

Assessment of Harbor Tugs Operational Profile in Various Ports

The Case of KOTUG SMIT Towage

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Assessment of Harbour Tugs Operational Profile in Various Ports

The Case of KOTUG SMIT Towage

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In God, we trust, all others bring Data

W. Edwards Deming

Preface

*George Lazaris
Delft, November 2017*

The current master thesis project was accomplished for the needs of the master of science degree in Marine Technology at Delft University of Technology. The selected track of this master was DPO, Design Production & Operation with specialization in Shipping Management.

The research that was carried out through the project, was achieved in an excessive collaboration with KOTUG SMIT TOWAGE company. At this point, I would like to thank from the bottom of my heart KOTUG SMIT TOWAGE for providing me all the necessary insights for my research concerning the optimization of the daily management tasks of their fleet. Even if the idea of constructing a unique tool was characterized from a high degree of complexity, the presence of multiple competitors in the area of Northern West Europe was always the biggest motivation to provide KST with a tool capable to raise its market shares.

During the eight-month's period that I worked with KOTUG SMIT TOWAGE, I managed to gain massive experience. The company offered me the opportunity to work in a professional and more than a friendly environment. At the same time, I had the opportunity to visit 55 out of the 64 tugs of the company and stay on board for two weeks in total. During these two weeks, I gained significant experience regarding the daily operations in the various ports, while allowed me to feel and understand better the followed procedures being followed during their daily tasks. I have to say that my experience on board will be unforgettable.

I would like to thank my supervisors, Mr. Jan Groeneweg and Mr. Joris Kremer as well as the crew members both tug masters and engineers on board, for this unique experience. Special thanks to Mr. Jan Groeneweg for being always a prodigious fleet superintendent supervisor, offering all the necessary insights for the completion of this thesis project. I would also like to thank both supervisors at Delft University of Technology Prof.dr.E.M. Van de Voorde and Mr. Ir.J.W. Frouws for the essential guidance they offered me during this period, which was more than necessary for the fulfilment of the research project at a high-quality level.

Finally, I would to express special thanks to my parents Hercules & Maria and my grandmother Charalambia, who are always at my side through my academics studies. I would like also to express my gratefulness to my friend and colleague Dick, George & Vasilis for the continuous support and motivation they offered me during the project.

Summary

The relationship among the main specifications of a harbor tug concerning its economic and technical performance as a result of its design, receives more and more attention in KOTUG SMIT TOWAGE company. Therefore, the objective of this thesis project was to build a tool capable to contribute on the optimization of towing operations, by evaluating the main characteristics of tugs, regarding the various types of operation within the port perimeter for minimizing the daily costs.

In order to be able to assess the basic insights of harbor tugs, a crucial definition and a general review of the various harbor tug types was required. Multiple tug types were extensively analyzed, for providing a complete assessment concerning their main capabilities and limitations. The evaluation and comprehension of harbor tug's main characteristics is high of importance, and allowed the assessment of the assisting methods to be offered. For this reason, the evaluation of KST fleet effectiveness was crucial, together with the type of vessel to be assisted.

The assessment of KST fleet operational profile is linked with the type of the merchant vessel to be assisted as a result of its bow design, speed, draught and load, leading to various wave distributions during the approach for the towline connection, and eventually to several resulted forces and turning moments. For this reason, KST fleet assessment will take place based in two groups of assisted vessels. The first group, (Group A), refers to Car Carriers, Containers, Passenger ships, while Group B refers to Bulk Carriers and Tankers. The special survey which took place during the thesis project, is aligned with a proper analysis of all KST ports of operations, for the entire year of 2016. In that perspective, minor changes are expected for the year of 2017 and therefore, KST will be able to align more efficiently KST fleet effectiveness levels for the various ports, with all the possible types of operation concerning every possible tug reallocation.

Since merchant vessels tend to grow their capacity and hence their size, the need for high levels of maneuverability during ship-handling tasks, becomes crucial, while KST aims through this project to assess and evaluate its fleet efficiency, combined with a solid investigation among all the ports of operation, for increasing the levels of services offered to its clients. Additionally, the analysis of all the main insights, towards the towage regulations & restrictions, as well as the environmental conditions for each port of operation, will be used as an essential input for the tool, which is required for verifying every possible tug reallocation, as well as the resulted efficiency for each selection.

The assessment for each tug type varies from port to port, as a result of the port complexity, and therefore the criteria to be evaluated towards each simulation through the tool, will consist from various weight factors. For this reason, a valuable analysis was required for offering solutions to all these complex decisions, while all the main parts will be established by using a decision-making tool for the evaluation of KST fleet, with the correspondent's weight factors, based on the ports configuration. Therefore, a compact analysis concerning the analytic hierarchic process, which is required for the needs of the tool was provided. After the main capabilities and weaknesses regarding KST fleet were addressed and correlated with the main characteristics towards the market trends for each port, the next step was to establish the method to be followed for combining the required input from all the pre-mentioned chapters for the tool needs, for evaluating tug's effectiveness in various ports, under various scenarios.

One of the most essential issues for KST tool, was referring to the determination of the number of criteria to be assessed in each case. For this reason, a decision-making process was used, which is defined as the process for making a choice among various alternatives, while each scenario to be simulated was based on established criteria. For this project, it was required to create a tool capable to provide several results depending on user's choices, and therefore AHP method was considered as the most ideal technique.

The next part of the thesis was aiming to establish the strategy for determining the cost indicators for each of the tug types of KST in the various ports. This part was vital for the tool function, offering the ability to assess all the possible tugs combinations to occur, based on user selections for each area. Afterwards it was possible to verify and compare not only the effectiveness results of the selected tugs, but at the same time the costs per job for each simulated scenario.

The main focus towards the scope of this project for the expenses to occur refers exclusively to fuel costs. For this reason, tool's main goal, was to indicate which tug type combination was characterized from the highest effectiveness level, together with the lowest fuel cost, concerning the amount of assistances for each area, as a result of the operational profile of the selected tugs. Moreover, the results regarding the total number of tugs per port, as well as their total fuel consumption, were extensively analyzed and assessed, during 2016, while it was proven that the resulted fuel cost for each port, was aligned with the types, as well as the number of tugs to be selected. Additionally, for each port of operation of KST, the tug types with the lowest fuel costs per job were discussed, while the comparison among the same tug types in various areas, proved the most optimum port of operation for achieving the highest fuel savings.

For the needs of the tool and for providing a good indication of the fuel costs per type and for all the unknown ports, various indicators based in analogous estimations were used. The presence of the same tug types among some ports, provided high of importance output, for establishing several metrics, which allowed to monitor the behavior of each type in every port of operation. These metrics offered the ability to define the benchmarks, since it was clear to define which tug was proven to be the most efficient during the tugs allocation for 2016; the performance metrics indicators offered also the ability to gain a solid average estimation, towards the predicted fuel cost of each tug in each port. Even if the indicators that are used are not capable to provide 100 % accurate results, still they were capable to provide fair good approximation, while due to the tremendously high impact of human factor, the trustworthiness level of the predicted indicators regarding the fuel costs for tug types in new ports, were evaluated under various uncertainty levels (sensitivity analysis).

As previously stated, one of the main complexities in this thesis project was related with the presence of several indicators that were used for defining the total fuel cost, for all the possible tug combinations to be decided. Therefore, the tool was constructed in a way, capable to recognize if the selected tugs per port for each scenario were based on known or unknown data; this is the reason that the user was capable to define the level of uncertainty for each new simulated scenario, and eventually to assess the range of minimum and maximum fuel cost. Consequently, each user can decide if the margin among the minimum and maximum costs is adequate for proceeding to a possible swap or not.

Due to time limitation, it was decided to proceed in four scenarios, by investigating eight possible reallocations, while each scenario was analyzed after including 10%, as well as 20% uncertainty level for verifying if KST would be capable to achieve fuel savings. The effectiveness results variances regarding the daily operations,

were evaluated for each scenario, while the main conclusions for each of the four simulated scenarios were deeply discussed.

Finally, by reviewing the tool results, it is evident that the optimum scenario in order KST to achieve considerably high fuel savings refers to the swaps 2 & 4. The reallocation of LIEVEN GEVAERT in the port of Liverpool and SMIT BELGIE in the port of Antwerp, will offer annual fuel savings equal 87,585.01 €, while the reallocation of RT EVOLUTION to Europoort and SMIT PANTHER to London, concerning the fourth swap, will lead to annual fuel savings equal to 106,987.69 €.

Both reallocations will lead KST to proceed in annual fuel savings equal to 194,572.7 € annually. Additionally, the fleet effectiveness results regarding swaps 2 & 4, will lead to a minor decrease of 5 %, while the rest ports will either increase or decrease slightly their effectiveness results by 1%. Therefore, the tool was capable to prove that by reducing slightly the effectiveness results among some ports, it was possible to achieve significantly high fuel savings, while in terms of flexibility, KST will not be influenced considerably.

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1

Introduction

1.1 Background Theory

Tugs that are used nowadays in ports are high of importance for the shipping industry. Their innovative designs and special hull constructions, are some of the most significant factors offering high maneuverability levels. These factors are vital for the execution of their daily tasks. Harbour tugs already count hundreds of years of operations while a rapid development has been observed the past few years.

Due to the fact that towage companies operate a mixed fleet with multiple technical aspects, they should come up with new tools capable to optimize their activities, regarding fleet characteristics performance and capabilities. Towage companies recognize that a port which is incapable of covering shipping industry requirements adequately, is unviable, consequently their fleet should be able to confront customer demands efficiently. On the other hand, as cargo vessels grow their size, tugs are enforced to raise their abilities in power, to meet the desired levels of maneuverability characteristics. KOTUG SMIT TOWAGE is a joint venture of two well-known tug boat operators, KOTUG and SMIT, with its head office in the largest port of Europe, Rotterdam.

The company offers high quality services in the maritime industry as well as sustainable towage services. In order to fulfil customer's needs, 24/7 services are offered in twelve different ports, covering four different countries. Up to now, KST has a significant share among the Netherlands, Belgium, Germany and United Kingdom. Due to the large success in daily operations among the four different countries, KST aims to expand its activities and become a leader in the Northern Europe in the near future, by covering new regions of operation.

The first step for proceeding to future investments in additional tugs, is the optimization of the current followed strategies and tactics. For this reason, the company aims to distribute tug capacity for the operational requirements more efficiently, leading to the minimizations of its costs towards the daily operations. Hence, the fundamental variances between the various types of tugs should be evaluated precisely. Tugs are mainly divided into harbor and seagoing tugs. Both categories are divided to multiple sub-categories, each with unique characteristics. Consequently, it is crucial to understand the basic designs and construction features as well as the importance of all the involved factors.

1.2 Objective of the Thesis

The relationship among the main specifications of a harbor tug and its economic and technical performance as a result of its design, receives more and more attention in KOTUG SMIT TOWAGE. Therefore, the objective of this thesis project is to build a tool capable to contribute on the optimization of towage operations in the various ports, by evaluating harbor tugs fundamental insights regarding all the possible types of operation within the port perimeter, for minimizing the daily costs.

1.3 Scope of Work

The construction of this tool will have an added value for KST for the optimization of its daily activities. The tool will combine both technical and economic factors concerning shipping towing operations, guiding the company to assign each harbour tug more efficiently within the port perimeter, taking also into consideration the regulations and specifications of each port. The scope of this thesis research project will focus on the harbour tugs and all the related operations within the port perimeter, excluding seagoing tugs.

The framework of this thesis project will start with all the necessary background theory linked to towage shipping companies, as well as the theory referring to the multiple types of harbour tugs and the different types of merchant vessels that need assistance in ports. Afterwards, the design factors for harbour tugs are analysed in order their main technical characteristics, capabilities and limitations to be examined. Additionally, the understanding of the general arrangement plans and requirements through the basic characteristics of a harbour tug, aims to offer a better comprehension towards their main advantages and disadvantages. Thus, each harbour tug will be evaluated by using a multi-criteria analysis with a grading score (weight factors) and will consist of a total score, based on its main advantages and disadvantages for each port. This score will be used for proving harbour tug suitability for the various types of operations in multiple scenarios. The next part to be deeply considered, are the different regulations and specifications of all the ports among the four countries. Therefore, the thesis will investigate the main variances of environmental and local conditions among the port of Rotterdam, (Europoort & Rotterdam City), London, Antwerp, Liverpool, Zeebrugge, Terneuzen, Gent, Vlissingen, Bremerhaven, Hamburg & Southampton.

The next part of the framework, is the investigation of the shipping economics in order each decision to be evaluated from a financial point of view. Towage market consists of unique characteristics and requires a specific approach, while the tool has to balance the variances amongst the multiple types of operation in ports perimeter, after considering the regulations and specifications for each case. The discussed technical and financial factors, through the tool will be assessed by using multiple scenarios. The optimum scenario, aims to show which tug's combination is capable to offer high levels of effectiveness results towards the daily operations, together with the lowest costs, compared to the current situation. For this reason, it is mandatory to simulate various scenarios under multiple tug's combinations for all the ports of operation of KST, where the tool will prove which combination is the most suitable, in order to guarantee the highest cost reduction concerning the daily operations. Conclusively, tool results among the generated scenarios will be extensively analysed, while the thesis will be completed after evaluating the flexibility levels to arise for each scenario as a result of the possible swaps to occur, in order to make sure that KST will be always capable to provide the highest level of satisfaction towards its clients. Both technical and financial perspectives will be considered as important dimensions for a consistent evaluation of the results.

An Overview of the Towage Industry

The purpose of this chapter is to set the basic insights of towage shipping industry, by analyzing all the related submarkets where tugs are involved. However, since the scope of this thesis project refers exclusively to harbor tugs, emphasis will be given only on the first three sub-chapters which are totally aligned with harbor tugs duties. Finally, the last two subchapters aim to give an idea of the alternative markets where tugs are involved without being extensively analyzed, since they are referring more to sea-going tugs which are entirely out of the scope of this thesis project.

2.1 What is a Tug?

The assessment of harbor tugs, requires a solid evaluation of marine towage industry, related with the vessels to be assisted. In general, harbor tugs are built to offer a variety of assisting methods inside ports. Apart from that, they can also escort a vessel through narrow harbor entrances, by controlling their speed. At the same time, harbor tugs are also capable to execute additional duties if it is required, as fire-fighting and salvage activities. On the other hand, deep sea-going tugs are capable of towing of massive floating structures over large distances, provide bunkering, and several offshore tasks and marine engineering projects. (Beegle, 2007)

Harbor tugs are the “ship dogs” of the marine world and there is no doubt that without harbor tugs, mega ships would never be able to enter ports. Following a chronological order, as the size of cargo ship has increased, so have the demands for tugs, causing unwelcome cost for the ship-owners. Tug assistance depends on two essential parameters; engine power and special hull design. Special hulls offer the ability to dig into the water, while their unique capabilities occur from their hull allowing them to move forward, backwards or sideways, depending on the tug type. Due to their heavy displacement hull, they ride low under the enormous weight of their propulsion line, and as soon as they power up they sink even further. In this way tugs have more contact with water, meaning more friction and consequently more pushing power. However, in order to guide efficiently ships through narrow port entrances, tugs need extra capabilities except from power. They consist of independently controlled propellers, keels that go in front of the boat and indestructible winches. Consequently, this chapter aims to deeply analyze and therefore assess all the possible types of tugs with their characteristics. Finally, even if tugs consist of exceptional capabilities, they often work in groups due to the high levels of the required bollard pull.

2.2 Towage Industry & Merchant Vessels

Shipping Industry is probably one of the most attractive businesses globally. Cargoes have been moving around the world for thousands of years in a global development, aiming to cover efficiently the requested demand. (Hensen C. H., TUG USE IN PORT - A practical Guide , p vii, 2003). Merchant ships vary regarding the transported cargo and therefore, they are divided in three major categories; Bulk cargo, General Cargo & Passengers. Each category is further analyzed in sub-categories indicating all the possible type of vessels that a port is possible to welcome. The construction of a framework consisting of the multiple merchant vessels types, will allow afterwards the correlation of the assisted vessels with the multiple harbor tugs in the following chapters.

Freight rates in parallel with the maritime transport costs are significant factors, aligned with the demand & supply rule. The apprehension of these factors, is high of importance, for the optimization of the operational profile of a maritime company. Even if the scope of this thesis project does not focus on the market trends and how freight rates and transportation costs are influenced, towage companies are enforced to assess and consider deeply the global sea trade. The understanding of the global sea trade offers the ability to recognize the cargoes that are transported in higher and lower volumes respectively; thus, towage companies are enforced to re-organize the followed strategies and tactics for the optimization of their daily operational activities. Most shipping segments during last year, suffered from historically low freight rates. The massive over-supply of vessels was the main reason for the significantly reduced freight rates which affected mainly the market of dry bulk cargo. (A.Argyriadis, p. 12). On the other hand, the market referring to tankers (liquid cargo) was proven to be the less volatile in comparison with dry bulk carriers, and the main reason was the rising demands for LNG fuel. Shipping industry is enforced to lower emissions; thus, LNG fuel is expected to be used in higher volumes.

Consequently, towage companies are recommended to strengthen the contracts with shipping companies related to the market of liquid bulk cargo. At the same time, the growth of brand new ports or the expansion of current ports has led to a general expansion in the bulk-type general cargo market, referring to containers where the last decade new designs of container vessels indicate higher capacities. Thus, towage companies by investigating the trends of a shipping industry, are capable to investigate in advance harbor tug's capabilities for assessing the daily services. At the same time, each type of merchant vessels has its specific maneuvering characteristics and therefore requires various assisting methods for entering or leaving a port. Hence, towage companies by looking the results of the global sea trade in a long and a short run, are capable to re-schedule more efficiently their activities for the upcoming period regarding the frequency of entrance for all the possible assisted vessels in harbors. This investigation is of high importance since each type of cargo vessel is diverse, thus towage companies after analyzing the main capabilities of their fleet, should match each case with the optimum tug types, by providing ship handling tasks in the most competent way. Since towage companies have no ability for predicting the freight rates and thus the volumes of cargoes to be transported from one port to another, they always proceed in contracts with ship owners for a certain period to serve ship-handling duties continuously, an attempt which has proven to be challenging. At the same time, special contracts are offered for specific tasks, either from port authorities or from oil terminal operators i.e. in the case of fire-fighting protection of a harbor or a terminal. (Julia 2009 , 178). Towage industry and fire-fighting duties of the various harbor tug types will be further analyzed in the following subchapter.

2.3 Towage Industry & Fire Fighting Duties

New generations of harbor tugs are constructed with improved ship-handling capabilities as well as unique fire-fighting systems. As it was already mentioned, the rising demands of oil and LNG cargoes, are the reason to establish new fire-protection measures in ports as well as in terminals all over the world. Governments are also willing to finance special contracts among tug-owners and port-authorities, for eliminating the possibilities of accidents leading to significant disruption of the ecosystems. Tug propulsion manufacturers must deal with strict instructions from tug owners in order the new tugs generations to be characterized from adequate power, capable to satisfy the needs for ship-handling duties as well as the needs of fire pumps. These pumps are responsible to supply water on the deck mounted fire monitors, as well as on the deck where fire hoses are connected. Thus, naval architectures have developed special nozzles, at fixed locations on the superstructure of the tug, also known as FiFi1, allowing to control the flow of water more accurately and alter direction and elevation required for the operation. Harbor tugs consist of multiple types of monitors capable to deliver water or foam or even both as a mixture. Furthermore, monitors are capable to deliver water in a range between 1,500 to 60,000 liters per minute. (Julia 2009 , 116)

Fire pumps are usually driven from the main engines of tugs. Since tugs are required to consist of increased maneuverability capabilities, manufacturers tend to couple each pump with one of the main engines, ensuring that tug efficiency will not be limited. Additionally, the connection with the main engines offers faster rotation at the pumps, which is needed to achieve the required FiFi1 capacity. Alternatively, fire pumps are driven from separate auxiliary engines. The establishment of power as well as the size of these pumps vary and depends entirely from the number of monitors to be established on each tug and requirements of class societies. The amount of power required for tugs for maintaining their position precisely should also interact with the thrust created from the monitors, explaining why maneuverable tugs are the most ideal for confronting fires. This is the reason that escorting tugs are also capable to control fires efficiently. Most of the harbor tugs with fire-fighting capabilities consist of two monitors.

The presence of extra monitors is entirely aligned with the profile of each tug as well as from the standards of the multiple oil and gas operators which occur from the various classifications concerning the fire-fighting assistance. Thus, a mutual symbolism is used for the total of oil and gas terminals and is represented as FiFiX. (Julia 2009 , 180). The letter X is substituted from a number which is 1,2 or 3. This symbolism is used for characterizing the capacity of pumps and thus the expected performance of monitors, specifying at the same time the level of protection for the tug. Nowadays, gas or oil coastal terminals consist of tugs with pumping capacity range of 3600 cubic meters per hour. KST tugs, comply with FiFi1 notation, consisting of two monitors. On the other hand, offshore tugs, dedicated to oil fields will consist from extra number of monitors thus their notation varies between FiFi2 & FiFi3. These types of tugs though will not be investigated further, since they are out of the scope of this thesis project.

2.4 Towage Industry & Salvage

Nowadays, one of the most captivating activities offered from tugs is salvage. Developing countries tend to legislate strict anti-pollution control measures, especially at locations with major oil installations. However, tugs devoted only to salvage are erratic. Consequently, new harbor tugs consist of unique fire-fighting capabilities, with all the necessary salvage equipment. Harbor tugs which are used mainly for escorting, and will be further analyzed in a following chapter, are also used for salvage operations. Fire-fighter monitors are capable to provide water with high pressure, aiming to fight the oil spills. Nevertheless, for those cases

chemical dispersants are required. The significant growth of ports for distributing oil and LNG cargoes globally, as well as the construction of new oil and LNG terminals, has enforced tug owners to proceed in high capital investments of tugs, capable to deal with hazardous cargoes. (Julia 2009 , 119). Escorting harbor tugs are constructed with a state-of-art pollution control equipment in order to control possible adverse cases with oil leaks within ports or at oil terminals. The revolution of technology has led towage companies to establish efficiently plans for removing all the pollutants from ships in short response time at emergency situations. Thus, most of the normal harbor tugs are capable to carry large amount of chemical dispersant in designated tanks. In general, pollution control measures include three main steps. The first step refers to the oil dispersal in order the oil to be split in small droplets, leading to multiple but much smaller oil spills. Afterwards, the second step is the containment of the oil spills, and finally the retrieval of the oil spills. For this reason, additional pumping equipment is installed. High capacity pumps, connected with auxiliary machinery are used for moving large water quantities in high rates. Additionally, in the cases that some harbor tugs lack salvage equipment, portable salvage pumps (mainly diesel driven) are possible to be attached on board of tugs from ashore. Alternatively, submersible pumps are used in the flooded areas for confronting oil spills. (Julia 2009 , 113)

2.5 Towage of large Floating Objects

An alternative form of towage industry is the pushing of various barges in various sizes and shapes. This form of towage takes place more on inland waterways areas but also at sea. This market includes specialized tugs also known as pusher tugs. Pusher tugs have a specific rectangular shape and conventional design, and they are mainly used in countries with inland waters i.e. in North and South America, Africa, some areas in Asia but also in multiple European countries i.e. The Netherlands as well as in Belgium. As soon as pusher tugs and barge are connected, then pusher tug and barge behave as one vessel, while they can connect and disconnect easily. Additionally, the operation of pusher tugs and barges has significantly lower costs in comparison with the rest self-propelled vessels with the same amount of cargo to be transported. (Julia 2009 , 221). Finally, pushing operations are entirely dependent from the local weather conditions. Weather conditions tend to affect dramatically the performance as well as the safety of pusher tugs and barges. The main reason for various limitations during complicated weather conditions, is the conventional design of pusher tugs as well as the method used for connecting tugs with barges. Consequently, in the recent year's extensive research takes place, concerning the connection between pusher tug and barge, for improving the performance of both elements as a rigid body even under adverse weather conditions.

2.6 Towage Industry & Offshore Operations

Towage industry dedicated to offshore world includes the largest and the most powerful tugs. Sea-going tugs are capable to travel thousands of miles under extreme sea conditions in order to be involved in long distance towing of offshore platforms, salvage activities, as well as anchor handling for the offshore oil industry. Nevertheless, multiple economic factors have led towage companies to emphasize more in activities related in long distance towing with the construction of very powerful tugs and less on salvage activities. Oceangoing tugs or deep-sea tugs are entirely involved in large distances towing and thus they have specific dimensions and equipment. Additionally, these tugs have different philosophy compared to harbor tugs, since the capital of the investment, as well as the operating costs including maintenance, are significantly higher. Multiple towage companies in Europe and Asia have proceeded in various investments during the past years, where the oil price was constantly high. However, the last two years have led to multiple challenges and unpropitious cases, as a result of the oil price reduction. Since tug owners had to deal with significant high operating and

maintenance costs, they decided to attribute a diverse identity to oceangoing tugs for satisfying adequately both offshore & salvage activities, consisting from a proper salvage equipment, capable to deal with groundings or collisions of massive cargo vessels. (Julia 2009 , 194)

2.7 Chapter Conclusion

In this chapter a literature research was made for defining all the possible markets of towage industry. The main goal of this chapter, was to clarify that the main market to be taken into consideration for KST study case, refers entirely to harbour towage for merchant vessels, while the company does not offer solely services either regarding fire-fighting, offshore or salvage duties. On the other hand, KST fleet is capable to combine harbour towage services, combined with fire-fighting or salvage duties within the port perimeter if necessary, a fact which offers higher flexibility levels towards its daily operations. Moreover, the field of floating objects & barges is entirely out of the business core of KST.

Moreover, one of the main goals of KST, is to strengthen the contracts with shipping companies and for this reason, it is crucial to investigate the vessels type to be assisted for each port of operation, for gaining valid insights regarding the market trends towards the shipping industry. Additionally, the investigation among the advance harbor tug's capabilities of KST, and all the possible types of merchant vessels to be assisted, will allow KST to assess more efficiently the effectiveness level of its daily services.

Each type of the merchant vessels has specific characteristics and therefore requires various assisting methods for entering or leaving a port. Consequently, by analyzing the results of the global sea trade in a long and a short run, KST will be capable to re-schedule more efficiently its activities for the upcoming period, after considering the frequency of entrance for all the possible assisted vessels in harbors. This investigation is of high importance, since each type of cargo vessel is diverse, and thus KST after analyzing the main capabilities of its fleet, will be able to match each case with the optimum tug types, by providing ship handling tasks in the most competent way.

Even if it is not possible for KST to predict the freight rates, and thus the volume of cargoes to be transported from one port to another, still the company will always be able to proceed in contracts with ship owners for serving ship-handling duties continuously, while by analyzing the market trends year by year for each port of operation, the company will be able to gain a significant advantage compared to its competitors, by predicting if an increase or a decrease of the transported cargo types will occur.

The next chapter objective, is to present the tug types of KST fleet, and analyse their main characteristics. This analysis aims to correlate the resulted capabilities/limitations for each of the tug type, with the possible types of merchant vessels to be assisted at each port, and for all the possible types of operations to be offered. For this reason, the following chapter will firstly analyse the main technical characteristics of each tug type, while the next step will be to assess their performance, as a result of the main fundamental insights of each category.

Definition & Characteristics of Harbour Tugs – Case of KST

This chapter aims to set the basic insights of harbor tugs, by providing a crucial definition and a general review of the various harbor tug types. Multiple types will be analyzed extensively, for providing a complete assessment concerning their main capabilities and limitations. The evaluation and comprehension of harbor tug's main capabilities are of high importance, for assessing the assisting methods to be offered within ports perimeter more efficiently. The dependency among assisting methods and harbor tugs capabilities will be further analyzed in a following chapter.

3.1 Importance of Harbor Tugs

Fifty years ago, no one could ever think that harbor tugs would be characterized from such unique characteristics associated to power and maneuverability. However, high levels of power and maneuverability were totally impossible to be achieved with conventional designs. A general revolution related to hull forms of tugs was necessary for all towage companies, in order to be more competitive, and therefore for gaining more shares in the towage market. (C. H. Hensen, TUG USE IN PORT - A practical Guide , p vii 2003, V) Thus, a significant agreement with high investments between towage companies, naval architectures and ship propulsion manufacturers has been observed the past few years. The core of this agreement is the construction of fully efficient harbor tugs, consisting of a state of art equipment for fulfilling customer's demands and environmental standards. (Julia 2009 , 139) Towage companies are convinced that ship handling will continue to expand in the near future, since merchant ships tend to raise their capacities simultaneously. Even if they are capable to maneuver in the open sea, they are totally hampered inside ports and narrow passages, while for sideways movements harbor tugs are more than required.

Tugs provide one excessive impression for their identity regarding their size and types of operation which are made for. Even if they are relatively small, there is an imbalance between their size and power. The primary reason for their usage is the assistance offered to merchant ships (bulk cargo, general cargo or passengers) in crowded ports and narrows passages. These ships will always demand tug assistance for safe handling within ports. Especially during the past few years till now, the increase in size of container vessels and the selection of LNG fuel for lower emissions and better fuel consumption, has led harbor tugs to be necessary all over the world. The construction of gas, bulk or oil terminals has given an overarching role to harbor tugs for precise assistance with short time responses even under extreme tidal conditions. (Julia 2009 , vii) Additionally, harbor tugs are also used for firefighting duties and therefore they consist of powerful firefighting guns and monitors.

Naval architectures aim to install engines with high power levels and strength without causing limitations to the flexibility & maneuverability of the tugs, since both elements are vital for their daily operations. Captain's experience, teamwork and the proper communication between all the involved crew is the fifty per cent of the success. (Julia 2009 , VI). The additional fifty per cent depends entirely from the capabilities and limitations

of both tugs and towed vessels. Hence, towage companies should consist of experienced crew, fully aware of tug's capabilities and limitations, and port regulations, for achieving the best results. The technological development in marine engineering contributed to the design of high tech tugs with extreme capabilities and larger engine powers with high performance levels. Thus, even if tug masters don't count dozens of years of experience, they are capable to control tugs accurately towards the daily operations. On the other hand, experience is always a large advantage since daily operations may take place under adverse weather and environmental conditions. Under these circumstances, harbor tugs should be handled efficiently and therefore experience and awareness of tug capabilities are crucial factors. This consciousness will lead to the utilization of tugs in the safest way leading also to the safety of the towed ship. (Julia 2009 , V).

One of the most important insights for all the towage companies is the operational performance of their fleet. Additionally, the brand-new tugs that have already started to replace conventional tugs, follow the trend of reducing the number of required tugs for assisting ships, consequently tugs role gains advanced importance levels. This thesis project aims to deeply analyze the various harbor tug types for the study case of KST, and the capabilities of each category providing all the required insights and their role. Each tug has a different behavior regarding the assistance to be offered. Consequently, there is an excessive willingness for KST for determining the type of tug to be used in each type of operation providing the optimum result. At the same time, the capabilities and main technical characteristics of each harbor tug should deal with the multiple port regulations as well as environmental and local conditions.

Nowadays, as towage companies keep updating their fleet with brand new tugs with exceptional capabilities, they still have to deal with the conventional tugs-older tugs of their fleet. For this reason, it is more than useful for a towage company to analyze the main advantages & disadvantages of each tug through its technical characteristics. Additionally, the relationship between the main specifications of a tug and its economic performance as a result of its design, is crucial. Therefore, KST would be interested to investigate the construction of a tool capable to contribute on the optimization of towing operations, by evaluating the main characteristics of its fleet, towards the offered types of operation within the port perimeter. This tool will offer added value to the company, aiming to the minimization of costs towards the daily operations.

3.2 Evolution of Current Harbor Tugs

3.2.1 Introduction

Harbor tugs behavior is totally aligned with their main technical characteristics, defining entirely their capabilities and limitations. Before analyzing KST fleet for the needs of the tool, this chapter aims to give an indication of the various harbor tug types, with their main characteristics. The company aims to provide high quality services, consisting of harbor tugs with high power levels, optimum hull configuration and equipment, at reasonable tariffs in unforeseen environments. Thus, a deep investigation concerning the variances of underwater hull and propulsion systems of KST fleet, is more than required and will take place in the following chapters. At the same time, the company aims to meet customer's demands in the most economical way. Tugs capabilities and limitations are entirely dependent from the hull shape, towing point and propulsion unit locations. Hence, harbor tugs are mainly divided in two different categories, as a result of the location of their propulsion system. Several categories exist, with their propulsion system forward or aft. Propulsion unit's location, defines also the towing point either near the middle or at the stern of the tug. Nevertheless, there are intermediate categories, capable to behave both as conventional and tractor tugs. Therefore, these tugs have

multiple towing winches either with their propulsion aft or near amidships. Figure 1, presents the various types of harbor tugs. (C. H. Hensen, TUG USE IN PORT - A practical Guide , p vii 2003, 8)

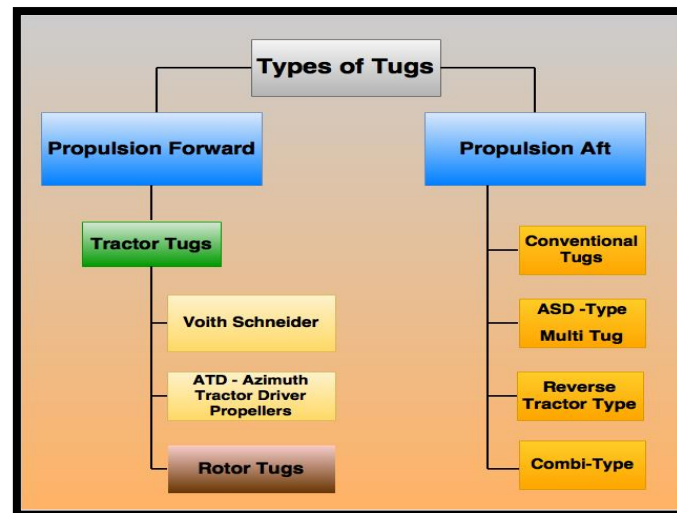


Figure 1: Types of Tugs, Own Composition ((Henk 2003, 8)

The left side of Figure 1, refers to tugs consisting of a forward location of propulsion units, known as tractor tugs. Tractor tugs are well-known to KST, as well as to the majority of the towage companies which have purchased either Voith Schneider's or Azimuth Tractor tugs. One additional type of tractors (with a third azimuth thruster fitted aft), is Rotor tug. On the other hand, the right side of the diagram, refers to the second category of tugs with aft propulsion, and covers a variety of tug types. The first type refers to conventional tugs, which are the most traditional and elder tug version, operating for dozens of years. ASD tugs (Azimuth Stern Drive propellers) is the next type to be discussed. Z-techs are a variation of ASD's and belongs equally on this type. ASD's are also known as Multi tugs, since they are capable to behave both as conventional and tractor tugs. The next type to be discussed is the Reverse Tractor type, meaning that the azimuth propellers are located at the stern. This tug type differentiates from ASD's, since they are incapable to behave as conventional tugs. Finally, the last type is the Combi tug, which is a pure conventional tug, and consists of a bow thruster.

The next part of this chapter, aims to investigate the main technical characteristics of all types from figure 1, leading to a solid evaluation of their main capabilities and limitations. Finally, the general requirements for a good performance and safety towards harbor assisting methods for each case, will be deeply analyzed.

3.2.2 Overview of Propeller Systems

Fixed Pitch Propellers

Fixed pitch propellers are characterized as a rigid body consisting of two main parts; the hub and the flukes, which are arranged in a fixed position on the outer hub of propeller. By selecting a random cut section on the blade, the pitch angle will consist of a specific magnitude, depending on the distance from the root of propeller. Hence, the final pitch will occur by adding all the possible radial cut sections of the propeller. At the same time, if any random radial cut section of the propeller rotates in the water, the axial distance to occur after one rotation, will be equal with the related pitch angle. In general, fixed pitch propellers consist of a simple construction while they are mostly used in large sea-going cargo vessels. At the same time, fixed pitch propellers are extensively used in a variety of conventional and unconventional harbor tugs, due to the lower levels of maintenance as well as capital of investment. Additionally, FPP's are smaller than CPP with consequential large open water efficiency (Asgeir J.Sorensen 2017, 4). On the other hand, FPP consist of some

significant disadvantages; one of them is the limited performance especially during off-design speeds. This situation explains the failure of cargo vessels to maneuver and operate under those conditions. Additionally, vessels with fixed pitch propellers are entirely unable to alter their thrust (forward to stern) without stopping the engine, unless a reverse gearbox is installed, while they are also prone to cavitation.

Controllable Pitch Propellers

Controllable pitch propellers are also characterized as a rigid body consisting of the hub and the flukes as FP. However, the blades are rotating in a variety of pitch angles. In general, controllable propellers are ideal for vessels that are used for sailing quite often and most importantly are enforced to operate in several conditions. CPP's, offer unique characteristics of maneuverability and superb performance in both adverse and calm weather conditions due to their ability to change pitch angle. Hence, this type is ideal for harbor tugs which must provide maximum bollard pull at constant power in various speeds and full speed when free sailing. (Asgeir J.Sorensen 2017, 5).

Additionally, one of the most essential advantage of controllable pitch propellers is the ability to be used in a large variety of rotational speed, moving the vessel either forward or stern within a few seconds, without reversing the engine rotation. Consequently, the possibility of wasting energy is eliminated while a significant amount of fuel is also saved through this transit mode. Moreover, since the thrust of the propeller is dependent from the pitch, it is feasible to increase vessel's speed simply by altering the pitch without increasing the rotational speed of the engine, leading to significant reduction in fuel consumption. However, CPP's also consist of several disadvantages, while the most crucial is related with the high levels of maintenance. The pitch control mechanisms of the blades are vulnerable, requiring regular inspection. Additionally, this type of propellers demands large capital of investment, in comparison with FPP. Furthermore, the size of CPP is considerably higher, in comparison with FPP since more mechanisms are used in the hub of propeller.

Azimuth Propellers

Azimuth thrusters consist either from FPP or CPP with special nozzles attached on 360 degrees rotating so called steering pipe, offering high levels of thrust in every direction. Depending on the number of the azimuth thrusters, the percentages of forward, stern and sideways thrust vary, as it will be analyzed in the following sub-chapters among the ASD, ATD and Rotor tugs of KST fleet. At the same time, the presence of special nozzles leads to better propeller thrust, and thus increase the maneuverability characteristics of harbor tugs.

Additionally, extra maneuverability is possible to occur by changing the thruster's elevation. Azimuth thrusters also improve the steering tug capabilities, making it ideal for pushing and pulling operations in a wide range of speeds. Last but not least, the usage of azimuth thrusters improves power efficiency and leads to lower maintenance costs. On the contrary, tug masters always must take into consideration the water depth by avoiding shallow waters, since the propulsion units are fitted below the hull. (Internationaljournalsrg 2015)

Voith Schneider Propellers

This system is characterized as a very maneuverable propulsion system, capable to change thrust direction rapidly. Thrust deviation of this system is based on Cartesian coordinates, offering precise positioning even in adverse weather conditions. For this reason, they are widely used in harbor tugs, offering high maneuverability characteristics. However, this system is known for its high redundancy levels, for obtaining full power even under limitations.

Furthermore, one significant advantage of this system is hidden on the tug shape itself, offering significant roll stability. This characteristic is vital especially during pushing or pulling mega ships. The selection of this system by itself is lower in price as capital of investment, in comparison with the combination of azimuth thrusters and a roll stabilization system. On the other hand, the vertical blades are vulnerable and if maintenance needs to be done it will be costly. Finally, even if the blades are protected in a special plate (working as a nozzle for raising propeller's efficiency), Voith's should always avoid shallow waters, since the propulsion system is again located below the hull perpendicularly. (seasteading 2010)

Evaluation of Propulsion Systems

The following table summarizes the main variances of the propulsion systems. Their main advantages and disadvantages, will make feasible to correlate each system, with the offered assisting methods and therefore to assess more efficiently the capabilities and limitations for each harbor tug of KST fleet, towards the optimization of the daily operations. (Agency 2000, 11)

Table 1: Evaluation of Propulsion Systems

Propulsion System	Propeller	Complexity	Speed control	Maneuverability	Cost
Ordinary shaft with Nozzles	FPP	√	√	√√	LOW
		√	√	√	LOW
	CPP	√√	√√	√√	MEDIUM
		√√	√√	√	MEDIUM
Azimuth Thrusters	FPP	√√√	√	√√√	HIGH
	CPP	√√√	√√	√√√	HIGH
Voith Schneider	-	√√√√	√√√	√√√√	HIGHER
Rotor Tug	FPP	√√√	√√√√	√√√√√	HIGHER

3.3 Overview of Propeller Systems

3.3.A. Propulsion Aft

3.3.A.1 Conventional Tugs

Conventional tugs are the most classical and first-born version of tugs, while since today large amount of conventional tugs is still built. In general, they consist from various number of screw propellers, and the simplest version consists of one propeller fitted in a nozzle with the presence of a rudder. On the other hand, conventional tugs with open propellers are erratic, since their efficiency is significantly lower. (C. H. Hensen, TUG USE IN PORT - A practical Guide , p vii 2003, 14)



Figure 2: Conventional Screw Tug, (Laan 2016, 1)

Conventional tugs face a lot of limitations to assist mega ships entering ports. First of all, the location of their towing point (0,45* LWL, from the stern), causes various safety and performance issues, while when towing on a line, there is always the risk of girting. Many conventional tugs capsized during the past years, and the main reason was the massive interaction forces after several fast actions at the bow of the assisted vessel. The location of the towing point combined with the limited maneuverability of this tug type, are the main reasons for sudden accidents. Thus, multiple solutions have been developed for reducing the possibilities of girting.

The method of gob rope, is one effective solution combined with quick release mechanisms of the towing winch. Additionally, conventional tugs have significantly reduced astern power while their main disadvantage is the limited maneuverability mainly due to presence of screw propellers. In general, several American towage companies still tend to prefer this type of tug for push n pull methods and alongside towing even today, while European towage companies as KST prefer to use conventional tugs for towing on a line. (C. H. Hensen, TUG USE IN PORT - A practical Guide , p vii 2003, 14)The towing point location offers high efficiency but at the same time increases the possibilities of girting (since the towing point is nearly at the center of the tug), hence it should be located further aft. The reduced efficiency from a further aft towing point is possible to be increased either with different types of propulsion or with alternative rudders.

The importance of Gob Rope System for Conventional Tugs

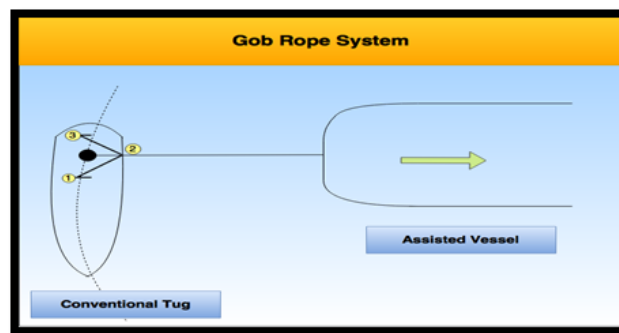


Figure 3: Gob Rope System, Own Composition ((Henk 2003, 47)

In case when a conventional tug is operating as a stern tug, either for direct towing operation, it can lead to hazardous situation with low safety margins. The reason for this risky situation is associated with the considerable high amounts of heeling moment that are generated. In these cases, the heeling moment caused from the transverse steering thrust, does not counteract the heeling moment due to the towline forces, and as a result the tug can be capsized. For this reason, when these tugs need to operate as stern tug, a well-known and safe solution is “gob rope system”, leading to the establishment of a “new” towing point further aft for decreasing the resulted heeling moments, for safer operations. This creates a “hoop” leading to a new radius for the towing point location including points 2 & 3 as it is shown in Figure 3.

Propeller Efficiency of Conventional Tugs – The Importance of Nozzles

In general, propellers are made to provide the maximum thrust when sailing forward. For conventional tugs with CPP, the main advantages are the high levels of maneuverability, as well as the optimization of bollard pull and speed compared to fixed propellers. Additionally, since harbor tug operate constantly at nominal speed, CPP offer improved fuel consumption. On the other hand, even if tugs with CPP are capable to move forward & reverse within short response time, they are characterized from reduced astern thrust. (Marine

2017). Table 2, indicates the variances among open fixed and controllable pitch propellers for conventional tugs.

Table 2: FPP VS CPP Thrust Effectiveness

Type	Thrust	% of Max Ahead Thrust
Open FPP	Astern	60 %
Open CPP	Astern	40-45 %

The presence of nozzles is crucial for both types of propellers. Since harbor tugs must be capable to operate with high propellers loads at low speeds, an increase of the thrust by 15 – 25 % due to nozzles can be crucial, and eventually to lead in large bollard pull levels. Nozzle types are mainly divided in two different categories.



Figure 4 Types of Nozzles, (Henk 2003, 15)

As it is indicated in Figure 3, harbor tugs consist either from Nozzle 19A or 37. Nozzle 19A is a common choice for the forward thrust needs of conventional tugs. On the other hand, nozzle 37 provides better efficiency for astern thrust with an insignificant difference in forward thrust compared with 19A, and thus the combination of fixed propellers with nozzles (type 37), is the most common choice for conventional tugs. (C. H. Hensen, TUG USE IN PORT - A practical Guide , p vii 2003, 15). Table 2 summarizes the differences among the efficiencies of FPP and CPP concerning the two types of nozzles.

Table 3: Efficiencies of propellers with nozzles

Type	Nozzle	Blades	Thrust	% of Max Ahead Thrust
FPP	19A	Normal	[Reverse Revolutions]	60-65 %
	37		Astern	65 %
CPP	19A		Astern	40-45 %
	37			45 %

3.3.A.2 Combi Type

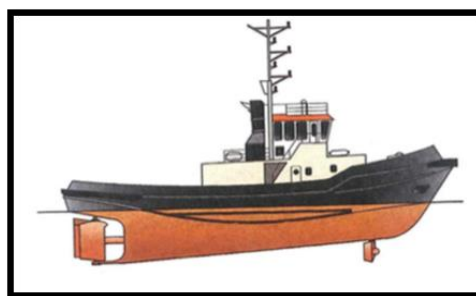


Figure 5: Combi Type Tug (Laan 2016, 2)

Combi tugs are almost identical with pure conventional tugs consisting of one screw propeller, and a retractable or fixed type of azimuth bow thruster, for increased maneuverability levels. The azimuth thruster includes a nozzle offering high efficiency in any direction. Additionally, the bow thruster provides extra bollard pull

within a range of 2 to 6 tones. Combi's are not capable to assist merchant vessels in narrow passages, due to reduced efficiency levels and therefore tugs with higher maneuverability tend to be used more often for ship-handling tasks, especially in narrow spaces. Combi tugs can tow on a line forward or aft of the assisted vessel. (Julia 2009 , 8). The presence of the extra bow thruster, offering advantages concerning the speed, maneuverability and bollard pull, by decreasing also the possibility of girting, since Combi tugs are capable to alter direction in a shorter period.

3.3.A.3 Azimuth Stern Drive Tugs - ASD's

Multi Tug



Figure 6: ASD Multi Tug, (Laan 2016, 1)

The main distinction among conventional tugs and ASD's refers to propulsion units. Normal propellers are replaced by innovative azimuth propeller units, able to improve harbor tugs capabilities considerably. The ability of thrusters to rotate 360 degrees, offers exceptional maneuverability, since the tug is capable to move precisely forward, stern or sideways. ASD's are characterized as one intermediate type, accomplished to operate as conventional and tractor tug. They are equipped with azimuth propellers at the stern, offering the ability to operate over assisted ship's bow as reverse tractor tugs (towing winch forward), while at the same time they are capable to operate as conventional tugs over their stern (by using towing winch or a hook at the stern). Due to their dual activity, this type of tugs is named multi-tug, while towing point location is $0,35-0,40 \cdot \text{LWL}$ from the stern, and $0,20 \cdot \text{LWL}$ from the bow. The exceptional characteristics of forward and stern thrust, make ASD's one of the most ideal type for ship-handling tasks. The table below indicates the thrust for each direction. (Julia 2009 , 28)

Table 4: ASD Thrust Effectiveness

Type	Thrust	% of Max Ahead Thrust
ASD	Forward	100 %
	Astern	90-95 %
	Sideways	60%

Reverse Tractor Type

Reverse tractor tugs are characterized from several benefits. They consist of a powerful forward towing winch, while their propulsion units are always far from the hull of the assisted vessel. Moreover, a smaller towing hook is located at the aft. In cases that reverse tugs have to operate over their stern, they use a towing a point which is placed further aft from the normal location, for increasing their efficiency and behave as conventional screw tugs. (C. H. Hensen, TUG USE IN PORT - A practical Guide , p vii 2003, 9). Reverse tugs consist of two azimuth propellers offering high maneuverability levels and precise control of movement, and therefore it is expected to lead at high levels of forward and stern thrust.



