926.6	5,773.3	8,488.4
Coating	COA @ current prices	Dep. Variable		3.0	3.0	3.0	3.0	3.0
	Escalated COA			5,449.2	8,012.0	11,779.9	17,319.9	25,465.3
	Discounted COA			6,317.2	10,767.4	18,352.7	31,281.6	53,318.6
	COA			4,299.3	4,987.4	5,785.5	6,711.4	7,785.5

			29,569					
Days in drydock	Ddock	Dep. Variable						
				12	19	26	33	40
Cost of unavailability	CUNA @ current prices	Dep. Variable						
	Escalated CUNA			1,477,086	2,320,823	3,164,560	4,008,297	4,852,034
	Discounted CUNA			1,712,347	3,118,992	4,930,281	7,239,430	10,159,081
Cost of unavailability	CUNA			1,165,395	1,444,697	1,554,230	1,553,207	1,483,408
	CODO - NPV	Dep. Variable	7,200,936					
			13,932,849					
MODEL 3								
Engine power max	Pmax	Dep. Variable						
Specific FOC (gr/KW*h)	SFOCmain	Constant		6,550	6,550	6,550	6,550	6,550
% of max speed	Fmean (%)	Constant		125	125	125	125	125
Daily fuel oil consumption (tons)	DFC	Dep. Variable		90	90	90	90	90
Days at sea	Dsea	Dep. Variable		17.7	17.7	17.7	17.7	17.7
Price of fuel	Prfuel	Constant		353	346	339	332	325
No of main engines	Nmain	Constant		320	320	320	320	320
Lub & Diesel oil correction factor	Oilcorr	Constant		4	4	4	4	4
Annual cost of fuel	ACOF @ current prices			1.15	1.15	1.15	1.15	1.15
	Escalated ACOF			9,185,062	9,004,137	8,823,212	8,642,288	8,461,363
	Discounted ACOF			10,648,004	12,100,807	13,746,277	15,608,933	17,716,215
	ACOF - NPV			7,246,852	5,605,015	4,333,400	3,348,869	2,586,885
			23,121,021					
MODEL 4								
Passenger capacity		Constant						
Car capacity		Constant		2500	2500	2500	2500	2500

Average daily passenger fee				430	430	430	430	430
Average daily car fee				40.7	40.7	40.7	40.7	40.7
				46	46	46	46	46
Revenue/annum	Rtm @ current prices	Dep. Variable						
	Escalated Rtm		7,077,855	35,389,275	70,778,550	106,167,825	141,557,100	176,946,375
	Discounted Rtm		8,205,174	41,025,869	82,051,738	123,077,607	164,103,476	205,129,345
	<u>Rtm - NPV</u>		9,512,045	47,560,226	95,120,453	142,680,679	190,240,905	237,801,132
			<u>713,403,395</u>	3,567,016,974	7,134,033,949	10,701,050,923	14,268,067,898	17,835,084,872
<u>MODEL 5</u>								
Price of dismantling/ton	Prdist	Constant						
Earning of dismantling	EDIS @ current prices	Dep. Variable						430
	Escalated EDIS							6824100
	Discounted EDIS							14,288,150
	<u>EDIS - NPV</u>							2,086,326
			<u>2,086,326</u>					
<u>SCENARIO 1</u>	-							
<u>SCENARIO 2</u>	-		**<u>34,967,543</u>**					
			<u>-701,556,872</u>					

Ropax running cost model with low repair work amount (9870 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	12870	
Original Displacement (in tonnes)	13560	
Original DWT (in tonnes)	3690	
New Lightweighti (in tonnes)	9870	Indep. Variable
Var (lightweight)	-3000	
New Displacement (in tonnes)	10560	
New DWT (in tonnes)	690	
V design speed (in knots)	21	

		Type						
			NPV	Age	Age	Age	Age	Age
MODEL 2				5	10	15	20	25
Amount of repaired steel	ARS	Dep. Variable						
Unit Price of steel replaement / kg	Prstrp	Constant		224.861147	237.454835	250.7538516	264.7976995	279.6280942
Cost of steel replacement	COSR @ current prices	Dep. Variable		5	5	5	5	5
	Escalated COSR			1124305.74	1187274.18	1253769.258	1323988.497	1398140.471
	Discounted COSR			1303378.49	1595597.21	1953331.652	2391270.5	2927395.661
	COSR			887057.501	739070.238	615771.6003	513042.7991	427452.1813
			3182394.32					
total area of coating (m^2)	TAC	Dep. Variable						
Price of coating	PrCOA	Constant		1653.39079	1745.99144	1843.778321	1947.041908	2056.088928
Coating	COA @ current prices	Dep. Variable		3	3	3	3	3
	Escalated COA			4960.17237	5237.97431	5531.334962	5841.125724	6168.266785
	Discounted COA			5750.19923	7039.39946	8617.639641	10549.72279	12914.98086
	COA			3913.48897	3260.60399	2716.639413	2263.424114	1885.818447

			14039.9749					
Days in drydock	Ddock	Dep. Variable						
				12.167	19.117	26.067	33.017	39.967
Cost of unavailability	CUNA @ current prices	Dep. Variable						
	Escalated CUNA			1477085.97	2320822.92	3164559.867	4008296.817	4852033.767
	Discounted CUNA			1712347.47	3118991.93	4930281.161	7239429.913	10159081.22
Cost of unavailability	CUNA			1165394.91	1444696.75	1554230.239	1553206.71	1483407.755
	CODO - NPV	Dep. Variable	7200936.37					
			10397370.7					
MODEL 3								
Engine power max	Pmax	Dep. Variable						
Specific FOC (gr/KW*h)	SFOCmain	Constant		6550	6550	6550	6550	6550
% of max speed	Fmean (%)	Constant		125	125	125	125	125
Daily fuel oil consumption (tons)	DFC	Dep. Variable		90	90	90	90	90
Days at sea	Dsea	Dep. Variable		17.685	17.685	17.685	17.685	17.685
Price of fuel	Prfuel	Constant		352.833	345.883	338.933	331.983	325.033
No of main engines	Nmain	Constant		320	320	320	320	320
Lub & Diesel oil correction factor	Oilcorr	Constant		4	4	4	4	4
Annual cost of fuel	ACOF @ current prices			1.15	1.15	1.15	1.15	1.15
	Escalated ACOF			9185061.56	9004136.94	8823212.315	8642287.691	8461363.067
	Discounted ACOF			10648003.7	12100807.1	13746277.3	15608932.89	17716215.24
	ACOF - NPV			7246852.43	5605015.06	4333399.892	3348868.571	2586884.633
			23121020.6					
MODEL 4								
Passenger capacity		Constant						
Car capacity		Constant		2500	2500	2500	2500	2500
Average daily passenger fee				430	430	430	430	430

Average daily car fee				40.7	40.7	40.7	40.7	40.7	
				45.7	45.7	45.7	45.7	45.7	
Revenue/annum	Rtm @ current prices	Dep. Variable							
	Escalated Rtm		7077855	35389275	70778550	106167825	141557100	176946375	
	Discounted Rtm		8205173.8	41025869	82051738	123077607	164103476.1	205129345.1	
	Rtm - NPV		9512045.27	47560226.3	95120452.7	142680679	190240905.3	237801131.6	
			713403395	3567016974	7134033949	10701050923	14268067898	17835084872	
MODEL 5									
Price of dismantling/ton	Prdist	Constant							
Earning of dismantling	EDIS @ current prices	Dep. Variable						430	
	Escalated EDIS							4244100	
	Discounted EDIS							8886202.911	
	EDIS - NPV							1297544.732	
			1297544.73						
SCENARIO 1									
SCENARIO 2			32220846.5						
			-704303569						

Ropax running cost model with low repair work amount (12870 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	12,870	
Original Displacement (in tonnes)	16,560	
Original DWT (in tonnes)	3,690	
New Lightweighti (in tonnes)	12,870	Indep. Variable
Var (lightweight)	0	
New Displacement (in tonnes)	16,560	
New DWT (in tonnes)	3,690	
V design speed (in knots)	21	

		Type						
			NPV	Age	Age	Age	Age	Age
MODEL 2				5	10	15	20	25
Amount of repaired steel	ARS	Dep. Variable						
Unit Price of steel replaement / kg	Prstrp	Constant		293.2	309.6	327.0	345.3	364.6
Cost of steel replacement	COSR @ current prices	Dep. Variable		5.0	5.0	5.0	5.0	5.0
	Escalated COSR			1,466,040	1,548,148	1,634,854	1,726,417	1,823,107
	Discounted COSR			1,699,542	2,080,581	2,547,049	3,118,100	3,817,182
	COSR			1,156,680	963,712	802,936	668,983	557,377
			4,149,687					
total area of coating (m^2)	TAC	Dep. Variable						
Price of coating	PrCOA	Constant		2,155.9	2,276.7	2,404.2	2,538.8	2,681.0
Coating	COA @ current prices	Dep. Variable		3.0	3.0	3.0	3.0	3.0
	Escalated COA			6,467.8	6,830.1	7,212.6	7,616.5	8,043.1
	Discounted COA			7,498.0	9,179.0	11,237.0	13,756.3	16,840.5
	COA			5,103.0	4,251.7	3,542.4	2,951.4	2,459.0