Figure 7: Reverse Tractor Type, (Laan 2016, 1)

Since their azimuth propellers are located at the stern, without overcoming the hull draft, reverse tugs are also a typical solution in cases of shallow water since their draft is less, compared to tractors, while their maneuverability, offers the ability to assist efficiently a merchant vessel during push n pull tasks towards berthing and un-berthing assistance. Finally, this type of tugs is capable to be used efficiently for escorting duties within port perimeter. The table below indicates the thrust for each direction.

Table 5: Reverse Tractor Tug Thrust Effectiveness

Type	Thrust	% of Max Ahead Thrust
Reverse Tractor Tug	Forward	100 %
	Astern	90 - 95 %
	Sideways	60%

3.3.B. Propulsion Forward

The next category to be analyzed is tractor tugs, which is divided in two sub-categories, concerning the type of propulsion. Both sub-categories will be analyzed in the next subchapters, for obtaining the most important insights for each case.

3.3.B.1 Voith Schneider's

By introducing the new concept of Voith Schneider propulsion, a new chapter for the towage industry had already started, leading to a brand-new type of harbor tugs, known as tractors. (VOITH 2017, 10). This type was about to set new principles, concerning the capabilities of harbor tugs by improving maneuverability and ship handling skills considerably, emphasizing deeply on the safety of operations. (C. H. Hensen, TUG USE IN PORT - A practical Guide , p vii 2003, 1).



Figure 8: Voith Schneider Tug, (Laan 2016, 4)

Voith's have been characterized from propulsion units located among the amidships and the forward part of the tugs. This system consists of vertical blades established in a fully cylindrical propulsion shape, behaving

in the same way as the controllable pitch propellers, since the vertical blades are entirely capable to change efficiently direction within the range of 360 degrees, at short responses times. Since, Voith's propulsion units are provided as a pair, the hull of the tug should be capable to fit both units, and therefore naval engineers should design tugs with wider beams. At the same time, their propulsion units are protected into a unique plate, reducing the possibilities of a serious damage, working also as a nozzle, offering significantly higher efficiency compared with open propellers.

Nevertheless, attention should be paid towards the draft of this type, which reduces the possibilities to operate in shallow waters. Hence Voith-Schneider tugs are advised to operate mostly in harbors with sufficient depth for avoiding possible damage to their propulsion units. Moreover, the plate provides considerable support during dry-docking tasks for the required maintenance. Some additional disadvantages, refer to the vulnerability of the blades as well as to the high capital of investments. (Julia 2009 , 14). One additional characteristic, is correlated with the presence of a long skeg at the stern, offering high levels of directional stability.

Voith's also consists from a towing point equal to $0,1-0,2 \cdot LWL$ from stern, while they are also extensively used for escorting duties in high range of speeds, especially during indirect towing operating as a stern tug. The skeg presence is vital, and allows tug to gain essential stability for generating high levels of indirect towline forces. Finally, they are equipped with adequate fenders and a well-rounded stern, for the required pushing duties when berthing mega ships. (C. H. Hensen, TUG USE IN PORT - A practical Guide , p vii 2003, 21). The following table summarizes the thrust percentages for all the possible directions.

Table 6: Voith Schneider Thrust Effectiveness

Type	Thrust	% of Max Ahead Thrust
Voith Schneider Tractor Tug	Forward	100 %
	Astern	95 %
	Sideways	80%

3.3.B.2 Tractor Tugs with an Aft Skeg

The second major category refers to Azimuth Tractor tugs, and the main distinction of this type, compared to Voith's, is related with the propulsion units. As it is already known, in reverse tractor tugs, the propulsion includes a pair of fully steerable azimuth propellers, capable to rotate within the range of 360 degrees. However, azimuth propellers are located between amidships and the forward part of the tug. Both azimuth propellers are built-in in open nozzles, aiming to improve propellers efficiency, as it is indicated in Figure 9, as well as for protecting the units in cases of groundings at shallow waters. Finally, a docking plate is also located in front of the azimuth propellers, aiming to assist docking & undocking tasks. Finally, a docking frame is also located at the opposite side of the hull, offering high levels of directional stability when sail astern, as well as for generating high levels of indirect towing forces, while their towing point location is equal to $0,1 \cdot LWL$, from the stern (Julia 2009 , 17).



Figure 9: Normal Tractor, (Laan 2016, 3)

A vital dissimilarity among the two types is associated with the draft, as well as the smaller skeg. Additionally, Tractors have less draft compared to Voith Schneider's, since the propulsion unit's weight less, leading to smaller hull displacement. This explains why tractors are less efficient for escorting duties, especially during indirect mode. The ability of thrusters to rotate within 360 degrees offers exceptional maneuverability, since the tug is capable of towing on a line precisely, and with high safety levels, as well as to provide pushing assistance. (C. H. Hensen, TUG USE IN PORT - A practical Guide , p vii 2003, 27). The following table summarizes the thrust percentages for all the possible directions.

Table 7:ATD Thrust Effectiveness

Type	Thrust	% of Max Ahead Thrust
ATD Tug	Forward	100 %
	Astern	95 %
	Sideways	80%

3.3.B.3 Tractor Tugs with Twin Fins- Azimuth Propellers - ATD



Figure 10: Twin Fins Normal ATD, (Laan 2016, 3)

The second category of tractors, is related with a brand-new design, consisting of twin fins at the stern. This remarkable design occurred from an excessive willingness for constructing a more compact tractor tug, with low levels of operational expenses, capable to guarantee advanced performance levels, especially when daily ship-handling operations take place in small port configurations consisting of locks and confined dock areas. Damen shipyards, was aiming to design a powerful tug with high levels of bollard pull and maneuverability levels, with considerable stability towards the daily ship-handling operations. For this reason, it was necessary to investigate the interaction among the single skeg and the thrusters. One of the main issues, was the opposing steering force especially for small range of angles, leading the first generation of normal tractor tugs to turn in the opposite direction, as it is indicated in Figure 12. Therefore, by using Dieudonne tests, a significant mismatch among steering and drift angles occurred. By looking Figure 11, it is evident that for a steering angle among 5 to 10 degrees, the resulted drift angle was equal to 3 -5 degrees.

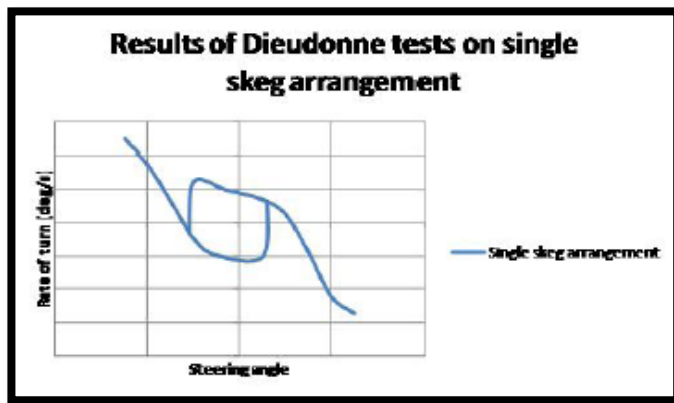


Figure 11: Dieudonne tests results (Boudesteijn 2010, 2)

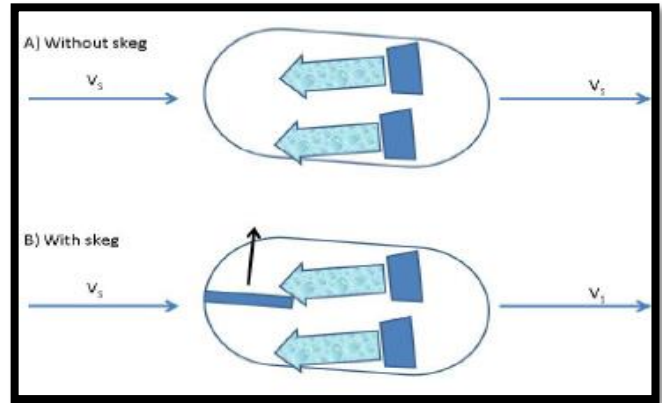


Figure 12: Opposing Steering Result (Boudesteijn 2010, 3)

For this reason, this new tug type is a result of a broad investigation for improving the sailing behavior for an ATD when sailing forward. Damen in cooperation with Marin came up with the idea to place a pair of fins, replacing the single skeg, in the same line with the azimuth thrusters. Multiple fin configurations were examined in Marin's basin with multiple aspect ratios, while in Figure 13, three Dieudonne tests are will be evaluated. Concerning the single skeg arrangement, tug's behavior was proven to be unstable. However, both twin fins configurations consisting from high & medium aspect of ratio, were characterized from high levels of directional stability. As a matter of fact, ATD 2412 contains twin fins with medium aspect of ratio, which eventually led to higher turning ability levels. (Boudesteijn 2010)

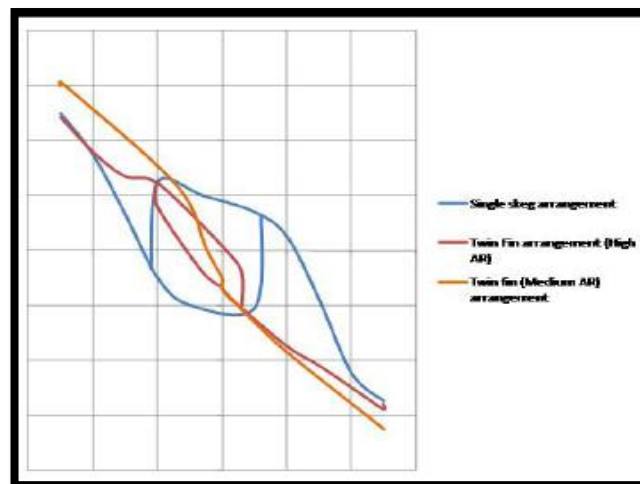


Figure 13: Dieudonne Tests for various skeg arrangements (Boudesteijn 2010)

3.3.B.4 Rotor Tugs



Figure 14: Rotor Tug, (Laan 2016, 4)

The construction of rotors is a result of a major drive to optimize harbor tugs, combining power and flexibility. This new concept, includes the installation of a third azimuth propeller at the stern, by replacing the skeg, for improving maneuverability and steering of the tug, providing at the same time high levels of stability and safety. At the same time, rotor tugs consist of two towing points locations, providing higher flexibility towards the operations. The presence of the third azimuth propeller, makes rotor tug one of the safest tug, capable to operate either from bow or stern, for extra safety. (Julia 2009 , 18).

Each azimuth propeller is driven from a separate engine; thus, each propeller can be controlled separately or all together by using the master stich if fitted. Additionally, the third azimuth is located exactly below the towing point, offering the ability to the tug for performing pushing duties towards the direction of the towing line. Towing lines, are continuously under tension offering also the opportunity to control steering forces in each direction. Various port authorities in a global scale, tend to prefer rotor tugs, since high levels of maneuverability are required in narrow passages, turning basins and special locks for ship-handling tasks, where tugs ability to move sideways is crucial. (P.Eng. 2014).

One of the main advantages of Rotor tug, except from the third azimuth propeller, is linked with their underwater hull. The combination of the propulsion units in a triangle shape with this unique hull form, increases the leverage and leads in higher steering moment. Rotor tugs consist of a nearly flat hard chine hull, offering the highest water flow to each of the three units. Thus, this tug type is capable to operate precisely, in a large variety of duties even under adverse weather conditions in short responses times. The excessive degree of maneuverability, in combination with a massive bollard pull, the high GM and the large freeboard, as well as their ability to change position rapidly, and maneuver so efficiently, makes them also ideal for escorting duties. The following table summarizes the thrust percentages for all the possible directions:

Table 8: Rotor Tug Thrust Effectiveness

Type	Thrust	% of Max Ahead Thrust
Rotor Tug	Forward	100 %
	Astern	100 %
	Sideways	90%

In general, rotor tug can offer various services towards the daily ship-handling duties. It can either push or pull by using towing on a line, however one of the most precise methods used by rotor tugs is called ‘rotoring’. During this method two rotor tugs are used for berthing precisely an assisted vessel in between a narrow space among other assisted vessels, as it is shown in Figure 15. (P.Eng. 2014)

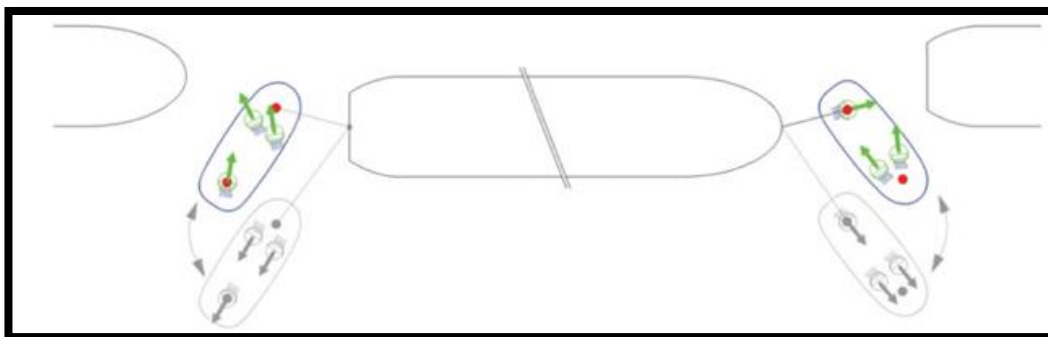


Figure 15: ‘Rotoring Method on A Berth’, (P.Eng. 2014, 2)

“Rotoring” method is also used for leading the cargo vessel through a narrow bridge passage precisely, as it is indicated in Figure 16. By looking both Figure 15 & Figure 16 and by considering all the above operational advantages, it can be proven that a pair of rotor tugs is capable to substitute the necessity of a larger number of tugs to be used in the various ship-handling duties, by justifying at the same time the high investments of capital for this state of art tug. (MARIN 1999, 5)

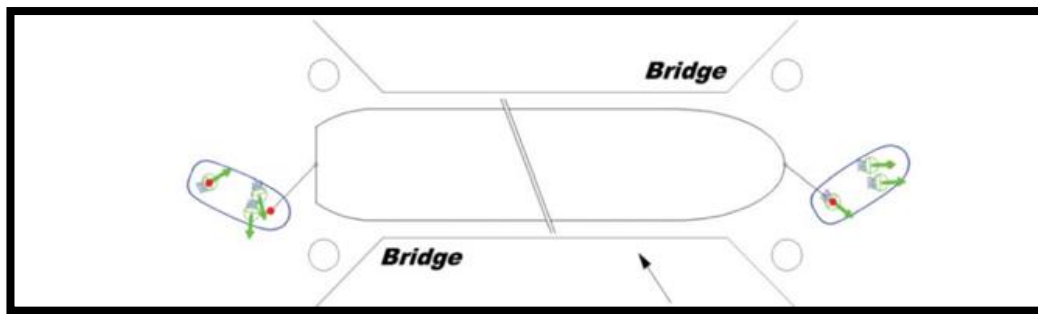


Figure 16: “Rotoring On a Bridge”, (P.ENG. January 2014, 4)

3.4 Market Fundamentals of Harbor Tugs

3.4.1 The Right Type of Tug

The comprehension of tug performance, concerning the assisting methods in the multiple ports of operation, is exclusively dependent from the main principles and unique characteristics of harbor tugs. Moreover, the bollard-pull delivered from each tug type, as well as the followed correct tug location concerning the various ports of operation, affects the tug assessment considerably. Thus, the following subchapters aim to set the insights for assessing properly the numerous features of KST fleet, by analyzing one by one each of the main elements which define tug performance.

Nowadays, harbour tugs efficiency has been by far improved. New designs consisting of advanced propulsion methods combined with underwater hull concepts, can guarantee high manoeuvrability levels, for applying the bollard pull in every possible direction. Consequently, a solid evaluation of KST fleet, includes the comprehension and assessment of the most important fundamentals that influence the daily operations, which are summarized in Table 9. (Slesinger 2008, 15). From those characteristics, this thesis project will evaluate tug effectiveness as a result of their underwater hull, together with the location of propulsion units & towing point, for assessing the influence towards the daily operations.

Table 9:Harbour Tug Fundamentals

Harbour Tugs Fundamentals
1.Towing Point Location
2.Lever x & y AND a & b
3.Underwater Hull Concept
4.Superstructure & Fendering
5.Dynamic Stability

Designing with CFD

The right type of tug and therefore its performance during ship-handling tasks is a result of its design. However, tug design is entirely linked with an extensive CFD analysis, by using panel methods, naval engineers aim to investigate the ship motions. At the same time, after studying hull resistance, it is possible to predict with high

levels of accuracy (90%) tug's behavior, as a result of its design. Afterwards, by adopting new ideas concerning the hull with the various appendages, they are able to optimize their initial design concept, before the model construction, which will allow to proceed in several experiments in a tank. Consequently, multiple configurations will be tested in various operation conditions while by using CFD analysis, the hull is divided in different colors because of the various CFD calculations as it is indicated in Figure 17 & Figure 18. (Wilco van der Linden 2010, 3)

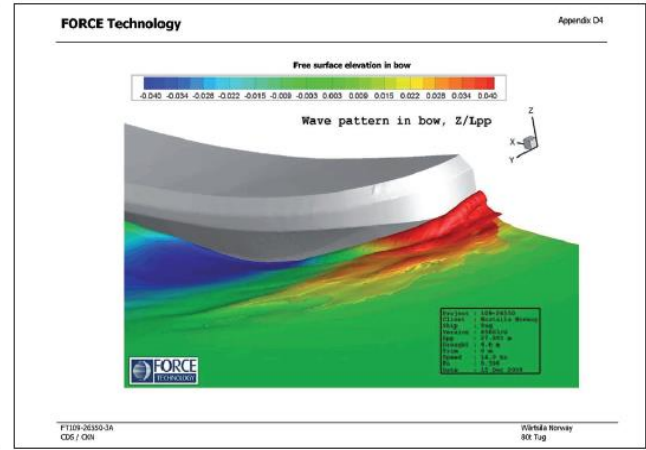
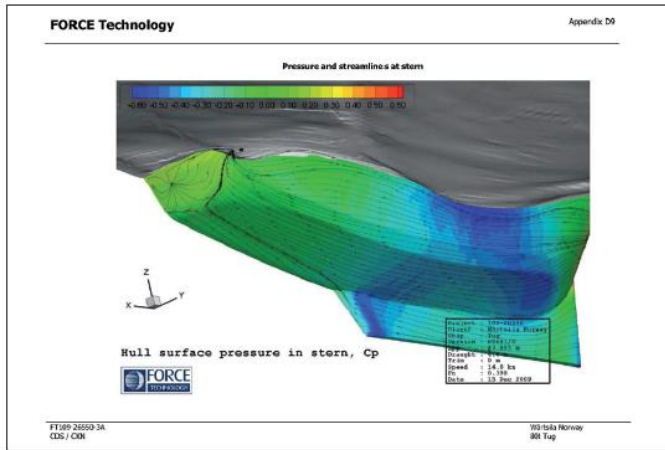


Figure 17: CFD Model A, (Jansen, Comparison Between Rotor Tugs 2017, 3)

Figure 18: CFD Model B, (Jansen, Comparison Between Rotor Tugs 2017, 3)

CFD investigation on each shipyard is linked with wide-ranging model testing, for examining precisely tug's behavior, while towing, escorting, free sailing forward & stern as well as when towing (bollard pull tests). For tugs to operate in exposed water areas and adverse environmental conditions, emphasis will be given especially on roll & pitch ship motions, where CFD analysis can provide essential insights towards their behavior.

However, for KST study case, it is impossible to analyze the entire fleet by using CFD analysis. The various shipyards, are not willing to share confidential information about the investigation that took place before finalizing tug's design. At the same time, it is not in the scope of this project to make models and analyze 19 different tug's behaviors. For this reason, for proceeding in a solid evaluation for each tug type of KST fleet, and categorize each type as a result of its main strengths and weaknesses, the first step includes a proper analysis of KST fleet fundamentals, in subchapter 3.6. Afterwards, a qualitative survey (with quantitative approach) will take place in subchapter 3.8 for evaluating tugs ability to operate in the various types of operations, which will be analyzed extensively in subchapter 3.7.

3.4.2 Towing Point Location

The location of the towing point for harbor tugs that were analyzed in chapter 3.3 vary, depending on the main hull and propulsion configuration of each type. Moreover, the location of a towing winch does not indicate the exact location of the towing point necessarily. In general, the location of towing point is defined from that point that the towline is straight line from the tug to the assisted vessel, while tug's capabilities and limitations are totally dependent from the location of the towing point in combination with the location of propulsion and the center of pressure for each tug. The following table summarizes the towing point locations for all the tug types that were analyzed in subchapter 3.3.

Table 10: Towing Point Locations for the various Tug Types

Tug Types	Location of Tow. Point	Distance	
		From Stern	From Bow
Conventional	AFT	$0.45 \cdot \text{LWL}$	
ASD	FORWARD	$0.35\text{-}0.40 \cdot \text{LWL}$	$0.2 \cdot \text{LWL}$
Reverse Tractor	FORWARD	$0.2 \cdot \text{LWL}$	-
Azimuth Tractor	AFT	$0.1 \cdot \text{LWL}$	-
Voith Schneider Tractor	AFT	$0.1\text{-}0.2 \cdot \text{LWL}$	-
Z-Peller	AFT	$0.1 \cdot \text{LWL}$	-
Rotor	FORWARD & AFT	$0.25 \cdot \text{LWL}$	$0.20 \cdot \text{LWL}$

The location of the towing point is of high importance for the characterization of tug's performance and therefore for its dynamic stability. Figure 19 presents two different locations of towing points. The first point, is located at the centerline of the tug and is known as the classic location of towing point. The second point, is located closer at the portside of the tug, and is assumed that the resultant towing force is located at the portside of the tug. The initial towline force B , is located at a distance a , from the centerline of tug, while the vertical distance from center of pressure of the water flow is equal with the distance d . Hence, the resultant heeling force to be created will be equal to $H1$. On the other hand, if the towing point is relocated at a distance b , from the location of the center of gravity, then its vertical distance from the center of pressure of the water flow, is equal with distance c . In this case, the total heeling moment will be equal with $H2$. By comparing the two heeling moments $H1$ and $H2$, it can be concluded that $H2$ is by far smaller. This system refers entirely to conventional tugs. On the other hand, tractors are characterized from improved maneuverability characteristics and high percentages of sideways thrust, and therefore the risk to capsize is limited.

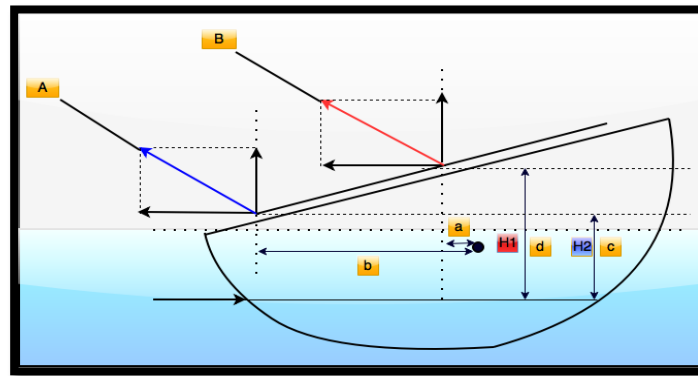


Figure 19: Importance of high Dynamic Stability Levels, Own Composition (Laan 2016, 48)

3.4.3 Levers x , y & a , b

Lateral & Vertical Centre of Pressure

One second factor affecting tug's behavior, is related with the lateral center of pressure point. In general, water flow around tug's hull has as a result hydrodynamic forces to be generated. This water flow occurs either from the tug itself (self-propelled), either in cases where tug is dragged through the water, or due to the wash effect of a similar tug or generally from another vessel. However, flow of the water around tug's hull leads to the presence of lift and drag forces, and their volume is regulated from the angle in between water flow and tug's hull.

The point where the summation of the of drag and lift forces is applied, is defined as the lateral center of pressure (COP). As soon as the tug applies towing forces, the COP is moving either forward or astern, depending on the hull configuration and towing point location. To make matters more complex, speed is also a significant factor, affecting the precise location of COP. Hence, COP is not a static point and is too complicated to calculate it precisely. Additionally, the underwater hull of each tug type, combined with the several appendages i.e. (skeg, rudder), trim of the tug and angle of attack of the water flow, influence the COP considerably. Hence, its précised location can be only calculated in a basin, after considering all the pre-mentioned factors. However, the scope of this thesis project, does not include the accomplishment of multiple experiments under various conditions for the determination of the COP points, and therefore an indication of levers x , y & a , b will be given, by using empiric equations. These equations have occurred after several experiments, in towing tanks for the various tug types; however, they only represent an indication of the COP points under specific circumstances and types of operations. At the same time, the exact location of COP, might show inclinations from the result obtained by those equations, due to the variety of skeg types, which in combination with the towline forces, tug speed and water angle of attack, are capable to push more forward or more astern the COP. (C. H. Hensen, TUG USE IN PORT - A practical Guide , p vii 2003, 45)

Table 11: Location of COP from Aft for Various Types

Tug Type	Location of COP from aft
Conventional Tugs	0,3* LWL
Tractor Tugs	0,4*LWL
Reverse Tractor Tugs (ASD)	0,5*LWL

As it will be explained in the following subchapter, harbor tugs can offer up to four different types of operations. However, the results of COP will vary considerably if the tug is sailing stern first. In the practical guide of Henk Hensen, a generic indication of COP points is mentioned; however, this representation refers only to the cases where the tug is sailing bow first. In that perspective, it is concluded that for conventional and tractor tugs the location of the COP lies further aft, (behind amid-ships). In those cases, the water flow encounters abeam the tug while, the location of the towing point, (also behind amidships), has as a result the location of the COP to lie in approximately 0,3 to 0,4* LWL from the aft. Several experiments have proven that conventional tugs, consist of a COP laying in a distance equal to 0,3*LWL from the aft while for normal ATD's 0,4*LWL from the aft. For reverse tractors, the COP normally lies at a distance equal to 0,5*LWL from the stern.

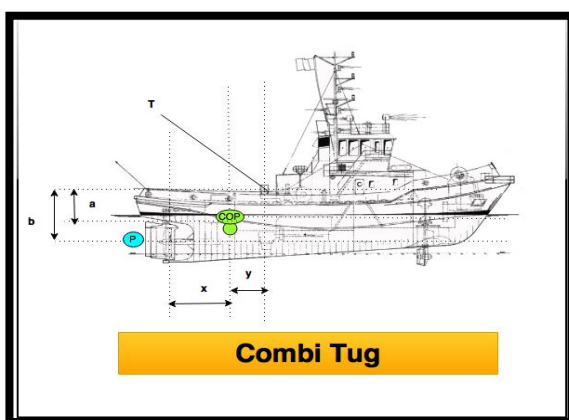


Figure 20: Combi Tug Analysis (KST Combi Tug Design)

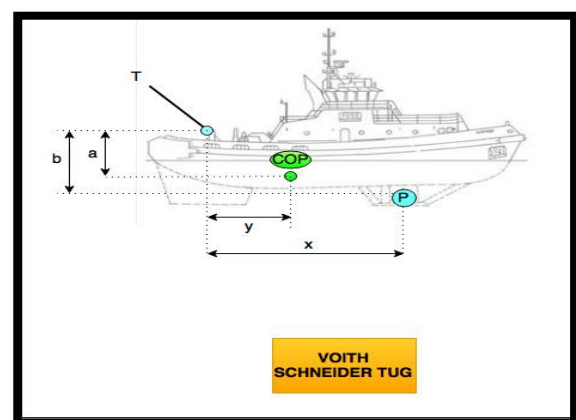


Figure 21: Voith Schneider Analysis (KST Voith Schneider Design)

The combination of longitudinal and vertical locations of COP and towing point, affect tug's performance extensively, while the distance among COP and towing point, as well as the distance among towing point and propulsion unit's, are titled as lever x and lever y, accordingly. Figure 20 & 21 present two different cases, referring to a tractor (P_t) and a conventional tug (P_s), when both are sailing bow first as forward tugs in a Bow to Stern operation.

By comparing the variances in results concerning levers x & y for each case, vital results can occur. The larger the lever x is, compared to lever y, the less sideways thrust is needed for neutralizing the hydrodynamic forces at COP, and therefore the higher the towlines forces will be. This situation is extensively analyzed in Figure 22. A reverse tractor tug is indicated operating stern first in a Bow to Bow operation. In that case the COP is in a different location compared with the pre-mentioned tug types, while the indicated COP, takes place under specific circumstances with certain speed and angle of attack of the water flow. In that case the efficiency of the tug is by far decreased, since the lever y, compared with lever x is by far larger, and therefore higher amount of sideways thrust forces are required, leading to smaller available amounts of thrust for the towline connection. By analyzing the forces at COP point, it is proven that the sideways force F is equal with the summation of towline and thrust forces.

By comparing levers x & y, it is clear that by moving the COP point as more forward as possible, less force (B) is required for maintaining tug in the desirable position and therefore, more power is available for the towline, leading to significantly high amounts of efficiency. On the other hand, COP point aft leads to considerably high lever y and therefore the tug needs to spend high amount of power for controlling its position, leading to lower levels of efficiency. Hence, the underwater hull concept with sophisticated skeg allows a harbor tug to apply the required steering forces more efficiently, and tug can deviate from a straight line in front of the ship, and return afterwards at its initial position, even at high range of speeds. There is no doubt that low resistance as well as high amount of power increases even more tug efficiency, however the hull profile is considered as the most vital factor for tug's efficiency. (C. H. Hensen 2016, 6&7).

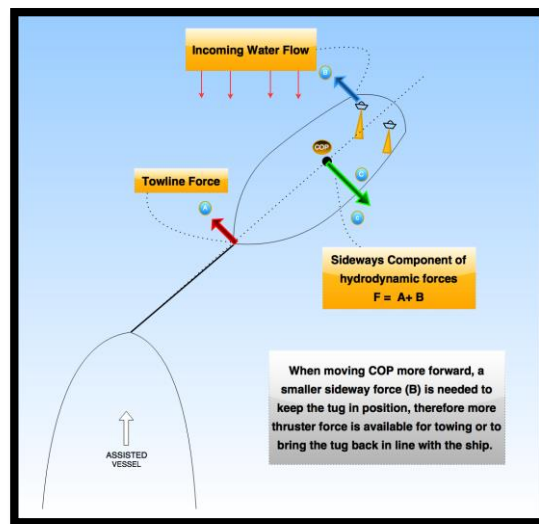


Figure 22: Distribution of Forces when Towing on A Line, Own Composition (C. H. Hensen 2016, 7)

Additional emphasis is given on the length of the lever a, where the larger it is, the larger the list of the tug will be. On the other hand, the larger the lever b is, the more list is reduced by using sideways thrust of the tug. Synchronous tug designs indicate the willingness of naval engineers for eliminating the required sideways thrust, capable to balance the hydrodynamic forces at the COP and thus, emphasis is given towards the vertical

distance among the towing point and COP, lever a, which should be capable to oppose the resulted heeling moments. In case of a larger lever a, combined with smaller lever b, higher list will occur since lever b is not enough for opposing the heeling moments.

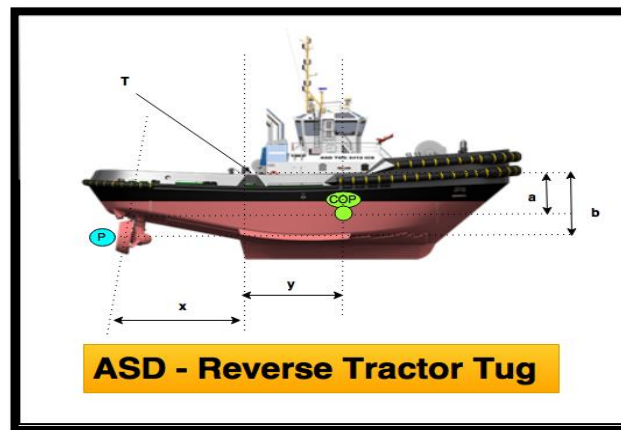


Figure 23: Reverse Tractor Tug Analysis

Intermediate Conclusion

In general, tugs are expected to deal with the resulted list, as soon as they start towing on a line towards the daily operation. By comparing the two different cases of Figure 20 & 21, the case of the Combi tug, is expected to have a larger list, since the location of propulsion unit's (P_s) is aft, and the sideways steering forces tend to increase tug list. On the other hand, for tractor tugs, the sideways steering forces oppose the list created from the towlines since the propulsion unit's location, P_t is after amid-ships. At the same time, since the ratio of harbor tugs tends to decrease continuously, the distance among lever x & y, is shrink and thus in case of reverse tractor tug, a larger amount of sideways thrust would be required for opposing the hydrodynamic forces at the COP. However, designers proceed on reduced levers a with lower towing points and raised levers b, which are capable to oppose the heeling moments. Additionally, in case that a reverse tractor tug (Figure 23), operates as a conventional tug, it deals with significantly high steering forces, as a result of the high heeling forces. This situation is related with the forward COP, and thus larger values of turning moments need to be overcome. However, naval engineers proceeded in designs with larger beams, capable to lead at higher righting arms for confronting the resulted heeling moment.

Moreover, larger beams offer higher GM and thus better directional stability, since the range of heeling angle becomes larger, and higher righting arms values are achieved in shorter range of heeling angles. Consequently, the tug is capable to overcome "easier" the resulted heeling moments. Finally, the longitudinal and vertical locations of COP are of high importance for the tug performance and are totally influenced from the location of the towing point as well as from the skeg configuration. The amount of thrust at the COP should be as low as possible for neutralizing the hydrodynamic forces, while the vertical distance among the towing point and the COP, a, is also vital. Since, towline forces are dependent on the lever x and y, the higher lever x is compared to lever y, the higher towline forces will occur. The following table summarizes the interaction of COP point and towline forces.

Table 12: Interaction Results Among COP & Towline Forces

Lever x > Lever y	↓ Sideways Thrust	↑ Towline Forces
↑ a		↑ angle

3.4.4 Underwater Hull Concept – Skeg & their Effect

Hull configuration is one of the most vital parameters of tug's performance. As it has already been explained, skeg configuration is the dominant factor affecting the location of COP point, and therefore tug efficiency towards the towline connection. Harbor tugs of KST as well as the rest harbor tugs globally, use to operate (towline connection) at speeds lower of 6 knots, and thus should be totally capable to apply the maximum level of towing forces (steering and braking duties) in all the possible directions and at short periods of time. Therefore, the underwater hull of harbor tug types, depending on the skeg configuration, aims to improve the capabilities of tugs towards the daily operations. Furthermore, the existence of various skeg designs is necessary during the indirect towing, leading to indirect hydrodynamic forces and thus to higher bollard pull for steering and braking the assisted vessel at speeds over 7 knots, as it will be explained in chapter 4, and is related with the offered escorting duties of KST. Consequently, it can be concluded that skegs can improve tug's performance for one task, however it is possible to cause limitations or inefficiencies for others, and the main reason is the variance of speed during the offered assistance. For this reason, the evaluation of skegs, is crucial for providing essential insights, towards KST fleet capabilities. In general, there are four major categories describing the skeg types which will be extensively analyzed. (C. H. Hensen, TUG USE IN PORT - A practical Guide , p vii 2003, 48). However, as it will be explained in the subchapter 3.6, for the KST fleet is divided in 19 different underwater hull concepts and therefore, in order to proceed in a solid evaluation of tug's behavior, KST tug's designs will be investigated one by one.

Tractor Tugs

1. Tractor Tugs and aft Skeg

The first category of skeg refers to a single (long) skeg at the stern of tractor tug, in the centerline, offering high levels of stability especially when the tug is free sailing forward, as well as to high amount of list forces. Additional towline forces will occur, during the indirect towing operations when tug sails stern first, since the presence of the skeg raises the lateral underwater area, leading to high amount of indirect hydrodynamic forces. Skeg presence, leads COP more aft, closer to the towing point, and therefore the lever y is becoming smaller compared to lever x leading to higher towline forces. However, the major disadvantage is the large resistance, making more difficult for the tug to alter position, especially in small range of speeds. Additionally, as it will be explained in subchapter 3.8 concerning KST fleet effectiveness, this skeg type leads to higher complexity during intermediate step (tug ready to make the towline connection). Especially in case where a tractor tug operates as a forward tug, its skeg is in a close distance with the bow of the assisted vessel. Therefore, in cases of tankers or bulk carriers, which are characterized from pronounced bow, the presence of the skeg during the speed of 6 to 7 knots, influence considerably tug's position and therefore tug master need to pay more attention by offering continuously thrust for keeping the tug in the desired position and make the towline connection.

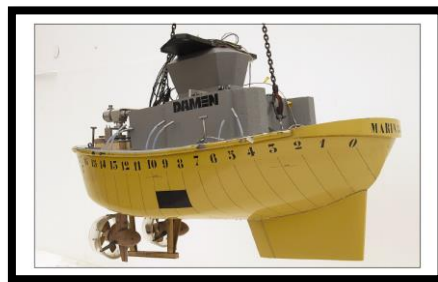


Figure 24: Tractor Tugs with an Aft Skeg (Boudesteijn 2010, 6)

2. Tractor Tugs with Twin Fins

The second skeg type refers to the relatively new twin fin concept. As it was already explained in subchapter 3.3.B.3, one of the main issues, which led Damen in cooperation with Marin to come up with this new concept, was associated with the opposing steering force especially for small range of angles, leading the first generation of normal tractor tugs to turn in the opposite direction. The usage of several Dieudonne tests, proved a significant mismatch among steering and drift angles that occurred. For steering angles among 5 to 10 degrees, the resulted drift angle was equal to 3 - 5 degrees, and for this reason, this new tug type is a result of a broad investigation for improving ATD sailing forward behavior. The new pair medium aspect ratio fins, at the same line with the azimuth thrusters, led to higher turning ability and directional stability levels.



Figure 25: Tractor Tugs with Twin Fins (Boudesteijn 2010, 6)

ASD - Reverse Tractor Tugs

3. Vertical short skeg aft on tugs with aft location of propulsion units

This skeg type is mostly found in the first generations of ASD's. Its main characteristics refer to the vertical shape, relatively small length, while its location is close to tug's propulsion units at the centerline (Figure 26). Its main purpose is to offer improved course stability especially during free sailing forward. However, the efficiency of the tug is by far decreased when tug is sailing astern. Therefore, by looking Figure 27, the wash effect has a noteworthy impact on the skeg. In this case the efficiency of the tug will be reduced since for a range of azimuth angles the wash hits the skeg and as a result a negative lift force is created, which is opposite form the expected one. Hence, the tug will need more power for maintaining its position either during the intermediate step to make the towline connection or for the towline connection step and therefore the safety levels are also reduced since the tug has less power available for avoiding a hazardous situation with the assisted vessel. Consequently, tugs with this underwater hull have a decreased efficiency for assisting the vessel during bow-to-bow operations (C. H. Hensen 2016, 7)

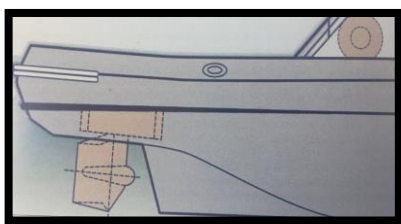


Figure 26: Vertical Short Skeg Aft (C. H. Hensen 2016, 6)

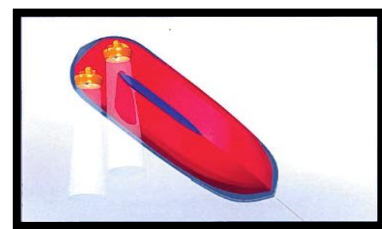


Figure 27: Vertical Short Skeg Aft & Wash Effect (C. H. Hensen 2016, 7)

4. Vertical lengthy flat skeg in ASD tug

Finally, the last major category of skeg type used in ASD's, refers to the vertical lengthy flat skeg on tug centerline. This type of skeg is extensively used in ASD's/ reverse tractor tugs while one of the main characteristics is the relatively large distance from the propulsion units (Figure 29). This characteristic

offers improved directional stability especially when tug is free sailing astern, while it is considered as safer during bow-to-bow operations. The advantage of improved directional stability increases the safety standards as well as the entire efficiency of this tug type. Additionally, ASD's tugs consisting of this skeg type are capable to generate high levels of indirect towing forces during escorting duties. The increased lateral area of the skeg generates high levels of indirect hydrodynamic forces, leading to high levels of steering and braking forces. Consequently, harbor tugs with vertical lengthy skeg consist of increased capabilities for pure harbor duties, while at the same time they are also capable to fulfill efficiently, escorting duties within port perimeter.



Figure 28: Vertical Lengthy Skeg in ASD's (Laan 2016, 1)

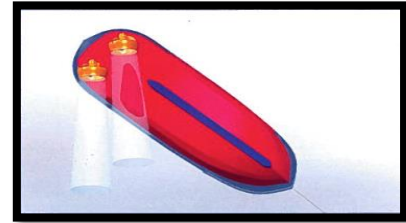


Figure 29: Vertical Lengthy Skeg in ASD's & Washing Effect (C. H. Hensen 2016, 7)

Intermediate Conclusion

It is evident that the better the underwater hull with skeg design is, the more efficient a tug will be for operating for sailing astern. The underwater hull concept provides tug the ability to apply increased steering and braking forces safely, and at the same time in higher range of speed. Consequently, the combination of an optimized underwater hull concept with an efficient skeg design, moving as forward as possible the COP point, where the summation of hydrodynamic side forces is generated, should always be the primary goal when designing a harbor tug. In that perspective, less amount of thruster forces will be required to compensate the hydrodynamic forces at COP, and therefore higher amount of power will be available for the pure ship handling duties (steering the assisted vessel). Alternatively, the lower the lever y is, compared to lever x, as a result of COP location, the tug is more capable to return at its initial position after a small or larger deviation from its initial position (centerline with the assisted vessel). Some extra important factors are the depth of the tug which has to be considered for these kinds of movements in these types of operations, due to the impact on tug's resistance as well as tug's available engine power. (C. H. Hensen, Azimuth Stern Drives-tugs, Guidelines for tug captains, shipmasters, pilots and operators of azimuth stern-drive tugs 2016, 68).

Figure 30, shows the relation among the tractor tugs skeg designs & LOA. One high of importance observation is the high demand for tugs consisting of 60 tons of BP, and azimuth drive propellers, with both skeg designs (type 3 & 4), especially the past 10 years. On the other hand, Voith Schneider tugs consisting of a single aft skeg, suffered from low levels, especially in cases of tugs for pure harbor towage duties. In subchapter 3.5, more information regarding the trades-off of the various tug types will take place, for revealing the significant relationship among bollard pull and propulsion systems of harbor tugs, with the several skeg concepts during the past years.

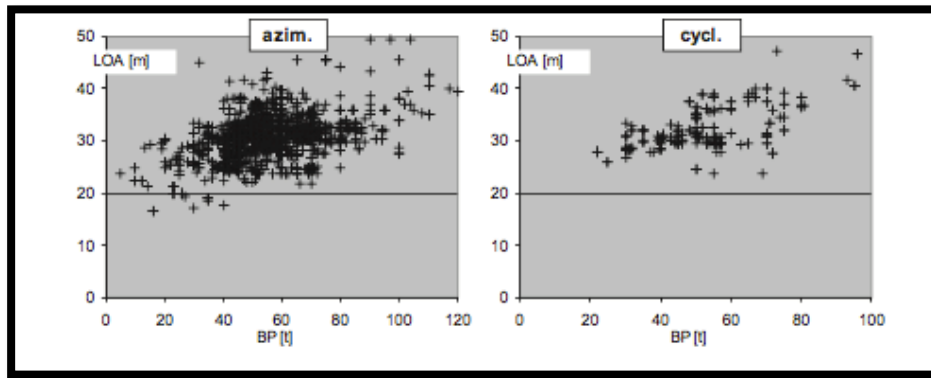


Figure 30: Trade-offs Skeg Designs VS LOA, (Artyszuk, TYPES AND POWER OF HARBOUR TUGS - THE LATEST TRENDS 2013, 17)

3.4.5 Superstructure & Fendering

Superstructure

One less important characteristic of all harbor tugs, is linked with their superstructure and the presence of low freeboard. The wheelhouse is in the middle of the rail, while the bulwarks are constructed with a slight angle towards the tug. Finally, the mast is capable to be lowered, providing extra safety towards the daily operations, especially in cases where the tug is operating under vessel's bow flare, vessel's stern or at the side. (Slesinger 2008, 72)

Fendering

Fenders are considered as one of the most important features of harbor tugs, providing essential functions (shock absorbers). The first main function is related with the absorption and disperse of energy. Additionally, fenders aim to increase and decrease the resulted friction and therefore protect both tug's and assisted vessel hull; therefore, the size as well as the material of the fenders is vital. The material is the main reason leading the energy to be absorbed while the size of fenders which covers a relatively large tug area, is responsible to dissipate the absorbed energy. New generation of harbor tugs include fenders, by using rubber as the dominant element, while each tug type consists from different shapes and sizes of fenders depending on its type and main capabilities. (Slesinger 2008, 76)

3.4.6 Dynamic Stability & Safety of Tugs

Longitudinal and transverse ship stability

The term stability is divided in two main categories and refers to longitudinal and transverse stability. For harbor tugs, special attention will be given only in the case of transverse resistance which is mainly divided at the initial and dynamic stability, while the latter one takes into consideration the tug's rolling energy. On the other hand, the stability of tugs towards the horizontal direction is known as course stability. Course stability for the entire fleet of KST will be evaluated and analyzed in subchapter 3.8.

Reason for High GM

Harbor tugs with omnidirectional propulsion units, consisting either from azimuth or Voith propellers, are designed with high dynamic stability, and thus high GM. Since harbor tugs consist of high dynamic stability, in cases of adverse environmental conditions (swells & waves) they will behave aggressively, for counteracting the heeling angles with large righting arms at small range of heeling angles. That explains why harbor tugs are designed with high stability, since they tend to operate within the port perimeter and thus it is not necessary to consist of lower dynamic stability as sea-going tugs which should consist of lower dynamic

stability due to the adverse environmental conditions they should deal with, for guarantee more friendly conditions for the crew on board towards the daily operations.

Tugs ability to resist the resulted forces on the towline during the daily operations either in normal or in adverse conditions, is aligned with their dynamic stability, correlated with the dimensions, location and height of the towing point and COP. Before explaining the dynamic stability of tugs, several parameters must be defined. By using the term stability, naval engineers aim to define the ability of the vessels to remain upright in a variety of conditions, while this capability is aligned and basically determined from the interaction of two significant forces. The first one refers to the gravity force, while the second one to the buoyancy; both forces tend to work against to each other. In general, the center of gravity lies at the point where the total weight of the tug with all its content interact, also defined as the balance point. On the other hand, the center of buoyancy, is the point where the upward force of buoyancy acts, while since the weight of the tugs is not altering during the offered assistance to a merchant vessel, it can be stated that the location of the center of gravity (G) remains static, and more specifically remains at the main center line of the tug. However, since the center of buoyancy is totally aligned with the shape of the underwater hull to be displaced, this means that its location is varying depending on the amount of the displaced mass.

Since harbor tugs consists of a symmetrical shape, it can be claimed that the center of the buoyancy (B) is also located in the same vertical line towards the center of the tug. Moreover, since the weight of the beam at the starboard as well as in portside is the same, it can be assumed that the point (B), is located below point (G). In order to explain efficiently the importance of GM, as well as the influence on the dynamic stability of each tug, several figures have been created, for a large range of heeling angles. The metacentric height should be always positive in order a tug to maintain its stability and never less than 0,15 m. (P&I 2015, 28). The figures below present a tug in various heeling angles. Since the total amount of weight has not changed, the location of (G) remains the same for all the cases. Nevertheless, the location of (B) will vary, and eventually it will be shifted at that region where the main amount of water is displaced.

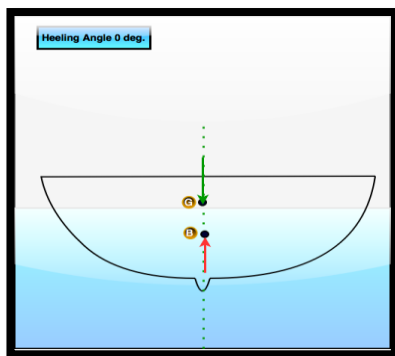


Figure 31: Tug with a list of 0 degrees, Own Composition (Laan 2016, 12)

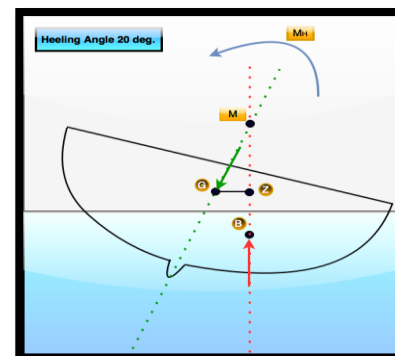


Figure 32: Tug with a list of 20 degrees (Laan 2016, 13)

Figure 31 shows a tug with a list equal to 0, where the center of gravity and buoyancy, are in the same vertical line. In Figure 32 the angle of heel equals to 20 degrees. In this case, the center of buoyancy is shifted to the right, since the amount water to be displaced at the right side is larger compared to the left side. Since the total amount of weight remains the same, the center of gravity remains in the same vertical line, as it was expected, (the same is applied for the rest cases of heeling angles). However, one new reference point is designed in this case, as it is indicated in Figure 32. Naval engineers use this reference point, which is defines as metacenter height (M).

By drawing the forces of gravity and buoyancy in Figure 32, the force of gravity pulls perpendicular to the surface of the earth, while the force of buoyancy pushes up to the surface of the water; thus, the point where these two forces lines intersect, is called metacenter height. The comprehension of this theoretical point M is important, for determining tugs stability while it defines the ability of the tug to correct its later position due to a heeling angle and return to its initial position; For this reason, there is a heeling moment with an anti-clockwise rotation which is called M_H . After the main parameters are defined, it is feasible to start analyzing the GM term, as well as its influence on the dynamic stability.

Righting Arm

Tug stability in various heeling angles is defined by the lever arm GZ, ($GZ=GM*\sin\alpha$). The location of G is influenced by the displacement of each tug, while the metacenter height M, for the various heeling angles, is influenced from the center of buoyancy, which varies depending on the tug's beam. (Laan 2016, 11)

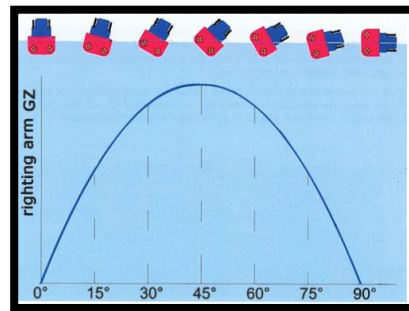


Figure 33: Righting Arm for various heeling angles (Laan 2016, 14)

Figure 32, shows the righting arm for a range of heeling angles, as well as the resulted list. At a heeling angle of 33 degrees, the largest value of the righting arm will occur, while afterwards, the stability starts to decrease, in angle of 50 degrees' water is getting inside the engine room. The stability will continue to decrease till it has a negative value at an angle of 75 degrees, where tug will be capsized. The draw of one-line perpendicular to the line from the center of (B), is defined as righting arm (GZ). In simple words, the righting arm refers to the interaction among the forces of gravity and buoyancy, leading the tug to return to its initial position. By comparing Figure 32, with Figure 34 & Figure 35, it is noted that the righting arm length varies; the larger the list of the tug, the larger the length of the righting arm.

The length of the righting arm consists of a maximum point, and if exceeded, the righting arm starts shrink, while it remains positive. This simply means that when a tug starts to tip, the rotation force to return the tug at its initial condition is also increasing till a maximum point. In case where a tug continues to increase its heeling angle, the length of the righting arm will start decreasing until it becomes zero. The heeling angle which lead the righting arm to become zero is called angle of vanishing stability, while at that point the location of center of gravity (G), is at the same location with the point Z. In cases that a tug continues to tip, as it is indicated in Figure 34 & Figure 35, the righting arm starts gaining negative values, while the tug is already capsized, since the location of M is below G and apparently offers a negative result.

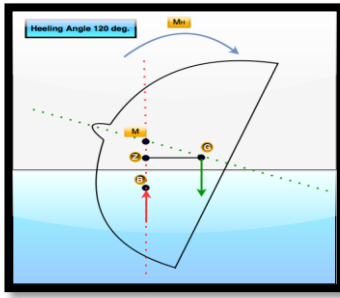


Figure 34: Heeling Angle 120 degrees, Own Composition (Laan 2016, 12)

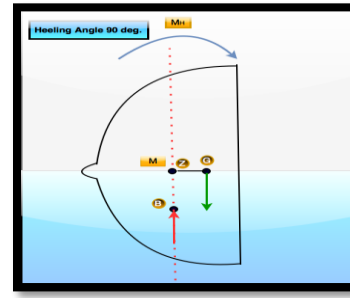


Figure 35: Heeling Angle 90 degrees, Own Composition (Laan 2016, 12)

By looking both figures the righting arm is also negative, while it is obvious that the buoyancy force is pushing down and thus turning the tug in the opposite direction, in comparison with the 20 degrees heeling of angle, where the buoyancy force pushes up, for making tug to gain its initial position. This explains the clockwise rotation of heeling moment M_H , which help tug to be capsized.

Intermediate Conclusion

It can be concluded that the heeling angles consist of a limit which tends to lead to positive righting arms and anticlockwise rotation heeling moment, while as soon as this limit is exceeded, the righting arm is negative leading to a heeling moment with a clockwise rotation. Additionally, the beamier a tug is, the “slower” the buoyancy point will be shifted either at starboard or portside, leading to higher righting arms in lower heeling angles, thus the tug will be able to overcome easier the heeling moments for returning to its initial position, and thus it will consist of higher dynamic stability levels. In this case the location of M will be at a higher point leading to the principle that the higher the GM, the higher the dynamic stability for the tug will be.

Reserve Stability

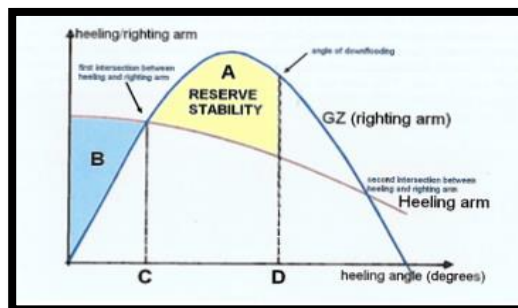


Figure 36: Stability Diagram, (Laan 2016, 34)

Figure 36, indicates a stability diagram. The curve shown with blue colour, refers to the righting arm GZ while the heeling arm is indicated with a brown colour curve. The first point to be discussed is point C, where at a heeling angle equals to that point, the righting arm is larger compared to the heeling arm therefore during static situation, heeling force does not cause larger heeling angle than point C. Hence, the area among points C & D represents the reserve stability area. Area B indicates an area where heeling arm is larger than righting arm, during static situation, where due to a force tugs are enforced to heel and they will be back at their original position only after the righting arm is larger, compared to the heeling. However, tug's stability should be evaluated during dynamic situations. The larger is the heeling arm till the point C, the faster will reach point C. On the other hand, the speed of the heeling arm at point C is considered as constant while after that point, it will be reduced. Figure 37 shows the heeling levers, A, B and C. During lever A, tug will start to heel as

soon as the heeling lever is active. Heeling will be increased till point b, since the heeling arm is larger than righting arm till that point, which is indicated with a green colour. After point b, heeling angle deaccelerate, since now the righting arm is larger compared to the heeling and finally will reach the end (20 degrees). At that moment where the maximum heeling angle is achieved, the area covered from the points b-m-n, will be equal with a-b-f area, stating that the heeling energy area a-f-b will be counteracted by the energy area b-m-n, for returning tug at its initial position. The tug will remain shortly at point m before returning to the equilibrium point b. (Laan 2016, 33)

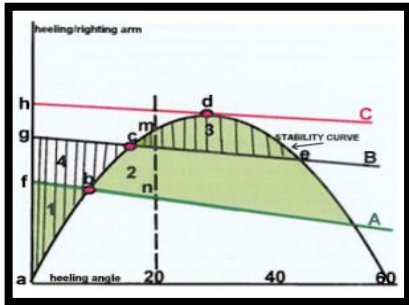


Figure 37: Heeling Levers VS Righting Arms, (Laan 2016, 35)

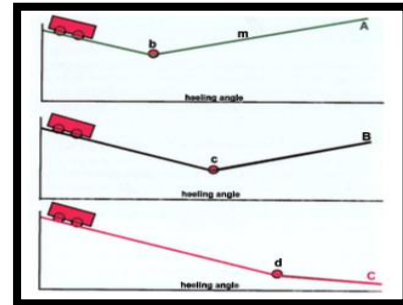


Figure 38: Various Cases of Heeling Angles, (Laan 2016, 35)

Figure 38 indicates three different cases of heeling angles by using a wagon for comparing the variances of heeling angle acceleration. Starting with green line A, the wagon will run free till point b and at that point it will be characterized from a lot of energy as exactly a harbour tug. This energy will make the wagon to have a speed towards its route uphill, where it will be stopped and at that point its energy becomes null; this point is equals to point m, where tug has the maximum heeling angle.

For the second case, the wagon will arrive at point C with higher speed, while the uphill route is by far reduced. Finally, the tug will reach equilibrium at point b, leading to a risky heeling arm for a tug. Finally, by looking the heeling area a-g-c, the counteracted area c-d-e is smaller and therefore it is not capable to provide the necessary energy for counteracting the heeling energy; thus, and the tug will be capsized. This is also indicated with the wagon at heeling lever C, where it will reach point D with high speed and it will not be able to brake on the short uphill, meaning that the tug will start to heel without being able to stop till it is finally capsized.

At this point where the fundamental insights of harbor tugs are well defined, the next section aims to present the market trends of the various towage companies during the past years globally. The various figures to be discussed will prove which tug types are considered as optimum, as a result of their main capabilities and limitations towards the daily operations.

3.5 Market Trends

The significant relationship among bollard pull and propulsion systems for the various harbor tugs, has led to remarkable market trends during the past years. One of the main goals of this sub-chapter, is to present which tug types were more selected compared to others from the towage companies globally, as a result of their fundamental insights. Additionally, this chapters aims to offer vital advices to KST regarding new-building projects in the near future, depending on the operational profile to be followed on each port of operation. Starting with the market of conventional tugs, the last 20 years have proved major deviations.

Conventional FPP tugs present a major increase in the bollard pull especially for the decade 2000-2010, where harbor tugs consist from a bollard pull range between 35 to 55 tons. At the same time, the decade 1970-1980

indicates large construction number of conventional tugs, while the following decade shows a general decline; the construction of new tugs started again after the year 1985. On the other hand, conventional CPP tugs are constructed in smaller quantities, while the majority of them was built between 1970 – 1985, either with low (~20 tons) or with higher bollard pull (60 – 70 tons). Figure 39 shows also that fewer CPP tugs are constructed from 1995 to 2005, while after 2005 the majority of new tugs had higher bollard pull for satisfying the increased needs of assisted vessels.

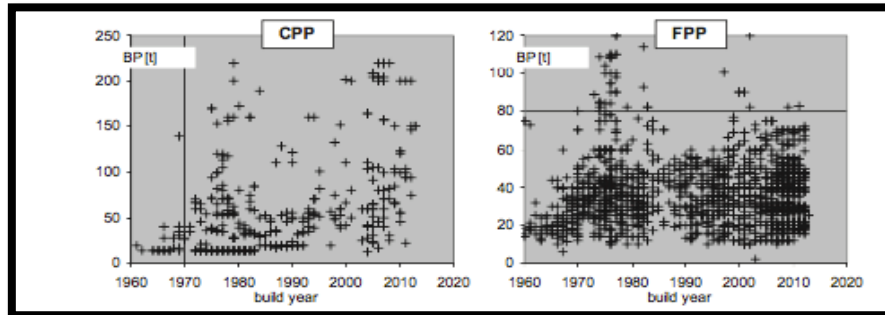


Figure 39: Market Trends for FPP & CPP (Artyszuk, TYPES AND POWER OF HARBOUR TUGS - THE LATEST TRENDS 2013, 10)

Figure 40 indicates the results for the next two types of harbor tugs. The first to be mentioned, is the ratio among tugs with azimuth propellers (ASD & ATD), and Voith Schneider, which is equal to 4 for the period 1990-1999 while for the period - 2000 till today -, is equal to 11. This massive increase is also explained from the entrance of a new state of art tug, the rotor tug (consisting from azimuth propellers) in the year 1999. This noteworthy imbalance among these two types, is a consequence of a technological progress combined with the willingness of towage competitors to raise their market shares.

On the other hand, azimuth propeller market, is characterized as a generic market, capable to cover the needs of multiple towage companies globally (concerning maneuverability and lower fuel consumption), while Voith Schneider market is characterized more as an anticompetitive market. The market denotes that Voith Schneider tugs were preferred from towage companies in cases of high levels of bollard pull, even up to 80 tons, and high levels of maneuverability and escorting needs, while the demand of towage companies for tugs with bollard pull equal to 50-60 tons, refers almost entirely to azimuth propellers tugs. On the other hand, very few Voith Schneider tugs were constructed for lower values of bollard pull. At the same time it can be concluded that the skeg design concept of Voith's is preferable for generating high levels of indirect towing forces during escorting, while Figure 40: Market Trends of Azimuth Propellers Units VS Voith Schneider's shows that towage companies proceeded in high order volumes of ASD's consisting of lengthy vertical skeg design (type 4), especially after 2010.

However, the continuous improvements of azimuth propellers tugs, especially after the year 2000, proved that towage companies were more favorable for ordering azimuth propeller tugs even for high values of bollard pull (80 or more tons), consisting initially with smaller skeg design, (type 3), and later on from skeg design type 4. The massive preference of towage companies to enrich their fleet with azimuth propeller tug, instead of Voith Schneider tugs, is mainly due to the demand for higher power levels. Voith Schneider demand about 10 % to 20 % more power for delivering the same amount of bollard pull, compared to a similar azimuth propeller harbor tug, thus higher fuel consumption will occur. (Artyszuk, TYPES AND POWER OF HARBOUR TUGS - THE LATEST TRENDS 2013)

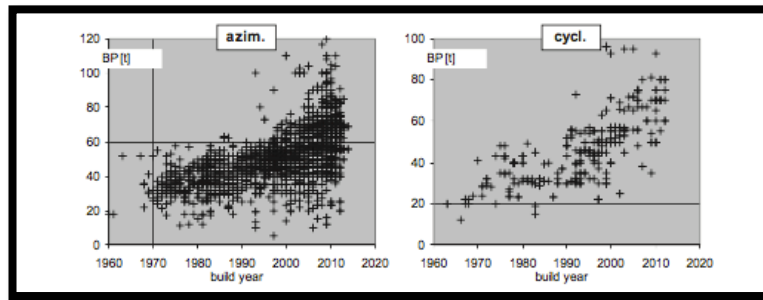


Figure 40: Market Trends of Azimuth Propellers Units VS Voith Schneider's (Artyszuk, TYPES AND POWER OF HARBOUR TUGS - THE LATEST TRENDS 2013, 11)

Finally, Figure 41 justifies in detail the higher fuel consumption of Voith Schneider's, compared to azimuth propeller tugs. These tugs are capable to provide 60 tons of bollard pull under 4000 KW of main engine output. On the other hand, Voith Schneider need 4000 KW. Additionally, for bollard pull value among 60-80 tons, the required power for azimuth propeller is equal to 3800-5000 KW in comparison with Voith Schneider, which demand 4000 – 5400 KW.

At the same time, significant variations are also observed among conventional FPP and CPP harbor tugs. For a bollard pull value equal to 50 tons, FPP tugs require ~3000 KW main engine output, while CPP tugs require 2500 KW, a result which also proves the improved fuel consumption of CPP tugs in comparison with FPP tugs. (Artyszuk, TYPES AND POWER OF HARBOUR TUGS - THE LATEST TRENDS 2013, 14)

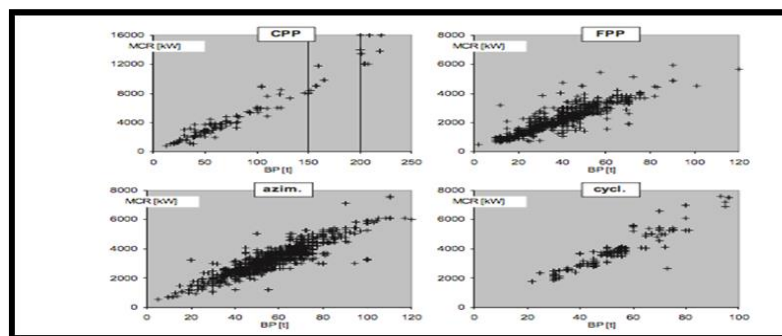


Figure 41: Comparison Among the Various Propulsion Systems (Artyszuk, TYPES AND POWER OF HARBOUR TUGS - THE LATEST TRENDS 2013, 12-13)

The market trends during the past 50 years show the fluctuations regarding the various harbor tug types. Towage companies emphasized towards the relationship among bollard pull and propulsion systems, while the underwater hull concept of each type was proven to be crucial. One of the main goals of this sub-chapter, was to present which tug types were more selected compared to others, offering a solid evaluation to KST for new-building projects, as a result of their fundamental insights. Additionally, the following chapter aims to offer vital insights to KST, regarding the operational profile of its fleet, after analyzing the main capabilities and limitations for each case.

3.6 KST Fleet Analysis

The next step in the research is to investigate the various tug types of KST. In Subchapter 3.3 all the possible harbor tug types were analyzed in detail concerning their main characteristics, regarding the location of propulsion units and towing point. However, as it will be explained in the next subchapter, the underwater hull design of each tug type is unique, and therefore influences tug behavior considerably. Therefore, it is more than required to analyze the multiple tug types of KST as a result of their propulsion and underwater hull concept.

KST Tractor Tugs

KST consists of four main categories regarding tractor tugs. Starting with Normal ATD, the tugs ZP Chalone, Texelbank, Thamesbank are located in the port of Rotterdam, while ZP Condon in the port of Hamburg. All of them are characterized from 45 tons of BP, consisting of flat vertical skeg (1st category of skeg designs in subchapter 3.4.4). This tug type consists of one winch at the stern and therefore is capable to proceed in bow to stern and stern to stern operation.

The second category of tractor tugs, ATD 2412, KST consists of four state of art Damen tugs. Each tug consists of 70 tons of BP, with the new concept of twin fins, (2nd category of skeg designs in subchapter 3.4.4), as well from two azimuth propellers units. The tugs ZP BISON & ZP BULLDOG are operating in the port of Hamburg. Finally, ZP BEAR is operating in the port of London offering harbor assistance in both London Gateway and river Thames. ATD 2412, as a pure tractor tug consists of one winch at the stern and therefore is capable to proceed in bow to stern and stern to stern operation.

Regarding Voith Schneider's, KST consists of six tugs in total, with various BP values (36-45 tons). Starting with SMIT SANDON and SMIT WATERLOO, consisting of 41 and 36 tons accordingly, while both operate in the port Liverpool. On the other hand, LIEVEN GEVAERT (45 tons) is operating in the port of Antwerp. Additionally, UNION 7,8 & 11 with the same amount of bollard pull as LIEVEN, operate in the ports of Rotterdam City and GTV respectively. All the pre-mentioned Voith tugs are characterized from the same propulsion unit and the vertical skeg at their stern (1st category of skeg designs in subchapter 3.4.4). Again, only two types of operations are available also for this type, referring to bow to stern and stern to stern operation, with variances concerning the efficiency results towards the ship handling duties. Last but not least Union 8 & Liven are the only Voith tugs, consisting of FiFi 1 notation, and they are capable to offer fire-fighting duties with total capacity of 2 x 1200 m³ water per hour. Figure 42: KST Tractor Tugs summarizes KST tractor tugs.

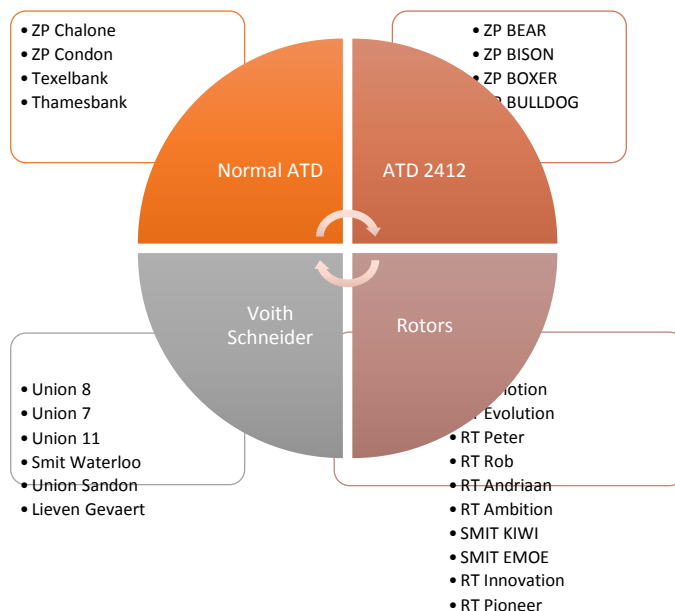


Figure 42: KST Tractor Tugs

KST Rotor Tugs

KST rotors are characterized from significant variances among the location of their towing points and propulsion units. The following table summarizes the different distances among the fundamental insights for each rotor type, which influences rotor behavior considerably. The behavior of each type will be discussed extensively in this subchapter.

Table 13: Rotors Variances Among Towing Point Location & Propulsion Units

Rotor Type	LOA	Tow.P – Forw.Thrust. (m)	Stern Thrust. – Stern (m)	Forw.Thrusters – Stern Thrust. (m)
RT 7532	32	9,4	11	12
RT8032	32	8,92	5,53	16,61
RT 8028	28	6,55	5,36	14,89
ART 8032	32	4,36	5,33	17,939

Tractor Type - RT 7532

By introducing the first generation of Rotor Tugs – RT7532, harbor tugs maneuverability goes one step beyond, since rotor tugs are considered as state of art tugs, with exceptional skills. RT7532, is considered as the first tug to replace the passive skeg at the stern with an active skeg, by adding a third azimuth propeller unit. The triangular set up of the azimuth thrusters offers incredible levels of maneuverability, leading to a massive increase towards the daily operations. During this project, MARIN was involved for optimizing the hull of RT 7532 while the Machine Padmos Stellendam BV shipyard, was responsible for the entire design of the project. KST consists of two tugs from this tug type, known as RT Innovation & RT Pioneer. Both tugs consist of 78 tons of BP, while initially, this tug was designed for providing 80+ tons of BP, however the Z drives units should be adapted in a way that tug was fulfilling light ice class regulations, which at the end had a negative impact on BP effectiveness. (Jansen, Comparison Among RT8032 & ART8032 2017). This tug type was especially designed for ports with high complexity, consisting of narrow locks & passages, as well as confined areas and swing-bridges. Therefore, the tugs were officially tested in the port of Bremerhaven, while till now they are operating in the same port, by providing services mainly to car carriers as well as to special projects.

One of the main coefficients of its underwater hull refers to the three parallels small skegs at the stern. Since this generation of tractors is not consisting from an active skeg at the stern, the three smaller skegs aimed to improve the poor course stability, when sailing forward. Additionally, this type is characterized from high levels of dynamic stability consisting of GM higher than 2 meters. At the same time, the large beam offers improved dynamic stability and therefore increased escorting capabilities are expected. However, the lower L/B ratio tends to lead in poor course stability, and therefore attention was given on the hull of this type. It consists of hard chine hull, where the water flow is following the chines as much as possible for avoiding undesired vortices. (Ton Kooren 2000, 3&4). Furthermore, the establishment of the three propulsion units in a close distance could lead to massive reduction on thrust efficiency due to the undesired interactions among the thrusters, especially when the units are in the same line. However, the triangle configurations led to significantly higher levels of improvement.

Moreover, one extra observation for RT 7532 is related with the distance among the three azimuth propellers units which is tremendously small. The consequences for this decision are significant and will be discussed, compared with the next generations of KST Rotor tugs, mainly in chapter 4. (MARIN 1999, 16). However, stern and forward thrusters were located at the maximum points forward and astern with a distance in between

of 12 meters, also after taking into consideration the presence of docking plates. Additionally, it is evident that the location of the stern towing point is not perpendicular on the aft azimuth unit, since they have 5,27 meter's variance, leading to an undesired lever arm and therefore a negative turning moment occurs, which should be counteracted, and eventually the effectiveness of bollard pull is reduced. Additionally, the large distance of 9,4 meters among the forward towing point and the forward azimuth thrusters leads to a large lever arm, and eventually more power from the forward stern thruster unit is required for counteracting the resulted arm, leading to lower levels of available power for the towline connection. (Jansen, Comparison Between Rotor Tugs 2017, 4). Finally, this tug type is also equipped with one fire-fighting monitor capable to deliver $600 \text{ m}^3 \text{ water/hr}$.

The next generation of rotor tugs known as RT8032, was developed based on the successful project of the first generation of rotors-RT7532. However, it was evident that tug efficiency could be improved by re-designing the locations among the towing points and the propulsion units. The new rotor version was also developed for the confined areas and locks presence in the port of Bremerhaven, as well as for terminal and offshore duties in the North Sea. However, the key for this new generation was the establishment of the stern thruster at a new position, closer to the stern and perpendicular to the stern towing point. In that perspective, the entire force from the stern thruster was fully delivered to the towline, without any loss. Additionally, the stern of the tug was redesigned for improving the sailing astern capabilities of the tug, while the docking plates as well as the small skegs were also present. Moreover, RT8032 hull is identical to RT7532 (single chine). One of the main characteristics for this type is the slightly less distance among the forward thrusters and the forward towing point which is 8,92 meters, while the most significant improvement was the reallocation of the stern thruster, where for this type the distance among the forward and stern thruster was equal to 16,61 meters. Therefore, the required power from the stern thruster for counteracting the resulted lever arm from the forward towing point and thrusters is lower. KST consists of four tugs known as RT Adriaan, Rob, Peter & Ambition, consisting of 84 tons of BP. RT Peter & Rob offer harbor assistance together in the port of Bremerhaven, while RT since June 2016 is operating in the port of Zeebrugge. Finally, RT Adriaan, (transformed to hybrid tug), is operating among the ports of Europoort and London. Finally, only RT AMBITION, consists of FiFi 1 notation, with two monitors capable to deliver $2 \times 1200 \text{ m}^3 \text{ water/hr}$.

Regarding the next type, RT8028, KST consists of two tugs known as SMIT KIWI & EMOE. Both tugs consist of 86 tons of BP with FiFi 1 notation. The two monitors are capable to deliver $2 \times 1200 \text{ m}^3 \text{ water/hr}$ and for this reason they are operating in the port of Zeebrugge, where all tugs are required to have FiFi 1 notation. This type has again the stern thruster perpendicular on the stern towing point, while the distance among the forward thrusters and the forward towing point is equal to 6,55 meters. Additionally, the distance among the forward and the stern thruster is equal to 14,89 meters. Therefore, the power which is required from the stern thruster is slightly lower for counteracting the resulted lever arm, compared with RT8032. (Coles n.d.)

Finally, the state of art rotor type refers to ART8032, consists of hybrid technology and a new adopted philosophy regarding its hull as well as towing points locations and propulsion units. The close cooperation among the Rotor Tug company & Robert Allan Shipyard in Canada had as a result a state of art tug with excellent capabilities towards ship-handling duties. KST consist of two tugs known as RT Evolution & Emotion, each with 80 tons of BP. The main idea behind this tug type was the increase of tug 's operational profile. For this reason, the new concept was characterized from improved hull form; thus, the first to be

mentioned is the removal of the docking stools, leading to an increase of the maximum forward speed (13.5 knots). At the same time, the new structural arrangement led to a total weight reduction of 37 tons.

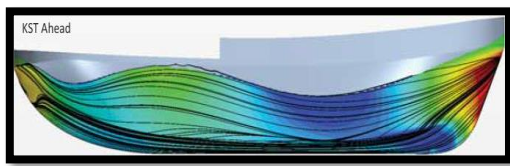


Figure 43: Resistance when Thrust Ahead with Single Chine, (Jansen, Comparison Among RT8032 & ART8032 2017, 2)

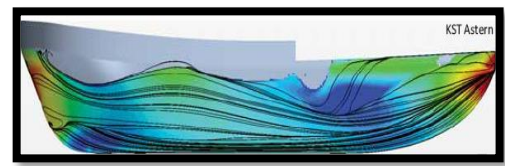


Figure 44: Resistance when Thrust Astern with Single Chine (Jansen, Comparison Among RT8032 & ART8032 2017, 2)

Moreover, some extra characteristics regarding this tug type refer to the high freeboard as well as the bilge keels and sponsons, which offer extra dynamic stability to the tug during escorting tasks. In cases with small heeling angles, less volume of the tug's hull is immersed, leading to lower resistance. Additionally, after several experiments, the type of hull was decided. Sponsons hulls and double chine hull was proven to be the best solution for increased seakeeping abilities, especially during adverse environmental conditions. CFD comparison analysis was required for the various hull concepts which were investigated at a speed of 12 knots. (Jansen, Comparison Among RT8032 & ART8032 2017, 2)

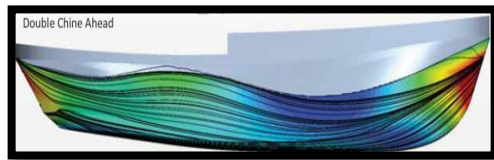


Figure 45 Resistance when Thrust Ahead with Double Chine (Jansen, Comparison Among RT8032 & ART8032 2017, 3)

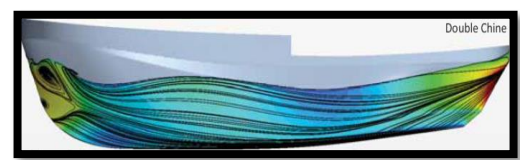


Figure 46: Resistance when Thrust Astern with Double Chine (Jansen, Comparison Among RT8032 & ART8032 2017, 3)

Resistance When Sailing Forward & Astern

Table 14: Total Resistance when Sailing Forward & Astern for Single & Double Chine, shows that the removal of the docking plates, had as a result the ART8032 tug resistance to be reduced by 8%, improving at the same time tug's side-stepping capability. For RT8032, the maximum side-stepping speed was 5,5 kn compared with the ART8032, which was measured to be equal to 7 kn. Moreover, the double chine hull concept, was proven to be more efficient, and was eventually selected, for improved sea-keeping capabilities. Additionally, one of the main goals for this new concept was the ability to provide increased levels of hydrodynamics forces during escorting and indirect mode. For this reason, there was a need for improving the towing arrangement of the rotor. Several studies showed that a possible reallocation of the forward thrusters, in a more forward point would improve tug behavior considerably (rotor-ring: ability to push on the line from the same position), moving the COP in a more forward point, for improving the indirect leverage. Both Figure 47 & Figure 48 show the variances among the lay-outs for RT8032 & ART8032. (Jansen, Comparison Between Rotor Tugs 2017, 3). Table 14 summarizes the variances of the total resistance for both directions, forward & astern, for the types RT8032 and ART8032, consisting of a single and double chine hull, at 10 knots speed after a solid CFD analysis.

Table 14: Total Resistance when Sailing Forward & Astern for Single & Double Chine

Direction	Ship Resistance (kN)		
	RT80-32	ART 8032 (Single Chine)	ART8032 (Double Chine)
Ahead	108	107	104
Astern	148	91	100

The reallocation of the forward towing point for the ART8032 to a more forward point by 23 %, compared with RT8032, had as a result the distance among the towing point and the propulsion units to be equal to 4,36 meters. It is also evident that the towing point was also shifted slightly astern, and therefore the new position for the staple is capable to increase the hydrodynamic lift and resistance during escorting in indirect mode. In the previous cases of rotor types where the towing point is at the maximum forward point, the tug must rely exclusively on the power of azimuth units for keeping the desired hull angle, for generating the proper lift and hydrodynamic lateral resistance during escorting within indirect mode. (Jansen, Comparison Among RT8032 & ART8032 2017). Eventually, the combination of a very forward towing point with a large distance among the forward and the stern thruster, (17,939 meters), has as result the lever to be created among the forward towing point and the forward propulsion units to be almost zero, and therefore the stern thruster is not required to give power for any counteraction, which increases the pull effectiveness considerably and therefore makes the ART8032 a state of art tug.

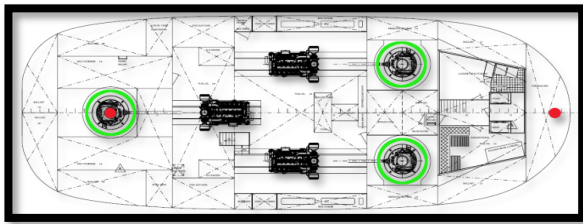


Figure 47: RT8032 Lay-out (Jansen, Comparison Among RT8032 & ART8032 2017, 3)

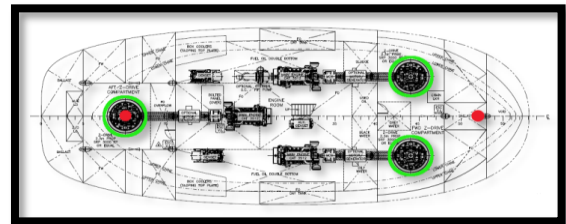


Figure 48: ART8032 Lay-out (Jansen, Comparison Among RT8032 & ART8032 2017, 3)

Hybrid Technology

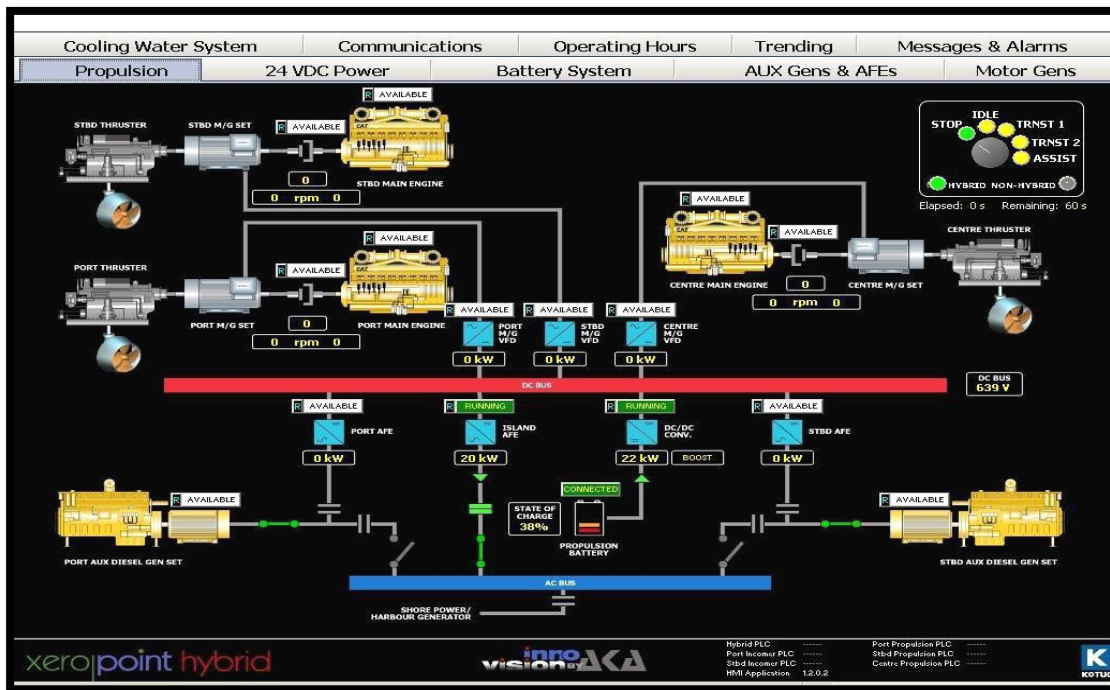
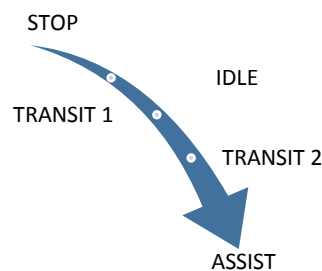


Figure 49: Hybrid Technology Dashboard in ART8032

Except from the new adopted design characteristics and hull concept, of ART8032, one additional vital characteristic is its hybrid technology, capable to drive the propellers directly, (diesel & electric power are combined towards the same shaft line). This technology offers vital advantages, especially towards Mobilization & Demobilization, as they will be extensively analyzed in subchapter 7.2, where tugs spend considerably high amount of fuel. The same technology was also adopted in RT Adriaan, which still operate

most of its time in the port of Rotterdam, as a part of busy fleet in this area for the daily ship-handling duties. The main purpose of this conversion was, the tug ability to operate efficiently during its hybrid modes, and at the same time as conventional diesel harbor tug when necessary.

The main objective of this conversion, except from the lower emissions was the reduction of fuel costs per job during the daily harbor towage duties, as well the maintenance & repair due to the significantly lower number of engines running hours. In general, for a conventional diesel harbor tug both main and auxiliary engines will be rarely used in the most efficient way, which is in a full load mode. Several study cases also proved that for harbor towage services, the maximum levels of BP requirements will take place only in 2% of the entire operational profile, leading to poor fuel consumption results. Moreover, the same situation also characterizes the auxiliary engines, which tend to spend most of their operational profile in idle mode or they are used in low loaded levels. Hence, before the conversion to hybrid technology, RT Adriaan used to operate by using its three engines and one auxiliary engine, leading the engines to operate in a significantly low operational profile, with reduced efficiency levels. With the adoption of the hybrid technology from ART8032 concept, tug masters are capable to select the desired mode of operation, depending on the type of activity to proceed. The analysis of this hybrid concept is characterized from simplicity, offering also the ability for operating either as a pure hybrid or a non-hybrid tug, while the four different modes to be selected are the following. (A first hand look in RT-Adriaan 2013)



The connection among the propulsion system components, for the resulted electrical and diesel power for each of the modes are indicated in the figure above. Starting the analysis of each mode, the first to be discussed, refers to the STOP mode, where the main engines are not running, while the tug's electrical system is fed up with the required energy from the two batteries. When batteries are fully charged, they are capable to provide power for 8 hours constantly, for fulfilling tug's power needs. In case where the battery capacity is lower than 30%, this is the point that triggers one of the auxiliary engines for coming on line.

When the tug is sailing in IDLE mode, the thrusters are power-driven by the motor-generators, entirely from the batteries in the shaft line, while the tug during this mode is capable to sail with a speed equal to 2,5 knots for thirty minutes. During TRANSIT 1, the thrusters are now power driven from motor-generators while both auxiliary diesel engines (C18/450 kW & C9/200 kW) are turned on, offering ability for sailing at a speed equal to 6,5 knots. Since in this phase the batteries are turned off, they will be re-charged in any case of spare power.

In TRANSIT 2, the C18 auxiliary engine is off, while the aft thruster is now power driven from the center main engine, while both forward thrusters, are power driven from the electric motor-generators by retrieving power from the small auxiliary engine (C9/200 kW) which is always running; during this mode, the tug is capable to achieve a speed equal to 11 knots. Finally, during ASSIST mode, all azimuth thrusters of the tug are driven from the main engines, offering the ability to the tug for sailing at 12,5 knots speed. During this mode, the motor-generators again provide any spare power for recharging the batteries. It can be concluded

that the hybrid technology for the ART8032 as well as for RT Adriaan (converted-RT8032), led to a total reduction in fuel consumption equal to 20%. (A first hand look in RT-Adriaan 2013)

KST ASD Tug Types

Conv.ASD	Rampart 3200	Rampart 3000	Armon Design	ASD 2810	ASD 3110	Aarts Marine	ASD 3212	ASD 3213	Citranaval Defcar	Compact Tug Design	Combi Tug
• Brugge • Gent • Zeebrugge • St. Annastrand • Union 5 • Union 6	• SD Seal • SD Stingray • Union Kodiak • Union Koala • Union Grizzly • Union Panda • SD Shark	• SD Jacoba	• Union Amber • Union Jade	• SD Rover • Smit Barbados • Smit Donau • Smit Ebro • Smit Hudson • SD Rebel • Smit Seine • Smit Schelde • Smit Elbe	• Smit Belgie	• Fairplay 21 • Fairplay 24	• SD Dolphin	• Smit Cheetah • Smit Panther • Smit Tiger	• Union Pearl • Union Coral • Union Emerald • Union Ruby	• Union Hawk • Union Eagle	• Braakman • Terneuzen

Figure 50:KST ASD Fleet

Conv. ASD's

Conventional ASD's consist of azimuth propulsion units, without the presence of any sophisticated skeg. They are considered as multi type tugs due to the double winch (bow & stern), offering the ability of operating in four different types (bow to bow, bow to stern, stern to bow, stern to stern). However, the underwater hull of this tug type causes various limitations and therefore, the efficiency of tug is reduced. Moreover, it is not capable to generate high levels of hydrodynamic forces and thus it is not able to fulfill escorting duties efficiently. The tugs Zeebrugge & ST. Annastrand, both consist of 39 tons of BP, and operate in the port of Liverpool and GTV area respectively, while Brugge & Gent from 45 and 40 tones, accordingly. Finally, Union 5 & 6 consist of 47 tons of BP, while, only Brugge consists of FIFI 1 notation, for firefighting duties, ($2 \times 1800 \text{ m}^3 \text{ water/h}$). Union 6 consists of two monitors capable to offer $2 \times 500 \text{ m}^3 \text{ water/h}$.

Rampart 3200

Regarding Rampart 3200, KST consists of seven tugs based on the Robert Allan Design. Both SD Seal & Stingray are operating in the Europoort while SD Shark since April, it is operating in the new entry port of Southampton. On the other hand, the rest 4 tugs are operating in the port of Antwerp. All the Robert Allan Design tugs consist of 65 tons of BP, combined with FiFi 1 notation, and hence they are equipped with two firefighting monitors. The underwater hull (double chine) of this type consists of a flat vertical skeg, located with an angle on the hull, from the tug's bow, with a significant distance from the propulsion units, (4th category of skeg designs in subchapter 3.4.4). Therefore, high levels of directional stability are expected especially when sailing astern. Furthermore, the skeg creates large lateral area, leading to high levels of hydrodynamic forces towards escorting duties. At the same time the bow has a V shape, and hence the tug can operate in exposed areas with adverse environmental conditions, with improved seakeeping performance and roll stability.

Rampart 3000

KST consists only from one tug belonging to the first generation of Robert Allan Design, known as Rampart 3000, (SD Jacoba) operating in the port of Rotterdam. It is considered as a reverse tractor tug with one winch at the bow. It is capable to operate as a forward tug in a bow to bow operation, or as a stern tug, in a stern to bow operation. Additionally, this tug type is consisting of double chine hull with a small aft skeg, in a very short distance from the propellers (3rd category of skeg designs in subchapter 3.4.4). However, the position and the skeg shape, have significant impact towards the daily operations as it will be extensively discussed in

chapter 4 through the survey, especially during bow to bow operations. The tug is not capable to follow a straight line when sailing astern while the tug master should always be aware for correcting tug's course; especially in a high range of speed, it can lead in a risky situation. The unavailability of maintaining a straight course, is linked with the low levels of directional stability due to the lack of a lengthy skeg. On the other hand, higher draught, would provide better seakeeping characteristics, as well as sailing astern abilities, however it would influence tugs maneuvers due to the higher resistance.

Armon Design

Regarding Armon Design, KST consists of two tugs, known as UNION Amber & UNION Jade, consisting of 65 tons of BP. Both tugs operate in the port of Antwerp, while even if they consist only from a fore winch, they are also capable to operate as a conventional tug by transferring the towline below the wheelhouse. Several limitations characterize this type, especially during bow to bow operations, as a result of its underwater hull with appendages. Therefore, the tug is limited to sail astern with a limited maximum speed. In general, it is characterized as an overpowered power tug, requiring experience for safe ship handling duties.

ASD2810

The next ASD type of KST refers to ASD2810, where 9 tugs belong to this tug family. This type is characterized from a range of BP in between 57 & 60 tons. The underwater hull of this tug includes a flat vertical skeg, placed with an angle at the underwater hull, (starting from tug's bow and has a significant distance from the stern, (4th category of skeg designs in subchapter 3.4.4). Therefore, this skeg concept is expected to provide improved sailing capabilities, especially when sailing astern, since it is characterized from high levels of directional stability. Additionally, the thrusters are placed with an angle for improving the thrust direction under the hull. In general, DAMEN was aiming to design a tug type with improved capabilities when sailing astern. Hence, ASD 2810 is considered as a state of art tug, for proceeding safely in bow to bow operations even at high range speeds, because of its underwater hull with appendages. The majority of ASD2810 are operating in the Europoort, while SD Rover is offering harbor assistance in the port of Hamburg, while Smit Barbados & Donau, operate in the port of Liverpool. Last but not least, the only ASD2810 consisting of firefighting pump is Smit Barbados, capable to deliver $1 \times 600 \text{ m}^3 \text{ water/hr}$.

ASD3110

ASD 3110 concept is identical to ASD 2810, while the only major difference in between the two tug types refers to their length, which is increased by 3 meters. Additionally, ASD 3110 is characterized from 55 tons of BP. KST consists of one tug belonging to this family, known as Smit Belgie. Initially, the tug was operating in the GTV area, however since January it is reallocated in the port of Liverpool. The tug in most of the cases will operate as a stern tug, for offering braking assistance to the assisted vessels in the port of Liverpool, while a technical issue towards its portside thruster, does not allow the tug to proceed efficiently in bow to bow operations. More information concerning this tug type behavior will be found in chapter 4.

Aarts Marine

This tug type is the only that is not actually purchased from KST. The company proceeded in a lease agreement with 20 years' duration in 2000 with the towage company known as Fairplay. The two tugs, Fairplay 21 & 24 consist of 55 tons of BP, and were chartered from KST for enriching the capacity in port of Rotterdam. The main characteristic of this design of the bulbous bow, which is working as a rudder for the cases where the tug is sailing astern. Additionally, its underwater hull is not characterized from any sophisticated skeg, sponsons

or bilge keels, while negative wash effect will be created when sailing astern, due to skeg presence which lies further aft. Finally, the tug consists of a large open aft deck, with special offshore cargo rails, offering the ability to proceed in multiple offshore and terminal duties. That also explains the reason that these tugs consist of a double winch capable to tow over the bow and stern combining both harbor and salvage duties.

ASD 3212

The powerful SD Dolphin consists of 80 tons of BP, and till today is operating in the port of Hamburg, offering pure harbor and escorting assistance. One of the main objectives of ASD 3212 design team, was the improvement of towing characteristics, for making it capable to work efficiently in areas with adverse weather conditions with waves up to 3 meters. This type is characterized from excellent seakeeping characteristics and maneuverability, while it is capable to fulfill multiple operations in exposed waters, with increased stability due to the V shape of the bow with slenderer waterlines. (SHIPYARD 2012, 55). At the same time, it is characterized from high dynamic stability, consisting of high GM (2 meters), while, its underwater hull includes the presence of a flat vertical skeg, for generating high levels of hydrodynamic forces towards escorting duties. Additionally, the skeg offers improved directional stability, especially when sailing astern. Finally, the tug is characterized from heavy fenders at the bow, capable to guarantee high levels of energy absorption. (SHIPYARD 2012, 19).