			18,307					
Days in drydock	Ddock	Dep. Variable						
				12	19	26	33	40
Cost of unavailability	CUNA @ current prices	Dep. Variable						
	Escalated CUNA			1,477,086	2,320,823	3,164,560	4,008,297	4,852,034
	Discounted CUNA			1,712,347	3,118,992	4,930,281	7,239,430	10,159,081
Cost of unavailability	CUNA			1,165,395	1,444,697	1,554,230	1,553,207	1,483,408
	CODO - NPV	Dep. Variable	7,200,936					
			11,368,931					
MODEL 3								
Engine power max	Pmax	Dep. Variable						
Specific FOC (gr/KW*h)	SFOCmain	Constant		6,550	6,550	6,550	6,550	6,550
% of max speed	Fmean (%)	Constant		125	125	125	125	125
Daily fuel oil consumption (tons)	DFC	Dep. Variable		90	90	90	90	90
Days at sea	Dsea	Dep. Variable		17.7	17.7	17.7	17.7	17.7
Price of fuel	Prfuel	Constant		353	346	339	332	325
No of main engines	Nmain	Constant		320	320	320	320	320
Lub & Diesel oil correction factor	Oilcorr	Constant		4	4	4	4	4
Annual cost of fuel	ACOF @ current prices			1.15	1.15	1.15	1.15	1.15
	Escalated ACOF			9,185,062	9,004,137	8,823,212	8,642,288	8,461,363
	Discounted ACOF			10,648,004	12,100,807	13,746,277	15,608,933	17,716,215
	ACOF - NPV			7,246,852	5,605,015	4,333,400	3,348,869	2,586,885
			23,121,021					
MODEL 4								
Passenger capacity		Constant						
Car capacity		Constant		2500	2500	2500	2500	2500

Average daily passenger fee				430	430	430	430	430
Average daily car fee				40.7	40.7	40.7	40.7	40.7
				46	46	46	46	46
Revenue/annum	Rtm @ current prices	Dep. Variable						
	Escalated Rtm		7,077,855	35,389,275	70,778,550	106,167,825	141,557,100	176,946,375
	Discounted Rtm		8,205,174	41,025,869	82,051,738	123,077,607	164,103,476	205,129,345
	Rtm - NPV		9,512,045	47,560,226	95,120,453	142,680,679	190,240,905	237,801,132
			713,403,395	3,567,016,974	7,134,033,949	10,701,050,923	14,268,067,898	17,835,084,872
MODEL 5								
Price of dismantling/ton	Prdist	Constant						
Earning of dismantling	EDIS @ current prices	Dep. Variable						430
	Escalated EDIS							5534100
	Discounted EDIS							11,587,176
	EDIS - NPV							1,691,935
			1,691,935					
SCENARIO 1	_							
SCENARIO 2	_		**32,798,017**					
			-703,726,399					

Ropax running cost model with low repair work amount (15870 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	12870	
Original Displacement (in tonnes)	19560	
Original DWT (in tonnes)	3690	
New Lightweighti (in tonnes)	15870	Indep. Variable
Var (lightweight)	3000	
New Displacement (in tonnes)	22560	
New DWT (in tonnes)	6690	
V design speed (in knots)	21	

		Type						
			NPV	Age	Age	Age	Age	Age
MODEL 2				5	10	15	20	25
Amount of repaired steel	ARS	Dep. Variable						
Unit Price of steel replaement / kg	Prstrp	Constant		361.554854	381.804279	403.1878039	425.7689454	449.6147777
Cost of steel replacement	COSR @ current prices	Dep. Variable		5	5	5	5	5
	Escalated COSR			1807774.27	1909021.4	2015939.02	2128844.727	2248073.888
	Discounted COSR			2095705.84	2565565.12	3140767.306	3844930.378	4706967.492
	COSR			1426302.18	1188353.06	990100.8406	824922.9202	687301.5316
			5116980.53					
total area of coating (m^2)	TAC	Dep. Variable						
Price of coating	PrCOA	Constant		2658.49157	2807.38441	2964.616205	3130.65401	3305.991012
Coating	COA @ current prices	Dep. Variable		3	3	3	3	3
	Escalated COA			7975.47472	8422.15322	8893.848616	9391.96203	9917.973037
	Discounted COA			9245.76107	11318.6697	13856.32635	16962.92814	20766.03305
	COA			6292.50963	5242.73408	4368.091944	3639.365824	3032.21264

			22574.9141					
Days in drydock	Ddock	Dep. Variable						
				12.167	19.117	26.067	33.017	39.967
Cost of unavailability	CUNA @ current prices	Dep. Variable						
	Escalated CUNA			1477085.97	2320822.92	3164559.867	4008296.817	4852033.767
	Discounted CUNA			1712347.47	3118991.93	4930281.161	7239429.913	10159081.22
Cost of unavailability	CUNA			1165394.91	1444696.75	1554230.239	1553206.71	1483407.755
	CODO - NPV	Dep. Variable	7200936.37					
			12340491.8					
MODEL 3								
Engine power max	Pmax	Dep. Variable						
Specific FOC (gr/KW*h)	SFOCmain	Constant		6550	6550	6550	6550	6550
% of max speed	Fmean (%)	Constant		125	125	125	125	125
Daily fuel oil consumption (tons)	DFC	Dep. Variable		90	90	90	90	90
Days at sea	Dsea	Dep. Variable		17.685	17.685	17.685	17.685	17.685
Price of fuel	Prfuel	Constant		352.833	345.883	338.933	331.983	325.033
No of main engines	Nmain	Constant		320	320	320	320	320
Lub & Diesel oil correction factor	Oilcorr	Constant		4	4	4	4	4
Annual cost of fuel	ACOF @ current prices			1.15	1.15	1.15	1.15	1.15
	Escalated ACOF			9185061.56	9004136.94	8823212.315	8642287.691	8461363.067
	Discounted ACOF			10648003.7	12100807.1	13746277.3	15608932.89	17716215.24
	ACOF - NPV			7246852.43	5605015.06	4333399.892	3348868.571	2586884.633
			23121020.6					
MODEL 4								
Passenger capacity		Constant						
Car capacity		Constant		2500	2500	2500	2500	2500
Average daily passenger fee				430	430	430	430	430

Average daily car fee				40.7	40.7	40.7	40.7	40.7	
				45.7	45.7	45.7	45.7	45.7	
Revenue/annum	Rtm @ current prices	Dep. Variable							
	Escalated Rtm		7077855	35389275	70778550	106167825	141557100	176946375	
	Discounted Rtm		8205173.8	41025869	82051738	123077607	164103476.1	205129345.1	
	Rtm - NPV		9512045.27	47560226.3	95120452.7	142680679	190240905.3	237801131.6	
			713403395	3567016974	7134033949	10701050923	14268067898	17835084872	
MODEL 5									
Price of dismantling/ton	Prdist	Constant							
Earning of dismantling	EDIS @ current prices	Dep. Variable						430	
	Escalated EDIS							6824100	
	Discounted EDIS							14288149.97	
	EDIS - NPV							2086325.724	
			2086325.72						
SCENARIO 1									
SCENARIO 2			33375186.7						
			-703149229						

Tanker running cost model with high repair work amount (7500 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	9500	
Original Displacement (in tonnes)	41500	
Original DWT (in tonnes)	32000	
New Lightweighti (in tonnes)	7500	Indep. Variable
Var (lightweight)	-2000	
New Displacement (in tonnes)	39500	
New DWT (in tonnes)	34000	
V design speed (in knots)	15	

		Type	Function of	NPV	Age	Age	Age	Age	Age
					5	10	15	20	25
MODEL 2									
Amount of repaired steel	ARS	Dep. Variable	Regression - New Lightweight		417.4991235	320.6370562	246.2475154	189.1167526	145.2406374
Unit Price of steel replaement / kg	Prstrp	Constant			5	5	5	5	5
Cost of steel replacement	COSR @ current prices	Dep. Variable	ARS and Prstrp		2087495.617	1603185.281	1231237.577	945583.7628	726203.1872
	Escalated COSR				2419979.549	2154546.958	1918228.027	1707829.457	1520508.206
	Discounted COSR				1646997.418	997972.1209	604705.4737	366411.7486	222021.4226
	COSR			6652934.4					
total area of coating (m^2)	TAC	Dep. Variable	ARS		3069.846496	2357.625413	1810.643495	1390.564357	1067.945864
Price of coating	PrCOA	Constant			3	3	3	3	3
Coating	COA @ current prices	Dep. Variable	TAC and PrCOA		9209.539488	7072.87624	5431.930486	4171.693071	3203.837591
	Escalated COA				10676.38036	9505.354228	8462.770706	7534.541723	6708.124437

	Discounted COA				7266.165081	4402.81818	2667.818266	1616.52242	979.5062762
	COA			29351.1812					
Days in drydock	Ddock	Dep. Variable	Regression - Unavailability		60.28747114	61.19850441	62.12330474	63.06208019	64.01504192
Cost of one day downtime (unavailability)	CDDT	Dep. Variable	Rtm and Dsea-ld		1096704	1096704	1096704	1096704	1096704
Cost of unavailability	CUNA @ current prices	Dep. Variable	Ddock and CDDT		66117510.75	67116644.58	68130876.81	69160435.59	70205552.53
	Escalated CUNA				76648316.07	90199157.98	106145686.1	124911439.7	146994836.4
	Discounted CUNA				52165556	41779662.61	33461547.07	26799525.47	21463878.05
Cost of unavailability	CUNA			313674475					
	CODO - NPV	Dep. Variable	COSR, COA and CUNA	320356760					
MODEL 3									
Engine power max	Pmax	Dep. Variable	New Displ., V and C		10643.68511	10643.68511	10643.68511	10643.68511	10643.68511
Specific FOC (gr/KW*h)	SFOCmain	Constant			125	125	125	125	125
% of max speed	Fmean (%)	Constant			90	90	90	90	90
Daily fuel oil consumption (tons)	DFC	Dep. Variable	Pmax, SFOCmain and Fmean		28.73794981	28.73794981	28.73794981	28.73794981	28.73794981
Days at sea	Dsea	Dep. Variable	Ddock		304.7125289	303.8014956	302.8766953	301.9379198	300.9849581
Price of fuel	Prfuel	Constant			320	320	320	320	320
No of main engines	Nmain	Constant			1	1	1	1	1
Lub & Diesel oil correction factor	Oilcorr	Constant			1.15	1.15	1.15	1.15	1.15
Annual cost of fuel	ACOF @ current prices		DFC, Dsea, Prfuel, Nmain & Oilcorr		3222507.316	3212872.624	3203092.338	3193164.257	3183086.148
	Escalated ACOF				3735769.186	4317832.145	4990313.495	5767209.838	6664675.524
	Discounted ACOF				2542501.736	1999991.732	1573154.934	1237344.533	973161.9569

	ACOF - NPV			14847485.2					
MODEL 4									
Average operating speed /hour	Stm	Constant			14	14	14	14	14
Loaded days at sea	Dsea-ld	Dep. Variable	Dsea		228.5343966	227.8511217	227.1575214	226.4534399	225.7387186
Dwt utilisation	DWUtm	Constant			0.8	0.8	0.8	0.8	0.8
Productivity tonmiles of cargo/annum	Ptm	Dep. Variable	Stm, Dsea-ld, DWUtm & NewDWT		50126917387	49977047313	49824912479	49670478662	49513711120
Freight rate Euro/ton mile	FRtm	Constant			0.005	0.005	0.005	0.005	0.005
Revenue/annum	Rtm @ current prices	Dep. Variable	Ptm and FRtm		250634586.9	249885236.6	249124562.4	248352393.3	247568555.6
	Escalated Rtm				290554178.8	335824862.4	388127950.9	448552047.7	518353577.8
	Discounted Rtm				197746291.9	155551889.4	122354117	96236037.76	75688903.43
	Rtm - NPV			1154781958					
MODEL 5									
Price of dismantling/ton	Prdist	Constant							430
Earning of dismantling	EDIS @ current prices	Dep. Variable	Prdist and Newlightweight						3225000
	Escalated EDIS								6752433.823
	Discounted EDIS								985976.2399
	EDIS - NPV			985976.24					
SCENARIO 1	Model 2 + Model 3 - Model 5			334218269					
SCENARIO 2	Model 2 - Model 4 - Model 5			-835411174					

Tanker running cost model with high repair work amount (9500 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	9500	
Original Displacement (in tonnes)	41500	
Original DWT (in tonnes)	32000	
New Lightweighti (in tonnes)	9500	Indep. Variable
Var (lightweight)	0	
New Displacement (in tonnes)	41500	
New DWT (in tonnes)	32000	
V design speed (in knots)	15	

		Type	Function of	NPV	Age	Age	Age	Age	Age
					5	10	15	20	25
MODEL 2									
Amount of repaired steel	ARS	Dep. Variable	Regression - New Lightweight		528.8322231	406.1402712	311.9135195	239.5478866	183.9714741
Unit Price of steel replaement / kg	Prstrp	Constant			5	5	5	5	5
Cost of steel replacement	COSR @ current prices	Dep. Variable	ARS and Prstrp		2644161.115	2030701.356	1559567.597	1197739.433	919857.3704
	Escalated COSR				3065307.429	2729092.814	2429755.501	2163250.646	1925977.061
	Discounted COSR				2086196.73	1264098.02	765960.2666	464121.5482	281227.1353
	COSR			8427050.24					
total area of coating (m^2)	TAC	Dep. Variable	ARS		3888.472228	2986.325524	2293.481761	1761.381519	1352.731427
Price of coating	PrCOA	Constant			3	3	3	3	3
Coating	COA @ current prices	Dep. Variable	TAC and PrCOA		11665.41668	8958.976571	6880.445282	5284.144557	4058.194281
	Escalated COA				13523.41513	12040.11536	10719.50956	9543.75285	8496.95762

	Discounted COA				9203.809103	5576.903028	3379.23647	2047.595066	1240.70795
	COA			37178.1628					
Days in drydock	Ddock	Dep. Variable	Regression - Unavailability		60.28747114	61.19850441	62.12330474	63.06208019	64.01504192
Cost of one day downtime (unavailability)	CDDT	Dep. Variable	Rtm and Dsea-ld		1032192	1032192	1032192	1032192	1032192
Cost of unavailability	CUNA @ current prices	Dep. Variable	Ddock and CDDT		62228245.42	63168606.67	64123178.17	65092174.67	66075814.15
	Escalated CUNA				72139591.6	84893325.16	99901822.24	117563708	138348081.3
	Discounted CUNA				49096993.88	39322035.4	31493220.77	25223082.8	20201296.99
Cost of unavailability	CUNA			295223035					
	CODO - NPV	Dep. Variable	COSR, COA and CUNA	303687263					
MODEL 3									
Engine power max	Pmax	Dep. Variable	New Displ., V and C		11000	11000	11000	11000	11000
Specific FOC (gr/KW*h)	SFOCmain	Constant			125	125	125	125	125
% of max speed	Fmean (%)	Constant			90	90	90	90	90
Daily fuel oil consumption (tons)	DFC	Dep. Variable	Pmax, SFOCmain and Fmean		29.7	29.7	29.7	29.7	29.7
Days at sea	Dsea	Dep. Variable	Ddock		304.7125289	303.8014956	302.8766953	301.9379198	300.9849581
Price of fuel	Prfuel	Constant			320	320	320	320	320
No of main engines	Nmain	Constant			1	1	1	1	1
Lub & Diesel oil correction factor	Oilcorr	Constant			1.15	1.15	1.15	1.15	1.15
Annual cost of fuel	ACOF @ current prices		DFC, Dsea, Prfuel, Nmain & Oilcorr		3330386.055	3320428.826	3310321.128	3300060.688	3289645.198
	Escalated ACOF				3860830.211	4462378.686	5157372.457	5960276.684	6887786.512
	Discounted ACOF				2627616.168	2066944.749	1625818.886	1278766.678	1005740.156

	ACOF - NPV			15344529.2					
MODEL 4									
Average operating speed /hour	Stm	Constant			14	14	14	14	14
Loaded days at sea	Dsea-ld	Dep. Variable	Dsea		228.5343966	227.8511217	227.1575214	226.4534399	225.7387186
Dwt utilisation	DWUtm	Constant			0.8	0.8	0.8	0.8	0.8
Productivity tonmiles of cargo/annum	Ptm	Dep. Variable	Stm, Dsea-ld, DWUtm & NewDWT		47178275188	47037221000	46894035274	46748685799	46601139878
Freight rate Euro/ton mile	FRtm	Constant			0.005	0.005	0.005	0.005	0.005
Revenue/annum	Rtm @ current prices	Dep. Variable	Ptm and FRtm		235891375.9	235186105	234470176.4	233743429	233005699.4
	Escalated Rtm				273462756.5	316070458.7	365296895	422166633.1	487862190.9
	Discounted Rtm				186114157.1	146401778.2	115156816	90575094.37	71236615
	Rtm - NPV			1086853608					
MODEL 5									
Price of dismantling/ton	Prdist	Constant							430
Earning of dismantling	EDIS @ current prices	Dep. Variable	Prdist and Newlightweight						4085000
	Escalated EDIS								8553082.843
	Discounted EDIS								1248903.237
	EDIS - NPV			1248903.24					
SCENARIO 1	Model 2 + Model 3 - Model 5			317782889					
SCENARIO 2	Model 2 - Model 4 - Model 5			-784415248					