By using the tug simulator, DAMEN was capable to measure the steering and braking forces during escorting duties at 10 knots of speed, and hence it was possible to proceed in further improvements for optimizing the existing design concept before the final assembly. The hull shape with presence of the sophisticated skeg and bilge keels, as well as the location of propulsion units and towing point are included in the hydrodynamic theory of Tugsim background for achieving the highest level of braking and steering forces.

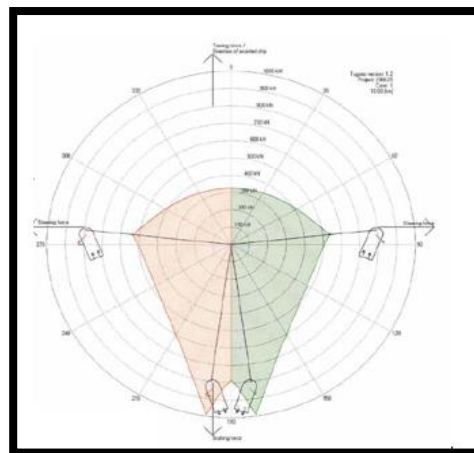


Figure 51: Tug Sim Diagram for ASD3212

In Figure 51, it is evident that at an angle of 175 degrees, the tug is capable to provide 100 tons of BP as braking force, while at an angle of 180 degrees the braking forces was measured to be 80 tons. On the other hand, at an angle of 150 degrees, the steering forces would be 30 tons and braking forces 60 tons. Finally, the maximum steering forces will occur at an angle of 90 degrees and will be equal to 52 tons of BP.

ASD3213

ASD 3213 is the most powerful tug type of KST. The company consists of three tugs, each with 95 tons of BP. Damen shipyards proceeded in over 9000 3d sketches, and 682 drawings, till the final design, where all

the major components for the final assembly, were delivered to Vietnam. DAMEN primary's goal was to design a harbor tug highly maneuverable, with increased capabilities for sailing in adverse environmental conditions. (Hopman 2017). At the same time, this tug type was designed as a multipurpose tug, capable to combine not only pure harbor duties, but also offshore and escorting duties. Therefore, the extended freeboard, the high forecastle deck and the wide beam, aim to contribute to the increased capabilities of this tug type. (Publication 2009). ASD 3213 consists of a hull with increased volume at the bow as well as from a flat vertical skeg. The sophisticated skeg offers the ability for sailing astern with high levels of directional stability. Furthermore, the large lateral area of the skeg, offers the ability of generating high levels of hydrodynamic forces, both braking and steering, during escorting duties. Additionally, the thrusters are placed with 7 degrees' angle for improving the thrust, especially when sailing astern. Finally, Smit Cheetah & Panther are operating in Europoort, and in most of the times operate as a big brake for the assisted vessels (stern). On the other hand, Smit Tiger, used to operate in the port of Zeebrugge, however it was reallocated in the port of Southampton since April, fulfilling company's needs to the new port. Last but not least, they consist of FiFi 1 notation, with two monitors capable to deliver $2 \times 1200 \text{ m}^3 \text{ water/hr}$.

Citranaval Defcar

KST consists of four tugs of this type, each consisting of 65 tons of BP. Additionally, they are equipped with FiFi1, with two monitors capable to deliver $1200 \text{ m}^3 \text{ water/hr}$. Additionally, they consist of a raised forecastle and heavily fenders at the bow. At the same time, they have low aft deck, capable to accommodate anchors or chains for salvage duties. This configuration will allow the tugs to work also in the exposed area Schelde area, offering high levels of seagoing duties. This explains, the decision of the company to locate these tugs in the port of Zeebrugge. Except from the FiFi 1 duties which must be satisfied in this port due to the LNG terminal, Union Coral & Pearl are capable to offer salvage duties in Schelde area.

On the other hand, Union Emerald & Ruby are switching port often among Zeebrugge, GTV and Antwerp for satisfying company's needs. The low and open aft deck is offering the required space to the anchor chain movement, while the open stern is also a crucial parameter for salvage, and special projects. However, these characteristics reduce the capabilities of this tug type as a pure harbor tug, since it is not capable to offer the same flexibility towards the daily operation, compared with the rest ASD tugs of KST. Last but not least the hull is of double chine construction with a large central skeg aft and an underwater shape giving good water flow to the propulsion units. (Journal 2004)

Compact Tug Design

Regarding the last ASD type KST, consists of two tugs, known as Union Hawk & Eagle, each with 86 tons of BP. Both tugs operate in Antwerp, while in most of the cases they will operate as a stern tug, as a "brake" for reducing the speed of the assisted vessel. At the same time, this tug type even if it consists only from a bow winch, it also capable to operate conventionally, since the towline can be transferred under the wheelhouse at the stern of the tug. Therefore, this tug type is capable to combine power and flexibility towards the daily towage operations in Antwerp.

Combi

The tugs, Braakman & Terneuzen are typical conventional tugs, with a bow thruster operating in GTV area consisting of 39 tons of BP. Most of the times this specific tug type is operating as a forward tug and rarely as a stern tug. This is also obvious from the propeller, rudder as well as from the hull concept of this tug type,

which aim to offer the maximum efficiency when tug is sailing forward. Additionally, in cases they operate as a stern tug, they will always make use of the gob rope system. Combi tugs are made in a way that the highest amount of force is generated when pushing their towing point. This situation will occur when the tug by using its propulsion system tries to establish a new towing point on a new desirable position, and hence high levels of force will be delivered to the assisted vessel through the towline.

Intermediate Conclusion

The goal of this section was to present KST fleet operational profile, as well as to divide each tug to the correspondent tug type. After the main characteristics of each tug type are established through subchapters 3.4 the next to be addressed is related to the number of types of operation that each tug type is capable to offer, as well as the effectiveness results for each type towards the types of operation to be offered, during the daily towage services. Subchapter 3.7 will firstly analyze the resulted types of operations for each tug type of KST fleet, while, subchapter 3.8 aims to assess the variances among the tug types of KST in the various ports.

3.7 Tug Types VS Types of Operations

KST fleet is divided based on the types of operations to offer, in the various ports. Starting with the tractor tugs, since their location of towing point is at the stern, they are capable to offer two types of operations. The same types of operations are also offered from the Combi tug. On the other hand, Rotor tugs even if they are considered as tractor tugs, they consist of double towing point locations and therefore they are capable to offer all the possible types of operations.

The rest fleet of KST, offers two or three types of operations, depending on their ability to behave as a multi tug. In case of Compact Tug Design & Armon Design, even if they consist only from one winch, they are capable to transfer the towline below the wheelhouse, and therefore the types of operations are equal to three. Additionally, the tug types ASD 2810, ASD3213 and the conventional ASD's consist from double winches, hence they can also operate "conventionally", which explains the three types of operations to be offered. Finally, the rest ASD's tug types are capable to offer only two types of operations, due to unique winch at the bow. Tug operations towards the merchant vessels in the various ports, are divided in four main categories. These categories are summarized for the entire fleet of KST in Table 15 below:

Table 15: KST Fleet VS Types of Operations

Tug Type	Types of Operation			
	Bow to Bow	Bow to Stern	Stern to Bow	Stern to Stern
Normal ATD	-	√		√
ATD 2412	-	√		√
Voith Schneider	-	√		√
RT 7532	√	√	√	√
RT8032	√	√	√	√
RT 8028	√	√	√	√
ART 8032	√	√	√	√
Conventional ASD	√	√	√	-
ASD 2810	√	√	√	-
ASD 3110	√	-	√	-
ASD 3212	√	-	√	-
ASD 3213	√	√	√	-
Rampart 3000	√	-	√	-
Rampart 3200	√	-	√	-
Aarts Marine	√	-	√	-
Citranaval Defcar	√	√	√	-
Armon Design	√	√	√	-
Compact Tug Design	√	√	√	-
Combi Tug	-	√	-	√

Table 16: Possible Types of Operations During Harbor Towage

Bow to Bow	Bow of the vessel, Bow of the Tug
Bow to Stern	Bow of the vessel, Stern of the Tug
Stern to Bow	Stern of the vessel, Bow of the Tug
Stern to Stern	Stern of the vessel, Stern of the Tug

The assessment of the KST fleet, requires each tug type behavior to be evaluated based on each possible type of operation. This behavior is entirely dependent from the fundamental insights of each tug type, as it will be explained in the following chapter, as well as from the levels of training and experience from tug master's perspective. Even if the various tug types of KST are capable to offer multiple types of operations, it is noticed that tug master's philosophy varies from port to port, and therefore it is vital to evaluate the strengths and weaknesses for each case. For multiple reasons, bow-to-bow operations tend to be used more and more nowadays, especially in Netherlands, German & Belgium ports. However, for some specific ASD tug designs a general discussion concerning the most optimum usage of ASD tugs, takes place among Bow-to-Bow or the Bow to Stern ("Conventional Way"). **Therefore, this chapter aims to prove which method is the optimum one for each tug type of KST fleet, as a result of each tug type fundamental insights.**



Figure 52: KST Harbor Towage Assistance

The ship handling tasks are divided in two main categories. The first category, named as Intermediate step refers to the phase where the tug is approaching the vessel for making the towline connection. On the other hand, the second category refers to the phase where the towline connection is already made, and the assisting procedure has started. Both phases refer to all the possible types of operations (Bow to Bow, Bow to Stern, Stern to Bow, Stern to Stern). Therefore, it is crucial to investigate the strengths and weaknesses for each phase and for each possible type of operation for the entire fleet of KST.

Intermediate Step

The first phase of harbor towage assistance refers to the intermediate step. This step is considered as the most critical phase in between harbor tugs and assisted vessels. Harbor tugs must approach the bow or the stern of the assisted vessel underway, for making the towline connection, a situation which can be characterized as tremendously risky. This explains the reason that the main capabilities and limitations of KST fleet need to be addressed, which vary because of the multiple tug designs, concerning the main differences among the underwater hull and propulsion units. (C. H. Hensen 2016, 1)

Towline Connection

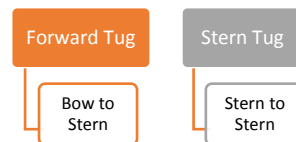
In all European ports, where KST is operating towline connection method is always the method to be used for handling the assisted vessels. Alternatively push n pull method is also used, however this method is mainly

used in non-European ports. (C. H. Hensen, TUG USE IN PORT - A practical Guide , p vii 2003, 34). The second phase of towage assistance, is considered as a less risky situation. At this moment, tugs are not in a close distance with the assisted vessel for making the towline connection (intermediate step). However, the behavior of each tug type of KST fleet varies considerably, as a result of the plenty underwater hull design concepts as well as from the rest fundamental insights of each category.

Speed

The speed among tugs and the assisted vessel has a range of 2 to 7 knots. Starting with the intermediate step the tugs are approaching the vessel (underway), with a speed equal to 7 knots, for making the towline connection. Emphasis to be given especially in bow to bow operations, where tug masters request from the vessel to reduce further its speed for making the towline connection safely. Therefore, the most applicable speed is between 5,5 and 6 knots, while higher speeds are aligned with well-designed underwater hull. Finally, one rule which always should be followed for safe towline connection, states that ship's speed should never exceed the 60 % of the tug maximum forward speed, since tugs should always be characterized from adequate reserved power, avoiding collision or girting phenomenon. (C. H. Hensen 2016, 10)

Conventional Tugs - Combi



The two Combi tugs of KST are capable to offer ship handling duties with two different types of operations. As it has already mentioned in subchapter 3.3.A.4, these tugs consist from one stern winch and therefore they are capable to proceed either in a Bow to Stern, as a forward tug as it is indicated in Figure 53, or in Stern to Stern operation as a stern tug, as it is shown in Figure 54, by using the gob rope system, which has already been analyzed in subchapter 3.3.3. A.1.

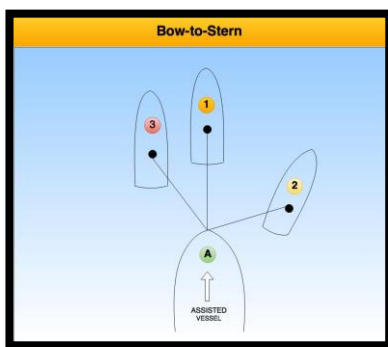


Figure 53: Bow to Stern Operation Combi Tugs, Own Composition

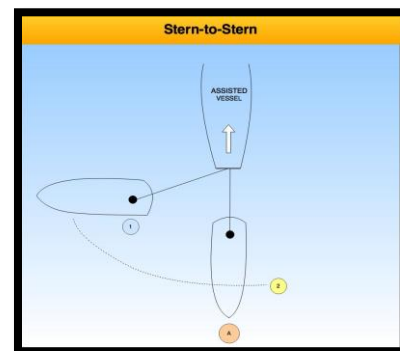
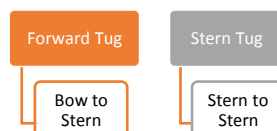


Figure 54: Stern to Stern Operation Combi Tugs, Own Composition

Tractor Tugs - Normal ATD, ATD 2412, Voith Schneider



Tractor tugs of KST, either with azimuth propeller units or with Voith Schneider, are also capable to offer the same types of operations as Combi tugs towards the ship handling duties, since they also consist from a stern

winch. Therefore, as a forward tug they will proceed in a Bow to Stern operation, as it is indicated in Figure 55 while as a stern tug, they will proceed in a Stern to Stern operation, which is indicated in Figure 56.

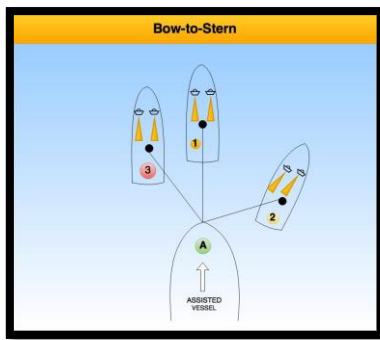


Figure 55: Bow to Stern Operation Tractor Tugs, Own Composition

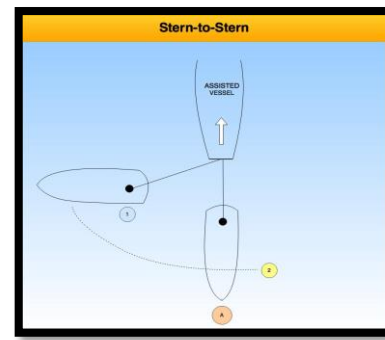
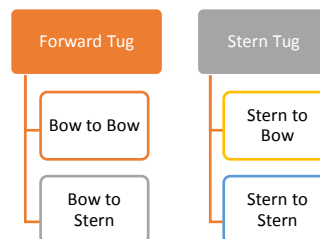


Figure 56: Stern to Stern Operation Tractor Tug, Own Composition

Tractor Tugs—Rotor Tugs



Rotor tugs are capable to offer all the possible types of operations since they consist from two winches and two locations of propulsion units. Therefore, in the case where the tug is a forward tug, it can offer ship handling duties either by proceeding in a Bow to Bow operation or in a Bow to Stern operation (Figure 57). On the other hand, in case where the tug is a stern tug, it can provide ship handling duties either in a Stern to Bow (Figure 58) or in a Stern to Stern operation (Figure 59). However, most of the tug masters in KST will never prefer to proceed in a Bow to Bow operation, since they have only one thruster to control their own tug, a situation which can be risky especially during adverse environmental conditions and demands considerable high levels of experience.

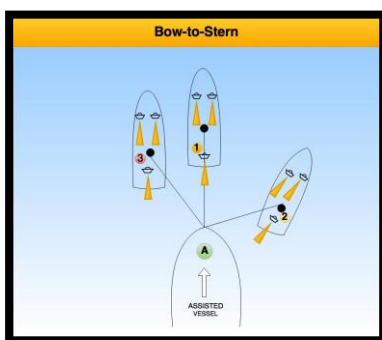


Figure 57: Bow to Stern Operation Rotor Tugs, Own Composition

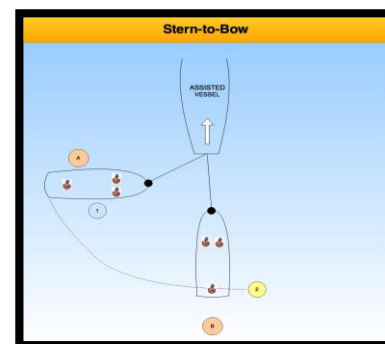


Figure 58: Stern to Bow Rotor Tugs, Own Composition

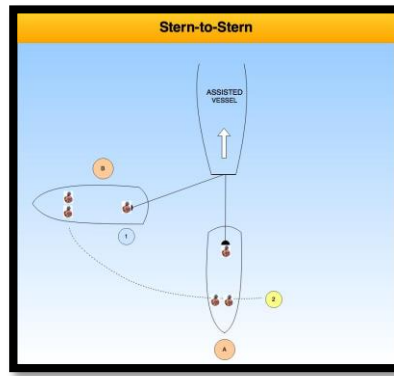
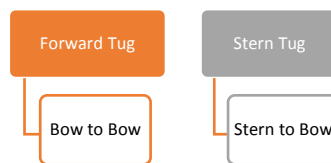


Figure 59: Stern to Stern Rotor Tugs, Own Composition

ASD Tugs

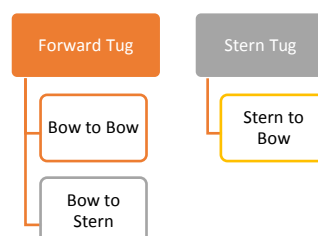
The majority of KST fleet consists of ASD tugs (60% of the entire fleet) towards the daily operations. ASD's are capable to offer two and/or three types of operations. As it has already been explained, most of the azimuth stern drives tugs consist of fixed pitch propellers, however there are also some cases where ASD tugs consist of controllable pitch propellers as ASD3212 & ASD 3213 or Rampart 3200. In most of the cases controllable pitch propellers are selected when the tug is consisting also from FiFi 1 notation. Finally, ASD's designs are made based on the type of operation they will operate, and therefore significant differences are addressed concerning their design as well as their equipment. Therefore, ASD's are mainly divided in the following categories.

ASD's Consisting from Bow Winch



In this category, ASD's are capable to operate as a forward tug and therefore to proceed in a Bow to Bow operation, as it is indicated in Figure 62, while as a stern tug, they will offer Stern to Bow operation as it is indicated in Figure 60. These reverse tractor tug are not capable to offer any other type of operation, since they consist only from a bow winch, while their stern in most of the cases will include a towing hook. However, this is not considered as a disadvantage, since these tugs were mainly built for operating as a forward tug in a Bow to Bow operation, and therefore they are characterized from state of art underwater hulls with sophisticated skegs, aiming to improve the directional stability of tug especially when sailing astern.

ASD's Consisting from Both Bow & Stern Winch



The second category of ASD's, consist of tugs with two winches, located at the bow as well as at the stern. Therefore, they are capable to operate as a forward tug by providing two different types of operations; either Bow to Stern (as a conventional tug) as it is indicated in Figure 61 or Bow to Bow, as it is indicated in Figure

62. On the other hand, as a stern tug, they are capable to proceed in a Stern to Bow operation as it is indicated in Figure 60.

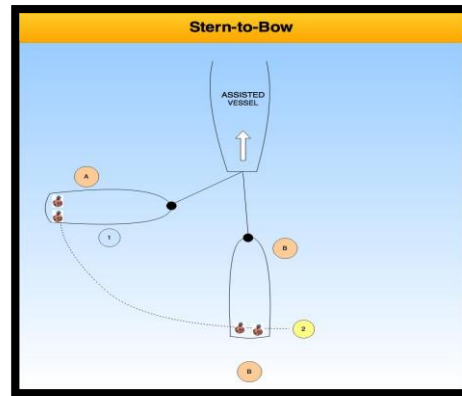


Figure 60: Stern to Bow Operation ASD Tugs, Own Composition

This category of azimuth stern drive tugs, also known as “Pure ASD tugs”, refers to ASD’s designs which vary compared to the first category. In that case, ASD’s are not built to provide exclusively Bow to Bow operations and therefore, significant variances concerning their underwater hull might occur. Hence, these tugs require high levels of directional stability also in cases where the tug is sailing forward, for achieving high levels of efficiency whenever the tug is operating as a pure conventional tug by using its stern winch.

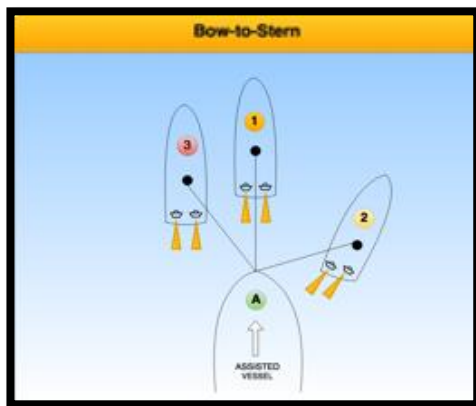


Figure 61: Bow to Stern Operation ASD's, Own Composition

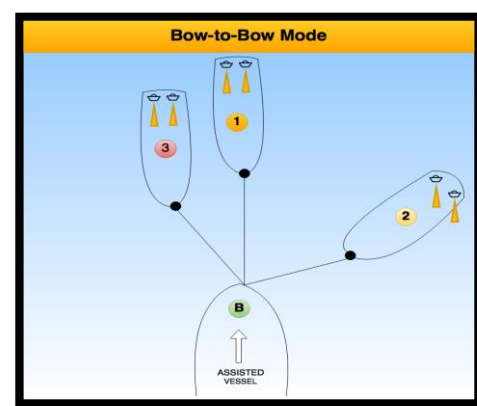


Figure 62: Bow to Bow Mode Operation ASD's, Own Composition

Bow to Bow Vs Bow-to-Stern Operations

Bow to Bow operations are influenced from the various underwater hull designs of the tug. The various skeg concepts especially for ASD's, lead to entirely different behavior and therefore the limitations and capabilities of harbor tugs vary considerably. Therefore, the assessment of KST fleet effectiveness requires the investigation towards the influence of the various underwater hull concepts with their appendages. In cases where the tug is in a parallel line with the assisted vessel, combined with good environmental conditions, the efficient underwater hull of the tug will offer, high levels of sailing astern capabilities. However, in cases where the tug is at the side of the assisted vessel and is attempting to move on the other side, fulfilling pilot commands for steering the assisted vessels, the impact of underwater hull can be crucial.

Special attention should also be given on the assisted vessel speed, in order the vessel not overcome the tug, leading to capsize phenomena. It is also critical the assisted vessel to have reduced speed, when entering the port, since the higher their speed is, the more power will be required for the tugs for moving their body and pulling at the same time efficiently the ship. ASD's require high levels of safety, explaining the reason that

Bow to Bow operations are so favorable. The propulsion units are on the opposite side of the assisted vessel bulbous bow, and therefore in any case of a risky situation, they can release the towline and move directly away from the assisted vessel. However, high levels of tug's effectiveness results towards Bow to Bow operations are only possible to be achieved with sophisticated designs of the underwater hull, and therefore special attention is given on skeg presence. The skeg concepts which have already been analyzed in subchapter 3.4.4, are capable to guarantee the application of the required steering forces, in the most efficient way, even at a high-speed ratio.

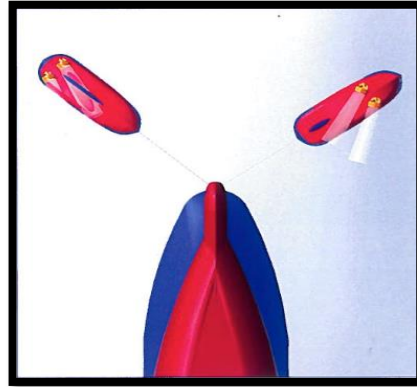


Figure 63: Bow to Bow with Skeg Design 3 VS Skeg Design 1, (C. H. Hensen 2016, 7)

In Figure 63, two different skeg designs are indicated. In the first case (left side), the ASD consists of a skeg lying further aft, (subchapter 3.4.4-skeg design 3) while, for the second case (right side), the shape of the skeg belongs to the normal ATD concept, (subchapter 3.4.4-skeg design 1). Therefore, it is evident that for the case of the tractor tug, the negative lift force to be created from the wash effect by hitting the skeg will be less, since the distance among the thrusters and the skeg is larger. On the other hand, for the case of the ASD the wash effect impact will be larger, and thus the ASD's are enforced to give more power for turning towards the desired direction, compared with the tractor. However, in case that the ASD was consisting from an alternative skeg design, its behavior would be different. For this reason, in Figure 64 & Figure 65, the skeg design type 3 and skeg design type 4 from subchapter 3.4.4 among the ASD tugs, would be compared. In Figure 65, the tug consists of a flat lengthy vertical skeg located at the bow of the vessel, with relatively large distance from the propulsion units. Hence, the wash from the thrusters does not hit the skeg and, eventually the intended turn is not influenced. On the other hand, in Figure 64, the skeg is lying further aft, thus a negative wash effect will occur. Therefore, it can be concluded that ASD's with skeg design (type 4) are expected to be more efficient towards Bow to Bow operations. (C. H. Hensen 2016, 7)

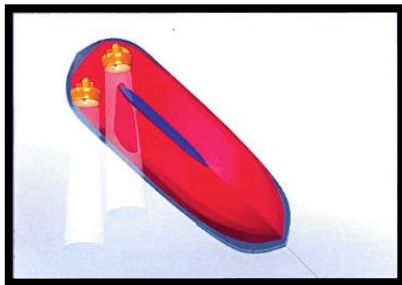


Figure 64: Skeg Design 3 VS Wash Effect (C. H. Hensen 2016, 7)

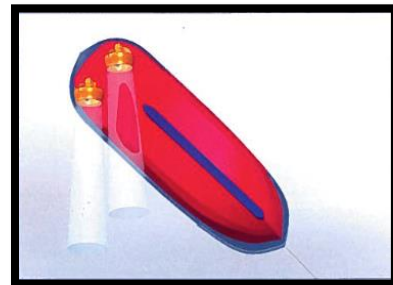


Figure 65: Skeg Design 4 VS Wash Effect (C. H. Hensen 2016, 7)

Furthermore, Figure 66, Figure 67, Figure 68 give also a clear indication that even at various azimuth angles there is always a negative wash effect result. On the other hand, if the forward tug was a tractor, this phenomenon would be significantly less. Starting with figure 33, the tug master has altered the azimuth thruster

angle for moving to portside, by avoiding being in the same centerline with the bow of the assisted vessel. This phenomenon normally will take place in cases of loaded bulk carriers or tankers (Group B). The pronounced bow of these vessels due to high levels of pressure, tends to create large waves, influencing tug approach for making the towline connection. Therefore, tug masters tend to approach the vessel either at portside or starboard, for maintaining more steadily the tug during the intermediate step. At the same time, the draught as well as the lateral surface of the underwater concept of tug is crucial. Since the skeg of this ASD lies further aft, the portside thruster hits the skeg and eventually the tug is not achieving the intended turn efficiently. Consequently, more power is required leading the tug to reach the desired position, while this is the moment where the thrusters hit the skeg almost at right angles.

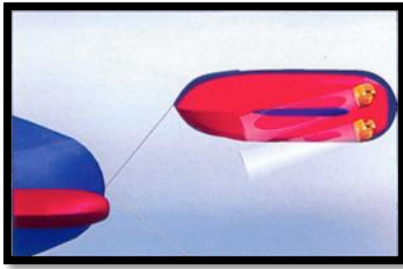


Figure 66: Bow to Bow VS Negative Wash Effect Angle A, (C. H. Hensen 2016, 8)

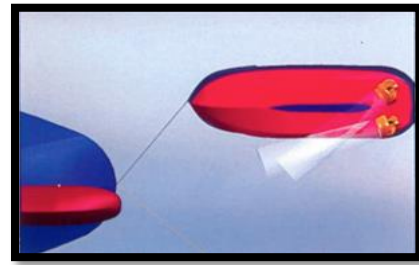


Figure 67: Bow to Bow VS Negative Washing Effect Angle B, (C. H. Hensen 2016, 8)

As it is indicated in Figure 67 & Figure 68, this situation can be significantly risky, since the tug speed will be reduced and can lead the tug hitting the bow of the assisted vessel. Finally, Figure 69 indicates the most efficient way, for reaching the desired position. However, in that case higher amount of time is required, since one thruster is set to stern while the second one to portside. Additionally, special attention is required because the portside thruster tends to create a turning moment which is opposite to the tug desired turn.

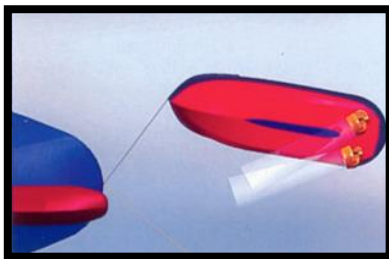


Figure 68: Bow to Bow VS Negative Washing Effect Angle C, (C. H. Hensen 2016, 8)

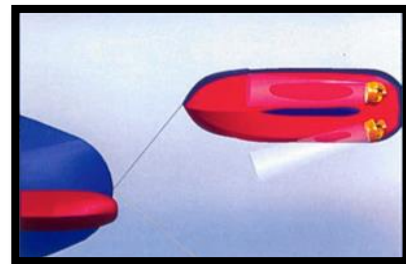


Figure 69: Bow to Bow VS Negative Washing Effect Angle D, (C. H. Hensen 2016, 8)

Approaching the bow of the ship having Headway

In Figure 76, an ASD tug is approaching the vessel with two different methods. Starting with Bow to Bow operations the tug is in position B. In case where the assisted vessel belongs to Group A (Car Carriers/Containers), the tug will be able to approach the vessel in position B-2. Since this vessel consist of a slenderer bow, higher pressure is expected more sideways (back from the bow), while near the bow it is more likely undistributed water flow to occur. On the other hand, if the assisted vessel belongs to Group B (Bulk Carrier/Tanker), the tug is more expected to approach the vessel from position B-1, due to the higher amount of pressure at the pronounced bow of the ship. Alternatively, for fully loaded Tankers or Bulk carriers, tugs are also capable to approach safely from position C. In that case, they approach the vessel from sideways, due to the significant amount of pressure at the bow of the vessel, and eventually they will end up again in position C-1. If the assisted vessel was a loaded Car Carrier or a Container vessel, even in the case of the sideways approach, the slenderer bow of the vessel would allow the tug to end up in a more forward position C-2. Last

but not least, the tug will be rarely in position A, since this position can be risky. Therefore, it will take place only in cases where tug master has a clear view of the ship, while it is suggested to take place only with smaller vessels and good environmental conditions. Finally, a second type of operation is also indicated, in case that a tug is operating “conventionally”. Therefore, it is vital to compare the effectiveness of these two methods for a forward tug. (C. H. Hensen 2016, 14)

Bow-to-Bow & Stern-to-bow for an ASD

Bow to Bow operations among an ASD and a tractor tug, are characterized from the same disadvantages. In both cases, tug is enforced to move its hull through the water and therefore its underwater profile is high of importance. The larger the resistance is, the more power is required and therefore less power is available for the towline forces. Additionally, in cases where ASD’s operate “conventionally”, they are capable to generate higher steering forces due to the generated hydrodynamic forces on the hull. Additionally, the speed of the vessel is vital for the comparison of both methods. For a range of speed around 7 knots the effectiveness of azimuth stern drive tugs will be higher, when they operate as conventional tugs (stern winch), since they are more capable to offer steering forces by using their hull. On the other hand, in cases where the speed is decreased then the steering forces are applied identically either by towing from the bow or stern of the tug. However, as for all the ports of operations of KST, the assistance will take place at speeds below 7 knots. Therefore, Bow to Bow operations are preferred since they are capable to guarantee increased levels of safety.

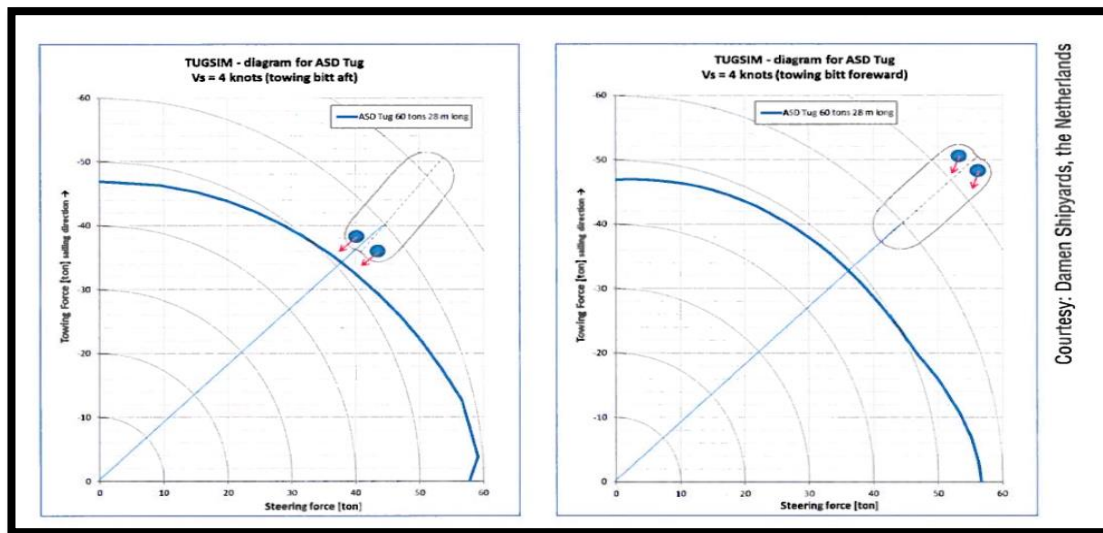


Figure 70: Tug Sim Diagram for ASD2810, Forces for Bow to Bow VS Bow to Stern at 4 knots (C. H. Hensen 2016, 20)

In Figure 70, two diagrams are shown as a result of the tug simulator for the evaluation of steering and braking forces from the Damen Shipyard. Both refer to an ASD2810, (28 meters long and 60 tons of BP) for the same speed (4 knots), while the types of operations are Bow to Bow and Bow to Stern. The steering forces are shown in x-axis while braking forces are shown in y-axis. It can be concluded that in both types of operations the forces (steering & braking) are of the same efficiency levels. Tug master is capable to operate either stern or bow first at the same efficient level. However, in terms of safety, Bow to Bow operations should always be preferable. On the other hand, in Figure 71 the amount of forces will vary. The tug type is again an ASD2810 under the same types of operation (Bow to Bow & Bow to Stern). In that case the tug simulator indicates the steering and braking forces when vessel’s speed is equal to 6 knots.

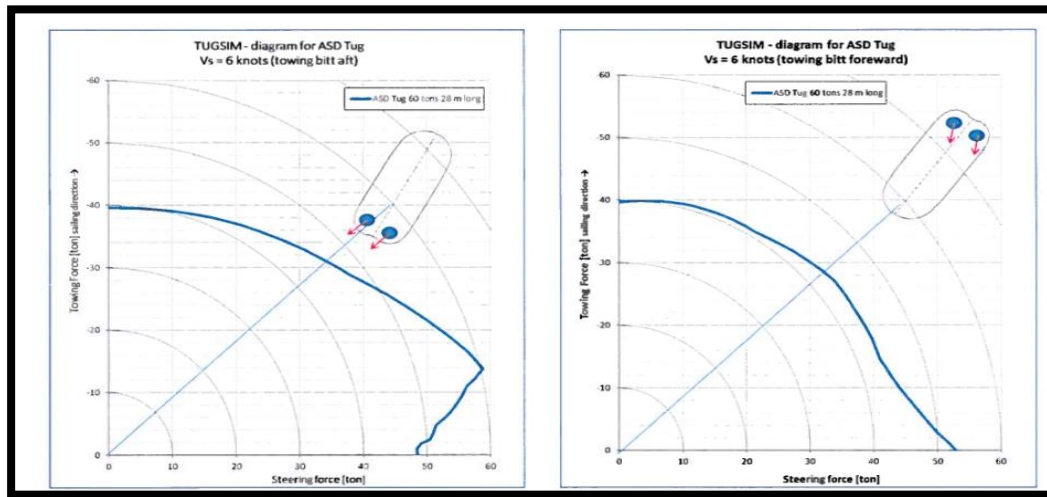


Figure 71: Tug Sim Diagram for ASD2810, Forces for Bow to Bow VS Bow to Stern at 6 knots, (C. H. Hensen 2016, 20)

From Figure 71 can be concluded that the Bow-to Stern operation effectiveness is improved by 15 to 20 % towards the steering forces at 6 knots. On the other hand, the braking forces will remain at the same level for both cases. Additionally, one extra observation is that when a tug is operating in a Bow to Bow operation, the maximum towline force while will be 5 to 10% less, as a result of the underwater hull with appendages (C. H. Hensen 2016, 19). The efficiency reduction occurs due to the wash effect from the propellers, which hits the underwater hull. One additional remark among the two methods, refers to the pushing assistance during vessel's berthing. In a Bow to Bow operation, the tug is more capable to offer pushing assistance more quickly. The second important remark refers to the efficiency of the tug in narrow passages. In this case, Bow-to-Bow operations are preferred since, the ASD propellers are in a faraway distance from ship's hull and therefore no negative wash effect will occur. Subsequently it can be concluded the pulling force for each type of operations is aligned with vessel's speed. Emphasis also to be given on the special maneuver to take place for controlling the vessel at each port. Therefore, multiple factors must be considered simultaneously for a solid evaluation of tug's behavior.

Bow to Stern VS Stern to Bow Among ASD & Tractor (VOITH)

In this subchapter, two different tug types will be compared. Again, by using the tug simulator program from DAMEN shipyards, the goal is to assess tug's performance concerning steering and braking forces for both direct and indirect towing methods. More information concerning direct & indirect towing can be found in subchapter 4.4. The most important distinction among the two modes is related with tug position. In the case where the tug and the towline are in the same line, then direct mode is applied. On the other hand, if the tug and the towline have an angle in-between, the tug is making use of its underwater hull for generating higher level of steering and braking forces compared with its total BP. This is the reason where for escorting duties, and therefore at higher speeds, well designed underwater hulls are required, with the presence of sophisticated skegs, capable to increase the lateral area and therefore the applied forces. The first type refers to an ASD, reverse tractor tug-ASD3110 from DAMEN with 31 meters' length and 40 tons of BP. KST fleet consists of one tug belonging to this family (SMIT BELGIE), as it has already been explained in subchapter 3.6, however instead of 40 tons is equal to 53 tons of BP. The second type refers to a tractor tug-Voith Schneider 2910 with 36 tons of BP. Both tugs are evaluated towards bow to Stern (forward tug) and Stern to Bow operations (stern tug) at 4,6 and 8 knots of speed. Starting with Figure 72, both tug types are assessed at 4 knots speed.

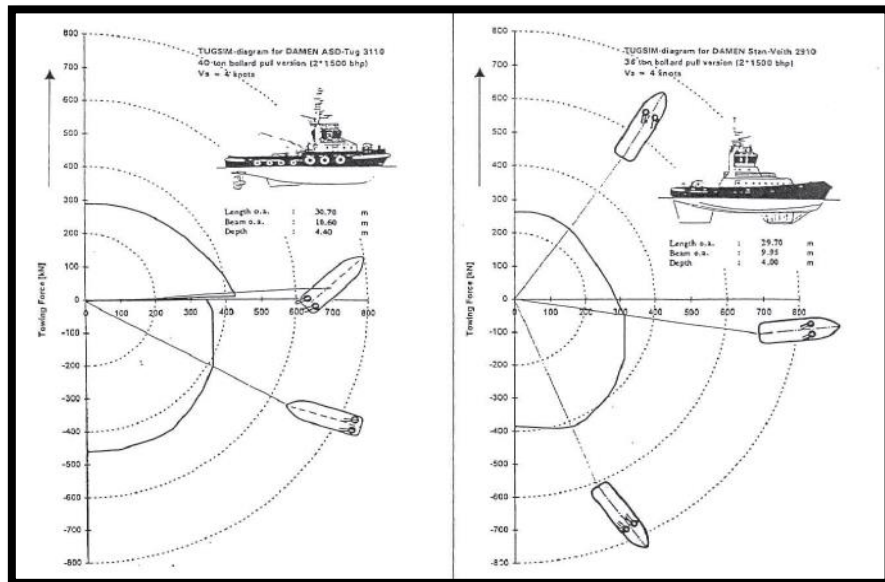


Figure 72: Tug Sim Diagram for ASD3110 VS Voith Schneider at 4 knots (Henk 2003, 59)

At speed equal to 4 knots, there is no reason for proceeding in indirect towing mode. Therefore, both tugs will apply towline forces only in direct mode. On the other hand, for Figure 73 & Figure 74, tugs proceed in both direct and indirect mode for applying towline forces. In Figure 73, it is evident that ASD's is significantly more efficient as a forward tug, capable to apply higher crosswise forces for handling the merchant vessels. For the ASD in Bow to Stern operation, the highest steering force is 45 tons of BP while for the Voith it will be below 30 tons. Additionally, for Stern to Bow operations, in direct mode, both are characterized from the same efficiency levels. (C. H. Hensen, TUG USE IN PORT - A practical Guide , p vii 2003, 61)

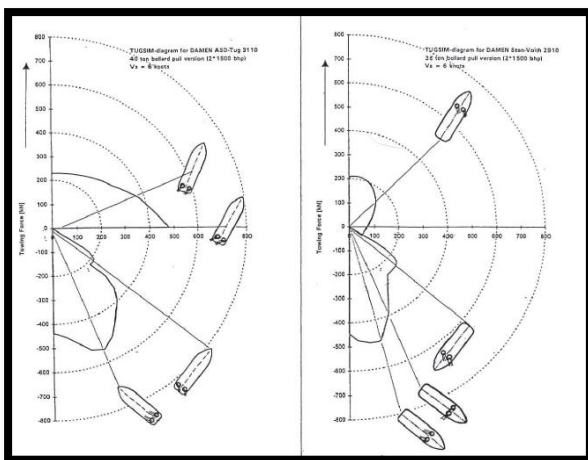


Figure 73: Tug Sim Diagram for ASD3110 VS Voith Schneider 6 kn (Henk 2003, 59)

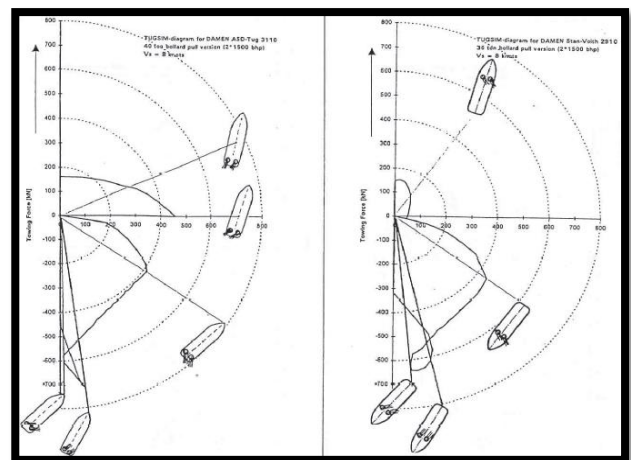


Figure 74: Tug Sim Diagram for ASD3110 VS Voith Schneider 8 kn, (Henk 2003, 59)

In Figure 73 & Figure 74, the assisted vessel speed is increased at 6 and 8 knots respectively. Starting with Figure 73, it is evident that the applied steering forces for the Voith Schneider are decreasing quickly for Bow to Stern operation. On the other hand, for the ASD tug the steering forces as a forward tug are decreasing in a much slower rhythm at 6 knots, while even at large towing angles, the steering results are significantly high. The same situation takes place also at 8 knots but a lower amount of steering forces will occur. Additionally, Figure 74 justifies that ASD's are operating more efficiently for providing steering forces at Stern to Bow operations during direct mode, while for indirect mode the efficiency results will be significantly lower. On the other hand, Voith Schneider has improved behavior during indirect mode, for applying steering forces.

Both tugs are capable to provide high levels of braking forces during direct mode at 6 knots and at small towline angles.

Finally, in Figure 74, both tug types are efficient during indirect mode towards steering forces at 8 knots. Additionally, high levels of braking forces are applied from both types in direct mode at a small range of towline angles, while a minor change among direct and indirect mode, with a minor change of towline angle, shows that tractor tugs are generating more quickly higher values of steering forces, compared with ASD's. (C. H. Hensen, TUG USE IN PORT - A practical Guide , p vii 2003, 61)

3.8 Tug KST Fleet Analysis - Survey

In subchapter 3.7, KST fleet was divided based on the types of operations to be offered. Therefore, for the assessment of KST fleet, the effectiveness of all the pre-mentioned methods under a range of speed for both intermediate and towline connection modes was required. However, the entire fleet of KST was not possible to be fully analyzed by using diagrams from the tug simulator. The reason was that KST is consisting from so many different tug types, (19 in total), and therefore it was totally impossible to retrieve confidential information from all the shipyards for assessing tugs efficiency under various circumstances and multiple speeds, for the applied towline forces.

Each shipyard, normally starts the tug design procedure, by proceeding in a CFD analysis; afterwards the construction of a smaller scale tug model is necessary, for evaluating tugs behavior under various conditions in a basin, where the final design occurs. The diagrams which were indicted from the tug simulator, in subchapter 3.7, where the only to be retrieved, and only from DAMEN shipyard. Therefore, for the needs of this thesis project, a special survey was more than required, for comparing the entire fleet and for all the types of operation, among 2 to 7 knots. Hence, the main core of that survey was a construction of sophisticated questionnaire, which should be filled in from every tug master in KST. At the same time, special attention was given to tug masters with many years of experience towards the multiple tug types, for providing more objective scoring results.

Additionally, each tug type was evaluated with multiple questionnaires, leading to a solid investigation by avoiding subjective opinions. In total, for the needs of the thesis project, two months of travelling were required, combined with 2 weeks of sailing and staying on board. The opportunity to sail on board allowed a general interview with every single tug master; he could fill in the questionnaire, and afterwards to explain his opinion, concerning the provided answers-scoring, as a result of tug's capabilities and limitations. Finally, 100 questionnaires were collected, within a period of 2 months while 52 different tug visits were made, in a fleet of 64 tugs, offering the opportunity to assess KST fleet in the most efficient way.

Survey Framework-Quantitative VS Qualitative Method

KST consists of 19 various tug types with various underwater hull concepts and appendages. Thus, tug's behavior differs depending on the type of operations and the vessel to assist. The construction of a tool capable to indicate the optimum tug types for each port, depending on the market and fuel cost for the minimization of KST costs, was requiring the investigation of the entire fleet of the company. Therefore, as it was explained in the introduction of this subchapter a special survey took place, for assessing KST fleet capabilities and limitations, as a result of the fundamental insights of each tug type, which are already analyzed in subchapter 3.4.

In general, surveys can be characterized either from a qualitative or quantitative perspective, while basic questions are considered as the main tool for a qualitative research. For this reason, the most efficient way to express the entire amount of all these questions is by constructing a sophisticated questionnaire. After deep investigation concerning the type of questions for the survey of KST fleet, closed type of questions was the most ideal solution to be selected. The reason was that closed type of questions require limit answers, while at the same time these types of questions are mainly used in a quantitative survey. At the same time, the researcher is capable to quantify the results, by using various statistical methods, while participants can provide possible answers.

Based on W. Dilthey, quantitative methods are mainly used in applied sciences for explaining multiple scientific phenomena. On the other hand, qualitative method is used for humanitarian and sociological sciences, for the understanding of those phenomena. Therefore, quantitative method represents the interaction model among cause and result, while qualitative method represents the explanation model, known also as “example model”. Consequently, quantitative method is used for inventing and regulating rules, while qualitative method is used for describing and analyzing an event. ([https://repository.kallipos.gr/bitstream/11419/5818/3/02_chapter 01.pdf](https://repository.kallipos.gr/bitstream/11419/5818/3/02_chapter%2001.pdf) n.d.). For the needs of KST survey, it was required to proceed in a combination of quantitative and qualitative survey.