Tanker running cost model with high repair work amount (10500 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	9500	
Original Displacement (in tonnes)	41500	
Original DWT (in tonnes)	32000	
New Lightweighti (in tonnes)	10500	Indep. Variable
Var (lightweight)	1000	
New Displacement (in tonnes)	42500	
New DWT (in tonnes)	31000	
V design speed (in knots)	15	

		Type	Function of	NPV	Age	Age	Age	Age	Age
					5	10	15	20	25
MODEL 2									
Amount of repaired steel	ARS	Dep. Variable	Regression - New Lightweight		584.4988	448.8919	344.7465	264.76345	203.337
Unit Price of steel replaement / kg	Prstrp	Constant			5	5	5	5	5
Cost of steel replacement	COSR @ current prices	Dep. Variable	ARS and Prstrp		2922494	2244459	1723733	1323817.3	1016684
	Escalated COSR				3387971	3016366	2685519	2390961.2	2128711
	Discounte d COSR				2305796	1397161	846587.7	512976.45	310830
	COSR			9314108.16					
total area of coating (m^2)	TAC	Dep. Variable	ARS		4297.785	3300.676	2534.901	1946.7901	1495.12
Price of coating	PrCOA	Constant			3	3	3	3	3
Coating	COA @ current prices	Dep. Variable	TAC and PrCOA		12893.36	9902.027	7604.703	5840.3703	4485.37
	Escalated				14946.93	13307.5	11847.88	10548.358	9391.37

	COA								
	Discounted COA				10172.63	6163.945	3734.946	2263.1314	1371.31
	COA			41091.6537					
Days in drydock	Ddock	Dep. Variable	Regression - Unavailability		60.28747	61.1985	62.1233	63.06208	64.015
Cost of one day downtime (unavailability)	CDDT	Dep. Variable	Rtm and Dsea-ld		999936	999936	999936	999936	999936
Cost of unavailability	CUNA @ current prices	Dep. Variable	Ddock and CDDT		60283613	61194588	62119329	63058044	6.4E+07
	Escalated CUNA				69885229	82240409	96779890	113889842	1.3E+08
	Discounted CUNA				47562713	38093222	30509058	24434861	2E+07
Cost of unavailability	CUNA			285997315					
	CODO - NPV	Dep. Variable	COSR, COA and CUNA	295352515					
MODEL 3									
Engine power max	Pmax	Dep. Variable	New Displ., V and C		11176	11176	11176	11176.005	11176
Specific FOC (gr/KW*h)	SFOCmain	Constant			125	125	125	125	125
% of max speed	Fmean (%)	Constant			90	90	90	90	90
Daily fuel oil consumption (tons)	DFC	Dep. Variable	Pmax, SFOCmain and Fmean		30.17521	30.17521	30.17521	30.175213	30.1752
Days at sea	Dsea	Dep. Variable	Ddock		304.7125	303.8015	302.8767	301.93792	300.985
Price of fuel	Prfuel	Constant			320	320	320	320	320
No of main engines	Nmain	Constant			1	1	1	1	1
Lub & Diesel oil correction factor	Oilcorr	Constant			1.15	1.15	1.15	1.15	1.15
Annual cost of fuel	ACOF @ current prices		DFC, Dsea, Prfuel, Nmain & Oilcorr		3383674	3373557	3363288	3352863.1	3342281
	Escalated ACOF				3922605	4533779	5239893	6055643.6	6997994
	Discounted ACOF				2669659	2100017	1651833	1299227.5	1021832

	ACOF - NPV			15590048.1					
MODEL 4									
Average operating speed /hour	Stm	Constant			14	14	14	14	14
Loaded days at sea	Dsea-ld	Dep. Variable	Dsea		228.5344	227.8511	227.1575	226.45344	225.739
Dwt utilisation	DWUtm	Constant			0.8	0.8	0.8	0.8	0.8
Productivity tonmiles of cargo/annum	Ptm	Dep. Variable	Stm, Dsea-ld, DWUtm & NewDWT		4.57E+10	4.56E+10	4.54E+10	4.529E+10	4.5E+10
Freight rate Euro/ton mile	FRtm	Constant			0.005	0.005	0.005	0.005	0.005
Revenue/annum	Rtm @ current prices	Dep. Variable	Ptm and FRtm		2.29E+08	2.28E+08	2.27E+08	226438947	2.3E+08
	Escalated Rtm				2.65E+08	3.06E+08	3.54E+08	408973926	4.7E+08
	Discounted Rtm				1.8E+08	1.42E+08	1.12E+08	87744623	6.9E+07
	Rtm - NPV			1052889433					
MODEL 5									
Price of dismantling/ton	Prdist	Constant							430
Earning of dismantling	EDIS @ current prices	Dep. Variable	Prdist and Newlightweight						4515000
	Escalated EDIS								9453407
	Discounted EDIS								1380367
	EDIS - NPV			1380366.74					
SCENARIO 1	Model 2 + Model 3 - Model 5			309562196					
SCENARIO 2	Model 2 - Model 4 - Model 5			-758917284					

Tanker running cost model with likely repair work amount (7500 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	9500	
Original Displacement (in tonnes)	41500	
Original DWT (in tonnes)	32000	
New Lightweighti (in tonnes)	7500	Indep. Variable
Var (lightweight)	-2000	
New Displacement (in tonnes)	39500	
New DWT (in tonnes)	34000	
V design speed (in knots)	15	

		Type							
			Function of	NPV	Age	Age	Age	Age	Age
MODEL 2					5	10	15	20	25
Amount of repaired steel	ARS	Dep. Variable							
Unit Price of steel replaement / kg	Prstrp	Constant	Regression - New Lightweight		2.899142939	7.083885192	17.30905667	42.29366153	103.3420735
Cost of steel replacement	COSR @ current prices	Dep. Variable			5	5	5	5	5
	Escalated COSR		ARS and Prstrp		14495.71469	35419.42596	86545.28333	211468.3077	516710.3675
	Discounted COSR				16804.50623	47600.74669	134834.7315	381935.2863	1081876.763
	COSR				11436.86458	22048.3559	42505.53064	81943.53101	157973.3784
				535193.7216					
total area of coating (m^2)	TAC	Dep. Variable							
Price of coating	PrCOA	Constant	ARS		21.31722749	52.08739112	127.2724755	310.9828054	759.8681874
Coating	COA @ current prices	Dep. Variable			3	3	3	3	3
	Escalated COA		TAC and		63.95168248	156.2621733	381.8174264	932.9484162	2279.604562

			PrCOA						
	Discounted COA				74.1375275	210.0032942	594.8591095	1685.008616	4772.985721
	COA				50.45675549	97.27215837	187.5243999	361.515578	696.9413751
				2361.148772					
Days in drydock	Ddock	Dep. Variable							
Cost of one day downtime (unavailability)	CDDT	Dep. Variable	Regression - Unavailability		20.84120732	24.45697762	28.70005299	33.67926546	39.52232848
Cost of unavailability	CUNA @ current prices	Dep. Variable	Rtm and Dsea-ld		1096704	1096704	1096704	1096704	1096704
	Escalated CUNA		Ddock and CDDT		22856635.43	26822065.19	31475462.91	36936185.14	43344295.73
	Discounted CUNA				26497104.88	36046612.73	49037745.64	66710858.95	90753329.78
Cost of unavailability	CUNA				18033484.35	16696556.29	15458742.54	14312695.2	13251611.08
	CODO - NPV	Dep. Variable		139817594.8					
			COSR, COA and CUNA	140355149.6					
MODEL 3									
Engine power max	Pmax	Dep. Variable							
Specific FOC (gr/KW*h)	SFOCmain	Constant	New Displ., V and C		10643.68511	10643.68511	10643.68511	10643.68511	10643.68511
% of max speed	Fmean (%)	Constant			125	125	125	125	125
Daily fuel oil consumption (tons)	DFC	Dep. Variable			90	90	90	90	90
Days at sea	Dsea	Dep. Variable	Pmax, SFOCmain and Fmean		28.73794981	28.73794981	28.73794981	28.73794981	28.73794981
Price of fuel	Prfuel	Constant	Ddock		344.1587927	340.5430224	336.299947	331.3207345	325.4776715
No of main engines	Nmain	Constant			320	320	320	320	320
Lub & Diesel oil correction factor	Oilcorr	Constant			1	1	1	1	1
Annual cost of fuel	ACOF @ current prices				1.15	1.15	1.15	1.15	1.15
	Escalated ACOF		DFC, Dsea, Prfuel, Nmain & Oilcorr		3639673.864	3601435.049	3556562.127	3503904.139	3442110.443

	Discounted ACOF				4219379.55	4840027.551	5541007.909	6328440.631	7207014.878
	ACOF - NPV				2871638.824	2241869.244	1746756.78	1357755.593	1052353.213
				16523994.8					
MODEL 4									
Average operating speed /hour	Stm	Constant							
Loaded days at sea	Dsea-ld	Dep. Variable			14	14	14	14	14
Dwt utilisation	DWUtm	Constant	Dsea		258.1190945	255.4072668	252.2249603	248.4905509	244.1082536
Productivity tonmiles of cargo/annum	Ptm	Dep. Variable			0.8	0.8	0.8	0.8	0.8
Freight rate Euro/ton mile	FRtm	Constant	Stm, Dsea-ld, DWUtm & NewDWT		56616048685	56021234222	55323224563	54504116229	53542899640
Revenue/annum	Rtm @ current prices	Dep. Variable			0.005	0.005	0.005	0.005	0.005
	Escalated Rtm		Ptm and FRtm		283080243.4	280106171.1	276616122.8	272520581.1	267714498.2
	Discounted Rtm				328167587.1	376439271.3	430958906.3	492202483.3	560534707.8
	Rtm - NPV				223345345.6	174364219.1	135856220.4	105601160.5	81848103.66
				1285174618					
MODEL 5									
Price of dismantling/ton	Prdist	Constant							
Earning of dismantling	EDIS @ current prices	Dep. Variable							430
	Escalated EDIS		Prdist and Newlightweight						3225000
	Discounted EDIS								6752433.823
	EDIS - NPV								985976.2399
				985976.2399					
SCENARIO 1	Model 2 + Model 3 - Model 5								
SCENARIO 2	Model 2 - Model 4 - Model 5			155893168.2					
				-1145805445					

Tanker running cost model with likely repair work amount (9500 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	9500	
Original Displacement (in tonnes)	41500	
Original DWT (in tonnes)	32000	
New Lightweighti (in tonnes)	9500	Indep. Variable
Var (lightweight)	0	
New Displacement (in tonnes)	41500	
New DWT (in tonnes)	32000	
V design speed (in knots)	15	

		Type							
			Function of	NPV	Age	Age	Age	Age	Age
MODEL 2					5	10	15	20	25
Amount of repaired steel	ARS	Dep. Variable							
Unit Price of steel replaement / kg	Prstrp	Constant	Regression - New Lightweight		3.672247723	8.972921243	21.92480511	53.57197128	130.8999598
Cost of steel replacement	COSR @ current prices	Dep. Variable			5	5	5	5	5
	Escalated COSR		ARS and Prstrp		18361.23861	44864.60621	109624.0255	267859.8564	654499.7988
	Discounted COSR				21285.7079	60294.27914	170790.6599	483784.6959	1370377.234
	COSR				14486.69513	27927.91747	53840.33881	103795.1393	200099.6126
				677912.0473					
total area of coating (m^2)	TAC	Dep. Variable							
Price of coating	PrCOA	Constant	ARS		27.00182149	65.97736208	161.2118023	393.9115535	962.4997041

Coating	COA @ current prices	Dep. Variable			3	3	3	3	3
	Escalated COA		TAC and PrCOA		81.00546447	197.9320862	483.6354068	1181.734661	2887.499112
	Discounted COA				93.90753484	266.0041727	753.4882054	2134.344247	6045.781913
	COA				63.91189028	123.2114006	237.5309065	457.9197321	882.7924085
				2990.788444					
Days in drydock	Ddock	Dep. Variable							
Cost of one day downtime (unavailability)	CDDT	Dep. Variable	Regression - Unavailability		20.84120732	24.45697762	28.70005299	33.67926546	39.52232848
Cost of unavailability	CUNA @ current prices	Dep. Variable	Rtm and Dsea-ld		1032192	1032192	1032192	1032192	1032192
	Escalated CUNA		Ddock and CDDT		21512127.47	25244296.65	29623965.1	34763468.37	40794631.28
	Discounted CUNA				24938451.66	33926223.75	46153172.37	62786690.78	85414898.62
Cost of unavailability	CUNA				16972691.16	15714405.92	14549404.75	13470771.96	12472104.54
	CODO - NPV	Dep. Variable		131593030.4					
			COSR, COA and CUNA	132273933.2					
MODEL 3									
Engine power max	Pmax	Dep. Variable							
Specific FOC (gr/KW*h)	SFOCmain	Constant	New Displ., V and C		11000	11000	11000	11000	11000
% of max speed	Fmean (%)	Constant			125	125	125	125	125
Daily fuel oil consumption (tons)	DFC	Dep. Variable			90	90	90	90	90
Days at sea	Dsea	Dep. Variable	Pmax, SFOCmain and Fmean		29.7	29.7	29.7	29.7	29.7
Price of fuel	Prfuel	Constant	Ddock		344.1587927	340.5430224	336.299947	331.3207345	325.4776715

No of main engines	Nmain	Constant			320	320	320	320	320
Lub & Diesel oil correction factor	Oilcorr	Constant			1	1	1	1	1
Annual cost of fuel	ACOF @ current prices				1.15	1.15	1.15	1.15	1.15
	Escalated ACOF		DFC, Dsea, Prfuel, Nmain & Oilcorr		3761517.94	3721999.017	3675623.901	3621203.1	3557340.759
	Discounted ACOF				4360630.228	5002055.443	5726502.273	6540295.602	7448281.569
	ACOF - NPV				2967771.662	2316919.508	1805232.34	1403208.697	1087582.47
				17077162.73					
MODEL 4									
Average operating speed /hour	Stm	Constant							
Loaded days at sea	Dsea-ld	Dep. Variable			14	14	14	14	14
Dwt utilisation	DWUtm	Constant	Dsea		258.1190945	255.4072668	252.2249603	248.4905509	244.1082536
Productivity tonmiles of cargo/annum	Ptm	Dep. Variable			0.8	0.8	0.8	0.8	0.8
Freight rate Euro/ton mile	FRtm	Constant	Stm, Dsea-ld, DWUtm & NewDWT		53285692880	52725867503	52068917236	51297991745	50393317308
Revenue/annum	Rtm @ current prices	Dep. Variable			0.005	0.005	0.005	0.005	0.005
	Escalated Rtm		Ptm and FRtm		266428464.4	263629337.5	260344586.2	256489958.7	251966586.5
	Discounted Rtm				308863611.4	354295784.8	405608382.4	463249396	527562077.9
	Rtm - NPV				210207384.1	164107500.4	127864678	99389327.5	77033509.33
				1209576111					
MODEL 5									
Price of dismantling/ton	Prdist	Constant							

Earning of dismantling	EDIS @ current prices	Dep. Variable							430
	Escalated EDIS		Prdist and Newlightweight						4085000
	Discounted EDIS								8553082.843
	EDIS - NPV								1248903.237
				1248903.237					
SCENARIO 1	Model 2 + Model 3 - Model 5								
SCENARIO 2	Model 2 - Model 4 - Model 5			148102192.7					
				-1078551081					

Tanker running cost model with likely repair work amount (10500 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	9500	
Original Displacement (in tonnes)	41500	
Original DWT (in tonnes)	32000	
New Lightweighti (in tonnes)	10500	Indep. Variable
Var (lightweight)	1000	
New Displacement (in tonnes)	42500	
New DWT (in tonnes)	31000	
V design speed (in knots)	15	

		Type	Function of	NPV	Age	Age	Age	Age	Age
					5	10	15	20	25
MODEL 2									
Amount of repaired steel	ARS	Dep. Variable	Regression - New Lightweight		4.058800114	9.917439269	24.23267933	59.21112615	144.6789029
Unit Price of steel replaement / kg	Prstrp	Constant			5	5	5	5	5
Cost of steel replacement	COSR @ current prices	Dep. Variable	ARS and Prstrp		20294.00057	49587.19634	121163.3967	296055.6307	723394.5144
	Escalated COSR				23526.30873	66641.04537	188768.6241	534709.4008	1514627.469
	Discounted COSR				16011.61041	30867.69825	59507.7429	114720.9434	221162.7297
	COSR			749271.2102					
total area of coating (m^2)	TAC	Dep. Variable	ARS		29.84411849	72.92234756	178.1814657	435.3759276	1063.815462
Price of coating	PrCOA	Constant			3	3	3	3	3
Coating	COA @ current prices	Dep. Variable	TAC and PrCOA		89.53235547	218.7670427	534.544397	1306.127783	3191.446387