Even if the survey was based on qualitative data, since each tug master was expressing his own opinion concerning tug effectiveness levels under various aspects, quantitative methods were also considered for illustrating evocative results through the qualitative survey. At the same time by using quantitative approaches, it was possible to provide essential conclusions with a high percentage of confidence. (Abeyasekera 2017, 2). Therefore, a quantitative approach was necessary for providing a data summary based on tug master’s opinions, and that was the main reason that the same questionnaire was used in each case, including certain closed type questions with scoring. In that perspective, the usage of quantitative approach through the qualitative survey, was vital since, the qualitative results were collected under a structured way. Additionally, the data structure was the main key for KST survey, capable to guarantee the proper analysis towards the qualitative data, by using the proper quantitative method. For this reason, attention was given to the proper data structure, in order the main questions to be addressed through the survey, leading to the proper visualization of the results.

Eventually the last part to be regulated, refers to the followed procedure for extracting the required information through the survey, while two possible methods through the quantitative approach were possible to be used; ranking or scoring. Even if the method of ranking provides the ability to judge (better or worse), it was not considered as the optimum method, for the KST fleet study case. The reason was related with the unavailability of providing reasonable results with a quantitative mean, since there is not a fixed distance among the different answers.

Consequently, the final information by using the ranking method is not capable to guarantee the expected result for the scope of this thesis project. On the other hand, scoring was capable to lead in a numerical meaning, since each of the following key words examples i.e. “Best” or “Poor”, is always connected with a ranking. For this reason, in KST fleet effectiveness study case, it was decided to construct a questionnaire with closed types of questions with the ability to be answered by using each one of the scores as they are indicated

in Figure 75. Finally, it is obvious that each score is aligned with a specific rank and each tug master was capable to evaluate precisely tug capabilities and limitations by providing the correspondent score. At the same time, it was then possible for the company and the researcher to proceed in multiple conclusions with quantitative mean. This explains adequately the reason that quantitative approach was used for extracting results from qualitative data. (Abeyasekera 2017, 5)



Figure 75: Scoring Scale Regarding KST Fleet Effectiveness (Abeyasekera 2017, 5)

3.9 Chapter Conclusion – Data Structure Survey

Harbor tugs efficiency is entirely linked with their main capabilities and limitations concerning the type of operation to be offered. Emphasis was already given towards Bow to Bow operations, where tugs are enforced to sail astern, and therefore good directional stability as a result of a well-designed hull is required. The evaluation of KST fleet concerning all the possible types of operations is crucial, and entirely linked with the various types of vessels to be assisted, due to the various amount of pressures to be created at the bow of the assisted vessel as a result of its bow design, speed, draught and load (laden/loaded), leading eventually in various wave distributions. Since the pressure field in each case will vary, the resulted forces and turning moments will also vary.

Hence, KST fleet evaluation will take place for Group A, referring to Car Carriers, Containers, Passenger ships, and for Group B referring to Bulk Carriers and Tankers. The special survey which took place during this thesis project for a solid evaluation of KST fleet, and will be fully analyzed in chapter 4, is aligned with a proper analysis of all KST ports of operations towards the number and the type of merchant vessels, for the entire year of 2016. In that perspective, minor changes are expected for the year of 2017 and therefore, KST will be able to align more efficiently KST fleet effectiveness levels for the various ports, and all possible types of operation concerning every possible tug reallocation. The main fields to be examined in the following chapter are the following.

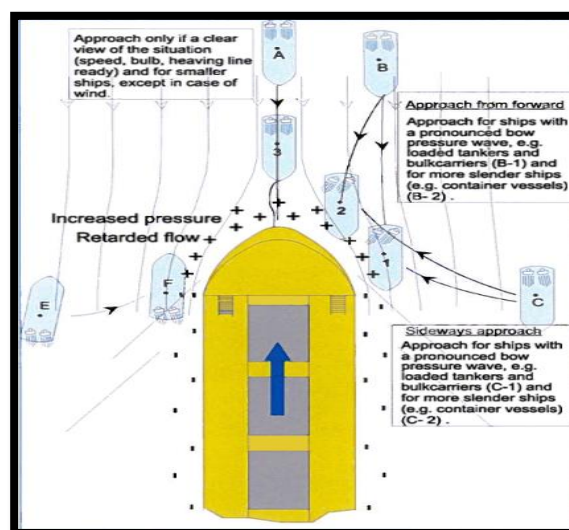


Figure 76: Various Methods of Approaching the Assisted Vessel for Towline Connection, (C. H. Hensen 2016, 13)

Course Stability

The first part of the questionnaire refers to the course stability of KST fleet. Even if this part is not influencing directly the assistance to be offered towards the assisted vessel, it was decided in cooperation with the researcher and the company to include some extra questions, concerning tugs course stability. Therefore, tug masters were also requested to provide answers related with the course stability in cases where the tug is sailing forward & astern for the range of speed among 3 knots and full speed.

Intermediate Step

The intermediate part is considered as the first vital part to be answered from tug masters concerning KST fleet effectiveness. As it has already been explained in subchapter 3.7, the intermediate step refers to the procedure where the tug is ready for making the towline connection. However, tugs underwater hull varies considerably and therefore depending on the speed, vessel to be assisted and the type of operation, tugs effectiveness will vary. Therefore, tug masters were requested to provide two different scores for all the possible types of operation, under the same range of speed, for assessing tug's ability to maintain their current position/course and manoeuvre efficiently when approaching the assisted vessel for making the towline connection, for both groups A & B.

Towline Connection

The same procedure takes place also for the towline connection. Tug masters were requested to provide again two scores, for the two groups, by evaluating tug effectiveness for maintaining its current position course, and manoeuvre when the towline connection is made for applying the requested steering and braking forces, towards all the possible types of operations, for both groups A, B.

Side Stepping

In this part, tug masters provided only one score. Side stepping capabilities for KST fleet was also essential to be investigated, since they can provide essential information towards the environmental conditions impact on tug's efficiency in the various ports of operations of KST.

KST Daily Operations Effectiveness

Fleet Analysis Survey Results – Ship Handling

In this subchapter, the main goal is to discuss and analyse the results from the survey concerning KST fleet. Therefore, the entire fleet will be discussed for its behaviour towards the course stability when sailing forward and astern. Afterwards, the intermediate step results will be discussed as well as the results regarding topline connection.

4.1 Course Stability

4.1.1. Sailing Forward

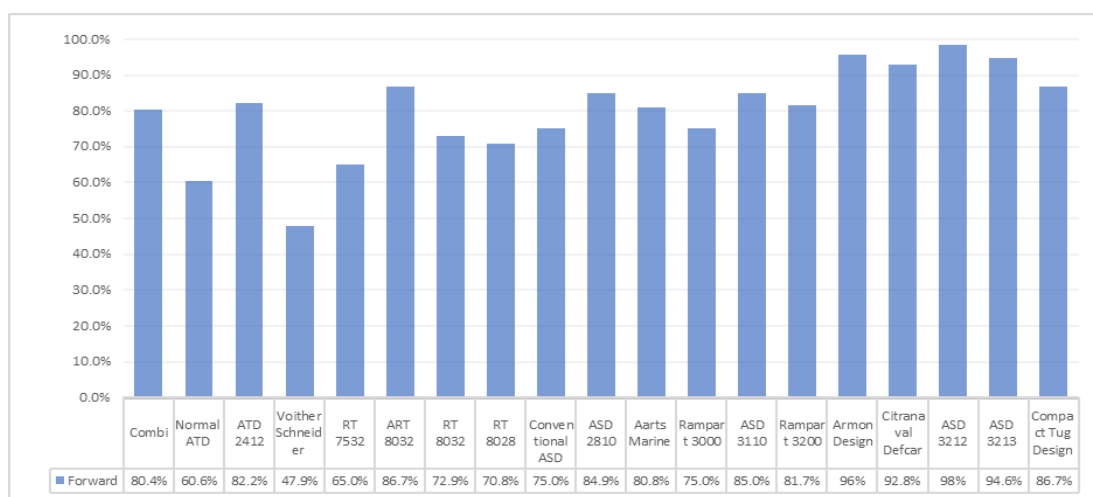


Figure 77: Sailing Forward KST Fleet Results

Course stability results when sailing forward regarding KST fleet are shown Figure 77. Starting with the Combi tugs they are characterized from high levels of course stability (80,4%), because of their underwater hull and design, which is made for pure sailing forward as it has been analyzed in subchapter 3.3.A.4 & 3.6. On the other hand, significantly lower scores are shown for tractors, especially for Voith Schneider's which are characterized from the lowest score (47,9 %). Normal ATD's have an average score (60,6 %) while the new concept of tractors, ATD2412 have the highest score, equal to 82,2 %. Among the rotor types, the most course stable tug was proven to be the ART8032, as a result of its improved double chine hull with over 15 % difference from the older versions and over 20 % compared to RT7532. Conversely, most of ASD's, are proven to have excellent levels of course stability. Starting with the Citrana val Defcar, a high score is expected due to its underwater hull; this tug type is designed to sail forward, and operating as a conventional tug and therefore, as a multi-tug (harbor and anchor handling/salvage tug), it is characterized from high levels of course stability (92,8 %), even in exposed areas with adverse environmental conditions. Additionally, all DAMEN

ASD tugs are characterized from high levels of forward course stability. Starting with ASD3212 which has a score of (98 %) and ASD3213 which has a lower score (94,6%), due to its more pronounced bow which adds more volume without the correspondent weight. ASD3213 was constructed for both harbor and terminal duties and, one of the major requests of customers was to increase the capacity of fresh water in the tug. Therefore, the design of more pronounced bow for fitting this extra capacity, led the tug to be more influenced in open sea with adverse environmental conditions. Concerning ASD2810, high levels of course stability occur as a result of its underwater hull with a score of 84,9%, while for ASD3110, (same underwater hull), its course stability is also equal to 85 %. On the other hand, for Robert Allan Design concepts, starting with Rampart 3000, the lack of skeg resulted in a less course stable tug (75 %), which is the lowest score among KST ASD's together with conventional ASD 's. However, the next generation of Robert Allan Design, Rampart 3200, with a large vertical skeg improved the course stability of tug considerably, (81,7 %). Finally, the Compact Tug Design is also evaluated with a high score 86,7 %, while Aarts Marine concept was evaluated with a score 80,8 %, which is expected since this tug type is possible to combine both harbor and terminal duties.

4.1.2. Sailing Astern

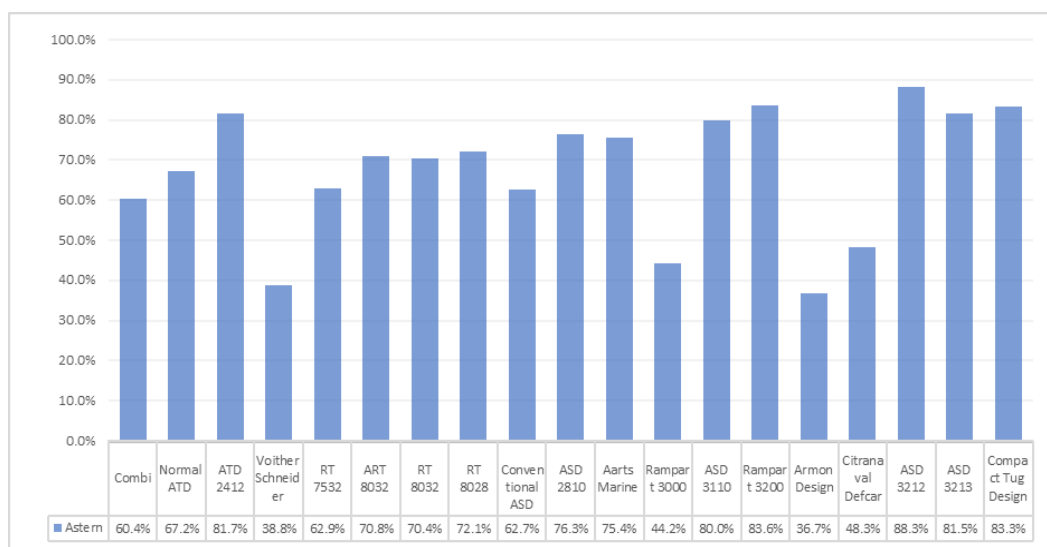


Figure 78: Sailing Astern KST Fleet Results

Significant variances concerning the course stability results when sailing astern for KST fleet are shown in Figure 78. Starting with ASD's with improved underwear hull and sophisticated skegs, they are evaluated with significantly high scores. The ASD types, Compact Tug Design, ASD3212, ASD3213 are evaluated with scores over 80%. On the other hand, for Armon Design, Citrana val Defcar and Rampart 3000 the course stability results are tremendously low. Starting with Citrana val Defcar, which is evaluated with a score equal to (48,3 %) as a result of the open aft deck. The tug is not designed for sailing astern and therefore its course stability is poor. Especially in cases of speeds over 5 knots the stern tug is filling in with water, leading to a change of center of gravity point, and hence to stability issues. In cases where the tug continues to sail astern, its stern is sinking even further, a situation which can be risky.

Moreover, Rampart 3000 is also evaluated with a low score (44,2%). The lack of large skeg makes this tug incapable to sail astern properly. Tug masters prefer to sail astern with this tug till the speed of 7 knots, since after that point the tug is not "obeying" tug master's orders, and hence they are continuously busy for maintaining the desired direction. Lastly, Armon Design has the lowest score among the entire KST fleet. This

tug type is considered as overpowered, and demands massive experience towards the harbor towage operations. Its underwater hull concept leads to a course unstable tug even at speeds higher than 5 knots and for this reason, is evaluated with a score of (36,7 %). On the other hand, for the tractors, the lowest score (38,8 %) refers to Voith Schneider's, while normal ATD's consist of score slightly above average (67,2 %). ATD's 2412 are characterized from the highest score among all tractor types (81,7 %). Finally, rotors are characterized from respectable results with scores over (70 %), except from the first generation, RT7532 which has a score equal to 62,9%.

4.2 Intermediate Step

4.2.1 Bow to Bow Group A VS Group B

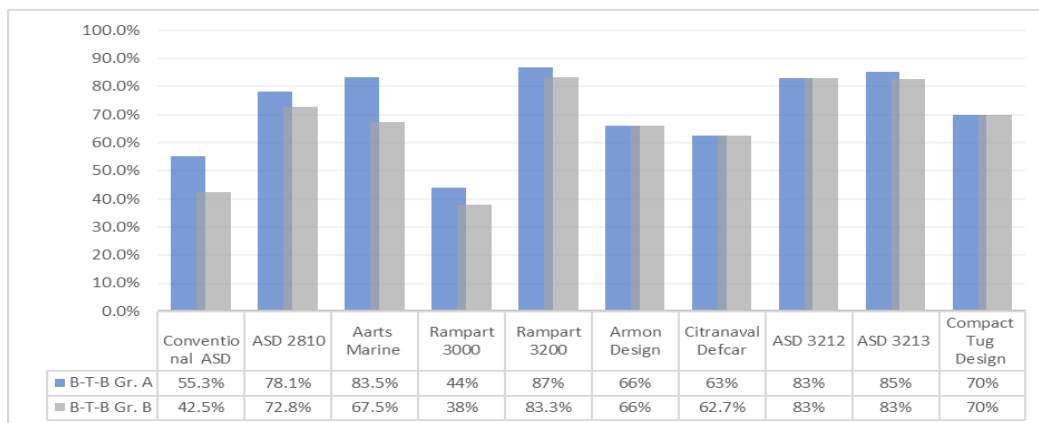


Figure 79: Bow to Bow Group A vs B KST Fleet Results for Intermediate Step

Starting with the first type of operation during the intermediate step, tug's bow is approaching vessel's bow for making the towline connection. In Figure 79, KST tug types are evaluated towards Bow to Bow operations for both groups A, B. The survey proved that the most efficient type towards bow to bow operations are Rampart 3200, ASD3212 & ASD3213, with scores over 80% for both groups. Additionally, Aarts Marine type is evaluated with a high score for group A, however its score towards group B is almost 20 % lower, due to the higher-pressure levels, which influences its bulbous bow.

Moreover, average scores characterize the conventional ASD's, Armon Design and Citranaval Defcar concept. Emphasis to be given especially for Citranaval tugs, which will never proceed in intermediate step at speeds higher than 5 knots. It is evident that this tug is not ideal for bow to bow operations and therefore it is better to operate as a stern tug for higher safety levels or in Bow to Bow operations with speed less equal or less than 5 knots. Additionally, the directional stability of Armon Design suffers from low score levels, a situation which can be critical. For this type the restriction is even higher, since the tug masters always should be in close communication with pilots, and proceed to the intermediate step in a Bow to Bow operation, only when the vessel's speed is 4 knots.

Finally, the tug type with the poorest results is Rampart 3000. In cases where the tug must sail astern in speeds over 7 knots, it is characterized as unstable and therefore it is better to operate as a stern tug in a stern to bow operation. The same low scores are also observed for conventional ASD in the case of Bow to Bow for group B. Finally, for bow to bow operations among the two groups, it is proved that for the most of tug types there is a percentage reduction around 5 %, while there are also types without any actual score variance.

4.2.2 Bow to Stern Group A VS Group B

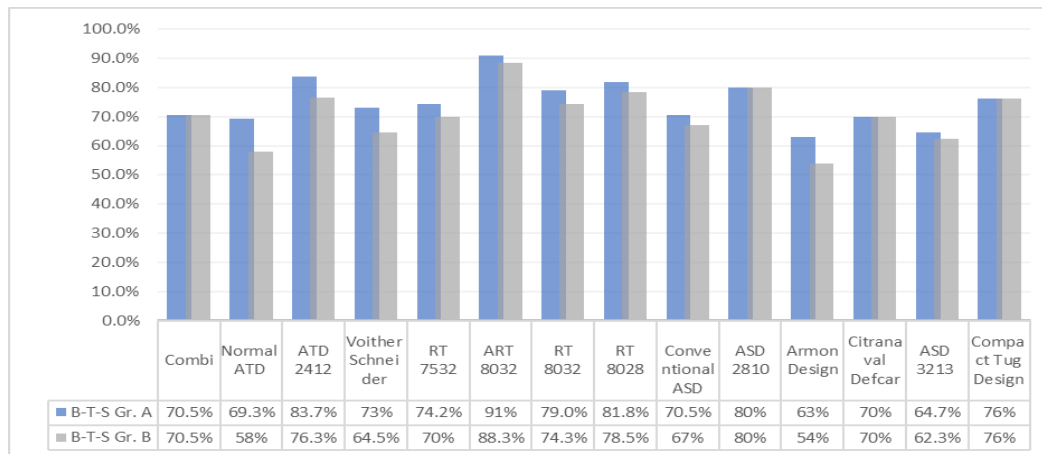


Figure 80: Bow to Stern Group A vs B KST Fleet Results for Intermediate Step

The next type of operation during the intermediate step refers to Bow to Stern operations. In this case the tug is approaching its stern towards the bow of the vessel for making the towline connection. In Figure 80, it is proven that ATD's, are the most optimum types for this type of operation. Starting with the ART8032, it is evaluated with a score of 91 % for group A, and with a slightly less score, 88,3 % for group B. The rest rotor types are also assessed with high scores (over 80 %), except from the first generation, which was proven to be less efficient, and eventually the scores for this type are in-between 70 % & 75 %.

On the other hand, lower results occurred for the Voith Schneider and for the first generation of ATD's. The presence of the single skeg at their stern was proven to be a drawback, affecting considerably their approach to the assisted vessel. This explains the lower scores, where for the case of Voith Schneider is equal to 73 % for group A and 64,5 % for group B, while Normal ATD's are evaluated with the same scores as Voiths with a slight reduction equal to 4 %. Combi tugs high scores are expected since they are made for operating in Bow to Stern operation, and hence their score is equal to 70,5 %, while, Conventional ASD's, with the same underwater hull concept were also evaluated with a score equal to 70,5 %.

From the rest ASD tugs, the highest scores refer to ASD2810 with a score equal to 80 %, as well as to Compact Tug Design concept with a score equal to 76 %. High scores characterize also Citranaval Defcar which is equal to 70 %. The lowest scores, 63 % for group A and 54 % for group B refer to Armon Design. Consequently, for Armon Design so far it is proven that it is capable to work under limitations in bow to bow operations, while at the same time average score occurred for bow to stern operations.

4.2.3 Stern to Bow Group A VS Group B

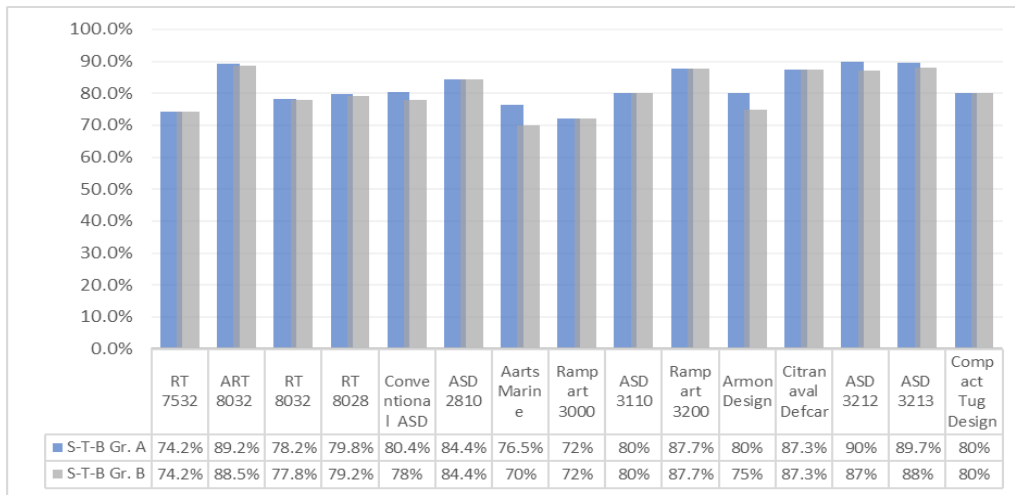


Figure 81: Stern to Bow Group A vs B KST Fleet Results for Intermediate Step

The third type of operation to be analyzed refers to Stern to Bow operation. For this type, the tug tends to work as a stern tug, and therefore it approaches the stern of the vessel for making the towline connection by using its bow winch. In general, this type of operations is considered as significantly easier, compared with the pre-mentioned types, where the tug used to operate as a forward tug. The pressure levels are meaningfully lower, and therefore higher scores are expected for the majority of KST tug types. Starting with the rotors, from Figure 81, the resulted scores are exceeding 75 %, while ART 8032 is evaluated with almost 90 % efficiency for group A, and 88,5 % for Group B. These results occurred from the updated double chine hull concept of this tug type without the presence of any docking plates or fins. The variance among the ART8032 and the rest rotor types is equal to 15 %, while the types RT8032 & RT8028 have a minor score difference equal to 1,5 %. On the other hand, for ASD tug types of KST, it is evident that the highest scores refer to DAMEN shipyard concept referring to ASD3212 & ASD3213, with a score of 90% and 89,7% respectively. However, Rampart 3200 design is also evaluated as a very efficient tug with a score 87,7%. Moreover, high scores reflect also the efficiency of Citranaval Defcar with a score of 87,3 % for both groups, as well as for Compact Tug Design Armon Design & Conventional ASD's. which are considered to have a score of 80 % for Group A. Additionally, the lowest score refers to Rampart 3000 which is evaluated with a score equal to 72 % for both groups.

4.2.4 Stern to Stern Group A VS Group B

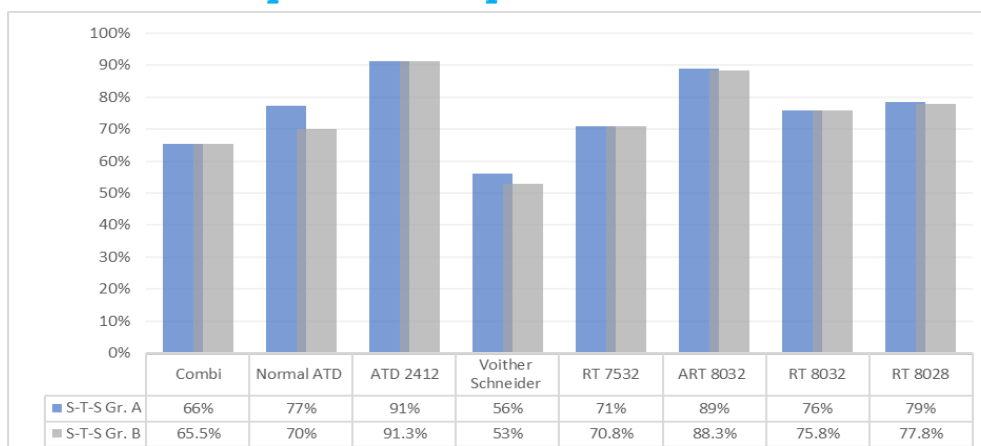


Figure 82: Stern to Stern Group A vs B KST Fleet Results for Intermediate Step

The last type of operation to be discussed concerning the intermediate step is related with Stern to Stern operation. In this case, the tug types to be discussed are mostly tractors, as well as Combi tugs which will offer harbor towage assistance only after using the gob rope system, for increasing the stability levels and the safety of the entire operation. Starting with the tractor tugs from Figure 82, it is obvious that the highest score refers to ATD 2412 twin fin and, was proven to be equal to 91%. The next type with the highest score once again is ART 8032 with 89%, while all the rest rotor types are also evaluated with significantly high scores, (over 70%). The lowest score for the tractor types characterizes Voith Schneider's, consisting of a score equal to 56% for group A, and 53% for group B. These low scores indicate the negative impact of the skeg at the stern of this tug type which makes the approach of the tug towards the assisted vessel more complex and therefore tug masters should be more concentrated, as well as to spend more power for maintaining the tug to the desired position for making the towline connection. The normal ATD, which has smaller skeg compared to VTS, it is proven to have higher results and its efficiency towards group B is improved by 17%, compared to Voith Schneider's. Finally, Combi tugs are also evaluated with a low score where for group A is equal to 68%, while for group B will be equal to 65,5 %. Combi tugs are expected to have low score towards this type of operation, since their propulsion is not capable to provide high levels of maneuverability when sailing astern.

4.3 Towline Connection

The second major part of the survey refers to the towline connection mode among KST tugs and assisted vessels. In this situation, the towline connection is already made and therefore, the aim of the survey is to assess KST tugs ability to maneuver and apply steering and braking forces towards the assisted vessel, as a result of their underwater hull and general design concept (tug type), which influence the COP point considerably, and eventually the levers x & y. Emphasis is also given especially on this part of survey and therefore, tug masters with generic experience to multiple tug types were selected, for providing various scores in a certain range of speed. Hence, in this subchapter the results for all the possible types of operations will be evaluated, depending on tug type's capabilities. Finally, it will be obvious that for the towline mode, the tug scores among the two groups are not expected to have large variances, since the tugs are in a larger distance from the propeller wash of the assisted vessel.

4.3.1 Bow to Bow Group A VS Group B

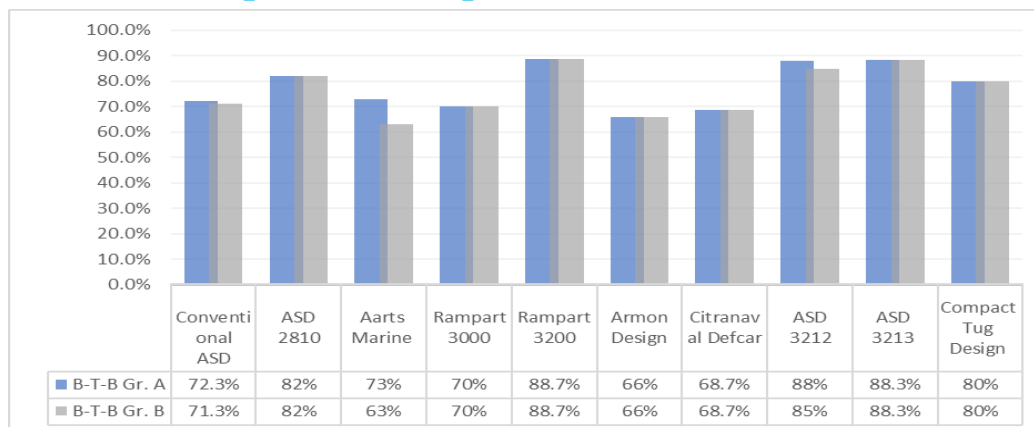


Figure 83: Bow to Bow Group A VS B KST Fleet Results for Towline Connection

Starting with Bow to Bow operations, and DAMEN tug types ASD2810, ASD3212 & ASD3213, from Figure 83, the scores are higher than 80 %, where ASD2810 is evaluated with 82% for both groups, and both ASD3212 & ASD3213 types with a score equal to 88% for group A. The underwater hull design of these types with the sophisticated skegs, shows that the lever x compared to lever y is considerably higher and therefore these tugs need lower amounts of power for compensating the forces at the COP point, leading to higher levels of bollard pull effectiveness. At the same time the type of skeg for these tug types (chapter 3.4.4 category 4),

offers increased levels of directional stability when sailing astern in a Bow to Bow operations, making these three types state of art tugs for this type of operation. Additionally, the highest score, refers to the new Robert Allan concept, Rampart 3200 which was evaluated with 88,7%, for both groups A & B. Its underwater hull, also consisting of flat vertical skag, (chapter 3.4.4 category 4), was proven to have exceptional results towards Bow to Bow operations, leading to high levels of steering and braking forces. Compact tug design is also evaluated with a high score, equal to 80% for both groups, which is expected since its hull also consists from a sophisticated skag. For the rest tug types, the scores are proven to be lower than 75 %. Starting with Conventional ASD's, it is evaluated with 72,3 % effectiveness results, while Aarts Marine with 73%, both for Group A. The lower score for Aarts Marine concept, compared to the rest tug types is expected due to the small skag, which is located further aft in a very close distance from the azimuth propellers, as it has already been explained in subchapter 3.4.4 - category 3, leading eventually to smaller steering and braking forces. The same results apply also for Rampart 3000 with the same underwater hull/skag, which was proven to have a score equal to 70% for both groups. Especially for Rampart 3000 a possible towline connection in a Bow to Bow operation at speeds higher than 7 knots, will not be ideal, since based on the survey it is characterized from results, significantly lower than 70 %.

Finally, the types with the lowest scores are the Armon Design as well as Citrana val Defcar. Both types should be involved in a bow to bow operation under specific conditions and after a proper discussion with the pilots. The weaknesses due to the underwater hull for Armon Design, make it risky to operate at speeds over 5 knots and for this reason tug masters evaluated this type with a score equal to 66% for both groups. Moreover, for Citrana val Defcar the score is 68,7%. The low score for this type is also expected due to the open aft deck, leading to several weaknesses for this type when sail astern. As soon as the speed exceeds 6 knots, the capacity of water filling in the aft deck is getting larger, making its stern to get immersed quickly. These extra tons of water in the aft deck make the center of gravity to change, leading to risky situations for the tug stability. Therefore, both Armon & Citrana val Defcar types should not be selected for a Bow to Bow operation, while as it will be proven in the following subchapters, they operate more efficiently either as a pure conventional tug, in Bow to Stern operation or as a stern tug in Stern to Bow operation for offering braking assistance.

4.3.2 Bow to Stern Group A VS Group B

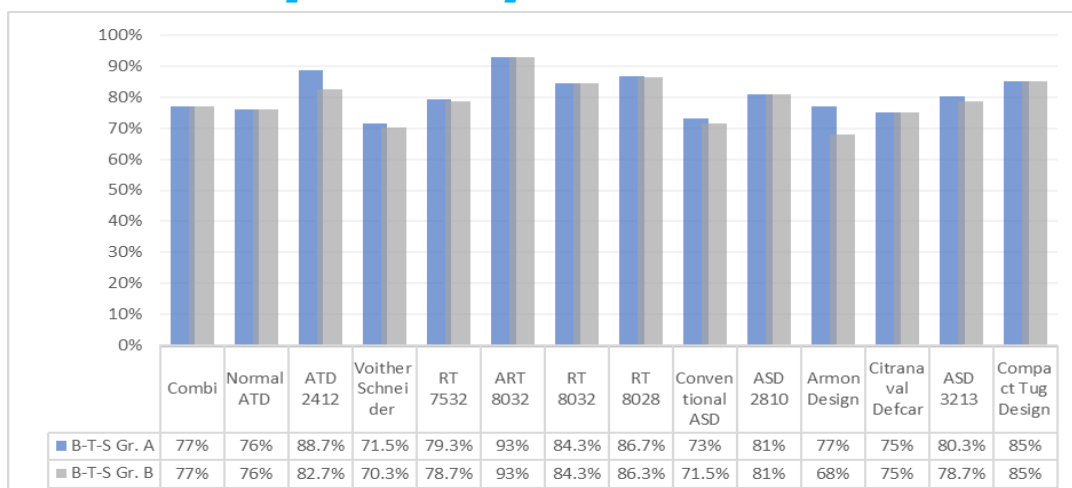


Figure 84: Bow to Stern Group A VS B KST Fleet Results for Towline Connection

The next type of operation to be discussed when the towline connection is made, for assessing KST fleet effectiveness towards their maneuverability and ability to apply steering and braking forces, is Bow to Stern

operation. Starting with rotor types, the ART8032 is considered again as the state of art of tug with a score equal to 91,3% for both groups. As it is indicated in Figure 84, the rotor types RT8032 & RT8028 are also evaluated with high scores, over 79% by proving the efficiency of this tug type to generate high levels of braking and steering forces. The reason that RT7532 is evaluated with 5 % less efficiency, compared with the rest rotor types is linked with distance among the stern towing point and stern thruster location; Hence the lever to be created, in this type of operation must be counteracted, which reduces the bollard pull effectiveness of this tug type. For the rest ATD types, the Normal ATD is evaluated with 76% effectiveness result, while Voith Schneider has a result equal to 71,5%. On the other hand, the new generation of tractor types, ATD2412 is proven to be an exceptional tug with a score equal to 88,7%. For the azimuth, stern drives, the type with the highest score is proven to be the Compact Tug Design, with a score equal to 85%. DAMEN tug concepts, ASD2810 & ASD3213 were also evaluated with high scores equal to 81% & 83% respectively. Finally, the types Armon Design, Conventional ASD's & Citranaval Defcar were assessed with lower scores in between 73% & 77%.

4.3.3 Stern to Bow Group A VS Group B

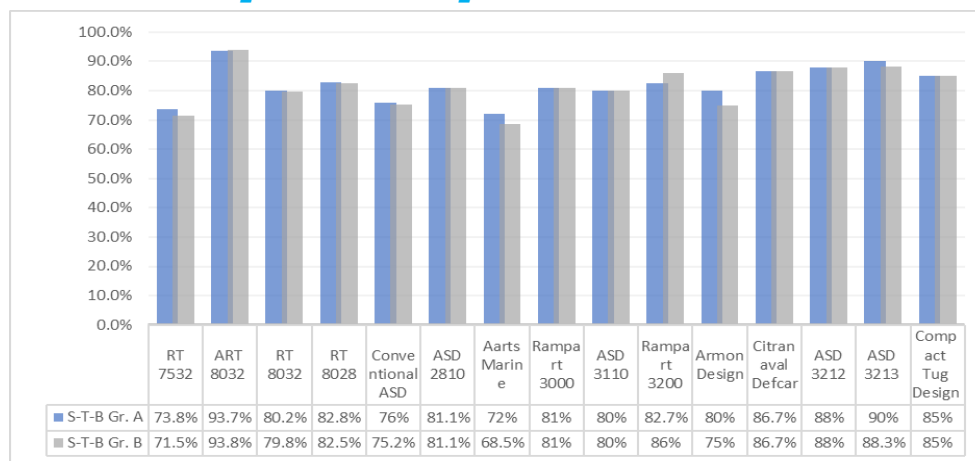


Figure 85: Stern to Bow Group A VS B KST Fleet Results for Towline Connection

Regarding Stern to Bow operations, Figure 85 proves once again that the state of art tug is ART8032, consisting of the higher score, equal to 93,7%. High scores also characterize the rotor types, RT8032 & RT8028, which are almost 10% less efficient compared to ART8032, due to the lever to be created when applying steering forces, from their bow winch to the stern of the assisted vessel. For ART8032 the lever to be created is almost zero, due to the small distance among the forward thruster and towing point, which is equal to 4,36 m, as it is shown in Table 13. On the other hand, for RT8032 the distance is 8,92 m, while for RT8028 is equal to 6,95 m. Therefore, the rotors need to provide an amount of their power for the counteraction of the resulted lever, which tends to rotate their stern on the opposite direction, when applying steering forces, and therefore, this weakness leads the bollard pull effectiveness to lower levels compared to ART8032. For RT7532, the lever to be created is even higher due to larger distance (9.4 m), among the forward thrusters and the forward towing point, as it is also shown in Table 13, explaining adequately the lower score in figure 60, which is equal to 73,8% for this type. Additionally, among the azimuth stern drive tugs, DAMEN concepts ASD3212, ASD3213 are assessed with 88% and 90% scores respectively, while ASD2810 has a score equal to 81,1%. Citranaval Defcar is also evaluated with a high score equal to 86,7%, as a result of its length, which leads to larger lever x. Rampart 3200 is also evaluated with a high score which is equal to 86%, proving once again the tremendous capabilities of this tug type, as a result of its underwater hull for operating efficiently in a stern to bow operation, by generating high levels of steering and braking forces. Finally, Armon Design and

Conventional ASD's are evaluated with scores equal to 80% and 76 % respectively for Group A. It is evident that Citranaval and Armon Design concepts, are recommended to operate as a stern tug for achieving higher effectiveness levels and not as a forward tug, since their ability to apply forces is reduced almost by 16 %.

4.3.4 Stern to Stern Group A VS Group B

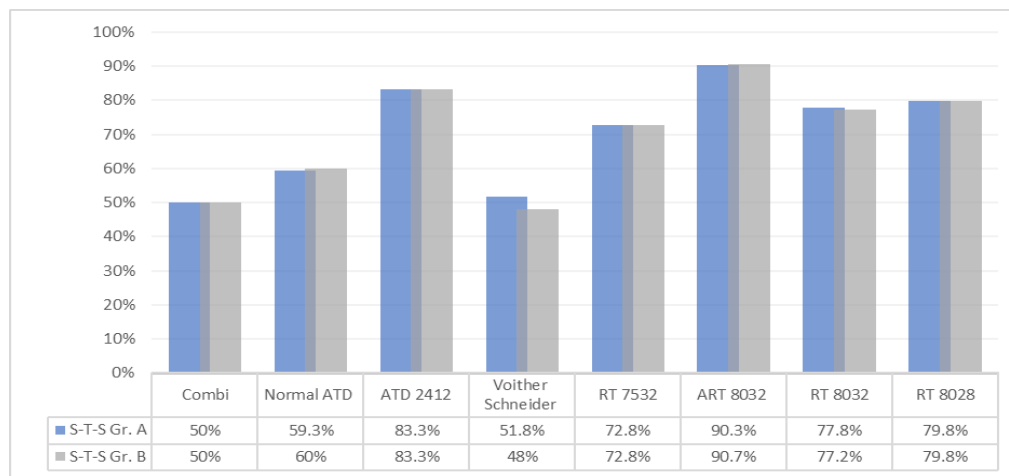


Figure 86: Stern to Stern Group A VS B KST Fleet Results for Towline Connection

The last type of operation among KST tugs and the assisted vessels refers to Stern to Stern. This type of operation refers mostly to ATD's, as well as to Combi's after the usage of the gob rope system. Starting with tractor tugs, Figure 86 shows that ART8032 is evaluated with the highest score, which is equal to 90,3%. Moreover, for the rest rotor types it is evident that their efficiency results are over 70%, and hence they are capable to apply high levels of steering and braking forces. For the Normal ATD and Voith Schneider tugs of KST, the scores are significantly lower. KST tug masters evaluated Normal ATD's for Group B with a score equal to 60% and Voith Schneider's with 51,8% for Group A. Consequently, the presence of the large aft skeg, at speeds lower than 6 knots was proven to be a weakness for these tugs for maneuver and apply efficiently the required forces for the ship-handling duties.

On the other hand, the new DAMEN concept of tractor tugs, ATD2412, was proven to be a tug with exceptional skills with a score equal to 83,3%. Subsequently, Normal ATD's & Voith Schneider's are more efficient to operate as a forward tug in Bow to Stern operation compared to Stern to Stern operation, since the efficiency is increased by 16% for Normal ATD'S and by 20% for Voith Schneider's. Finally, Combi's are assessed with a score equal to 50%. Combi's are not capable to maneuver efficiently, and therefore to apply the required steering forces, due to their propulsion unit; They are only capable to apply braking forces. At the same time, the usage of the gob rope system offers the ability the towing point to be transferred in more sideways positions capable to reduce the resulted heeling moments, in order the tug to avoid girting phenomena. It is evident that Combi's should always operate as a forward tug in a Bow to Stern operation, and rarely in a Stern to Stern operation, since their efficiency is reduced by 27%.

Intermediate Results

In this subchapter, the main goal was to discuss and analyse the results from the survey concerning KST fleet. The entire fleet was deeply analysed and compared, regarding its behaviour towards the course stability when sailing forward and astern. Afterwards, KST fleet was assessed towards intermediate step (approach for making the towline connection), while the last part was referring to the towline connection procedure for both

groups A, B. The results regarding the survey, offered a significant added value for assessing the operational profile of KST fleet, while the results for each type of operation and for each tug type for both groups of vessels to be assisted, will be implemented in the new-built of KST for discovering the optimum tug combination for each port.

Starting with Bow to Bow operations during towline connection, the survey showed that DAMEN tug types ASD2810, ASD3212 & ASD3213, were evaluated with scores higher than 80 %. Moreover, ASD2810 was proven to be also one of the most optimum tugs, while both ASD3212 & ASD3213 were evaluated with a score equal to 88%. These high scores are explained based on the advanced underwater hull, consisting of sophisticated skegs, proving that lever x compared to lever y is considerably higher and therefore these tugs need lower amounts of power for compensating the forces at COP point, leading to higher levels of bollard pull effectiveness. Additionally, the skeg of these tug types (chapter 3.4.4 category 4), offers increased levels of directional stability, and therefore these three types are the state of art tugs for Bow to Bow operations.

Additionally, Rampart 3200 was evaluated with the highest score, (88,7%) during Bow to Bow operations, for both groups, while its underwater hull, (chapter 3.4.4 category 4), was proven to have exceptional results, leading to high levels of steering and braking forces. Compact tug design was also evaluated with a high score, equal to 80% for both groups. For the rest tug types, the scores were proven to be lower than 75 %. The lower score for Aarts Marine concept, occurred due to the small skeg, located further aft in a very close distance from the azimuth propellers, leading eventually to smaller steering and braking forces. The same results apply also for Rampart 3000 with the same underwater hull/skeg, which was proven to have a score equal to 70% for both groups, and are not recommended to proceed in towline connection at speed higher than 7 knots.

The types with the lowest scores concerning Bow to Bow, are Armon Design & Citranaal, and therefore are recommended to be involved only under specific conditions. The weaknesses due to the underwater hull for Armon, make it risky to operate at speeds over 5 knots, for both groups of assisted vessels. The low score for this type is also expected due to the open aft deck, leading to several weaknesses for this type when sail astern. As soon as the speed exceeds 6 knots, the capacity of water filling in the aft deck is getting larger, making the stern of the tug to get immersed quickly. These extra tons of water in the aft deck make the center of gravity to change, leading to risky situations for the tug stability. Therefore, both Armon & Citranaal types should not be selected for this type of operation, while it is recommended to operate more efficiently either as a pure conventional tug, in Bow to Stern operation or as a stern tug for in Stern to Bow operation for offering braking assistance.

In Bow to Stern operations, ART8032 is considered again as the state of art of tug with a score equal to 91,3% for both groups, while the rest rotor, RT8032 & RT8028 were also evaluated with high scores, over 79%, proving their ability to generate high levels of braking & steering forces. RT7532 was evaluated with 5 % less effectiveness results, due to the distance among the stern towing point and stern thruster location; Hence the lever to be created, in this type of operation must be counteracted, which reduces its bollard pull effectiveness. Normal ATD's & Voith Schneider were evaluated with scores over 71,5%, while the new generation of tractor types, ATD2412 was proven to be an exceptional for Bow to Stern operation with a score over 85%. Last but not least both Compact Tug Concept & DAMEN concepts, ASD2810 & ASD3213 were evaluated with high scores over 80%, and therefore KST can definitely use this tug type “conventionally”, by increasing its flexibility levels towards its clients.

During Stern to Bow operations the state of art tug was proven to be again ART8032, while the types RT8032 & RT8028, are almost 10% less efficient compared to ART8032, due to the lever to be created when applying steering forces, from the bow winch to the stern of the assisted vessel. For ART8032, the lever to be created is almost zero, due to the small distance among the forward thruster and towing point, which is equal to 4,36 m, as it is shown in Table 13. On the other hand, for RT8032 the distance is 8,92 m, while for RT8028 is equal to 6,95 m. Hence, rotors need to provide an amount of their power for the counteraction of the resulted lever, which tends to rotate their stern on the opposite direction, when applying steering forces, and therefore, this weakness leads the bollard pull effectiveness to lower levels compared to ART8032. For RT7532, the lever to be created is even higher due to larger distance (9.4 m), among the forward thrusters and the forward towing point, as it is also shown in Table 13.

DAMEN concepts ASD3212, ASD3213 were assessed with 88% & 90% scores respectively, while ASD2810 had a score equal to 81,1%. Citranaal was also evaluated with a high score, as a result of its length, leading to a larger lever x. Rampart 3200 was also evaluated with a high score equal to 86%, proving once again the tremendous capabilities of this tug type, as a result of its underwater hull, by generating high levels of steering and braking forces. Finally, Armon Design and Conv. ASD's were evaluated with scores, over 75 %, while it is evident that Citranaal and Armon Design concepts should operate as a stern tug for achieving higher effectiveness levels and not as a forward tug, since their ability to apply forces is reduced almost by 16 %.

Finally, regarding Stern to Stern operation, mostly ATD's, as well as Combi's were assessed. Starting with ART8032, it was once again evaluated with the highest score. The rest rotor types were evaluated with effectiveness results over 70%, and are capable to apply high levels of steering and braking forces. On the other hand, Normal ATD's & Voith Schneider's tugs of KST, were assessed with lower scores. Consequently, the presence of the large aft skeg, at speeds lower than 6 knots, was proven to be a weakness, during maneuvering and applying efficiently the required forces for the ship-handling duties. On the other hand, the new DAMEN concept of tractor tugs, ATD2412, was proven to be an exceptional tug with score over 80%.

Subsequently, Normal ATD's & Voith Schneider's are more efficient to operate as a forward tug in Bow to Stern operation compared to Stern to Stern operation, since the efficiency is increased by 16% for Normal ATD'S and by 20% for the Voith Schneider's. Finally, Combi tugs were assessed with a low score equal to 50%, since they are not capable to maneuver efficiently, and therefore to apply the required steering forces, and hence only braking forces can be applied. It is evident that Combi tugs should always operate as a forward tug in a Bow to Stern operation, and rarely in a Stern to Stern operation, since their effectiveness results are reduced by 27%.

4.4 KST Fleet Effectiveness VS Escorting

This subchapter aims to discuss KST Fleet effectiveness during Escorting duties. At this point, each tug type has already been assessed towards its effectiveness results regarding all the possible types of operations and for both groups of merchant vessels to be assisted. Additionally, since several port authorities request passive escorting for incoming vessels, for KST is crucial to proceed in a solid evaluation regarding the escorting capabilities of its fleet for serving its clients always at the highest level. Consequently, the goal of this subchapter is to link the effectiveness results of KST survey, with the capabilities and limitations of each tug type during active or passive escorting.

Definition of Escorting

As it is already known from subchapter 2.2, the assisted vessels require towage assistance when entering or leaving a port, since in a low range of speed they are not able to rely on their own capabilities for achieving the desired manoeuvrability. The following figure aims to describe more in detail and for a specific range of speed, the phase where escorting duties takes place. Hence, in cases where the speed of the assisted vessel is among 4 to 10 knots the offered towage activity is considered as “escorting”. In general, the meaning of escorting has two different versions. The first version refers to the “active escorting” which is considered to refer in speeds over a range of 8 to 12 knots. On the other hand, the second version of escorting is known as “passive escorting”. The main distinction among the two versions is related with the amount of steering and braking forces to be generated.