	Escalated COA				103.7925385	294.0046119	832.8027533	2359.012062	6682.180009
	Discounted COA				70.63945768	136.1810217	262.5341598	506.1218092	975.7179252
	COA			3305.60828					
Days in drydock	Ddock	Dep. Variable	Regression - Unavailability		20.84120732	24.45697762	28.70005299	33.67926546	39.52232848
Cost of one day downtime (unavailability)	CDDT	Dep. Variable	Rtm and Dsea-ld		999936	999936	999936	999936	999936
Cost of unavailability	CUNA @ current prices	Dep. Variable	Ddock and CDDT		20839873.48	24455412.38	28698216.19	33677109.98	39519799.05
	Escalated CUNA				24159125.04	32866029.26	44710885.73	60824606.69	82745683.04
	Discounted CUNA				16442294.56	15223330.73	14094735.85	13049810.33	12082351.28
Cost of unavailability	CUNA			127480748.2					
	CODO - NPV	Dep. Variable	COSR, COA and CUNA	128233325					
MODEL 3									
Engine power max	Pmax	Dep. Variable	New Displ., V and C		11176.00466	11176.00466	11176.00466	11176.00466	11176.00466
Specific FOC (gr/KW*h)	SFOCmain	Constant			125	125	125	125	125
% of max speed	Fmean (%)	Constant			90	90	90	90	90
Daily fuel oil consumption (tons)	DFC	Dep. Variable	Pmax, SFOCmain and Fmean		30.17521257	30.17521257	30.17521257	30.17521257	30.17521257
Days at sea	Dsea	Dep. Variable	Ddock		344.1587927	340.5430224	336.299947	331.3207345	325.4776715
Price of fuel	Prfuel	Constant			320	320	320	320	320
No of main engines	Nmain	Constant			1	1	1	1	1
Lub & Diesel oil correction factor	Oilcorr	Constant			1.15	1.15	1.15	1.15	1.15
Annual cost of fuel	ACOF @ current prices		DFC, Dsea, Prfuel, Nmain & Oilcorr		3821703.82	3781552.577	3734435.439	3679143.883	3614259.717
	Escalated ACOF				4430402.158	5082090.448	5818128.734	6644943.101	7567457.227

	Discounted ACOF				3015257.265	2353991.201	1834116.822	1425660.631	1104984.25
	ACOF - NPV			17350404.57					
MODEL 4									
Average operating speed /hour	Stm	Constant			14	14	14	14	14
Loaded days at sea	Dsea-ld	Dep. Variable	Dsea		258.1190945	255.4072668	252.2249603	248.4905509	244.1082536
Dwt utilisation	DWUtm	Constant			0.8	0.8	0.8	0.8	0.8
Productivity tonmiles of cargo/annum	Ptm	Dep. Variable	Stm, Dsea-ld, DWUtm & NewDWT		51620514977	51078184143	50441763572	49694929503	48818526143
Freight rate Euro/ton mile	FRtm	Constant			0.005	0.005	0.005	0.005	0.005
Revenue/annum	Rtm @ current prices	Dep. Variable	Ptm and FRtm		258102574.9	255390920.7	252208817.9	248474647.5	244092630.7
	Escalated Rtm				299211623.6	343224041.5	392933120.4	448772852.4	511075763
	Discounted Rtm				203638403.4	158979141	123868906.8	96283411.01	74626212.16
	Rtm - NPV			1171776858					
MODEL 5									
Price of dismantling/ton	Prdist	Constant							430
Earning of dismantling	EDIS @ current prices	Dep. Variable	Prdist and Newlightweight						4515000
	Escalated EDIS								9453407.352
	Discounted EDIS								1380366.736
	EDIS - NPV			1380366.736					
SCENARIO 1	Model 2 + Model 3 - Model 5			144203362.8					
SCENARIO 2	Model 2 - Model 4 - Model 5			-1044923900					

Tanker running cost model with low repair work amount (7500 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	9500	
Original Displacement (in tonnes)	41500	
Original DWT (in tonnes)	32000	
New Lightweighti (in tonnes)	7500	Indep. Variable
Var (lightweight)	-2000	
New Displacement (in tonnes)	39500	
New DWT (in tonnes)	34000	
V design speed (in knots)	15	

		Type							
			Function of	NPV	Age	Age	Age	Age	Age
MODEL 2					5	10	15	20	25
Amount of repaired steel	ARS	Dep. Variable							
Unit Price of steel replaement / kg	Prstrp	Constant	Regression - New Lightweight		1.721198538	3.324943217	6.422993718	12.40768507	23.96867496
Cost of steel replacement	COSR @ current prices	Dep. Variable			5	5	5	5	5
	Escalated COSR		ARS and Prstrp		8605.992688	16624.71608	32114.96859	62038.42534	119843.3748
	Discounted COSR				9976.704207	22342.22825	50034.07465	112048.297	250925.4132
	COSR				6789.977245	10348.77463	15772.827	24039.76126	36639.60313
				163900.4827					
total area of coating (m^2)	TAC	Dep. Variable							
Price of coating	PrCOA	Constant	ARS		12.6558716	24.44811189	47.22789498	91.23297844	176.2402571
Coating	COA @ current prices	Dep. Variable			3	3	3	3	3
	Escalated COA		TAC and PrCOA		37.9676148	73.34433566	141.683685	273.6989353	528.7207713
	Discounted COA				44.0148715	98.56865403	220.7385646	494.330722	1107.023882
	COA				29.95578196	45.65635868	69.58600146	106.0577703	161.6453079

				723.090365					
Days in drydock	Ddock	Dep. Variable							
Cost of one day downtime (unavailability)	CDDT	Dep. Variable	Regression - Unavailability		17.07	17.07	17.07	17.07	17.07
Cost of unavailability	CUNA @ current prices	Dep. Variable	Rtm and Dsea-ld		1096704	1096704	1096704	1096704	1096704
	Escalated CUNA		Ddock and CDDT		18720737.28	18720737.28	18720737.28	18720737.28	18720737.28
	Discounted CUNA				21702465.38	25159105.46	29166298.7	33811733.92	39197066.54
Cost of unavailability	CUNA				14770333.27	11653533.82	9194433.729	7254246.902	5723473.535
	CODO - NPV	Dep. Variable		86677426.46					
			COSR, COA and CUNA	86842050.03					
MODEL 3									
Engine power max	Pmax	Dep. Variable							
Specific FOC (gr/KW*h)	SFOCmain	Constant	New Displ., V and C		10643.68511	10643.68511	10643.68511	10643.68511	10643.68511
% of max speed	Fmean (%)	Constant			125	125	125	125	125
Daily fuel oil consumption (tons)	DFC	Dep. Variable			90	90	90	90	90
Days at sea	Dsea	Dep. Variable	Pmax, SFOCmain and Fmean		28.73794981	28.73794981	28.73794981	28.73794981	28.73794981
Price of fuel	Prfuel	Constant	Ddock		347.93	347.93	347.93	347.93	347.93
No of main engines	Nmain	Constant			320	320	320	320	320
Lub & Diesel oil correction factor	Oilcorr	Constant			1	1	1	1	1
Annual cost of fuel	ACOF @ current prices				1.15	1.15	1.15	1.15	1.15
	Escalated ACOF		DFC, Dsea, Prfuel, Nmain & Oilcorr		3679556.515	3679556.515	3679556.515	3679556.515	3679556.515
	Discounted ACOF				4265614.472	4945016.269	5732629.157	6645688.36	7704174.221
	ACOF - NPV				2903105.535	2290499.334	1807163.789	1425820.525	1124947.379
				17036427.81					
MODEL 4									
Average operating speed /hour	Stm	Constant							

Loaded days at sea	Dsea-ld	Dep. Variable			14	14	14	14	14
Dwt utilisation	DWUtm	Constant	Dsea		260.9475	260.9475	260.9475	260.9475	260.9475
Productivity tonmiles of cargo/annum	Ptm	Dep. Variable			0.8	0.8	0.8	0.8	0.8
Freight rate Euro/ton mile	FRtm	Constant	Stm, Dsea-ld, DWUtm & NewDWT		57236433408	57236433408	57236433408	57236433408	57236433408
Revenue/annum	Rtm @ current prices	Dep. Variable			0.005	0.005	0.005	0.005	0.005
	Escalated Rtm		Ptm and FRtm		286182167	286182167	286182167	286182167	286182167
	Discounted Rtm				331763566.8	384604901.8	445862491.5	516876827.1	599201905.2
	Rtm - NPV				225792708.9	178146486	140554452	110894996.7	87494206.82
				1325029745					
MODEL 5									
Price of dismantling/ton	Prdist	Constant							
Earning of dismantling	EDIS @ current prices	Dep. Variable							430
	Escalated EDIS		Prdist and Newlightweight						3225000
	Discounted EDIS								6752433.823
	EDIS - NPV								985976.2399
				985976.2399					
SCENARIO 1	Model 2 + Model 3 - Model 5								
SCENARIO 2	Model 2 - Model 4 - Model 5			102892501.6					
				-1239173671					