In general harbour tugs are capable to make use of their underwater hull, consisting also from sophisticated skegs for generating high levels of hydrodynamic forces, which in total are meaningfully higher compared to the generated forces only from their total BP. Active escorting is vital, mainly in ports, consisting of long & narrow channels, where vessels can have high range of speeds, (higher than 8 knots). (Kasteren 2012, 1). In those cases, the harbour tugs operating from the stern can make use of their underwater hull for generating hydrodynamic forces, explaining at the same time the need for a large lateral area. These forces will allow the tug to apply in the most efficient way the required steering and braking forces to the assisted vessel, which are necessary for improving the safety levels in maritime transportation.

Numerous accidents in the past, with large tankers which lost their steering abilities in narrow passages and confined areas, had as a result environmental pollution with massive economic impacts. Therefore, several port authorities demand escorting duties, mainly for certain tankers for making sure that similar accidents of the past will be prevented. On the other hand, in cases of passive escorting, the tug is not making any use of its underwater hull for generating high amount of hydrodynamic forces for steering and braking the assisted vessel. During passive escorting, the tug might proceed in a towline connection with the assisted vessel, however it will remain at its stern, without creating any angle among its hull and water flow, for generating forces. In those cases, the tug is operating as a “guard”, which will be involved only if necessary. In those cases, the vessel normally brakes slowly as soon as it approaches in the port, while if suddenly any damage to its propulsion system occur, the tug will be capable to be involved directly. (Kasteren 2012, 2)

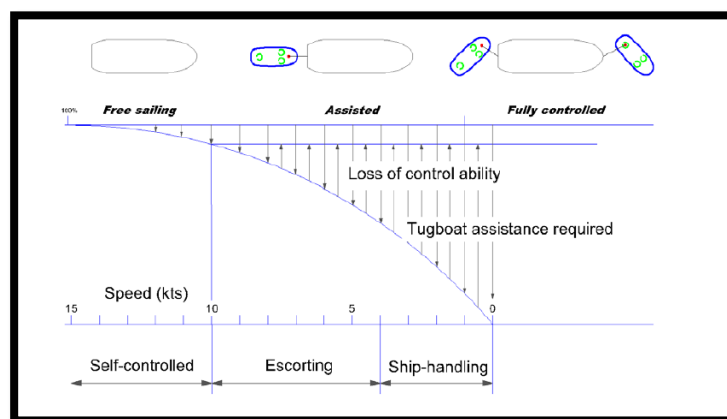


Figure 87: Speed Range VS Towline Assistance, (Kasteren 2012, 2)

For a lower range of speed, (below 5 knots), the normal ship-handling duties start to take place, as it is also indicated in Figure 87, while the effectiveness results among KST fleet towards the daily operations for KST has already been analysed in chapter 4.

Active Escorting performance criteria

In general, harbour tugs escort notation is awarded after it is validated that the tug complies to the established benchmarks from Lloyds Regulations Ships Class Rules towards tugs escorting performance. Tugs during active escorting duties should be capable to offer steering forces, for assisting the merchant vessel turn on the desired direction in cases where failure of its propulsion system occur, while they should also be capable to provide braking forces for controlling the vessel on time (retard manoeuvre). Moreover, most of classification societies will make use of the reaction times for validating the required time and hence for applying the requested forces towards the merchant vessels. Alternatively, the range of towing angles to generate the requested forces can be also used for evaluating the levels of those forces, and therefore the reaction time will be evaluated for various tug types in the following figures based on the towing angles. Additionally, the crucial question regarding escorting duties is always correlated with vessels speed and the related impact to the resulted forces to be applied, while polar diagrams are used for plotting the towline forces to occur, as a result of the towline angles;(angle of attack: angle between tug and water flow). (M.W.Jansen 2012, 1)

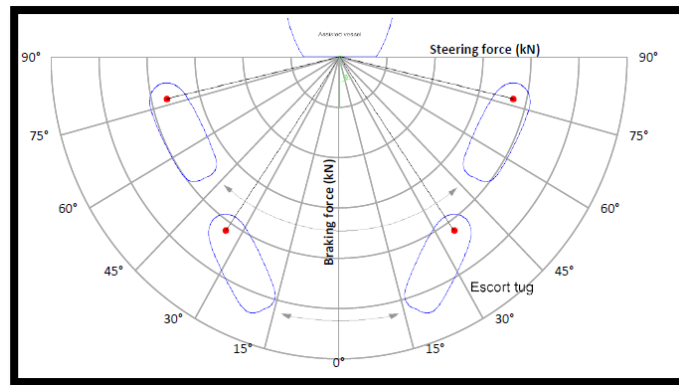


Figure 88: Tug Sim for Rotor Tug, (Jansen, Ship Handling in Port 13 of September 2012, 1)

Figure 88 provides a solid visualization of various tug's positions during active escorting. In the illustrated diagram, the reader can be informed for the generated steering forces in kN, which is shown in x-axis, while in y-axis the results towards the braking forces are shown, by using the same unit of measurement. Moreover, the resulted figures for each position are shown based on the fixed towing angle among the tug and the assisted vessel. Finally, as it was already mentioned the reaction time to be measured will occur from the towing angle where the tug is proven to apply the highest levels of steering & braking forces. Based on the international Association of Classification Societies, the maximum towline angle for applying the requested steering forces during escorting is equal to 60 degrees. Finally, for calculating the generated forces for both steering & braking forces in a range of speed, a polar diagram for each speed will be required. However, it was impossible to retrieve information for various speeds, while the assessment of the following tug types towards active escorting will take place for a speed equal to 10 knots.

Azimuth Stern Drives VS Conventional Rotors

All the conventional tugs are capable to generate high levels of hydrodynamic forces by using their hull under various angles of attack. The increase of the lateral areas is also achieved through the presence of sophisticated skegs (3.4.4 Underwater Hull Concept – Skeg & their Effect, design 3 & 4). On the other hand, Rotor tugs are

capable to proceed in the same principle as conventional tugs, by using the direct thruster forces and wake interaction throughout transverse arrest operations, which eventually leads to higher levels of towline forces for a lower range of angles and speed. The distinction among the conventional & rotor tugs is evident in Figure 89, where both tugs operate in indirect mode.

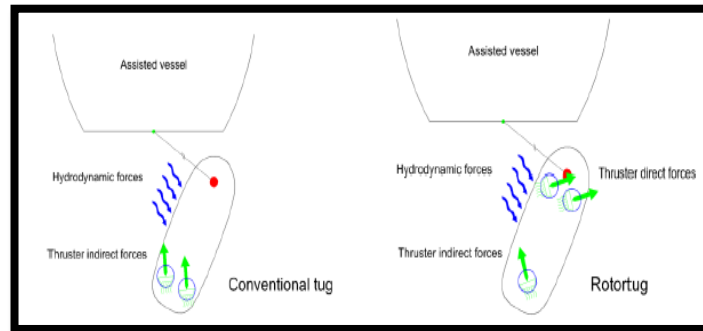


Figure 89: Conventional Tug VS Rotor Tug Towards Indirect Mode (Jansen, Ship Handling in Port 2012, 2)

The following polar diagram, illustrates the variances among two different tugs of the same bollard pull. Both consist of 80 tons of BP, however the green figure shows the steering forces of an azimuth stern drive tug, while the red line shows a rotor tug. Both operate as a stern tug for applying high levels of hydrodynamic forces during active escorting. (M.W.Jansen 2012, 3)

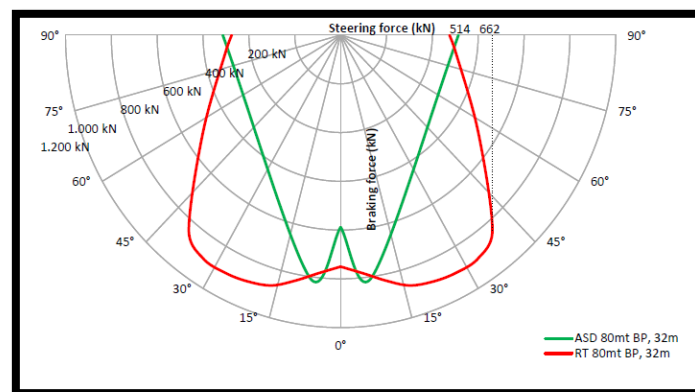


Figure 90: Polar Diagram - ASD VS Rotors at 10 knots (Jansen, Ship Handling in Port 2012, 3)

From the comparison among the two pre-mentioned tug types of Figure 90: Polar Diagram - ASD VS Rotors at 10 knots, the rotor tug is proven to consist from higher levels of steering forces at smaller towing angle, (meaning shorter reaction times), leading to higher safety levels, as a result of the combination among the direct thrust forces, wake interaction as well as due to the hydrodynamic forces acting on tug's hull. Additionally, the maximum steering forces for rotor tugs will be achieved at 40° angle, while for the azimuth stern drive tugs, the correspondent towline angle would be equal to 90 degrees. However, as it was already mentioned, the international Association of Classification Societies, request the maximum towline angle for applying the requested steering forces during escorting, to be equal to 60 degrees.

Voith Schneider's VS ART

In general tugs dedicated entirely to escorting duties, consist of big hulls configurations, combined with large & vertical skegs and the main reason for that is the need for increasing dramatically the resulted hydrodynamic forces for applying the requested steering forces. However, these tugs are proven to be less efficient towards pure harbour ship-handling duties, especially in low range of speeds, since their increased resistance tends to decrease their resulted manoeuvrability and raise the fuel consumption considerably. Therefore, it is evident

that tugs dedicated to escorting duties are without any doubt less efficient for pure ship-handling duties. However, in case of KST this is not the case, since none of company's tugs is dedicated entirely in escorting duties. Figure 91 aims to show the variances among a Voith Schneider, which is entirely dedicated to escorting duties. On the other hand, the rotor tug is significantly smaller in length and hence it is clear that is capable to provide both escorting & ship-handling duties. (M.W.Jansen 2012, 4)

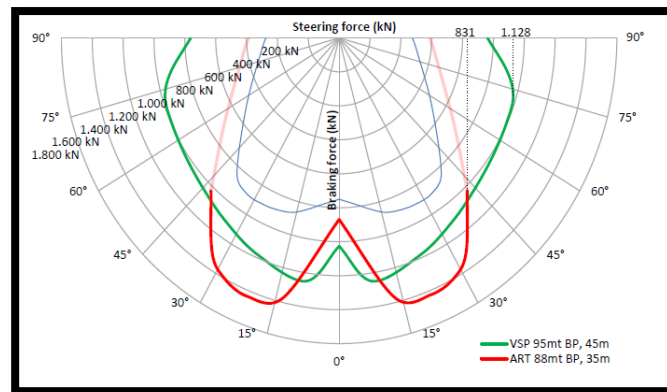


Figure 91: Polar Diagram between ART vs Voith Schneider at 10 knots (Jansen, Ship Handling in Port 2012, 4)

By comparing the results among the two tugs which are indicated in Figure 91 at the speed of 10 knots, again the rotor tug is proven to offer higher levels of towline forces, both steering and braking forces among the range of 10 to 40 degrees of angle. Even if the Voith Schneider consists from more power, and has larger lateral area, again the combination of direct thrust forces, together with the wake interaction and the generated hydrodynamic forces acting on rotor hull, eventually produce higher amount of towline forces. This comparison also proves that eventually, there is no any actual reason for investing exclusively in tugs, fully dedicated in escorting duties, since they are proven to have less efficient escorting behaviour and by far reduced ship-handling behaviour at lower range of speed, with low offered steering assistance due to the inferior levels of hydrodynamic forces. Finally, the major advantage of Rotors is linked with the triangle configuration of their propulsion units, where they are capable to provide advanced levels of towline forces during escorting duties at speeds over 6 knots for both direct/indirect modes. Additionally, rotors proved that during escorting the resulted heeling angle is equal to 7 degrees, leading to higher safety levels during the daily operations

KST Fleet Escorting Duties

In cases that, conventional or reverse tractor tugs should operate as a stern tug, it is required to deal with large longitudinal towline forces. During the direct towing as it is indicated in Figure 92, either the assistance is offered by using a tractor tug figure (scheme A) or by using a reverse tractor tug, (scheme B) high towlines can occur, hence it is necessary tugs to be characterized from high operational stability levels, capable to deal with the maximum levels of safety during harbor towage tasks.

Especially, in cases of indirect towing, Tractor as well as reverse tractor tugs consisting from azimuth propulsion units, should deal with high heeling angles. Figure 93, shows that as the tug is moving from point 2 to point 1, for steering the assisted vessel, its azimuth propulsion units will take a longitudinal direction to the assisted vessel leading to considerable high heeling angles. In both cases of tractor and reverse tractor tugs, they are characterized as powerful tugs, with respect to their dimensions, offering high righting arms, leading to higher righting moments. During direct or indirect towing, the resulted heeling moment that is created, tends

to neutralize the heeling moment created from the towlines leading to high levels of efficiency as well as to safe operations.

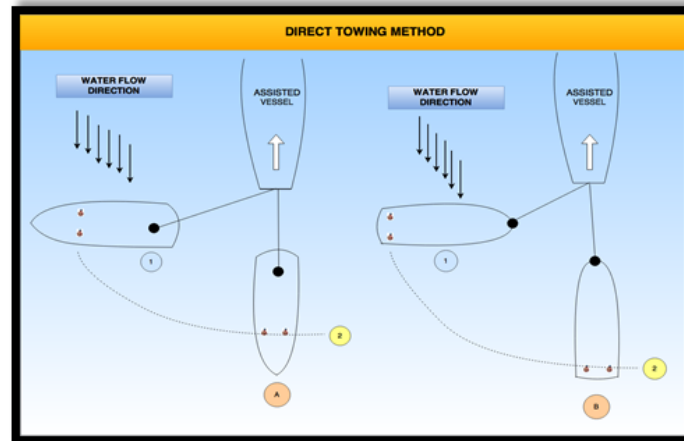


Figure 92: Direct Towing Method VS Escorting, Own Composition (Henk 2003, 140)

Conclusively for KST fleet the only way to provide a solid evaluation among escorting capabilities and application of towline forces, similar experiments and actual comparison among KST tug types need to take place, under a range of speed. In general, as it was already proven from Figure 90, KST rotor tugs are expected to have higher escorting capabilities compared to the azimuth stern drives tugs. In this perspective, the underwater hull of KST various tug types together with the combined appendages needs to be evaluated towards the generated steering and braking forces to occur as well as the correspondent reaction time.

However, the effectiveness of escorting duties for KST fleet is less of importance for company's daily operations since the company offers mostly pure ship-handling duties and for a speed below 6 knots, and therefore it is not necessary to define at which angle of attack and speed, the generated towline forces to occur are maximum, among the various tug types. Additionally, for the ports of Hamburg & Southampton where escorting is requested, the tugs will always proceed in "passive escorting" and eventually the tug will proceed in towline connection as a stern tug and escort safely the vessel inside the harbor, while the main purpose of tug presence is to brake the vessel as soon as possible in any case of rudder failure without the need to provide steering and braking forces at speed over 6 knots.

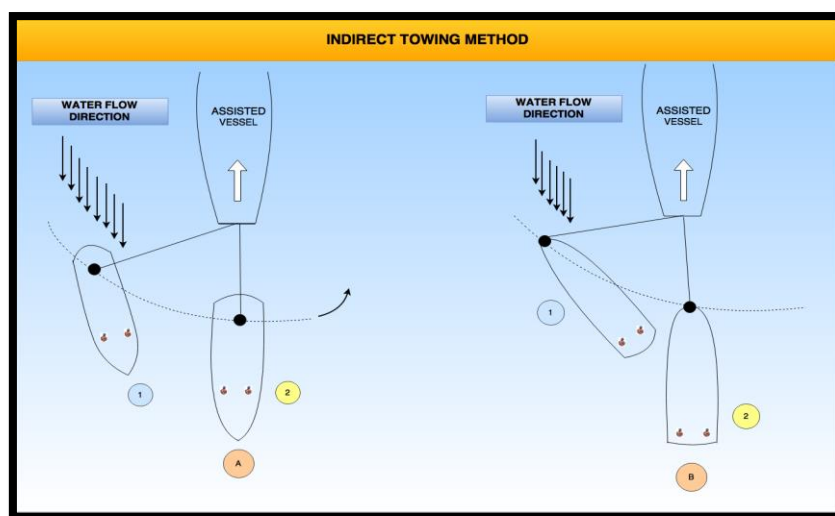


Figure 93: Indirect Towing Method VS Escorting, (Henk 2003, 140)

KST Ports of Operations

The effectiveness of harbor towage duties is aligned with the size as well as the type of vessel to be assisted. Since merchant vessels tend to grow their capacity and hence their size, the need for high levels of maneuverability during ship-handling tasks, becomes crucial. As it was already mentioned in chapter 3, KST harbor tugs are mainly divided in three major categories, as a result of the position, type and number of their propulsion units. Company's fleet is capable to offer high levels of harbor duties, and eventually high-quality services towards its clients. KST aims through this project to assess and evaluate its fleet efficiency, combined with a solid investigation among all the ports of operation, for increasing the levels of services offered to its clients. Additionally, the analysis of all the main insights, towards the towage regulations & restrictions for each of KST ports of operation, will be used as an essential input for the tool, which is required for verifying every possible tug reallocation among the various ports, as well as the resulted efficiency for each selection.

5.1 Fundamental Insights for KST Ports of Operations

The first part to be analyzed refers to the type of merchant vessels calling at each port. Depending on the cargo type, merchant vessels have various shapes and designs, and therefore KST fleet effectiveness, should be aligned with all the possible vessel types for each area. By collecting essential data from company's records, for the entire year of 2016, it is then possible to analyze the types of vessels calling at each port, and therefore to align KST fleet effectiveness results with the vessels to be assisted. In Figure 94, the fundamental insights for each port are indicated.

The second part, which influence ship-handling duties considerably, refers to the environmental conditions. The influence due to high levels of wind, current & swells have a significant impact and therefore the environmental conditions will be investigated and analyzed for all KST ports of operations extensively. High or moderate yaw moments occur, due to the wind forces as well as due to the angle of water flow on vessel's hull, as a result of the trim, type of cargo and draught. Consequently, the types of tugs to assist, as well as the required BP for each case, becomes a critical issue. Additionally, the presence of current, in combination with the underkeel clearance of the assisted vessel, have a significant impact towards the handling of the ship, especially in ports with current's speed over 3 knots. (C. H. Hensen, TUG USE IN PORT - A practical Guide , p vii 2003, 76).

The third major part to be analyzed refers to the various ports regulations and restrictions. Therefore, the current regulations for each port, will be discussed for both normal and adverse environmental conditions, which is vital input for the tool construction. Finally, the last part to be analyzed, refers to the port configuration analysis. A proper investigation among the main characteristics of KST ports of operation is vital, for assessing the port complexity of each case. The presence of locks, confined areas or narrow passages raise the complexity levels, as well as the average time for each operation (tugs stand-by), by requiring also in some cases specific tug types with increased capabilities and high maneuverability levels for safe ship handling duties.

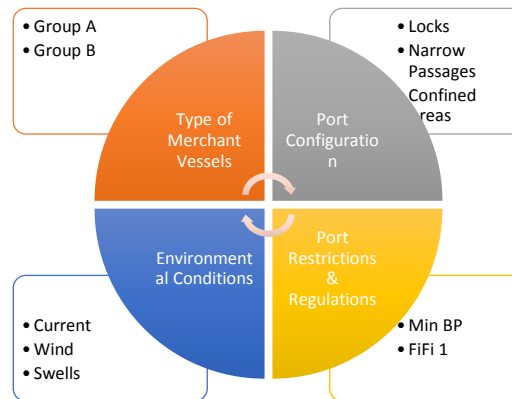


Figure 94: Fundamental Insights for KST Ports of Operations

Customer Demands

KST is operating among 12 ports in 4 countries. Each port is characterized from unique characteristics and principles, and therefore, the assessment of each port will provide the required input for the tool. In Figure 95, KST ports of operation are shown. Starting with Netherlands, the company is operating in the port of Rotterdam, Terneuzen & Vlissingen. In Belgium, KST offers services in the ports of Antwerp, Zeebrugge and Ghent while for Germany towage services are offered in the ports of Hamburg and Bremerhaven. Finally, for UK towage services are offered in the ports of Liverpool, London and since April also in the port of Southampton.

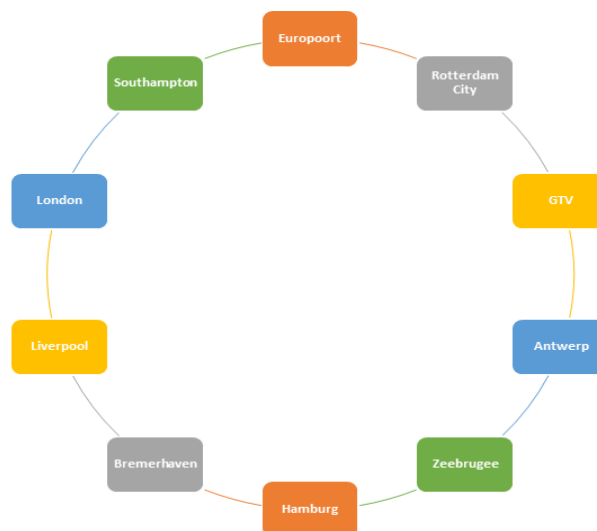


Figure 95: KST Ports of Operations

KST ports of operations were selected from both shareholders KOTUG & SMIT, as a result of their strategy, for establishing towage operations and developing market shares in new ports. SMIT was one of the firstborn towage companies in the port of Rotterdam, while at the same time its presence in South Holland and Belgium was also significant. Later on, the company decided to expand its activities in UK, and more specifically in the port of Liverpool. On the other hand, KOTUG which started operating in the port of Rotterdam at a later stage, was aiming to provide towage services at lower costs, compared to its competitors, while its main goal was to proceed directly in contracts with international shipping companies by avoiding the usage of agents. The next step for KOTUG was to expand to new ports, and therefore the ports of Hamburg & Bremerhaven were selected after request from their existing clients. The high demand levels especially from several containers & car-carrier's vessels for the two German ports, convinced KOTUG to investigate the possibilities for expansion, after evaluating the new ports configurations and the requested services. By following the same

process, KOTUG also decided to expand its activities in the port of London. Therefore, after the joint venture KST is capable to provide high quality of harbor towage services in multiple European markets.

Market Definition /Demand & Supply of Harbor Towage

Harbor towage can represent efficiently the meaning of “derived demand”, and the main reason for that is the continuous demand from merchant vessels to be assisted when entering or leaving a port for providing the goods transportation. In general, the demand is influenced from several factors which are mainly driven from the global economy and eventually from the freight rates which will eventually influence the tariffs of harbor towage services. The type of towage to be offered on each port, is entirely connected with the merchant vessel to be assisted (dimensions, DWT), while the environmental conditions are always crucial for defining the number of tugs to be used, and will eventually be finalized from pilot’s either for an incoming or an outgoing vessel. Therefore, each towage company in order to investigate the demand on each port, should firstly investigate the established towage restrictions and regulations in order to comply with, and at the same time it is crucial to investigate the volume of goods which are transported as well as the number of contracts with its clients to occur, for selecting its fleet capacity. These decisions are without any doubt some of the most vital key drivers for the towage costs and should always follow the demand pattern for each port. (King 2002, 5)

Determinants of demand

The most important key factor for a towage operator for defining the demand for the required towage services in a port is driven from the volume of merchant vessels in this port. This number is connected with the ships capacity for transporting cargo, as well as the cargo volume to be transported each time. It is also observed that more and more ships are used with increased capacities, and therefore less ships will be used for carrying goods among various ports. This trend, tends to reduce eventually the number of tugs to be requested, while at the same time the ship-owners enforcement for lesser and more powerful and manoeuvrable tugs to be used, lead to higher capital of investments and less revenues.

Towage operators as KST needs to invest in multiple new-tug buildings which are characterized from unique capabilities and state of art technology, by squeezing even more tugs demand. However, in several cases, even if tug operators use state of arts with increased manoeuvrability levels, the port authorities will always demand certain number of tugs to be used, depending on the vessel to be assisted. Consequently, it can be concluded that technological progression tends to decrease the demand of tugs, and therefore it is necessary for each tug operator to re-evaluate its fleet capacity as a result of the current situation on each port. (Comission 1995, 33) As it is already analyzed in chapter 3, each tug type consists of unique fundamental elements, and therefore harbor towage companies have to investigate each port complexity, for defining the ideal combination of tug types to operate with. Since the port configuration varies per port, it would not be wise for a towage company to operate with the exact tug types in various ports, unless their configuration is identical. (Davies 2011, 2)

Market Shares in the port of Rotterdam for 2016&2017

KST, as well as each towage company needs to deal with the market power, by investigating the demand elasticity as well as the market size for a port. Moreover, the expansion in a new port, should be aligned with the capital costs, as well as the commercial relationships, for establishing new contracts with existing or new clients. KST is capable to proceed in future ports expansion after a solid assessment of the existing demand and supply elements for the offered harbor towage services in a new port, by investigating the important role of competitors.

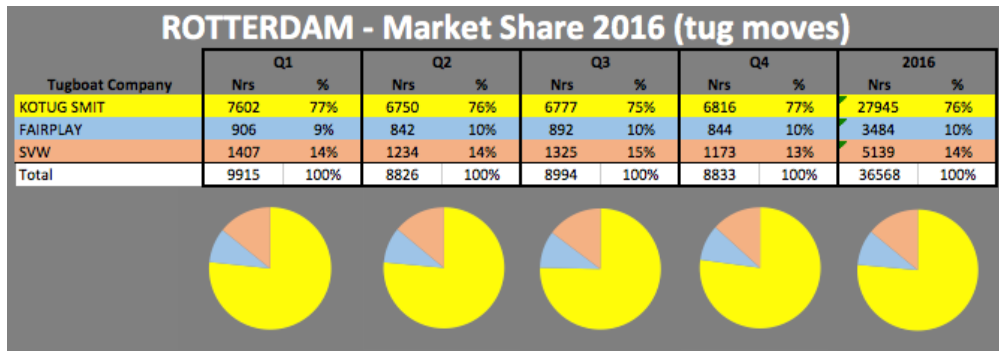


Figure 96: Market shares port of Rotterdam 2016

Figure 96 aims to show the tug moves of KST, as well as of its competitors in the port of Rotterdam after the joint venture in 2016. The figure shows that KST is the leader of harbor towage services in this port, with a total percentage equal to 76%. It is also obvious that company's market shares among the four quarters remain almost identical, while the market shares of its competitors are significantly lower. The willingness of Svitzer to enter the port of Rotterdam (2014), had as a result to gain 14% of shares, within 2 years while Fairplay was proven to consist of a market share equal to 9%. On the other hand,

Figure 97 presents the tug moves results also for the first two quarters of 2017, and therefore it is possible to investigate if KST will eventually manage to deal with an increase or decrease of its market shares. Fairplay managed to increase its percentage by 4%, while Svitzer maintained the same market shares compared to 2016, (14%). For KST the first quarter was proven to be 3% lower, while during the second quarter the company managed to increase its shares by 6%. Also for the year 2017, KST is proven to be once again the leader towards the harbor towage services in the port of Rotterdam.

The same analysis is necessary to take place for all the ports where KST is operating, for assessing its market shares each quarter. Moreover, in cases where KST would like to expand and investigate the possibilities for operating in a new port, it is more than required to monitor the tug moves of the towage operators who already operate, as well as to investigate their market shares in this port. Additionally, after considering the number of clients and the cargo volume to be transported, it would then be feasible for KST to assess if there is room for expansion or not.

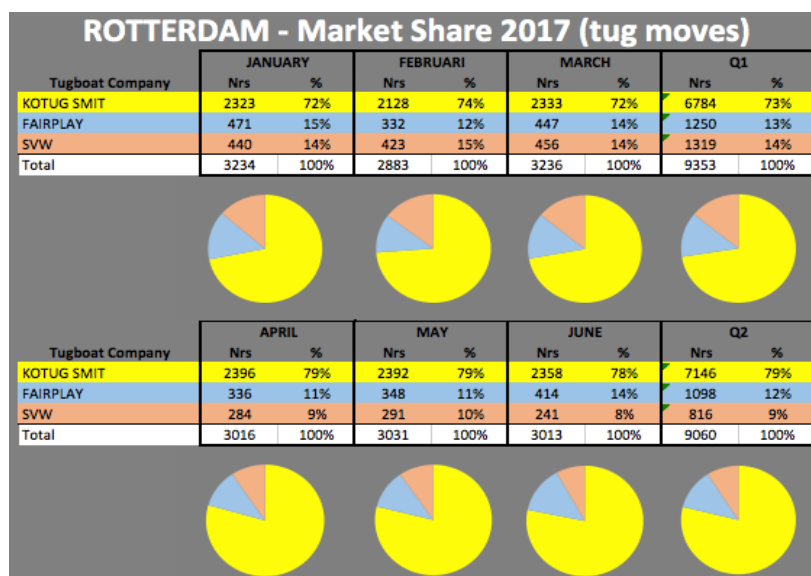


Figure 97: Market Shares port of Rotterdam 2017

5.2 Port of Rotterdam

5.2.1 Types of Ships Calling in Europoort & Rotterdam City

Both companies (KOTUG & SMIT) before the joint venture were characterized from a strong presence, especially in the port of Rotterdam, while Svitzer entrance during 2014 was aligned with changes towards the market shares in the port. SMIT was the major player in the port of Rotterdam, running more than 50% of the towage services, while KOTUG market shares approximately 30 %. At the same time, it is evident that both Fairplay & Svitzer (main competitors of KST), increased by 5% their presence within 1 year. At this point, the discussions within KOTUG & SMIT started to take place, and as a result one year later KOTUG SMIT joint venture was established, while Figure 97 proves that KST is the leader in the port of Rotterdam.

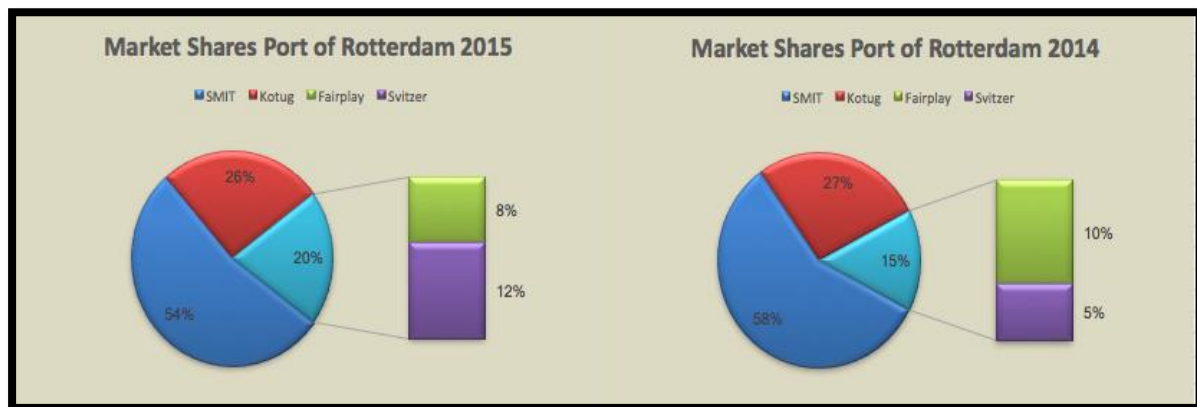


Figure 98: Market Shares Port of Rotterdam 2014/2015

The types of merchant vessels calling in this port, for the entire year of 2016, belong mostly to Group B, with 49% of tankers and 16% of bulk carriers. The rest 35% refers to vessels from group A, where 30% were container vessels and 2% car carriers while the rest 3%, refers to general cargo carriers and refrigerator vessels.

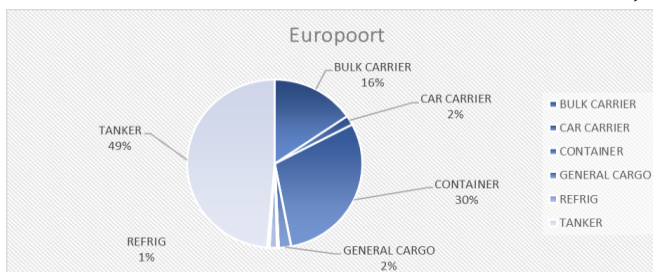


Figure 99: Europoort Market Trends 2016

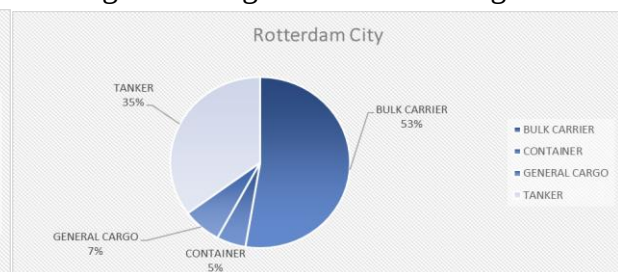


Figure 100: Rotterdam City Market Trends 2016

The same results were also shown for Rotterdam City. Figure 100 shows that 88% of the vessels in that area were from Group B. On the other hand, vessels from Group A were proven to be minority, since general cargo and container vessels were proven to be equal to 12%. The port configurations for the port of Rotterdam is characterized from open large areas without the presence of confined areas, leading to low complexity towards the harbor assistance. Additionally, the configuration does not include any lock or narrow passage, while the open areas, make feasible for any tug type to operate, no matter of its type.

5.2.2 Towage Restrictions & Regulations in port of Rotterdam

The port of Rotterdam is not demanding specific towage requirements. Consequently, pilots decide the minimum required BP and hence the number of tugs to be involved based on their experience, depending on assisted vessel main characteristics, (draught & loading conditions), while the environmental conditions during

the requested assistance are also vital. It is evident that since the port of Rotterdam, is a multi-cargo port, capable to deal with the largest ships of the world, high amount of BP is required.

Tugs consisting of high amount of BP, +70 tons of BP, are mainly requested to operate as a stern tug, (in a Stern to Bow operation), for offering the required braking assistance, especially for incoming vessels. At the same time the operations in this port, take place in a slower rhythm, due to the larger areas for braking the vessels, while pilots are favorable of using Bow to Bow Operations. They tend to use this method due to the increased levels of safety, since the propulsion units are away from vessel's hull and therefore in any case of emergency, the tug will be capable to leave immediately.

As it will be proven later in this chapter, the adopted philosophies concerning the types of operations to be used vary, while conventional methods are also used. For this reason, pilots and tug masters are in a close communication, for deciding each tug position, forward or astern. Therefore, KST needs to provide services with tugs capable to proceed efficiently in Bow to Bow operations even at high range of speeds. The efficiency of the current tugs combination in the port of Rotterdam will be extensively analyzed in chapter 8 during the analysis for the current situation for all KST ports. The large areas in the port of Rotterdam, allow pilots and tugs to proceed in a towline connection even at a speed among 7-8 knots, and therefore high effectiveness levels regarding Bow to Bow operations are mandatory.

5.3 Port of Ghent, Terneuzen & Vlissingen

5.3.1 Types of Ships Calling in GTV

The next ports where KST offers harbor towage assistance, are Ghent, Terneuzen & Vlissingen. The port of Ghent is included in this configuration, even if it belongs in Belgium, since the vessels with direction to the port of Ghent should firstly enter the canal, after passing the lock in Terneuzen. Company's tugs, can be located anytime at each of the pre-mentioned ports, depending on the requested towage assistances. Tugs are also capable to sail from Terneuzen to Vlissingen in a short period of time, while in some cases tugs from that area are requested to offer services either in the port of Antwerp or in the port of Zeebrugge, for increasing the capacity levels, or for replacing a tug which is under dry dock. In Figure 101, is evident that the majority of vessels calling for assistance belong to Group B, with 31% of them to be tankers, while the presence of VOPAK in Vlissingen Area was proven to be essential. The second type of vessels belonging to Group B, refers to Bulk Carriers with a percentage equal to 49%. The high numbers of bulk carriers have occurred mainly due to the vessels with destination to the port of Ghent, for the transportation of iron ore, as well as scrap. On the other hand, car carriers (Group A) have a percentage equal to 4%, mainly due to the factories of Volvo and Honda again in the port of Ghent.

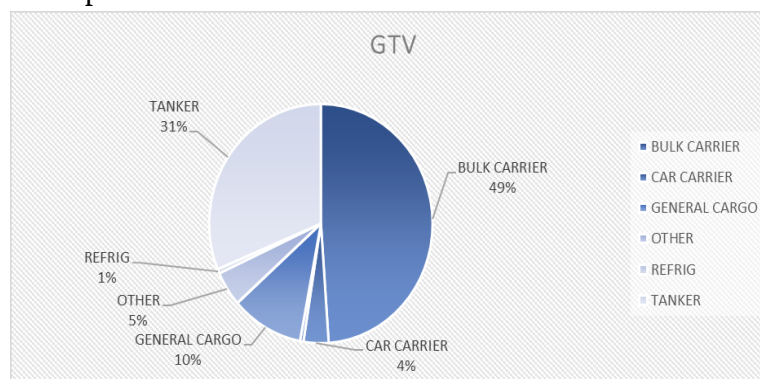


Figure 101: GTV Market Trends 2016

The port of Terneuzen, also consists from one operational lock, known as West Lock, to be used for all merchant vessels for sailing towards the port of Ghent, with a width equal to 40 meters, and a length equal to 290 meters.

Table 17: Terneuzen Locks Dimensions (Terneuzen 2015)

Terneuzen	L (m)	W (m)	Type of Vessels
West Lock	290	40	All types
New Lock (2021)	427	55	All types

Ports of Ghent and Vlissingen do not consist of any lock. Finally, the Terneuzen area includes chemical plants, while, an oil jetty is established in Vlissingen. The specific requirements and regulations for both chemical plants and oil jetty, as well as for the lock of Terneuzen and for the channel in between Terneuzen and Ghent, are further analyzed in the following subchapter.

5.3.2 Towage Restrictions & Regulations in GTV

Lock of Terneuzen Regulations

Starting with Terneuzen lock regulations, which are indicated in Table 18, is evident that the length as well as the draught of the assisted vessel are the two major factors to define the number and the required BP of the requested tugs. Additionally, at least one tug in GTV area should consist of FiFi1 notation.

Table 18: Terneuzen Lock Regulations (Terneuzen 2015, 1)

LOA	Draught	# of Tugs	
In meters		Forward Tug	Stern Tug
>= 180 AND < 210	> 12,30 AND <= 12,50	Minimum 1 Tug with sufficient pulling force	
>= 210 AND < 245	> 12,30 AND <= 12,50	2 x >= 25 t	1 x >= 39 t
>= 245 AND < 265	> 12,30 AND <= 12,50	2 x >= 30 t	1 x >= 39 t

Starting with vessels with length between 180 and 210 meters and draught among 12,30 and 12,50 meters, the pilots will request 1 tug without minimum required BP. However, in cases where the vessel is among 210 & 245 meters, consisting also from 12,30 to 12,50 meters of draught, three tugs will be requested for assistance. The two forward tugs should be characterized from minimum 25 tons of BP, while the stern tug should have minimum 39 tons of BP. Finally, for those vessels with length in between 245 & 265 meters and draught among 12,30 & 12,50 meters again three tugs are requested. The stern tug should consist at least from 39 tons of BP or more, while the two forward tugs should each consist of minimum 30 tons of BP.

In cases where vessel's length is around 260 meters, there is a possibility that the stern tug, with the assisted vessel do not fit together inside the lock and therefore the tug will be disconnected, for using the smaller lock, which is used only for barges and sailing boats, for entering the canal towards the port of Ghent. In cases of vessels over 33 meters' width, mainly 4 tugs will be used; two of them will operate over the bow, one over the stern while the fourth one, will work as a shoulder tug for pushing the vessel in a parallel way with the lock. However, depending on the situation, pilots might decide to alter tug's configuration to be followed. Table 19 shows the number of required tugs under various wind conditions in Terneuzen:

Table 19: Number of Required Tugs in Various Wind Conditions in Terneuzen (Terneuzen 2015, 2)

Wind	Loaded ship			Ship in Ballast		
Bf	Forward: 1 tug	Middle: 2 tugs	Stern: 1 tug	Forward: 1 tug	Middle: 2 tugs	Stern: 1 tug
<= 5	>= 30 t	>= 30 t	>= 39 t	>= 30 t	>= 30 t	>= 39 t
<= 6	>= 30 t	>= 30 t	>= 60 t OR 2 x >= 30 t)	NO SAILING		
> 6	NO SAILING			NO SAILING		

Restriction for the canal - Terneuzen to Ghent

KST should provide towage assistance in GTV area capable to satisfy the required restrictions regarding the canal among Terneuzen & Ghent. The port authorities' states that all the vessels with direction to Ghent, should always been assisted from tugs, in case where they are not equipped with a bow thruster; Hence, the forward tug should be characterized with minimum 30 tons of BP, while in cases that vessel's length is equal or less to 160 meters, the stern tug should also be at least 30 tons of BP. In case where vessel's length is larger than 160 meters, the stern tug must be at least 35 tons of BP. On the other hand, for vessels which are equipped with bow thruster, only one stern tug will be required. This tug should be at least 30 tons, for vessels smaller or equal to 160 meters' length, while for vessels larger than 160 meters, the stern tug should consist at least from 35 tons of BP. Therefore, tugs with exceptional efficiency towards Bow to Stern operations would be ideal for this area, since tug masters would be able to use auto pilot for towing the merchant vessels, "conventionally" till the port of Ghent. Additionally, Bow to Bow operations offered from a forward tug, consisting only from a bow winch, would not be ideal, since tug masters have to pay continuously attention to their position and followed direction into the canal since they are sailing stern first.

Restriction for the port of Vlissingen

The incoming vessels for the port of Vlissingen equal or larger than 235 meters with draught equal to 12,50 meters or more, are requested to have always 3 tugs, each consisting at least of 30 tons of BP. On the other hand, for outgoing vessels, the total number of tugs can be reduced by one. In cases where the incoming vessels are over 260 meters, four tugs will be requested, each with minimum 30 tons of BP, while for outgoing vessels three tugs will be requested. In case where the draught of the vessel is equal to 15,50 meters or more, one of the predefined tugs is required to consist at least from 60 tons of BP.

Restriction for the Oil Jetty in Vlissingen Area

For the oil jetty in the Vlissingen Area, all the vessels with 115 meters' length are requested to use a tug, while in case that their length is in between 115 & 175 meters, two tugs will be requested. For all vessels with a length over 175 meters, three tugs are required while four tugs are required for merchant vessels with deadweight tonnage over 40000 tons. For the last two cases, the stern tug is required to be always a tractor type of at least 25 tons of BP. Finally, during departure, merchant vessels consisting of a powerful bow thruster, are capable to reduce the required number of tugs by one, while in case where vessels consist of both bow and stern thruster, the number of the required tugs can be reduced by two.

Table 20: Chemical Plant Terneuzen Regulations for Outgoing Vessel
(Terneuzen 2015, 3)

Outgoing Ship Length	Bow Thruster	Stern Thruster	# Tugs
<125 m	NO	NO	1
	YES	NO	0
	YES	YES	0
< 200 m	NO	NO	2
	YES	NO	1
	YES	YES	0
< 225 m	NO	NO	2
	YES	NO	1
	NO	NO	1
L >= 225 m	-	-	2/3

Table 21: Chemical Plant Terneuzen Regulations for Incoming Vessel
(Terneuzen 2015, 4)

Incoming Ship Length	Bow Thruster	Stern Thruster	# Tugs
< 125 m	NO	NO	1
	YES	NO	1
	YES	YES	0
125 m >= L < 200 m	YES	YES	2
	YES	YES	1
125 m >= L < 150 m	YES	NO	1
150 m >= L < 200 m	YES	NO	2
200 m >= L < 225 m	NO	NO	3
	YES	NO	2
	NO	NO	1
>= 225 m	-	-	4/3** (4 or 3:1x60 + 2x35 BP)

5.4 Port of Antwerp

5.4.1 Types of Ships Calling in Antwerp

The port of Antwerp is considered as the second largest port for container vessels after the port of Rotterdam. KST has a strong presence in the port, operating with 9 tugs, with a capability to increase by one the fleet capacity from GTV area. Figure 102 shows that most of the assisted vessels during 2016 belong to Group A, where 63% of the assisted vessels were container vessels and 11% were Car Carriers & General Cargo ships. On the other hand, the bulk market was proven to be equal to 5 % while the percentage of tankers was slightly higher and equal to 20%. Therefore, KST fleet effectiveness results for this port should be aligned mostly with Group A and less with Group B.

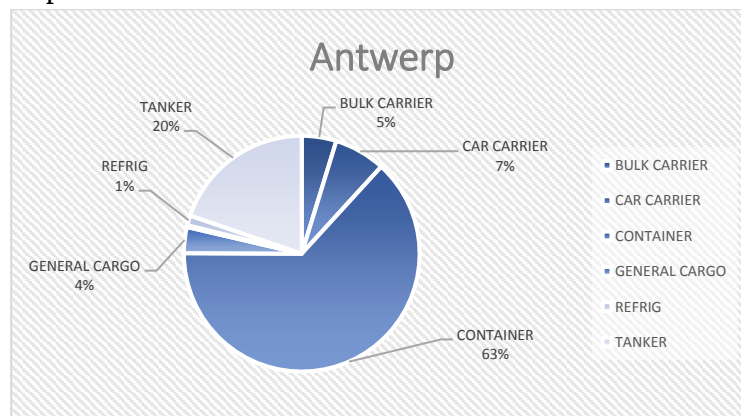


Figure 102: Antwerp Market Trends 2016

The port of Antwerp consists of the largest port area all over the world with several bridges, docks and terminals for fulfilling the needs of the various merchant vessels. Additionally, multiple locks are in use, allowing the vessels to load and unload their cargoes among the several terminals of the inner and outer port. From Table 22 Table 22: Antwerp Locks Dimensions is evident that the towage assistance will vary compared to GTV area as well as to the rest ports of operations of KST, due to the various locks dimensions, explaining the need for assessing company's fleet effectiveness for each case.

Table 22: Antwerp Locks Dimensions (Antwerp 2016, 3)

Antwerp	L (m)	W (m)	Type of Vessels
Zandvliet Lock	500	57	All Types
Berendrecht Lock	500	68	
Deurganck Lock	500	68	Containers / Car Carriers
Kallo lock	360	50	Car Carriers / Small Containers
Cauwaert Lock	270	35	Barges

5.4.2 Towage Restrictions & Regulations in Antwerp

The port of Antwerp has not established specific requirements concerning the minimum required BP. Therefore, towage companies are free to decide their fleet allocation based on the capacity and size of the merchant vessels; therefore KST should provide a flexible fleet towards the offered BP. Additionally, pilot's philosophy for this port varies compared to the rest ports of operation of KST; there no regulations for each vessel to enter a lock with tug assistance, and therefore pilots might decide to assist the vessel without tug's presence, especially under normal environmental conditions and in cases where merchant vessels are equipped with bow and/or stern thrusters. Additionally, pilots might also request only one tug, operating at the stern of the assisted vessel (as a brake) instead of two. The port of authorities requires from KST to operate continuously with four tugs, while two more tugs should be stand-by if necessary. Even if there are no specific requirements concerning tug's minimum bollard pull, the port request each tug to consist from ISM

certification. KST is operating always with nine tugs in total in the port of Antwerp. Three of them are in rest, while the rest 6 are always stand-by and fully operational. Always one tug will have increased amount of BP, for operating at the stern of the vessel as a brake.

5.5 Port of Zeebrugge

5.5.1 Types of Ships Calling in Zeebrugge

The second port of operation for KST in Belgium is the port of Zeebrugge. It is one of the world's leading port concerning RO-RO vessels, while at the same time one large part of it, is dedicated to container terminals. Additionally, the port emphasizes on liquefied natural gas as well as on automobile vehicles. Figure 103 shows that most of the merchant vessels calling in the port of Zeebrugge were car carriers, making Zeebrugge one of the most important car-handling ports globally. Furthermore, by considering also the percentage of containers, and general cargo carriers, it can be concluded that the port of Zeebrugge consists mostly from vessels belonging to group A with a total percentage equal to 80%. The rest 20% is divided to vessels from group B, where tankers had a percentage of 14% and LNG's 1%.

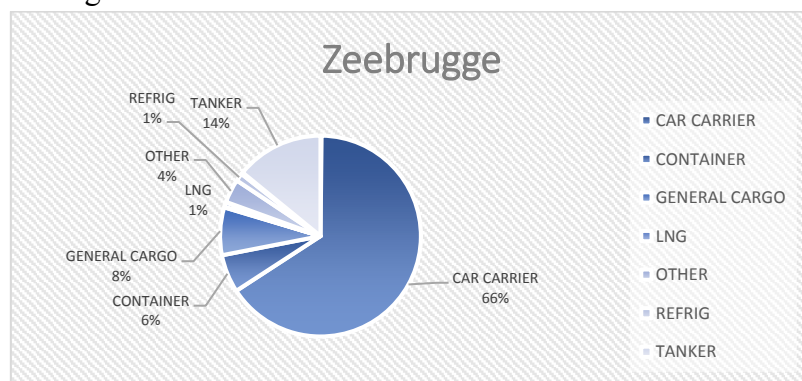


Figure 103: Zeebrugge Market Trends 2016

The port of Zeebrugge consists of one major lock, which is used mainly from car carriers and special projects vessels for entering the inner harbor. Container vessels as well as LNG terminals are located on the outer part of the harbor and therefore do not require assistance through the lock. The dimensions of the lock indicate sufficient length and width, while P. Vandamme lock in Zeebrugge is identical with Zandvliet lock in Antwerp. However, the main distinction among the port of Zeebrugge and Antwerp, is that the port authorities will always impose car carriers to use tugs for entering or leaving the port. These stricter rules in the port of Zeebrugge, are also explained from the fact that locks are used mostly from car carriers, consisting of huge later surface areas, and consequently the wind influence, (which can be up to 9 or even 10 Bf), has a significant impact on the ship-handling duties. Finally, the methods to be used among pilots and tug masters for operating in this lock also vary from the methods used in the rest ports of operations of KST.

Table 23: Zeebrugge Locks Dimensions (Zeebrugge 2016, 4)

Zeebrugge	L (m)	W (m)	Type of Vessels
P. Vandamme	500	57	Car Carriers (32-38 m Beam) / General Cargo
Visart	261	19.7	-

5.5.2 Towage Restrictions & Regulations in Zeebrugge

The towage restrictions for the port of Zeebrugge are indicated in Table 24. The first to be mentioned is that the port requests four tugs with minimum required bollard pull equal to 80 tons, while two more tugs are required to have minimum 60 tons of BP. Additionally it should be noted that all the tugs to operate in this

port should comply with FiFi 1 notation. The reason for this requirement is related with the presence of the LNG terminal. At the same time when an LNG carrier is in the port, one tug is always stand by in a short distance, for being involved if necessary. Larger LNG carriers require 5 tugs for safe berthing and un-berthing, while smaller LNG's require 4 tugs. Moreover, in case where LNG is entering or leaving the port, the entire traffic in the port is stopped. Currently, KST is operating with three rotor tugs and three ASD's. Official experiments from the company, proved that rotor tugs were the only capable tugs to push on the line adequately (rotoring), while assisting the vessel to moor safely in the LNG terminal, since approximately 15 meters at the stern of the terminal, a sudden draught reduction occurs.

Table 24: Towage Regulations in Port of Zeebrugge (Zeebrugge 2016, 5)

Zeebrugge	LNG Terminal & Lock	
1.	4 x 80 t of BP	2 x 60 t of BP
2.	Always 1 Tug STAND-BY WHEN LNG IS IN THE PORT	
3.	ALL FiFi 1	
4.	5 TUGS: Big LNG	4 TUGS: Smaller LNG
5.	ALWAYS TRAFFIC STOPPED WHEN LNG COMES IN	

Finally, the port authority recommends due to the high wind levels in Schelde area all incoming vessels to enter the port with adequate speed, for avoiding the strong current at the port entrance. Consequently, all the types of merchant vessels will enter by themselves into the port, while in case of container vessels, tugs should offer braking assistance as soon as possible since the container terminal is at the outer harbor near to the port entrance. On the other hand, tugs are capable to apply braking assistance for larger period of time in cases of car carrier's, since all the car carriers will get through the lock which is located in a sufficient distance from the port entrance. Finally, the port authority enforces tugs to move out of the port for assisting an LNG carrier. LNG's will never enter the port without towage support, due to safety reasons and therefore the required time for this type of operations will be higher.

5.6 Port of Hamburg

5.6.1 Types of Ships Calling in Hamburg

KST offers towage assistance in the two major ports of Germany, Hamburg & Bremerhaven. The port of Hamburg, is considered as one of the largest container ports globally, and the third largest one in Europe, which I also explained in Figure 104, with a percentage equal to 57%. By considering also, the percentages of car carriers & roro/containers as well as the general cargo carriers, the entire percentage of Group A was proven to be equal to 71%. Additionally, the port of Hamburg proves its high levels of flexibility, for the bulk cargoes market, where from the figure below, bulk carriers were equal to 12% while the rest 16% refers to tankers.

Consequently, Hamburg is the second port with significantly high levels of Group A vessels, together with the port of Zeebrugge. In general, this port configuration is characterized from simplicity, without the presence of confined areas, narrow passages or locks. However, the port of Hamburg is a tidal port, and therefore vessels are capable to enter or leave the port based on the windows which can guarantee sufficient draught levels. Especially, the big container vessels with length among 360 & 400 meters are capable to reach the port of Hamburg only during high tide.

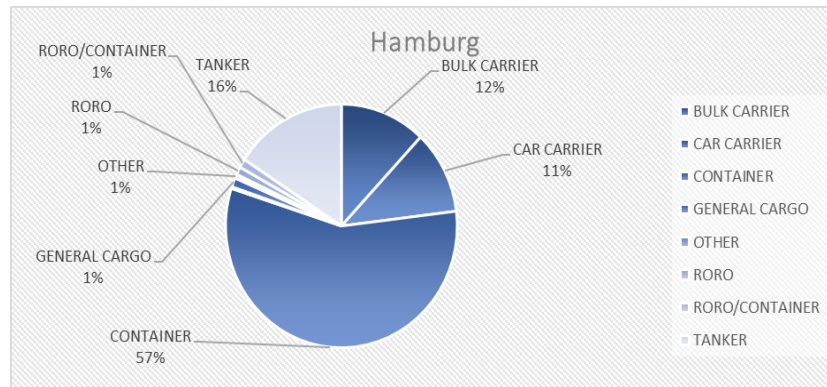


Figure 104: Hamburg Market Trends 2016

5.6.2 Towage Restrictions & Regulations in Hamburg

The towage restrictions for the port of Hamburg are indicated in the following tables. Starting with Table 25, for the Altenwerder container terminal, it is evident that in order the company to be characterized from the highest flexibility, requires as minimum 210 tons of BP, while for fulfilling the escorting needs, one tug with minimum BP of 70 tons is required. Furthermore, the regulations for Parkhafen container Terminal, require 100 tons of BP, under normal environmental conditions for carriers consisting of 13000 TEU's, while container vessels of 16000 TEU's require 140 tons of BP. However, up to 6 Bf, 240 tons of BP are required.

Table 25: Altenwerder Towage Restrictions (Hamburg 2016, 1)

Altenwerder		
TEU	9500	10000 - 13000
Min. BP	1 Tractor	2 x 70 t
4 Bf	1 Tractor	3 x 70 t BP
5 Bf	1 Tractor	3 x 70 t BP
6 Bf	1 Tractor	3 x 70 t BP
Escorting	-	1 x 70 t when L >= 360 m

Table 26: Parkhafen Waltershof Towage Restrictions (Hamburg 2016, 1)

Parkhafen/Waltershof			
TEU	8500 - 9500	13000	16000
Min. BP	Captain Decision	2 x 50 t	2 x 70 t
4 Bf		2 x 50 t	2 x 70 t
5 Bf		3 x 50 t	2 x 70 t & 2 x 50 t
Up to 6 Bf		4 x 50 t	2 x 70 t & 2 x 50 t
Escorting		1 x 50 t	1 x 70 t
Max Wind	Until 7 Bf	6 Bf	6 Bf

On the other hand, for the last two terminals, shown in Tables 27 & 28 the requested amount of BP, even under adverse environmental conditions is less. Starting with Tollerort, in cases where the wind is up to 6 Bf the regulations state that four tractors will be used with total amount of BP equal to 200 tons for container vessels of 13000 TEU's. Moreover, for ACL terminal there is not any specific tug regulation while at 6 Bf incoming vessels are enforced to get towage assistance from three tugs.

Table 27: Tollerort Towage Restrictions (Hamburg 2016, 1)

Tollerort		
TEU	8500 - 9500	13000
Min BP	2 x 40 t	2 x 50 t
4 Bf	2 x 40 t	2 x 50 t
5 Bf	2 x 40 t	3 x 50 t
Up to 6 Bf	2 x 40 t	4 x 50 t
Escorting	-	1 x 50 t
Max Wind	6 Bf	6 Bf

Table 28: ACL Towage Restrictions (Hamburg 2016, 1)

ACL Terminal	Always	At 5 Bf		At 6 Bf	
	# Tugs	Total BP	Tot. BP	# Tugs	Tot. BP
Inc. Vessel	2	n. a	120	3	170
Out. Vessel	n. a	n. a	100	2	150

5.7 Port of Bremerhaven

5.7.1 Types of Ships Calling in Bremerhaven

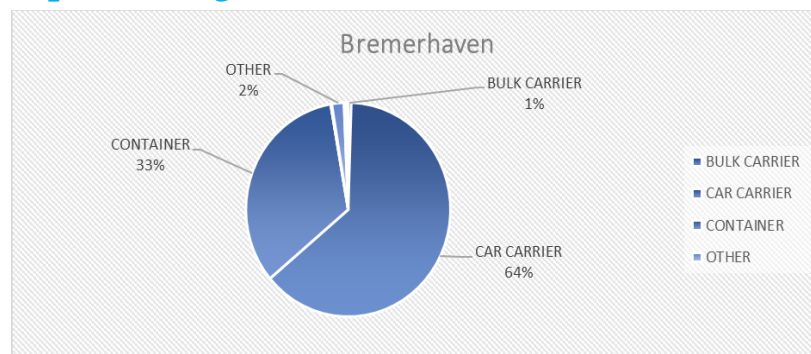


Figure 105: Bremerhaven Market Trends 2016

The second port of operation of KST in Germany to be analyzed towards the market trends of 2016, is the port of Bremerhaven. The main activities which take place in this port are associated with the handling of cars & containers, while a smaller percentage refers to the handling of passengers and fruits. In Figure 105, 64% of the assisted vessels, was proven to be car-carriers while 33% was containers. Consequently, the port of Bremerhaven is a port providing mainly services to vessels from Group A, together with the port of Zeebrugge & the port of Hamburg. The rest minor percentage, (3%), refers to bulk carriers or to any other type of vessel.

The configuration of this port is complex, where except from the container terminal, and a smaller part of the fruit terminal, the rest port is protected from two different locks for controlling the water level among the high and ebb tide. In Table 29, the main dimensions concerning the North & Kais Lock are indicated. The first to be mentioned for Bremerhaven locks, is related with the smaller length and especially the smaller width, compared to the locks of Antwerp and the lock of Zeebrugge. At the same time, since the only types of vessels entering the lock are car carriers, a significant amount of lateral area must be considered, especially in a port consisting of high current & wind levels. Therefore, high levels of capabilities and BP are required for compensating the massive levels of wind forces towards the car carriers surface area. This explains also the strict port regulations for the port of Bremerhaven, where the only tug types which are capable to offer towage services inside the lock are tractors. Currently, KST operates in this complex port only with rotor tugs, and therefore high levels of effectiveness levels and safety are expected.

Table 29: Bremerhaven Lock Dimensions (h. M. Bremerhaven 2016)

Bremerhaven	L (m)	W (m)	Type of Vessels
North Lock	372	45	Car Carriers (32 to 37 m Beam)
Kais Lock	305	55	

5.7.2 Towage Restrictions & Regulations in Bremerhaven

Table 30: Bremerhaven Towage Restrictions (P. o. Bremerhaven 2016, 1)

Fahrzeugklassen -Großcontainerschiffe-			Notes
1.	Gross Tonnage < 140000	2 all min. 100 t	-
2.	Gross Tonnage > 140000	3 all min. 170 t	5 Bf: 2 x total min 140 t
3.	Gross Tonnage > 170000	2 all min. 140 t	-
4.	Gross Tonnage > 170000, Maersk E-Class	3 each min. 65 t	-
5.	Gross Tonnage > 187000, Maersk Triple E-Class	3 each min. 65 t	-

In Table 30, the restrictions for the port of Bremerhaven are indicated, based on the gross tonnage of the assisted vessel. Due to the strong current on the Weser canal with average speeds among 3 to 3,5 knots, in

combination with the strong wind forces at 5 Bf, all the container vessels with gross tonnage over 140000 tons should be assisted from two tractors with minimum BP equal to 140 tons. Additionally, for Maersk E-Class containers with gross tonnage over 170000 gross tonnages, three tractors are required with minimum BP 65 tons each. Except from the container terminal, the port authority enforces all the towage companies to use tractors and preferably rotor tugs for the ship-handling duties of car carriers in the locks.

As it was already explained in chapter 3 & 4, the unique capabilities of rotor tugs to proceed in indirect mode, by pushing on the line into the lock, without altering position, as a result of the triangle propulsion configuration, offers a significant advantage for mooring car carriers safely into the locks. Azimuth tractors, i.e. ATD2412, are also capable to push on the line, however less efficiently compared with rotors since they lack the triangle propulsion configuration. On the other hand, ASD's are not capable at all to push on the line and control the vessel efficiently into the lock, since their propulsion units are positioned astern and therefore they can only push on the line only at speed over 5 knots; hence for this operation they require open space, which is not the case in the locks. Inside locks ASD's are capable only to pull the vessel explaining the lower efficiency levels, compared to ATD's. More information about KST fleet effectiveness in the various ports, as a result of their design & type of operation will be provided in chapter 6, after establishing a solid multi-criteria analysis for each case.

5.8 Port of London

5.8.1 Types of Ships Calling in London

The last country to be analyzed concerning KST daily operations is UK. Starting with the port of London, it is divided in two main parts. The first part includes all the possible docking areas in the river Thames, while the second part refers to the London Gateway port area which is located at the end of the river Thames. During the year of 2016, 51% of the assisted vessel were proven to be tankers & bulk carriers. On the other hand, vessels from Group A, were equal to 38%. For London Gateway, Figure 107 shows that all the assisted vessels belong to Group A, with container vessels to be equal to 94% of the total assisted vessels.

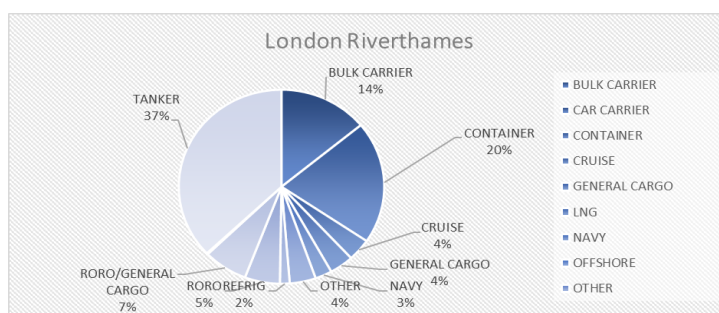


Figure 106: London River Thames Market Trends 2016

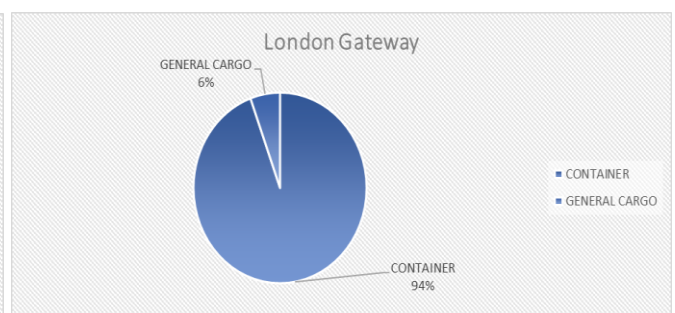


Figure 107: London Gateway Market Trends 2016

For KST is also very common to offer towage services, especially during spring and summer period to several cruise ferries. Special contract already takes place with a known cruise line, where the towage assistance takes place with two rotor tugs in and out of the Thames barriers. The port of London in general is not characterized from high levels of complexity. At the same time, it consists from one lock, (Tilbury Lock), in order vessels to reach Tilbury dock. Lock's width is 33,5 m and port authorities allow bulks, container carriers and RO-RO vessels up to 32,5 meters' width and 250 meters' length to enter. For this lock one or two tugs may be used, depending on vessel's size. In case where one tug is used, it is more possible to operate from astern, while in cases where two tugs are requested, both bow and stern of the vessel will be used. At the same time depending

on the tide, (high/ebb), the tug position to swing efficiently the vessel will vary. Finally, during ebb tide, only vessels up to 166 meters or vessels with 8 meters' draught can enter the lock. Apart from the lock, the port is not characterized from confined areas, while the only narrow passage is linked with the barriers in Thames river, where cruise ferries should always make use of tugs.

Table 31: Tilbury Lock Dimensions (London 2015)

Port of London	Max Vessel length (m)	Max Vessel Width(m)
Tilbury Lock	250	32,5

5.8.2 Towage Restrictions & Regulations in London

The port of London, also known as PLA has regulated specific towage requirements for all the possible areas, where vessels can berth for loading and loading cargo. Each area in the port, is characterized from a specific notation (Letter A-D), depending on vessels dimensions and destination. After the ship type code is recognized, the next to be investigated is the maneuverability capabilities of the vessel, where based on vessel maneuverability, (bow and/or stern thruster and its KW), the required amount of BP will be defined for each vessel type. Special attention is given to London Gateway area where the authorities state minimum BP at least for one of the tugs to be used, as it is shown in Table 32.

Table 32: London Gateway Restrictions (London 2015)

London Gateway			
	L AND/OR D		Tug Specific.
1.	<=250 m	12 m	MIN 1 x 60 ton. BP
2.	<=320 m	13,5 m	MIN 1 x 60 ton. BP
3.	>320 m	13,5 m	MIN 1 x 80 ton. BP

5.9 Port of Liverpool

5.9.1 Types of Ships Calling in Liverpool

The port of Liverpool is considered as a multi cargo while, from Figure 108, shows that KST offered the most towage services in vessels from Group B, where tankers and bulk carriers together were equal to 42%. Scrap vessels have also strong presence in this port while the presence of container vessels is also high, with a percentage equal to 40%. The port is also dealing with several RO-RO, general cargo and car carriers. Therefore, KST tug's efficiency for this port should satisfy both groups of vessels, while at the same time tugs should be capable to deal with several complexities.

The port configuration is characterized from poor maintenance and low investments during the last decades. At the same time, various narrow passages and confined areas, take place while due to locks presence, the average time of operation is considerably higher, compared to the rest ports of operations. The port is also characterized from adverse environmental conditions, with high levels of wind and current and hence both tug masters and pilots should guarantee the safest transaction levels of vessels among the river Mersey and the various docking areas, through the locks.

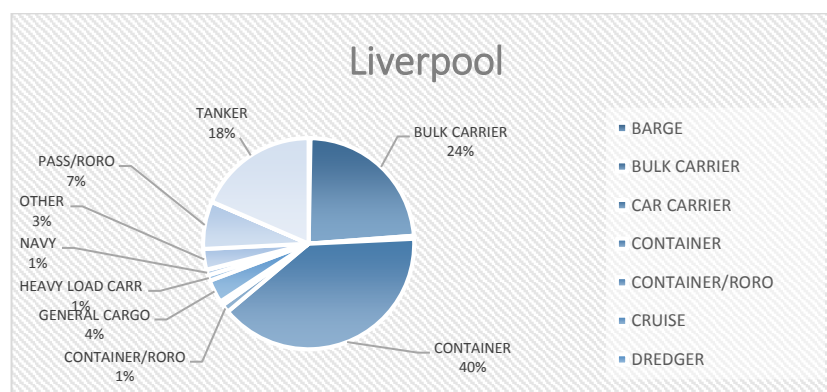


Figure 108: Liverpool Market Trends 2016

Compared to the rest ports consisting of locks, the port of Liverpool consists of the smallest locks in terms of width. Emphasis is given to Gladstone & Canada Langton locks where their width is equal to 40 & 39 meters respectively.

Table 33: Liverpool Locks Dimensions

Liverpool Locks	L (m)	W (m)	Type of Vessels
Gladstone Lock	330	40	<=275 m
Canada Langton	251	39	<=200 m
Alfred Lock	146	30	-
Eastman	182	24	<=170 m Vessels
QEII	246	30	

5.9.2 Towage Restrictions & Regulations in Liverpool

The towage regulations in the port of Liverpool state clearly that all the tugs to be used, should be characterized from minimum of 30 tons of BP. Apart from this rule, no other regulation for using specific tug types in & out of the lock takes place. Table 34 shows the minimum required number of tugs, depending on vessel's length, and docking area into the port. The average number of required tugs is two, while a third tug might also be used for assisting the vessel enter safely the lock. This tug will assist as a "shoulder tug", pushing on the side of the vessel, aiming to keep the ship in a straight course into the lock for mooring safely. The rest two tugs, are operating as a forward and stern tug responsively. For the shipyard Cammell Lairds, four tugs might be used only if the assisted vessel is over 210 meters, while the shipyard frequently requests tractors, and preferably Voith Schneider's for the removal of the dry-dock gates. Due to the vertical propulsion units, this tug type is considered as the most efficient for this operation, since the wash effect does not influence the gate removal. Consequently, even if KST is not obligated to have tractor tugs in this area, because of the towage regulations, it is crucial, the port of Liverpool to be characterized from a multi-type fleet for serving clients in the most efficient way.

Table 34: Restrictions for Liverpool Locks

Liverpool Vessel LOA (m)	Regulations & Restrictions for Liverpool Locks								
	MINIMUM REQUIREMENT FOR ALL TUGS: AT LEAST 30 T OF BP								
	1. Gladstone River Ent.	2. Langton River Ent.	3. Alfred River Ent.	4. 12 Quays	5. Bromborough Wall	6. Cammell Lairds	7. Eastham Locks	8. QEII Lock	9. Garston
< 95	-	-	-	1	-	1	-	-	-
95 - 120	1	1	1	2	1	2	1	1	1
120 - 140	2	2	2	2	2	2	2	2	2
140 - 160	2	2	3	2	2	2	2	2	2 (<=152 m)
160 - 180	2	2	3	2		3	2	2	
180 - 210	3	2	3	2		3		2	
> 210	3	3				4			

5.10 Port of Southampton

5.10.1 Types of Ships Calling in Southampton

The final port of operation of KST to be analyzed is the port of Southampton. The company started operating in this port since last April, while the results among April & May, proved that the type of the assisted vessel were container vessels. In general, the configuration of this port is characterized from low complexity without locks. Additionally, the docking areas consist of open areas, leading to smaller average times for the towage operations.

5.10.2 Towage Restrictions & Regulations in Southampton

The port authorities of Southampton, have also divided the port in several parts, while each part requires specific minimum number of tugs for vessel's assistance, while no specific tug types are required. However, the minimum number of tugs to be used for the various areas in the port, should comply with the special notes which are indicated in Table 35. Hence, for all the vessels with DWT equal or larger than 60000 tons, one tug should be at least 50 tons. Additionally, for vessels with length larger or equal to 240 meters, each tug should be characterized from minimum 40 tons of BP, while at least one should be tractor. Finally, for the large container vessels which are larger than 365 meters, with 45 meters' beam, three to four tugs are required, where at least one tug should be at least 70 tons of BP while all the others more than 50 tons.

Table 35: Additional Towage Regulations for Southampton (Southampton 2017)

Notes		
	Vessel Info	Tug Restriction
1.	>= 60000 DWT	1 x AT LEAST 50 t OF BP
2	>= 240 m	Each Tug min BP AT LEAST 40 t & 1 Tractor
3.	Large Container Vessels: L > 365 m & B = 45	REQUIRE 3/4 tugs: 1 AT LEAST 70 T, THE OTHERS > 50 T

5.11 Environmental Conditions in KST Ports of Operations

The conclusive subchapter of chapter 5, aims to analyse the environmental conditions for each port. The weather conditions can have negative impact towards the daily operations and for this reason, for assessing efficiently all the possible reallocations among KST fleet among the various ports, the current and the wind levels will be investigated among all the ports of operations of KST. In Table 36, the main port characteristics and environmental conditions for each port are summarized, as a result of their unique configuration.

Table 36:KST Ports Characteristics

	Port Name	Locks	Barriers	Passages	Wind	Current
NL	Europoort	NO	NO	WIDE	HIGH	LOW
	Rotterdam Area	NO	NO	WIDE	HIGH	LOW
	Terneuzen	YES	NO	WIDE	MODERATE	MODERATE
	Vlissingen	NO	NO	WIDE	MODERATE	MODERATE
BE	Antwerp	YES	NO	WIDE	MODERATE	HIGH
	Zeebrugge	YES	NO	MODERATE	HIGH	HIGH
	Ghent	NO	NO	MODERATE	MODERATE	LOW
GE	Hamburg	NO	NO	WIDE	MODERATE	MODERATE
	Bremerhaven	YES	NO	MODERATE	HIGH	HIGH
UK	London	YES	YES	WIDE	MODERATE	HIGH
	Liverpool	YES	NO	NARROW	HIGH	HIGH
	Southampton	NO	NO	WIDE	MODERATE	LOW

Table 37: Current Scale

Speed < 2 kn	Low
2 < Speed ≤ 3 kn	Moderate
Speed > 3 kn	High

Starting with the port of Rotterdam the amount of current during high tide has an average value speed equal to 2,5 knots, while during ebb tide its average speed is 2 knots. At the same time during spring period there is a minor increase, leading to an average speed of 3 knots, while during storms it can be even up to 4 knots. For the ports of Terneuzen and Vlissingen area in GTV area, the average current speed is equal to 2,5 - 3 knots. However, during spring period the current can reach up even the speed of 6 knots in the Scheldt canal. On the other hand, the port of Ghent is protected from both tide and current influence.

For the port of Antwerp, the average current speed is about 3 to 3,5 knots combined with high wind levels equal to 6 -7 Bf, while there are cases that wind can be up to 9 or even 10 Bf. The same adverse environmental conditions will take place also in the port of Zeebrugge with even higher amount of current levels, which as an average at the mouth of the port has a value of 4 knots combined with 9 to 10 Bf. However, the current will not influence the inner port of Zeebrugge, since the port is protected. This explains why the port authorities' advice vessels to enter with speed, for compensating the strong impact of wind and current forces. Special attention is required for container vessels which should slow down as soon as possible, due to the limited distance among the port entrance and the container terminal, while car carriers have more time since they will always head to the inner part of the port through the lock. For the safe-handling in the lock, special attention is needed for compensating the large wind forces acting on their large lateral surface areas.

The port of the Liverpool, is also considered as a port with adverse environmental conditions with wind levels equal to 9 or even 10 Bf during winter time, while the average speed of current in river Mersey, has average speed equal to 4 to 4,5 knots. Consequently, tug masters are requested to deal with several complexities in and out of the lock, in a port with multiple confined areas and narrow passages. Additionally, the poor fenders at the jetties near the lock entrance, create further problems to the merchant vessels, while in cases of very windy days' vessels will come alongside to the jetty, for entering the lock, where due to swells, multiple hull damages are possible to occur. Unless the tugs to assist are ATD's and mainly Rotors, they cannot proceed in indirect towing method at low speeds, for handling the vessels efficiently and consequently tugs are capable only to pull on the line. The swells on the River Mersey are also the main reason that the new container terminal in the port of Liverpool faces several problems, since it is exposed to the river, making infeasible for container vessels to moor safely and load or unload their cargo. Even if tugs are requested to push continuously vessels alongside the berth, the swells will cause massive problems to both hull of the tugs and assisted vessel.

Finally, Gladstone Lock, is in a more exposed area and hence higher levels of swells and current are expected. For this reason, tug masters need to be more aware during the towage operations. Concerning the rest ports of United Kingdom, the port of London is also characterized from high levels of current with an average of 4 to 4,5 knots. Therefore, the towage operations in the Thames river demand increased levels of awareness and consideration. On the other hand, for the port of Southampton, lower current speeds are expected. Conclusively, the environmental conditions for German ports will vary. The port of Bremerhaven faces the same adverse environmental conditions levels as Liverpool and Zeebrugge, with high levels of current which have average speed of 3 to 3,5 knots combined with high levels of winds. High levels of efficiency are required also in a port with stricter regulations for controlling efficiently mainly the car carriers in the port of

Bremerhaven. On the other hand, for the port of Hamburg, the maximum average current speed can be up to 3 knots with wind forces equal to 7 Bf.

5.12 Chapter Conclusion

In this chapter, the main goal was to align KST fleet effectiveness with the ports of operations. Figure 94, established the fundamental insights for each port where KST is operating, while in total four main elements were investigated. The first part was related with the type of merchant vessels calling at each port. Depending on the cargo type, merchant vessels have various shapes and designs, and therefore the efficiency of KST fleet should be aligned with all the possible vessel types in the various ports. By using essential data from company's records, during 2016, it was then possible to analyze the types of vessels calling at each port, and therefore to align KST fleet effectiveness results with the vessels to be assisted.

The second part, refers to the environmental conditions for each area. The influence due to high levels of wind, current & swells have a significant impact and therefore the environmental conditions were deeply analyzed for all KST ports of operations. The third major element that was discussed, was related with the towage regulations and restrictions, for both normal and adverse environmental conditions, which is a vital input for the tool construction. At the same time, this chapter was aiming to re-evaluate if the capacity at each port is adequate or if modifications are required.

The last part which was analyzed was related with a solid port configuration analysis. A proper investigation among the main characteristics of KST ports of operation is vital, for assessing the port complexity for each case. The presence of locks, confined areas or narrow passages raise the complexity levels towards the towage services, as well as the average time for each operation, by requiring also in some cases specific tug types with higher efficiency levels in order to guarantee safe ship handling duties.

Finally, since the assessment for each tug type varies among the ports, as a result of port complexity, the criteria to be evaluated towards each simulation through the tool, will consist from various weight factors, and hence a deep analysis will take place in order to provide solutions to all these complex decisions. Consequently, the main goal of the following chapter is to establish the main coefficients which are required through the decision-making tool for achieving a solid evaluation of KST fleet, with the correspondent's weight factors, which should be aligned with all the involved ports configurations.

6

Multicriteria Analysis for Assessing KST Operational Profile

The assessment for each tug type varies from port to port, as a result of port complexity, and therefore the criteria to be evaluated towards each simulation will consist from various weight factors, and hence a valuable analysis is required for offering solutions to all these complex decisions. Therefore, the goal of this chapter is to establish the main parts to be used in the decision-making tool for the evaluation of KST fleet, with the correspondent's weight factors, which should be aligned with the ports configuration where KST is operating.

6.1 Analytic Hierarchic Process - AHP

In this chapter, an analysis will be performed concerning the analytic hierarchic process, which is required for the needs of the tool. In chapter 4, the main capabilities and weaknesses for the entire fleet of KST were addressed, for all the possible types of operation, while chapter 5 discussed the main characteristics towards the market trends and KST ports of operations. This chapter aims to establish the method to be followed for combining the required input from all the pre-mentioned chapters, which is required for the tool needs, for evaluating the effectiveness of each tug in various ports, under various scenarios.

Chapter 6 is one of the most essential chapters for the tool construction, which is extensively analysed in chapter 8, and therefore the determination of all the associated criteria is vital. For this reason, decision making process will be used which is defined as the process for making a choice among various alternatives, while each of the choice to be made, is based on established criteria. For this project, it was required to create a tool capable to provide several results depending on user's choices. These choices reflect the tug selection to be made for each of the various harbours of KST.

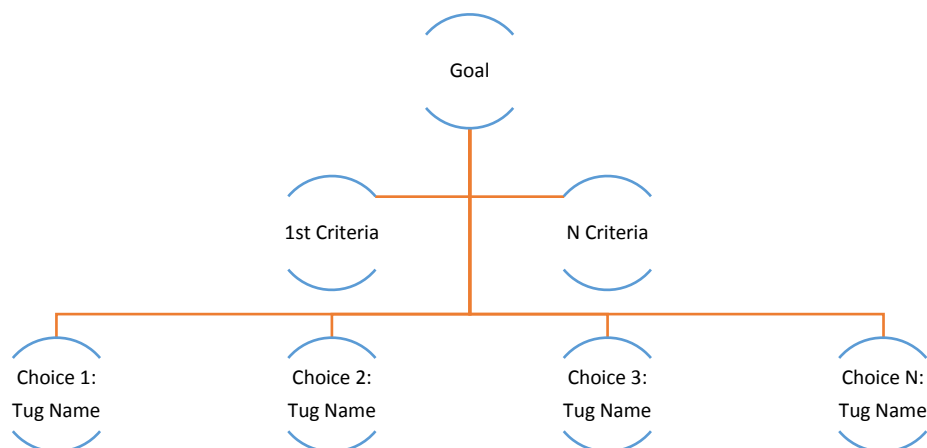


Figure 109: Optimum Goal VS Number of Criteria

By looking Figure 109, it is evident that for achieving the optimum goal, towards the optimum tug selection per port, several scenarios need to be established. Afterwards, the effectiveness of each of the selected tug for the discussed port needs to be retrieved from a database, which will provide the effectiveness results for all the established criteria, while the result will occur based on the weight factors of the discussed port. Consequently, the combination of results for every port will define tug's effectiveness for all the possible types of operations, for the towline connection mode. At the same time, the choices to be available for each user, refer to the entire fleet of KST, while the determination of all the various criteria among the ports of operations, has occurred exclusively for the study case of KST and therefore represents company's insight towards the daily operations.

Why AHP Method

Analytic Hierarchy Process, also known as AHP, is one of the most known multi-criteria decision-making method. This method is ideal for multi-criteria analysis of various criteria with a total number equal or less to seven, in terms of consistency. Therefore, it fits perfectly in KST study case, since the maximum number of criteria among the ports can be up to four. (Coyle 2004). The main concept behind this method is to originate ratio scales among various comparisons between pairs and consequently to assist on defining the weights for all the criteria to be used. This method already counts several decades, and is considered as one of the most solid decision-making methods to be used in mathematical processes for ranking the importance of all the related criteria pair-wise. (Thomas L.Saaty 2012). For this reason, by using Table 38 each of the criteria to be used for the several ports, is characterized from a score linked with the degree of importance. For KST, the required input was retrieved from the subjective opinion of operation managers and tug masters, depending on each port, which fully represents their personal experience towards the daily operations among the various ports. The most important criteria, is ranked with 9, while in the case that two criteria are same of importance, the degree of importance is equal to 1. Consequently, multiple matrixes will be created for calculating the weight factors for each of port in KST. (L.Saaty 1977)

Table 38: Saaty's Semantic Scale

Degree of Importance	Level of importance among criteria
1.	Same of Importance
2.	Weak
3.	Moderate
4.	Moderate Plus
5.	Strong
6.	Strong Plus
7.	Very Strong
8.	Very, Very Strong
9.	Extreme

Afterwards, as soon as the weighting factors tables are defined, the next step refers to the consistency ratio (CR), which is required for evaluating the level of consistency towards the survey results from the collaboration among operation managers and tug masters for the ranking calculations. AHP, allows low levels of inconsistency related with the judgments to occur, while most humans tend to judge with high levels of inconsistency (Chou 2010). However, before calculating the consistency ratio, the consistency index, (CI) needs to be defined. Finally, the ratio scales to be used for judging all the criteria between each other, in KST, have occurred from the principal of Eigen vector (λ), which is compared with the total number of criteria for each case.

Both equations concerning the calculation of Consistency Ratio & Consistency Index, show how CR will be calculated, depending on consistency index as well as from a constant, known as RI. This constant has various values, as a result of the number of criteria to be compared for each port. In cases where the number of criteria

is equal to 1 or 2 , Table 39 shows that the constant value will be equal to 0, meaning absolute consistency. On the other hand, for larger values of criteria to be compared, the constant will consist of higher values. In general, the consistency ratio should have values equal or below to 10% in order the answers to be trustworthy. Therefore, for all the cases where the ratio is proven to have higher values, the re-evaluation of pair-wise comparison is necessary for redefining the influence among the criteria in the most optimum way. (Staay 2003)

$$CI = \frac{\lambda - n}{n - 1} \quad \& \quad CR = \frac{CI}{RI}$$

Table 39: Constant RI for various number of criteria

<i>n</i>	1	2	3	4	5
RI	0	0	0.58	0.90	1.12

6.2 Number of Criteria Per Port

Pair-wise Comparison

The first to be analysed related to AHP method refers to the pair-wise criteria comparison. This comparison is high of importance for evaluating the importance variances among the main criteria to be used when applying the method. Eventually, by filling in a new matrix with all the various scores for each case, (after using the scores from Table 38), all the possible comparisons among the involved criteria will occur. However, the number of criteria per port for KST study case varies, and therefore several tables will be created due to the port complexity. Table 40 summarizes the number of criteria to be considered for each port, as they have already been explained in chapter 5.

Table 40: Number of Criteria Per Port

Port	# Criteria			
	Tug Type	Locks	Env. Conditions	Confined Areas
Europoort	√	-	√	-
Rotterdam City	√	-	√	-
GTV	√	√	√	-
Antwerp	√	√	√	-
Zeebrugge	√	√	√	-
Hamburg	√	-	√	-
Bremerhaven	√	√	√	√
London	√	√	√	-
Liverpool	√	√	√	√
Southampton	√	-	√	-

The ports of Liverpool and Bremerhaven consist of 4 criteria while the ports of GTV, Antwerp, Zeebrugge & London, consist of 3 criteria. Finally, the ports of Hamburg, Rotterdam & Southampton consist of 2 criteria. The matrixes to be created regarding all the various ports of operations of KST, will always consist of value 1 in the diagonal, since in these cells the criterion is compared to itself. All the rest cells will be filled in towards the importance of the criterion in column with the correspondent criterion in the row. Figure 110 shows the resulted tables for all the ports of KST. In case of Bremerhaven there are 4 criteria to be considered. It is evident that the diagonal consists of 1, while the red cells indicate the importance of the horizontal criteria compared to the correspondent criterion in each column, by using the ranking from Table 38. Therefore, the tug type criterion is considered as “strong”, compared to the environmental conditions in this port, while the lock presence is considered as “strong plus” against the tug type. At the same time for the port of Bremerhaven

the confined areas are considered as “moderate”, compared to the tug type. Consequently, it is proven that the usage of AHP method is vital for evaluating precisely the entire behaviour of a tug towards the daily operations for each port, consisting of various criteria number. After the same procedure takes place for all the ports of operation, the rows are summed up and are normalized, for representing the final weight factor for each criterion and for each port which are shown in Figure 110.

Table 41: Summary of Criteria Number Per Port

Group	Port									
	Eur.	Rot. City	GTV	Ant	Zeeb.	Ham.	Bremer	Lon.	Liver.	South.
4 Criteria	-	-	-	-	-	-	√	-	√	-
3 Criteria	-	-	√	√	√	-	-	√	-	-
2 Criteria	√	√	-	-	-	√	-	-	-	√

6.3 KST Tug Type Effectiveness VS Port Configuration: Weight Factor Analysis

In Figure 110, the number of criteria for each port are summarized. The calculation of the Eigen vector, λ , for each port of KST ports will occur by calculating the column with name “Product”. For example, for the port of Bremerhaven, 4 criteria are considered. Hence, each of the element of “Product” column has occurred by summing up the multiplication of each of the cells horizontally per criterion, with the correspondent weight factor. The same procedure is followed for all the criteria till the column is filled in. Afterwards, for calculating the Eigen vector λ , the column “Ratio” will occur by diving each of the calculated product, because of each criterion with the calculated weight factor (Normalized). The average values of “Ratio” values will lead to the Eigen vector, λ . In Table 42 the averages of the calculated vectors for all the ports of KST will be used, together with the consistency indexes for each case, for evaluating the consistency ratio.

Weight Factors Calculation

Bremenhaven	4 Criteria	Weight Factors	Tug Type	Locks	Conf. Areas	Env. Cond	Column Sum	Normalized	Product	Ratio
		Tug Type Score	1	0.17	0.3	4	5.50	0.18	0.56	3.19
		Locks	6	1	2	6	15.00	0.48	2.43	5.07
		Confined Areas	3	0.17	1	5	9.17	0.29	1.16	3.35
		Environmental Conditions	0.3	0.17	0.2	1	1.62	0.05	0.23	4.53
							31.28	1.0	-	4.19
Liverpool	4 Criteria	Weight Factors	Tug Type	Locks	Conf. Areas	Env. Cond	Column Sum	Normalized	Product	Ratio
		Tug Type Score	1	0.167	0.5	3	4.67	0.17	0.57	3.43
		Locks	6	1	4	5	16.00	0.57	2.69	4.68
		Confined Areas	2	0.17	1	2	5.17	0.19	0.76	4.11
		Environmental Conditions	0.3	0.20	0.5	1	2.03	0.07	0.34	4.61
							27.87	1.0	-	4.21
GTV & London	3 Criteria	Weight Factors	Tug Type	Locks	Env. Cond	Column Sum	Normalized	Product	Ratio	
		Tug Type Score	1	0.25	3	4.3	0.29	0.73	2.53	
		Locks	4	1	4	9	0.61	2.16	3.52	
		Environmental Conditions	0.17	0.25	1	1.42	0.10	0.30	3.09	
						14.67	1.0	-	3.05	
Zeebrugge & Antwerp	3 Criteria	Weight Factors	Tug Type	Locks	Env. Cond	Column Sum	Normalized	Product	Ratio	
		Tug Type Score	1	0.3	3	4.3	0.31	0.84	2.71	
		Locks	3	1	4	8	0.57	1.96	3.42	
		Environmental Conditions	0.33	0.25	1	1.58	0.11	0.36	3.18	
						13.92	1.0	-	3.10	
Hamburg- Europoort- Rotterdam- Southampton	2 Criteria	Weight Factors	Tug Type	Env. Cond	Column Sum	Normalized	Product	Ratio		
		Tug Type Score	1	5	6	0.83	1.67	2		
		Environmental Conditions	0.20	1	1.20	0.17	0.33	2		
					7.2	1.0	-	2		

Figure 110: Weight Factors Calculation

AHP, allows low levels of inconsistency related with the judgments to occur, while most humans tend to judge with high levels of inconsistency, However, by looking the results in the column of consistency ratio for all

the ports of KST, it is evident that consistency ratio is below 10% for all the cases, proving the high consistency levels of the results and not random entries among the pair-wise comparisons.

Table 42: Consistency Ratios for KST Ports of Operations

Port	Crit.	RI	Eigen Vector (λ)	Consistency Index (CI)	Consistency Ratio (CR)
Bremerhaven	4	0,9	4.19	0.06	7 %
Liverpool	4	0,9	4.21	0.07	8 %
GTV-London	3	0,58	3.05	0.02	4 %
Ant.- Zeebrugge	3	0,58	3.10	0.05	8.73 %
Rot-Ham-South	2	0	2	0	Perfect Consistency

6.4 Analysis of Tug Types Score Per Port

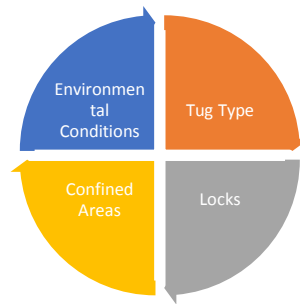


Figure 111: Tool Input Implementation

After the definition of the various criteria among the ports of KST, and the explanation of the weight factor analysis for each case, this subchapter aims to analyse tugs effectiveness through the locks and confined areas, for the various environmental conditions. Figure 111 explains the output to occur from the tool, which will combine tug's effectiveness for each of the main parts, where each score will be evaluated based on the weight factors of the criteria towards the port to be assigned. The tool will be able to provide two different scores, depending on the vessel to assist, explaining the analysis of market trends in chapter 5, which indicate the various types of ships calling at each port. Therefore, the user will be also able to assess the type of vessels for each port, and therefore to assign tugs with higher effectiveness towards the daily operations. The first part of Figure 111, is already defined from chapter 4, and indicates tug effectiveness for all the possible types of operations as a result of their design. Afterwards in subchapter 6.4.1, tug effectiveness for operations through the confined areas will be evaluated as a result of their length, while subchapter 6.4.2 aims to discuss tug effectiveness though the locks. Finally, in subchapter 6.4.3 the effectiveness results of KST tugs for compensating the adverse environmental conditions, are aligned with their ability towards the side-stepping mode.

6.4.1 KST Fleet VS Confined Areas

The maneuverability of tugs in confined areas, combined with the minimum reaction delay times, is an essential factor for assessing the ability of tugs to operate efficiently in confined areas. Therefore, the combination of tug's length, combined with the tug concept design are the two key factors for the assessment of tug's effectiveness through confined areas and narrow passages. (Jansen, Ship Handling in Port 13 of September 2012, 13). Therefore, the first step for assessing efficiently the fleet in the study case of KST, was to establish the different categories among the tugs based on length variances. In Table 43, five different categories with a steady range occurred after the proper guidelines from KST tug masters. The first category consists of tugs with length below 25 meters, while the second category consists of tug's length among 25 &

28 meters. Additionally, the third category, is related to tugs, with length among 28 & 31 meters. Finally, the last two categories, correspond to tugs with length among 31 & 34 meters of length or larger.

Table 43: Length Categories of KST Fleet

Length Categories of KST Fleet				
1 st Category	2 nd Category	3 rd Category	4 th Category	5 TH Category
L ≤ 25m	25m < L ≤ 28 m	28m < L ≤ 31 m	31 < L ≤ 34 m	L > 34 m
1) ATD 2412 2) Armon Design	1) ZP CONDON 2) ZP CHALONE	1) TEXELBANK 2) THAMESBANK 3) UNION 11 4) UNION 7 5) UNION 8 6) LIEVEN GEVAERT 7) SMIT SANDON 8) ZEEBRUGGE 9) ST. ANNASTRAND 10) ASD2810 11) Rampart 3000 12) ASD3110 13) Compact Tug Design	1) COMBI TUG 2) SMIT WATERLOO 3) BRUGGE 4) GENT 5) UNION 5 6) UNION 6 7) Rampart 3200 8) Citranaval Defcar 9) ASD3212 10) ASD3213	1) Aarts Marine

Together with the assessment of the harbor tugs effectiveness depending on the types of operations, tug masters were also capable to quantify the capability of the various tug types to operate efficiently in confined areas. Therefore, in Figure 112, a comparison among the tug types of company's can be addressed. Starting with the Rotors, it is evident that they were assessed with 100%. This result is expected for this tug type since rotors are capable to proceed in "rotor ring" movement, as a result of their triangular configuration of the propulsion system, which will be analyzed extensively in subchapter 6.4.2. By proceeding to this movement, tugs are capable to push on the line by their current position without requiring extra space, which makes this tug type ideal for confined areas & locks.

On the other hand, all the rest tug types are expected to consist of lower scores due to their lower effectiveness among the confined areas. By looking Figure 112 and Table 43, an important correlation is proven. For the 5th category, which consists of the largest tugs of KST, Aarts Marine Concept, the effectiveness result for confined areas will be equal to 57.4% as a result of the LOA which is larger than 34 meters. On the other hand, for the 4th category, it is evident that the average results for the tug types among 31 & 34 meters, were proven to be 63%, improved by almost 7% from the previous category. For the third category, the improvement is equal to 6% while the tug types of this type were assessed from effectiveness equal to 68%, and for the second category the results were equal to 70%. Finally, ATD2412 & Armon Design were improved by 10% and therefore their effectiveness was proven to be equal to 82%.