Tanker running cost model with low repair work amount (9500 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	9500	
Original Displacement (in tonnes)	41500	
Original DWT (in tonnes)	32000	
New Lightweighti (in tonnes)	9500	Indep. Variable
Var (lightweight)	0	
New Displacement (in tonnes)	41500	
New DWT (in tonnes)	32000	
V design speed (in knots)	15	

		Type	Function of	NPV	Age	Age	Age	Age	Age
					5	10	15	20	25
MODEL 2									
Amount of repaired steel	ARS	Dep. Variable	Regression - New Lightweight		2.180184814	4.211594741	8.135792043	15.71640109	30.36032162
Unit Price of steel replaement / kg	Prstrp	Constant			5	5	5	5	5
Cost of steel replacement	COSR @ current prices	Dep. Variable	ARS and Prstrp		10900.92407	21057.97371	40678.96021	78582.00543	151801.6081
	Escalated COSR				12637.15866	28300.15578	63376.49455	141927.8428	317838.8567
	Discounted COSR				8600.637844	13108.44787	19978.9142	30450.36426	46410.16396
	COSR			207607.2781					
total area of coating (m^2)	TAC	Dep. Variable	ARS		16.03077069	30.96760839	59.82200031	115.5617727	223.237659
Price of coating	PrCOA	Constant			3	3	3	3	3
Coating	COA @ current prices	Dep. Variable	TAC and PrCOA		48.09231208	92.90282517	179.4660009	346.6853181	669.712977

	Escalated COA				55.75217057	124.8536284	279.6021819	626.1522478	1402.23025
	Discounted COA				37.94399049	57.83138766	88.14226852	134.3398423	204.7507234
	COA			915.9144623					
Days in drydock	Ddock	Dep. Variable	Regression - Unavailability		17.07	17.07	17.07	17.07	17.07
Cost of one day downtime (unavailability)	CDDT	Dep. Variable	Rtm and Dsea-ld		1032192	1032192	1032192	1032192	1032192
Cost of unavailability	CUNA @ current prices	Dep. Variable	Ddock and CDDT		17619517.44	17619517.44	17619517.44	17619517.44	17619517.44
	Escalated CUNA				20425849.77	23679158.08	27450634.07	31822808.4	36891356.75
	Discounted CUNA				13901490.14	10968031.83	8653584.686	6827526.496	5386798.622
Cost of unavailability	CUNA			81578754.31					
	CODO - NPV	Dep. Variable	COSR, COA and CUNA	81787277.51					
MODEL 3									
Engine power max	Pmax	Dep. Variable	New Displ., V and C		11000	11000	11000	11000	11000
Specific FOC (gr/KW*h)	SFOCmain	Constant			125	125	125	125	125
% of max speed	Fmean (%)	Constant			90	90	90	90	90
Daily fuel oil consumption (tons)	DFC	Dep. Variable	Pmax, SFOCmain and Fmean		29.7	29.7	29.7	29.7	29.7
Days at sea	Dsea	Dep. Variable	Ddock		347.93	347.93	347.93	347.93	347.93
Price of fuel	Prfuel	Constant			320	320	320	320	320
No of main engines	Nmain	Constant			1	1	1	1	1
Lub & Diesel oil correction factor	Oilcorr	Constant			1.15	1.15	1.15	1.15	1.15
Annual cost of fuel	ACOF @ current prices		DFC, Dsea, Prfuel, Nmain & Oilcorr		3802735.728	3802735.728	3802735.728	3802735.728	3802735.728
	Escalated ACOF				4408412.941	5110558.831	5924538.358	6868163.721	7962084.14

	Discounted ACOF				3000291.773	2367177.571	1867661.573	1473552.214	1162606.845
	ACOF - NPV			17606750.28					
MODEL 4									
Average operating speed /hour	Stm	Constant			14	14	14	14	14
Loaded days at sea	Dsea-ld	Dep. Variable	Dsea		260.9475	260.9475	260.9475	260.9475	260.9475
Dwt utilisation	DWUtm	Constant			0.8	0.8	0.8	0.8	0.8
Productivity tonmiles of cargo/annum	Ptm	Dep. Variable	Stm, Dsea-ld, DWUtm & NewDWT		53869584384	53869584384	53869584384	53869584384	53869584384
Freight rate Euro/ton mile	FRtm	Constant			0.005	0.005	0.005	0.005	0.005
Revenue/annum	Rtm @ current prices	Dep. Variable	Ptm and FRtm		269347921.9	269347921.9	269347921.9	269347921.9	269347921.9
	Escalated Rtm				312248062.8	361981084	419635286.1	486472307.8	563954734.3
	Discounted Rtm				212510784.9	167667280.9	132286543	104371761.6	82347488.77
	Rtm - NPV			1247086818					
MODEL 5									
Price of dismantling/ton	Prdist	Constant							430
Earning of dismantling	EDIS @ current prices	Dep. Variable	Prdist and Newlightweight						4085000
	Escalated EDIS								8553082.843
	Discounted EDIS								1248903.237
	EDIS - NPV			1248903.237					
SCENARIO 1	Model 2 + Model 3 - Model 5			98145124.55					
SCENARIO 2	Model 2 - Model 4 - Model 5			-1166548444					

Tanker running cost model with low repair work amount (10500 lightweight ton)

Escalation Rate (as %)	0.03	
Discount Rate (as %)	0.08	
Original Lightweight (in tonnes)	9500	
Original Displacement (in tonnes)	41500	
Original DWT (in tonnes)	32000	
New Lightweighti (in tonnes)	10500	Indep. Variable
Var (lightweight)	1000	
New Displacement (in tonnes)	42500	
New DWT (in tonnes)	31000	
V design speed (in knots)	15	

		Type	Function of	NPV	Age	Age	Age	Age	Age
					5	10	15	20	25
MODEL 2									
Amount of repaired steel	ARS	Dep. Variable	Regression - New Lightweight		2.409677953	4.654920504	8.992191205	17.37075909	33.55614495
Unit Price of steel replaement / kg	Prstrp	Constant			5	5	5	5	5
Cost of steel replacement	COSR @ current prices	Dep. Variable	ARS and Prstrp		12048.38976	23274.60252	44960.95603	86853.79547	167780.7248
	Escalated COSR				13967.38589	31279.11955	70047.70451	156867.6158	351295.5785
	Discounted COSR				9505.968143	14488.28449	22081.9578	33655.66576	51295.44438
	COSR			229460.6758					
total area of coating (m^2)	TAC	Dep. Variable	ARS		17.71822024	34.22735664	66.11905298	127.7261698	246.7363599
Price of coating	PrCOA	Constant			3	3	3	3	3
Coating	COA @ current prices	Dep. Variable	TAC and PrCOA		53.15466072	102.6820699	198.3571589	383.1785094	740.2090798
	Escalated COA				61.6208201	137.9961156	309.0339905	692.0630108	1549.833435

	Discounted COA				41.93809475	63.91890215	97.42040205	148.4808784	226.3034311
	COA			1012.326511					
Days in drydock	Ddock	Dep. Variable	Regression - Unavailability		17.07	17.07	17.07	17.07	17.07
Cost of one day downtime (unavailability)	CDDT	Dep. Variable	Rtm and Dsea-ld		999936	999936	999936	999936	999936
Cost of unavailability	CUNA @ current prices	Dep. Variable	Ddock and CDDT		17068907.52	17068907.52	17068907.52	17068907.52	17068907.52
	Escalated CUNA				19787541.96	22939184.39	26592801.75	30828345.64	35738501.85
	Discounted CUNA				13467068.57	10625280.83	8383160.164	6614166.293	5218461.165
Cost of unavailability	CUNA			79029418.24					
	CODO - NPV	Dep. Variable	COSR, COA and CUNA	79259891.24					
MODEL 3									
Engine power max	Pmax	Dep. Variable	New Displ., V and C		11176.00466	11176.00466	11176.00466	11176.00466	11176.00466
Specific FOC (gr/KW*h)	SFOCmain	Constant			125	125	125	125	125
% of max speed	Fmean (%)	Constant			90	90	90	90	90
Daily fuel oil consumption (tons)	DFC	Dep. Variable	Pmax, SFOCmain and Fmean		30.17521257	30.17521257	30.17521257	30.17521257	30.17521257
Days at sea	Dsea	Dep. Variable	Ddock		347.93	347.93	347.93	347.93	347.93
Price of fuel	Prfuel	Constant			320	320	320	320	320
No of main engines	Nmain	Constant			1	1	1	1	1
Lub & Diesel oil correction factor	Oilcorr	Constant			1.15	1.15	1.15	1.15	1.15
Annual cost of fuel	ACOF @ current prices		DFC, Dsea, Prfuel, Nmain & Oilcorr		3863581.109	3863581.109	3863581.109	3863581.109	3863581.109
	Escalated ACOF				4478949.414	5192329.936	6019333.48	6978057.248	8089480.856
	Discounted ACOF				3048297.712	2405053.414	1897544.949	1497129.674	1181209.046

	ACOF - NPV			17888465.74					
MODEL 4									
Average operating speed /hour	Stm	Constant			14	14	14	14	14
Loaded days at sea	Dsea-ld	Dep. Variable	Dsea		260.9475	260.9475	260.9475	260.9475	260.9475
Dwt utilisation	DWUtm	Constant			0.8	0.8	0.8	0.8	0.8
Productivity tonmiles of cargo/annum	Ptm	Dep. Variable	Stm, Dsea-ld, DWUtm & NewDWT		52186159872	52186159872	52186159872	52186159872	52186159872
Freight rate Euro/ton mile	FRtm	Constant			0.005	0.005	0.005	0.005	0.005
Revenue/annum	Rtm @ current prices	Dep. Variable	Ptm and FRtm		260930799.4	260930799.4	260930799.4	260930799.4	260930799.4
	Escalated Rtm				302490310.9	350669175.1	406521683.4	471270048.2	546331148.9
	Discounted Rtm				205869822.9	162427678.4	128152588.6	101110144	79774129.75
	Rtm - NPV			1208115355					
MODEL 5									
Price of dismantling/ton	Prdist	Constant							430
Earning of dismantling	EDIS @ current prices	Dep. Variable	Prdist and Newlightweight						4515000
	Escalated EDIS								9453407.352
	Discounted EDIS								1380366.736
	EDIS - NPV			1380366.736					
SCENARIO 1	Model 2 + Model 3 - Model 5			95767990.25					
SCENARIO 2	Model 2 - Model 4 - Model 5			-1130235831					

Table 1 Basic coating system requirements for dedicated seawater ballast tanks of all type of ships and double-side skin spaces of bulk carriers of 150 m and upwards

	Characteristic/ Reference standards	Requirement
1 **Design of coating system**		
.1	Selection of the coating system	The selection of the coating system shall be considered by the parties involved with respect to the service conditions and planned maintenance. The following aspects, among other things shall be considered : *.1* location of space relative to heated surfaces; *.2* frequency of ballasting and deballasting operations; *.3* required surface conditions; *.4* required surface cleanliness and dryness; and *.5* supplementary cathodic protections, if any (where coating is supplemented by cathodic protection, the coating shall be compatible with the cathodic protection system). Coating manufacturers shall have products with documented satisfactory performance records and technical data sheets. The manufacturers shall also be capable of rendering adequate technical assistance. Performance records, technical data sheet and technical a ssistance (if given) shall be recorded in the Coating Technical File. Coatings for application underneath sun-heated decks or on bulkheads forming boundaries of heated spaces shall be able to withstand repeated heating and/or cooling without becoming brittle.
.2	Coating type	Epoxy-based systems. Other coating systems with performance according to the test procedure in annex 1. A multi-coat system with each coat of contrasting colour is recommended. The top coat shall be of a light colour in order to facilitate in-service inspection.
.3	Coating pre-qualification test	Epoxy-based systems tested prior to the date of entry into force of this Standard in a laboratory by a method corresponding to the test procedure in annex 1 or equivalent, which as a minimum meets the requirements for rusting and blistering; or which have documented field exposure for 5 years with a final coating condition of not less than "GOOD" may be accepted. For all other systems, testing according to the procedure in annex 1, or equivalent, is required.
.4	Job specification	There shall be a minimum of two stripe coats and two spray coats, except that the second stripe coat, by way of welded seams only, may be reduced in scope where it is proven that the NDFT can be met by the coats applied, in order to avoid unnecessary over-thickness. Any reduction in scope of the second stripe coat shall be fully detailed in the CTF. Stripe coats shall be applied by brush or roller. Roller to be used for scallops, ratholes, etc., only. Each main coating layer shall be appropriately cured before application of the next coat, in accordance with coating manufacturer's recommendations. Surface contaminants such as rust, grease, dust, salt, oil, etc., shall be removed prior to painting with proper method according to the paint manufacturer's recommendation. Abrasive inclusions embedded in the coating shall be removed. Job specifications

		shall include the dry-to-recoat times and walk-on time given by the manufacturer.
.5	NDFT (nominal total dry film thickness) see footnote	NDFT 320 µm with 90/10 rule for epoxy-based coatings; other systems to coating manufacturer's specifications. Maximum total dry film thickness according to manufacturer's detailed specifications. Care shall be taken to avoid increasing the thickness in an exaggerated way. Wet film thickness shall be regularly checked during application. Thinner shall be limited to those types and quantities recommended by the manufacturer.
2 **PSP (Primary surface preparation)**		
.1	Blasting and profile see footnote see footnote	Sa 2½; with profiles between 30-75 µm Blasting shall not be carried out when: *.1* the relative humidity is above 85%; or *.2* the surface temperature of steel is less than 3°C above the dew point. Checking of the steel surface cleanliness and roughness profile shall be carried out at the end of the surface preparation and before the application of the primer, in accordance with the manufacturer's recommendations.
.2	Water soluble salt limit equivalent to NaCl see footnote	≤ 50 mg/m^2 of sodium chloride.
.3	Shop primer	Zinc containing inhibitor free zinc silicate based or equivalent. Compatibility with main coating system shall be confirmed by the coating manufacturer.
3 **Secondary surface preparation**		
.1	Steel condition see footnote	The steel surface shall be prepared so that the coating selected can achieve an even distribution at the required NDFT and have an adequate adhesion by removing sharp edges, grinding weld beads and removing weld spatter and any other surface contaminant. Edges shall be treated to a rounded radius of minimum 2 mm, or subjected to three pass grinding or at least equivalent process before painting.
.2	Surface treatment see footnote	Sa 2½ on damaged shop primer and welds. Sa 2 removing at least 70% of intact shop primer, which has not passed a prequalification certified by test procedures in 1.3. If the complete coating system comprising epoxy-based main coating and shop primer has passed a pre-qualification certified by test procedures in 1.3, intact shop primer may be retained provided the same epoxy coating system is used. The retained shop primer shall be cleaned by sweep blasting, high-pressure water washing or equivalent method. If a zinc silicate shop primer has passed the pre-qualification test of 1.3 as part of an epoxy coating system, it may be used in combination with other epoxy coatings certified under 1.3, provided that the compatibility has been confirmed by the manufacturer by the test in accordance with 1.7 of appendix 1 to annex 1 without wave movement.
.3	Surface treatment after erection see footnote	Butts St 3 or better or Sa 2½ where practicable. Small damages up to 2% of total area: St 3. Contiguous damages over 25 m^2 or over 2% of the total area of the tank, Sa 2½ shall be applied. Coating in overlap shall be feathered.
.4	Profile requirements see	In case of full or partial blasting 30-75 µm, otherwise as recommended by the coating

	footnote	manufacturer.
.5	Dust see footnote	Dust quantity rating "1" for dust size class "3", "4" or "5". Lower dust size classes to be removed if visible on the surface to be coated without magnification.
.6	Water soluble salts limit equivalent to NaCl after blasting/ grinding see footnote	≤ 50 mg/m^2 of sodium chloride.
.7	Oil contamination	No oil contamination.
4 **Miscellaneous**		
.1	Ventilation	Adequate ventilation is necessary for the proper drying and curing of coating. Ventilation should be maintained throughout the application process and for a period after application is completed, as recommended by the coating manufacturer.
.2	Environmental conditions	Coating shall be applied under controlled humidity and surface conditions, in accordance with the manufacturer's specifications. In addition, coating shall not be applied when: *.1* the relative humidity is above 85%; or *.2* the surface temperature is less than 3°C above the dew point.
.3	Testing of coating see footnote	Destructive testing shall be avoided. Dry film thickness shall be measured after each coat for quality control purpose and the total dry film thickness shall be confirmed after completion of final coat, using appropriate thickness gauges (see annex 3).
.4	Repair	Any defective areas, e.g., pin-holes, bubbles, voids, etc., shall be marked up and appropriate repairs effected. All such repairs shall be re-checked and documented.