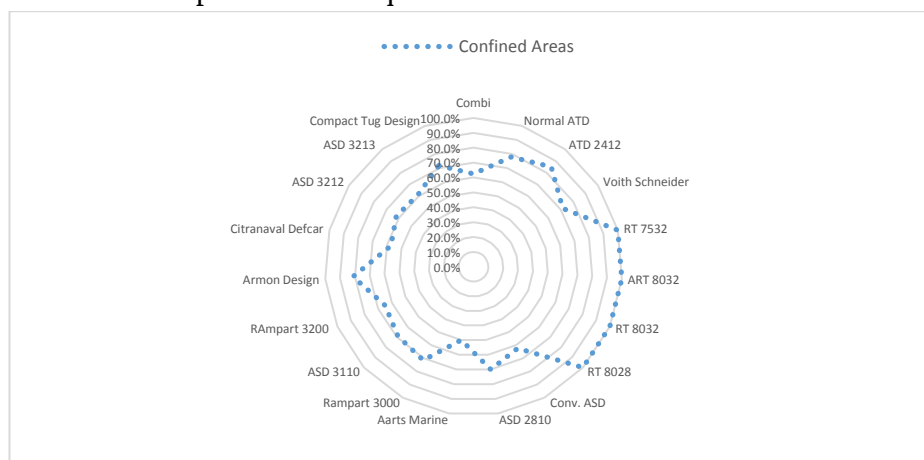


Figure 112: Confined Areas KST fleet Effectiveness Results

6.4.2 KST Fleet VS Locks

The next major criterion for characterizing KST fleet effectiveness in the various ports refers to the presence of locks. As it has already been addressed in chapters 5 and subchapter 6.3, 50% of the ports where KST is operating, consists of locks with various sizes towards their length and mainly towards their width, while the usage of multi criteria analysis with the AHP analysis, was necessary for using the proper weigh factors as a result of the lock configuration for each port. In general, the effectiveness of harbor tugs to operate inside the lock is entirely linked with their design and mainly connected with the location of the propulsion units.

Rotoring

In ports, which are characterized from high levels of complexity, the tugs to be selected should be capable to provide superior agility as well as direct manoeuvrability, towards the narrow passages and most importantly inside locks. As it has been already explained, tugs effectiveness to operate inside the locks is directly aligned with the vessels to assist. Hence in cases of narrow locks, with short widths and particularly, in cases of vessels from Group A, i.e. car-carriers or fully loaded container vessels, the manoeuvrability levels depend on the number and location of their propulsion units.

Tractor types and more specifically rotors, are capable to deliver high Bollard Pull levels in the desired direction of the towline connection, without repositioning the tug, offering a major asset for efficient and safe ship-handling conditions. At the same time, since rotors consist of 3 instead of 2 azimuth propellers units, high levels of manoeuvrability levels are expected, and therefore they are capable to proceed from direct to indirect mode in a very short period. The same philosophy refers also to the rest tractors, i.e. ATD2412 or Voith Schneider's, consisting of forward location of propulsion units, and hence they are also capable to "push on the line" however in lower levels compared to rotors. On the other hand, the Azimuth stern drive tugs are not capable to steer the vessel, unless a fully reposition of the tug takes place, which is not the case in confined areas and locks. Additionally, ASD's can start steering the vessel in indirect mode only at speeds higher than 4 knots, which is also not the case inside locks, while inside locks they are capable only to pull on the line for keeping away the vessel from the jetty. (Slesinger 2008, 62).

In Figure 113, one of the most significant advantages of rotors, due to their triangle configuration of their propulsion units, is explained, known as "Rotor Ring". The two rotors of the figure, assist a vessel moving through a very narrow passage, consisting of a bridge. It is evident, that even at very low range of speeds, the tugs are capable to proceed in indirect mode, as it is indicated below, and therefore they are capable to push on the line efficiently for steering and braking the vessel at the same time, without requiring large amount of space, as it would be required for other tug types. This substantial advantage of rotors, is a result of the triangle configuration, which offer the ability to rotate the thrusters in the most efficient direction for controlling the vessel in short responses time and in narrow spaces.

The same situation takes place inside locks, where tugs need to assist merchant vessels mooring at the jetty, as long as they are waiting for gates to open and close for controlling the sea water level among the inner & outer port. (P.ENG. January 2014). In some cases, the situation inside the lock can be so risky, where only the usage of rotors can guarantee high levels of effectiveness and therefore the highest levels of safety during the daily operations. This situation in case of KST, applies in the port of Bremerhaven where the presence of fenders inside the lock, exist only partially (only at the right side has fenders), when entering the lock from the Weser river. To make matters worse, as it was indicated in subchapter 5.6.2, most of the vessels calling for

assistance in the port of Bremerhaven were proven to be Car-Carriers, and therefore tugs need to compensate the high amount of forces, due to the large lateral surface area of this vessel type, which lead to a significant impact towards the daily operations. For this reason, rotors ability in the port of Bremerhaven for pushing on the line efficiently into a narrow space, by applying the “Rotor Ring” method is ideal and required for the proper handling of merchant vessels.

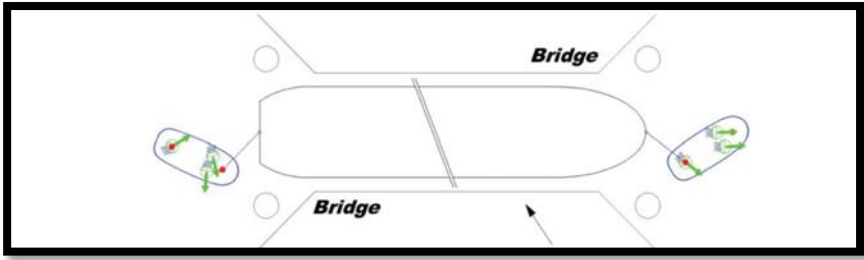


Figure 113: “Rotoring On a Bridge”

However, for the rest tug types, their effectiveness for handling a merchant vessel inside the lock will be by far less, and the main reason is the smaller number and the position of the azimuth thrusters. In general tractors, are somehow more efficient for controlling the vessels compared to ASD’s. This explains, why ASD’s consist of such a lower effectiveness levels when operate in the locks. Additionally, in cases of locks with small widths for example in the case of Liverpool or Terneuzen, emphasis to be given on the type of tugs to be used, especially in cases of vessels with large beams and lateral surface area. Consequently, it can be proven that a pair of rotor tugs is capable to substitute the necessity of a larger number of tugs for assisting in the various ship-handling duties. For this reason, KST tug masters were also requested to evaluate the effectiveness of the tug types of the company regarding the confined areas VS locks, where each master was evaluating the tug type based on his experience. The figure below summarizes the results for each type.

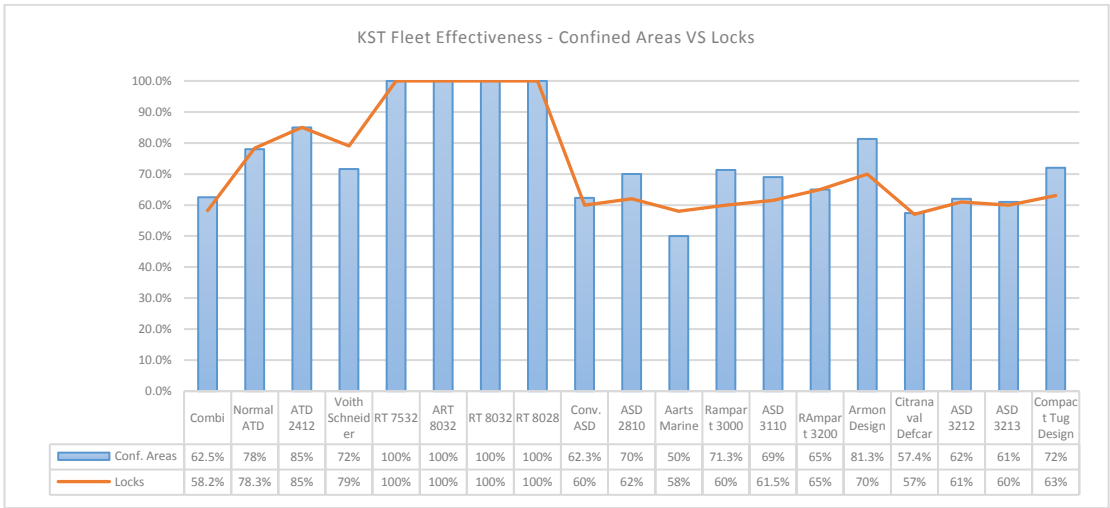


Figure 114: Confined Areas Vs Locks KST Fleet Effectiveness Results

In Figure 114, the entire fleet of KST is assessed towards its effectiveness to operate in the locks, while the effectiveness results are also compared with the confined areas fleet effectiveness, for obtaining a more solid overview towards the deviation of tug types among the two criteria. Starting with rotors, zero deviation is shown among the two criteria. These results were expected due to the rotor ring method which was already explained. Afterwards, the tractors are proven to have significantly low levels of deviation, where ATD2412 was proven to consist of the largest effectiveness and no deviation towards the two criteria. Finally, the ASD

tug types show the largest deflections. The effectiveness of these types is by far reduced towards the locks, since they are capable to apply only pulling forces, while due to the length variances for some ASD types, the effectiveness in confined areas is slightly improved. This situation corresponds for example to Armon Design tug type which was evaluated with 70% effectiveness through the lock; however, its effectiveness towards the confined areas was higher due to the fact that its length is only 24 meters.

6.4.3 KST Fleet VS Environmental Conditions

Side Stepping

The final criterion to be deeply considered for evaluating tug effectiveness in the various ports of operations of KST, is correlated with the environmental conditions, due to the various wind and current conditions that take place in each port, as it was already explained in subchapter 5.10. Harbour tugs of KST should be evaluated towards their ability to compensate the adverse environmental conditions, based on their side-stepping capabilities. Afterwards the correspondent weight factors as a result of wind & current levels for each port will be used through the tool, for defining the effectiveness of company's tugs.

Side Stepping - ASD VS ATD

ASD's are characterized from high levels of manoeuvrability, including their ability to move sideways. However, the efficiency among ASD and ATD's, for side-stepping varies considerably, due to the propulsion unit's location. As it is indicated in Figure 115 the azimuth thrusters are turned almost in a contrary position, leading to high levels of power at their stern, for dragging their hull sideways. This type of tug movement is known as "side stepping" and has the direction of the resultant force as it is shown in Figure 115. ASD portside thruster must produce larger amount of thrust (thrust with orange colour in Figure 115, compared with the starboard thruster (thrust with red colour in Figure 115), which produces significantly lower amount of thrust, for maintaining the desired (vertical) course of the tug. Consequently, when an ASD proceed in side-stepping at a speed range of 2 to 3 knots, for swinging an assisted vessel, the towline force is expected to be lower, since the tug must provide a percentage of its thrust for maintaining a specific course. Consequently, side-stepping movement is possible to be used for swinging and not for steering assistance. On the other hand, ATD's are more efficient towards side-stepping ability, since they must deliver less amount of their thrust. (E. T. Association, Guidelines For Safe Harbour Towage Operations February 2015, 16)

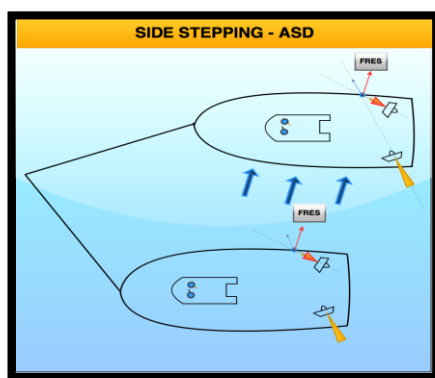


Figure 115: ASD Side Stepping

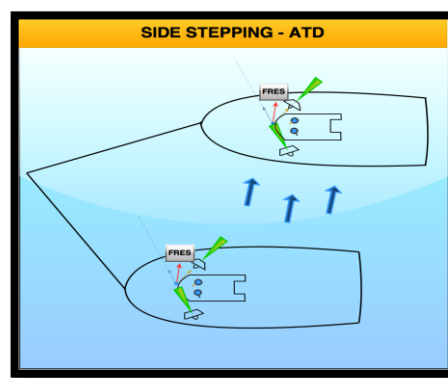


Figure 116: ATD Side Stepping

ATD's consisting of azimuth or Voith Schneider propulsion units, are characterized from higher levels of maneuverability compared with ASD's. Therefore, their ability for moving sideways is expected to be even higher, because of the propulsion unit's location. When an ATD proceeds in side stepping, the resultant force

occurs more efficiently in the desired direction, from both thrusters. Figure 116 shows that both thrusters produce the same amount of thrust (shown with green color), with 45 degrees of angle. Additionally, the resulted turning lever x for ATD's is significantly lower. Consequently, ATD's do not require high amount of thrust for maintaining their course during side-stepping, and therefore higher levels of towline forces will occur. Additionally, the smaller the resistance is, the less drag force will occur, and therefore the amount of thrust to be delivered for overcoming the drag force will be less. Consequently, more thrust is available for towline; this explains adequately why rotors are expected to have the finest side-stepping movement, while they are followed by tractors with azimuth propellers and finally Voith-Schneider's, consisting from high resistance due to the vertical propulsion units. Moreover, Voith Schneider will be less efficient during this movement due to their propulsion units, which are vertical to the sea water, and therefore they will be more influenced in ports with levels of current. (E. T. Association, Guidelines For Safe Harbour Towage Operations February 2015, 20).

Finally, conventional tugs are characterized from low levels of maneuverability and therefore the side-stepping ability of this tug type is limited, leading also in risky situations, at a high range of speed. Hence, the conventional tugs require high experience, for anticipating the resulted dynamics of this operation efficiently. Most conventional tugs require special equipment for safer operations i.e. radial hook, for raising the levels of the towline forces as well as the safety of operations. Additionally, Combi tugs consisting of a bow thruster, tend to have improved maneuverability.

By comparing conventional tugs with ASD's & ATD's, it is evident that conventional tugs perform in the less efficient way, while careful consideration is also addressed to special equipment, for eliminating girting phenomena. Consequently, all types of tugs should be capable to move sideways if necessary, where by using their hull underwater form, they are capable to generate high levels of hydrodynamic forces for increasing the exerted towline forces. (E. T. Association, Guidelines For Safe Harbour Towage Operations February 2015, 15). In Figure 117, a quantified indication was made from tug masters of KST, which proves efficiently the pre-discussed theory concerning the effectiveness of the various tugs, as a result of their design concept towards the side-stepping movement.

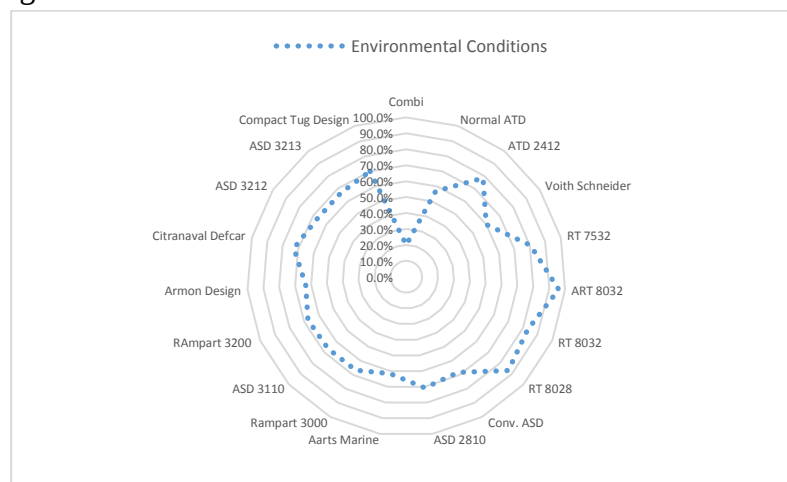


Figure 117: KST Fleet Effectiveness VS Environmental Conditions

Starting with Rotors, it is proven that they are evaluated with the highest scores, with an average score for the four types, RT7532, RT8032, RT8028, ART8032 equal to 86,66%. The highest score is given to ART8032, and is equal to 95%, which is explained due to the significantly lower draught and resistance (no docking

plates or fins), compared to the rest rotor types. Consequently, this type is the state-of-art tug for moving sideways and applying the highest thrust levels, without any influence due to wind and current levels among the various port. Afterwards, as it was expected, the tractors with azimuth propellers were evaluated with an average score of 75%, which is considered as the second-best score, while Voith Schneider's were evaluated with a score equal to 60%, due to their higher draught which causes significant reduction towards this movement. Additionally, the scores for the azimuth stern drive tugs were proven to be among 50 % & 65%, as a result of their underwater hull with appendages and location of their propulsion units, while Combi-tugs were proven to be the less efficient with a score equal to 20%.

6.5 Chapter Conclusion

The goal of chapter 6 was to discuss the implementation of AHP through a decision-making process for the tool needs. Since AHP, allows low levels of inconsistency related with the judgments to occur, it was considered as the most ideal method to be used, while after evaluating the consistency ratio results for all the ports, it is evident that consistency ratio is below 10% for all the cases, proving the high consistency levels of the results and not random entries among the pair-wise comparisons.

After defining the various criteria among the ports of KST, and the related weight factors for each case, a compact analysis related with tugs effectiveness through the locks and confined areas, under various environmental conditions was established. The output to occur through the tool, will combine tug's effectiveness for each of the main parts, where each score will be evaluated based on the weight factors of the criteria towards the port to be assigned. KST fleet effectiveness in confined areas showed that the Aarts Marine Concept, suffered from the lowest results equal to 57.4% as a result of their LOA. On the other hand, the tug types among 31 & 34 meters, were proven to be improved by almost 7%, while ATD2412 & Armon Design concepts were proven to consist from effectiveness results equal to 82%.

Moreover, rotors, were proven to consist from the highest effectiveness results, due to the rotoring method. On the other hand, Azimuth stern drive tugs suffered from significantly lower effectiveness results, for handling the vessel into the lock, unless a fully reposition of the tug takes place, which is not the case in confined areas and locks. Additionally, the effectiveness results of KST tugs for compensating the adverse environmental conditions, were aligned with their ability towards the side-stepping mode.

In cases of ASD's, the towline force is expected to be lower, since the tug must provide a percentage of its thrust for maintaining a specific course. On the other hand, ATD's are more efficient, since they must deliver less amount of their thrust, while rotors, were evaluated with the highest scores (86,66%). Tractors with azimuth propellers were assessed with the second-best score, while Voith Schneider's were evaluated with a lower score due to their higher draught. Additionally, the azimuth stern drive tugs were evaluated with scores among 50 % & 65%, as a result of their underwater hull with appendages and location of their propulsion units, while Combi-tugs were proven to be the less efficient with a score equal to 20%.

Finally, the main subject of the next chapter, is to establish the method to be followed for the cost indicators for each of the tug types of KST in the various ports. This part of the thesis project is vital for the tool function, offering the ability to assess all the possible tugs combinations to occur, based on user selections for each area. Afterwards, through the tool would be possible to verify and compare not only the effectiveness results of the selected tugs for each scenario, but at the same the costs per job for each simulated scenario.

Cost Indicators of KST Tug Types

The main subject of this chapter is to establish the method to be followed for providing a trustworthy indication towards the costs for each of the tug types of KST in the various ports. This part of the thesis project is tremendously important, for the tool function, offering the ability to the user for assessing all the possible tugs combinations to occur, based on the selections for each port. Consequently, the user will be also able to verify and compare not only the effectiveness of the selected tugs, but at the same the costs per job for each simulated scenario among the various ports.

7.1 Type of Expenses

Each company can calculate its profit after all the involved expenses are categorized. In general, there are three main categories based on which the expenses are divided. These costs are the operational expenses, the capital expenses as well as administrative costs. All the pre-mentioned costs are characterized from further sub-categories; however, this is entirely dependent from the nature of the company. Therefore, this subchapter will discuss the cost variances for each tug type of KST fleet.

OPEX Overview

The operational voyage costs, also known as OPEX, refer to all the costs which are required for maintaining the tug on a daily base operational. Hence the four major categories of operational expenses can be divided in crew salaries, fuel cost, maintenance & repair, as well as to all the related costs concerning the license to operate for each tug. (Pruyn 2014)

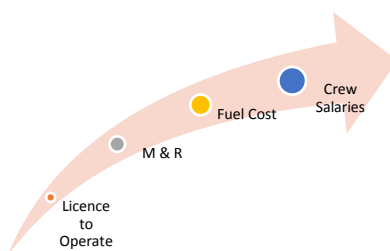


Figure 118: OPEX Overview

Moreover, except from the usual small maintenance tasks that take place in a daily basis, small amount of works during dry dock, will be also included in OPEX. In case of KST, the superintendents are responsible for each of the port where the company is operating for the complete management of OPEX, capable to guarantee high levels of control and execution of all the required tasks. Figure 119 shows a solid overview of the maintenance and repair costs for the tugs, including also the annual inspections for the license to operate.

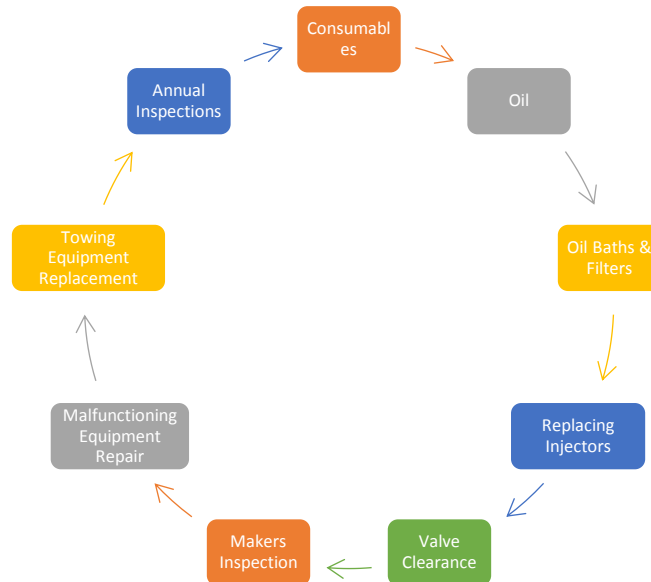


Figure 119: M & R Costs

CAPEX Overview

On the other hand, the capital expenditures expenses, also known as CAPEX, refer to the interest, depreciation as well as amortization, explaining why they are always considered as separate category in the profit-loss statement. Moreover, the planned work related to dry docking procedures, as well as all the necessary modifications, refer to tug's technical CAPEX. In reality, the costs can be depreciated over a long period of time, equal to 5 years. Moreover, the capital expenditure expenses include the required maintenance leading to high levels of safety and operational ability of the tugs towards their daily tasks, as it shown in Figure 120.

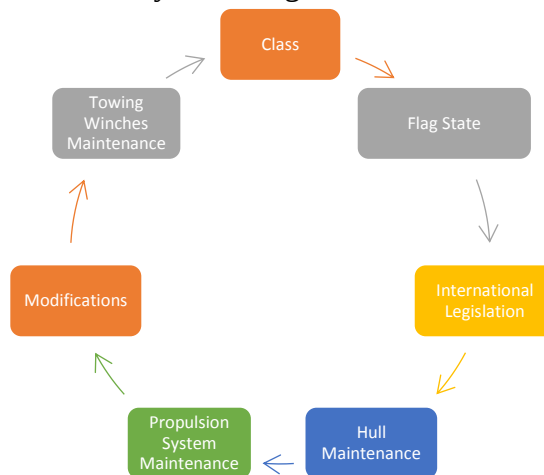


Figure 120: CAPEX Overview

At this point, after all the main types of expenses are explained, it is vital to establish the types of expenses which are included in the scope of the current thesis project. Since the core of this project, was to create a tool capable to provide essential information for assessing harbor tugs effectiveness, towards the daily operations in the various ports, it was also crucial to include all the associated expenses for each port of operation, for assessing all the possible tug-reallocations, for achieving both high levels of effectiveness towards the assisted vessel and at the same time lower daily costs for KST. However, for the scope of this project the main attention will be given only to the fuel costs. The amount of data and input to be collected was incredibly high, while the period of the thesis as well as several restrictions, did not allow to include further expenses. The major part of crew expenses, which reflects over 50 % of KST annual expenses, is about to be modified. The company is

already working for establishing a new system, which will be the same for all the countries and for all the crew members. The joint venture among KOTUG & SMIT, brought together four different countries and 12 ports of operations. Therefore, it was not possible to evaluate and check all the possible variances in the crew expenses, if a tug is reallocated, together with all the possible crew nationalities to be selected, due to the multiple CLA's (Crew Labor Agreements), that take place so far in the company.

Additionally, the variances among the maintenance and repair expenses among the various tug types in each port, would lead to a complex tool, not capable to provide trustworthy indications of M & R costs for every tug type and for every port. Finally, CAPEX expenses vary for each tug due to the various shipyards, and hence it was not possible to provide a good estimation of the CAPEX expenses for each tug type, since there are various tug types that never sailed in some ports, and therefore only rough estimations would be possible to be made. Consequently, the focus in the scope of this project for the expenses to occur through the tool results, refer exclusively to fuel costs and hence tool's main goal as it has already been explained in the objective of the thesis project, is to indicate which tug type combination is characterized from the highest effectiveness level, together with the lowest fuel cost towards the amount of jobs to take place in each port.

7.2 Fuel Distribution Based on Activities

In reality, a solid evaluation of harbor tugs fuel consumption is considered to be a complex issue. The first complexity, refers to the case that KST tugs, as all the rest harbor tugs can offer various types of activities. In general, harbor tugs activities are divided in three major categories. Figure 121 shows clearly these three phases. The first major part refers to the mobilization phase. This phase refers to the time required for the tug to reach the assisted vessel either from the pontoon (berth) or the time in between assistances from one ship to the other. The second phase refers to the towline connection hours. This phase includes several possible sub-categories, i.e. stand by while connected, pushing on the side of the vessel while mooring, passive escorting while connected or active escorting. Therefore, it is evident that the offered types of activities from a tug towards the assisted vessel vary, leading to large fluctuation towards the required fuel liters per hour, depending on the nature of the activity. The last phase, refers to Demobilization, reflecting the situation where job is completed and the tug is sailing back to the berth.

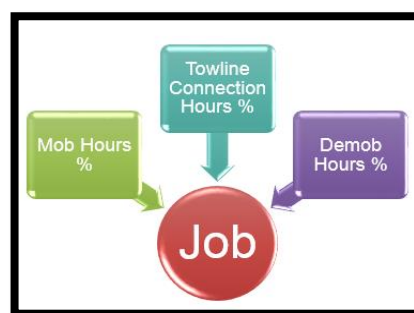


Figure 121: Distribution of Tug Activities

One of the main challenges concerning the fuel cost analysis was the fuel distribution for the entire fleet of KST in the various ports. During the period where this thesis project took place, it was not possible to proceed in precise measurements of the fuel distribution towards the jobs. At the same time, generic assumptions for each of the indicated activities of Figure 121, would not provide any actual value, due to the fact the tugs used to operate under various speed range during mobilization and demobilization. This situation

will be proved and extensively analyzed in Figure 122. Even if tug masters must obey on company's rule and sail with a speed of 7 knots during demobilization, Figure 122 proves that this situation does not occur always. Additionally, during mobilization is also proven that in cases where the tug needs to reach the assisted vessel in very short period, since it is already late due to another job that took place earlier, the tug master will sail with full speed, instead of 7 knots, and therefore the levels of fuel per hour will be significantly higher. In the year of 2016, one of the shareholder of the company, KOTUG, established a new software system which was capable to provide information related with the fuel liter per hour per activity, in one of the tugs in the Rotterdam City area. Consequently, readers are capable to confirm all the pre-mentioned information i.e. for ZP Chalone which is an azimuth tractor tug, and was evaluated for 6 days. The variances among the fuel consumption per activity are shown in Figure 122.

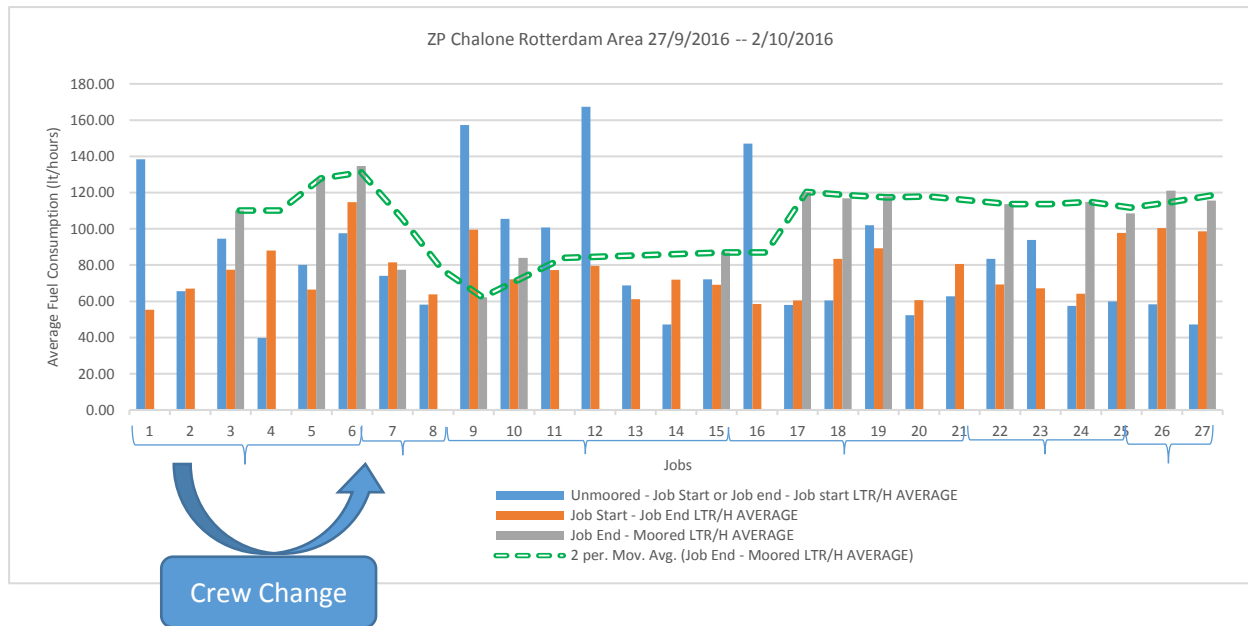


Figure 122: ZP Chalone Fuel Distribution Per Activity

The period as it is shown in the figure was in between 27th of September and 2nd of October. The x-axis shows the amount of jobs that took place each of the days, while the y-axis shows the consumed liters per hours for each activity. Starting with the first day, major fluctuations are shown especially during the demobilization phases. Additionally, it was confirmed from the crewing department of KST, that on 27th (every Wednesday), there was a crew change and therefore, different tug master was sailing from 28th till 2nd of October. The first to be noted, is related with the enormous variances of fuel consumption especially during mobilization for the various jobs. At the same time, the towline connection phase is characterized from high fluctuation levels, since it is entirely dependent on pilot's command for the ship-handling tasks. Hence, for the 6th job, the fuel consumption during the towline connection was over 100 lit/hour, while during the 20th job the fuel consumption was slightly higher than 50 lit/hour. The green line proves the fluctuation of demobilization among the jobs for the pre-discussed period. Therefore, it is evident that every possible assumption to be made towards the fuel consumption per activity during a job, would lead to poor results and significantly low trustworthiness levels.

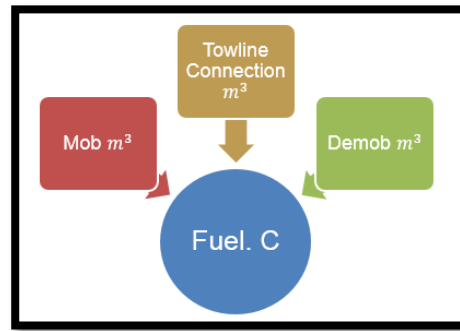


Figure 123: Distribution of Tugs Fuel Consumption

Figure 123 presents the ideal situation for a solid evaluation of the fuel cost per tug type and per port, which would be to distribute the fuel consumption based on the three pre-mentioned phases. However, as it was proven from Figure 122, the lack of similar systems for the entire fleet of the company, in twelve different ports, cannot guarantee precise results towards the fuel consumption per activity. At this stage, the main information which can be collected towards the fuel consumption per tug type and for the entire fleet of KST, refers to the total number of cubic meters which were consumed per day, as well as the running engine hours per tug in the correspondent port of operation. Additionally, the existing tools are not capable to split the cubic meters which were consumed for each of the phase, which are indicted in Figure 123. The only way to proceed in trustworthy results towards the consumed cubic meters during mobilization & demobilization, is by using performance diagrams as the one which is shown from Caterpillar and at the same time, monitor the speed of the tug continuously during Mob & Demob, for each assistance.

The combination of those two elements can provide more precise results towards the consumed cubic meters during Mob/Demob, as a result of the relationship among the type engine and therefore, engine's rpm, with the resulted liters per hour. This figure presents in y-axis the liters to be consumed based on the engine rpm, x-axis, which are aligned with tugs speed. The figure is made for SD Dolphin, (ASD3212), and shows that the relationship among liters per hour and engines rpm are connected exponentially.

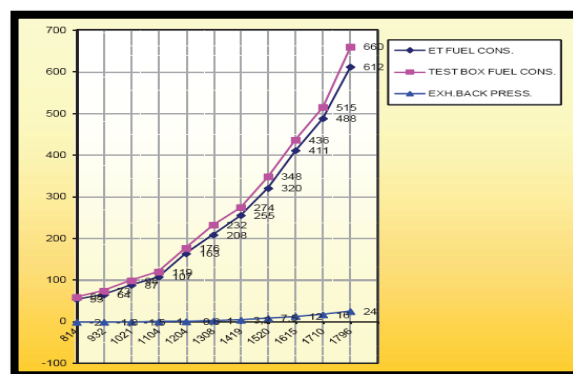


Figure 124: Correlation of Liters per Hour with Engines rpm for ASD3212 – SD Dolphin

Intermediate Conclusion

Consequently, one essential information would be to define the optimum speed for each of the tug types of KST, which demands the availability of the performance diagrams for the entire fleet. These performance diagrams would be capable to show the critical rpm points where the amount of power to occur is significantly

lower, while the fuel consumption is tremendously higher. However, this procedure is not considered in the scope of this project, since these diagrams exist only for limited tug types and therefore it is not feasible to define the optimum speed for each tug type. It is evident that only by having both the speed of the tug during mobilization & demobilization activities, together with the engine performance diagram per tug type, indicating the fuel consumption for each speed, it is then possible to define how many cubic meters were consumed during mobilization and demobilization activities, after all the jobs are monitored towards tug's speed, as it is indicated in Figure 122.

For the scope of this project, it was not possible to monitor the speed of its tug type per job for each area for the entire year of 2016. Moreover, the correlation of fuel consumption graphs for all the tug types, in a range of speed requires significant amount of time, while for providing a good approximation of the fuel cost per job for all the tug types and for all the ports of operation, process performance indicators will be used. Additionally, a solid investigation towards the fuel cost for the various tug types would also require a precise analysis of the sailing profiles for all the ports where KST is operating.

This means that each port should be evaluated towards all the possible routes which could be followed from a tug, as a result of the berthing location of the vessel, for evaluating the time and fuel to be spent, especially during mobilization and demobilization. For this reason, it will be confirmed that the tug types which are in each port during the current situation are following the same operational/sailing profile, meaning that every new tug type in any case of a reallocation to an unknown port, will follow the same sailing profile routes. In order to provide a solid approach towards the sailing profiles for each area, special figures about towline connection and Mob/Demob activities are required and hence will be presented in subchapter 7.5.

It is evident that by using multiple indicators for the various tug types among the ports, a good indication of the fuel cost per tug type, and for each port is possible to occur. These indicators will establish a fuel cost for each type, which is considered as a vital input for the tool, and will be further explained in chapter 8, for assessing KST tugs effectiveness and fuel cost efficiency under various scenarios.

7.3 Process Performance Indicators – PPI

Performance Process Indicators as Navigational Tools

Process performance indicators is a way to measure the effectiveness level of companies, towards their strategic goals and objectives. Therefore, these indicators are high of importance since they deliver instantly the requested performance information to company's stakeholders, for tracking efficiently the progress towards the defined objectives. By establishing premium metrics, KST will be capable to get a clear overview of its operational profile performance, in a daily, monthly or annually basis, highlighting at the same time all these aspects that require more emphasis. Process performance indicators are the necessary metrics that's needed to be established in order afterwards the related KPIs environment to be set up. The presence of KPI's for a company is vital, while they are used as useful decision-making tools, for improving the daily performance in a business, by using a range of well-established indicators.(Marr 2017). The indicators have the same meaning as the GPS tracking for all the automotive vehicles. Both provide essential input which is required, for making some critical decisions. Therefore, multiple different metrics can be used for providing essential information for evaluating company's progress. Performance indicators can be used as navigation tools, capable to deliver the right messages to the managers, about the path which is followed making obvious business progress. Nowadays, most of businesses require the establishment of a solid system capable to

evaluate their followed strategy. This willingness is linked with their strong motivation to overcome their competitors, by adapting smaller or larger changes in their followed tactics, in parallel with the fluctuating market trends. These changes will proceed through the proper indicators establishment and therefore are the ideal tactic to be followed for the fleet assessment of KST.

How PPIs make KPI'S decision-making tools

The main reason that performance indicators are so high of importance for organizations, is related with the ability for taking important decisions, as a result of the offered output towards the strategic objectives in a company. Therefore, a valuable starting point is the identification of all the questions of stakeholders and their connection to the established objectives. Afterwards it is possible to create the interrelated key performance indicators, for monitoring the progress in the company and eventually if its activities are moving towards the established objectives or not. However, the selection of these performance metrics is not always an easy case. In practice, companies are capable to monitor a large amount of information almost on everything which can be quantified. This is unfortunately one of the main disadvantages of indicators establishment. Therefore, KPI's are necessary, and they should be used as a powerful tool capable to guarantee business performance improvement. (Marr 2017)

7.4 Fuel cost Performance Indicators

Process performance indicators will be used for approaching a fair estimation/indication of the fuel distribution based on the activities per tug type for all the possible ports where KST is currently operating, as it has been introduced in subchapter 7.2. The usage of performance indicators for this case, was considered to be the best solution, due to the fact that PPI's are used from all shipping companies for measuring not only their financial but at the same time their operational goals. Consequently, they can really fulfill the objective of the thesis project for assessing efficiently KST daily operations, and assessing efficiently tug performance in each port. In this way KST will be capable to achieve higher levels of flexibility and therefore to combine efficiently tug effectiveness in all the possible types of operations with the fuel cost of each type per port. This investigation will allow KST to proceed directly to all the possible reallocations among the tug types which will be proven to be less efficient. Afterwards the company will be able to set its goals per port and therefore by using the KPI's, will be able to monitor the achieved goal levels.

Cubic Meters Per Job Per Tug Type based on their port of operation for 2016

Starting with the analysis of the current situation, the first part to be analyzed refers to the fuel costs per tug type in the ports of operation for the year of 2016. Therefore, the first to be noted for each tug & for each port is the number of cubic meters to be consumed for the whole year of 2016. After combining the two different ERP systems of the company (Dynamics & IFS), it was then possible to retrieve the offered amount of assistances from each tug in its port of operation for the same year. The high collaboration levels of superintendents among the ports of operations of KST, allowed to collect vital information concerning the fuel consumption of tugs per day, while Table 44 shows the cubic meters per job, for each tug type. Hence, for the scope of this thesis project, the PPI's to be used and therefore to be evaluated will based in the following equation:

$$PPI = \frac{\text{Cubic Meters Annually}}{\text{Jobs Annually}}$$

The above ratio fulfills all the required elements for the establishment of an added value indicator, since its corporate goal is to achieve the company's main objective for defining which tug type is more efficient as a result of the various operational/sailing profiles in the multiple ports, and then to combine fuel efficiency with fleet effectiveness towards the daily operations.

Table 44: KST Tugs PPI's for 2016

Tug Types/Port	Cubic Meters 2016/Total Amount of Jobs 2016									
	Europ.	Rot.Cit	GTV	Ant.	Zeeb.	Hamb.	Bremer.	Liv.	London	South.
Combi			0.29							
Normal ATD		0.29				0.28				
ATD 2412						0.26	0.33		0.43	0.39
Voith Schneider		0.35	0.67	0.31				0.46		
RT 7532							0.52			
RT 8032					0.43		0.48			
RT8028					0.50					
ART 8032	0.39						0.38		0.60	
Conv. ASD			0.42					0.30		
ASD 2810	0.31					0.26		0.36		
Citranaval			0.57	0.25	0.35					
ASD 3110			0.43					0.40		
ASD 3212						0.32				
ASD 3213	0.60				0.54					1.03
Fairplay	0.33									
Rampart 3200	0.48			0.27					0.47	0.46
Rampart 3000		0.30								
Armon Design				0.22						
Compact Tug Design				0.30						

In Table 44, the consumed cubic meters per tug type are indicated. From the above matrix, only the cells with orange color are filled in, since for the year 2016 each of the pre-mentioned tug types were operating in this specific port. For the rest cells, which are characterized from yellow color, the company so far has not a clear indication of the fuel cost per job. At the same time, the cells with the red color show which tug types are prohibited for sailing on which ports, due to the local port restrictions and regulations, and hence these types do not require at all fuel cost indication; hence for Combi tugs, the only ports which are capable to give an indication of the fuel cost per job, refer to the GTV area, since both Braakman & Terneuzen, operate in the same area. The same situation occurs for ASD 3212, where SD Dolphin is operating in Germany and therefore the required cubic meters for this tug type is only known for the port of Hamburg. Another example, is the Compact Tug Design concept, where both tugs of this type, UNION HAWK & UNION EAGLE, are operating in Belgium, and therefore the cubic meters for this type are known only for the port of Antwerp.

On the other hand, the fuel needs per job for the types of Rampart 3200, ASD 2810 & ATD 2412, can be retrieved for more than one ports, since the company consists of several tugs, which are allocated in various ports. Consequently, a solid evaluation is more than necessary among the tug types in the four different countries, for filling in entirely Table 44.

Why Cubic Meters and not Tons as Unit of Measurement - MARPOL 73/78 ANNEX VI

MARPOL agreements and their associated Annexes, which are created from IMO, explain why harbor tugs are enforced to use as fuel type marine gas oil, EN590, with a density at 15 °C equal to 835 kg/m³. (IMO Maritime Environmental Protection Committee 2017). As it was already shown in Table 44, the unit of measurement towards the fuel per job, in the various ports of operation of KST is cubic meters. However, most of the record keeping calculations in the engine rooms of merchant vessels, are based in tons and rarely in cubic meters, and the reason for this preference is linked with the temperature impact (expansion/contraction).

For this reason, it is always more convenient to use tons, since the mass of the fuel oil will always remain the same, even if temperature is characterized from fluctuations. However, this situation refers mostly to merchant vessels, travelling all over the world, in areas with larger or smaller fluctuations of temperature. For those vessels, engineers are requested to proceed in record keeping sounding measurements of the fuel oil tanks always in tons and not in cubic meters for avoiding mistakes during sounding measurements which can prove if the bunkering was accurate or not. However, in cases of harbour tugs this situation is rare.

The flow meters from the bunker companies will indicate the precise, at least for them, transferred bunkers, by assuming steady average of 15 degrees of calcium temperature in the North Europe area. Afterwards, by using a steady density value regarding EN590 fuel type, (835 kg/m³) for converting the delivered bunkers also in tons, as it is required from MARPOL. At the same time, the engineers from the entire fleet of KST tend to use tank sounding tables, and deliver weekly record to the fleet superintendents for the consumed bunkers, by using cubic meters as unit of measurement and not tons.

Therefore, cubic meters will be used in terms of simplicity for the entire chapter 7, as the main unit of measurement instead of tons. However, one recommendation would be to measure the bunkers directly in tons and not in cubic meters for avoiding misunderstandings and false implementation of data, due to the temperature impact, as it was explained earlier.

Current Situation

The current situation of KST fleet is characterized from different tug types, located in the various ports of operations. The four major components which were required for a proper fuel cost analysis, as well as the assessment of the corresponding sailing profiles for each case are summarized in Figure 125. The cooperation with the technical superintendents for collecting two out of four basic elements of Figure 125, was crucial. Superintendents are responsible for keeping a weekly record of the running hours of each tug per week, as well as to measure the fuel tank capacity, at the start and at the end of the week for defining the fuel consumption in cubic meters (sounding method). Consequently, the entire amount of the running hours and cubic meters per tug and area were collected, during 2016.

The second vital information refers to the amount of jobs & the towline connection hours per job. By combining the information from the two different ERP (Enterprise Resource Planning) systems, the Microsoft Dynamics which was used from KOTUG, and IFS which was used from SMIT, it was then feasible to retrieve the history data related with the amount of assistances and the towline connection hours per tug for the port of operation during 2016, for assessing the operational profile for all tug types of KST fleet.

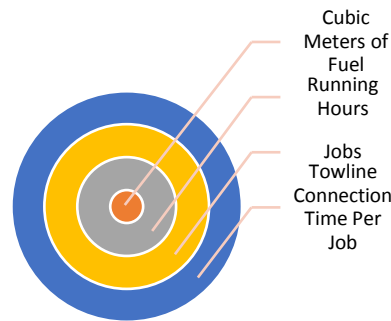


Figure 125: Four Major Components

Table 45 summarizes the retrieved information for each of KST tug type for 2016. The first column of the table indicates the port while the second column the tug type. The primary reason that tugs are grouped in this way, is related with the correlation among effectiveness results for each type towards the daily operations, as it has already been explained in subchapter 4.3. The rest columns, show the total amount of running hours for each tug family, as well as the fuel consumption. Since the amount of topline connection hours is known, as well as the amount of running hours, it was then feasible to define the correspondent percentage of the running hours, referring entirely to the job as pure topline connection time, as well as the amount of time which was spent during mobilization and demobilization.

Finally, the ratio of cubic meters divided with total amount of jobs for each type will occur, and will be explained extensively in the following subchapter. The fuel cost per job in the final column will arise after assuming a fixed price of 400 euro per cubic meter.

$$\text{Fuel Cost per Job} = \text{Ratio} * \text{Cubic Meter Price}$$

Table 45: Fuel Costs Per Job Per Tug Type Per Port for 2016

Port of Operation	Tug Type	BP	Power (KW)	Jobs	R. Hrs.	Tow.Con. Hrs. %	Av. Mob/Demob	Av. Fuel Cons. (m3)	Ratio: Cub.m/J obs	Mob-Dem Time / Job	Tow. Con. Time/Job	Fuel Cost /Job
Europoort	Rampart 3200	65	3840	1611	3691	45,8%	54,2%	773	0,48	1,25	1,05	€192,03
Europoort	ASD 2810	60	3678	1405	2891	56%	44%	442	0,31	0,92	1,14	€125,79
Europoort	ASD 3213	95	5420	1098	2408	56,8%	43%	653	0,60	0,95	1,25	€238,07
Europoort	Fairplay	55	3292	1550	2974,5	53,8%	46,2%	515	0,33	0,89	1,04	€132,79
Europoort	ART 8032	80	5295	1227	3153	41,8%	58,2%	480	0,39	1,49	1,08	€156,45
Rotterdam Area	Rampart 3000	52	2943	1330	2510	48,9%	51,1%	394	0,30	0,96	0,92	€118,57
Rotterdam Area	Normal ATD	45	2207-2470	1228	2152	51,6%	48,4%	357	0,29	0,84	0,90	€116,27
Rotterdam Area	Voith Schneider	45	3100	1603	2774	51,2%	48,8%	554	0,35	0,85	0,89	€138,25
GTV	Combi	39	2130	845	2492	62,8%	37,2%	246	0,29	1,10	1,85	€116,60
GTV	Conv. ASD	37-49	2000-2800	921	2675	61,9%	38,1%	384	0,42	1,11	1,80	€166,77
GTV	Citranaval Defcar	65	3700	900	2792	61,3%	38,7%	517	0,57	1,20	1,90	€229,93
GTV	Voith Schneider	45	3100	792	2406	61,8%	38,2%	531	0,67	1,16	1,88	€268,33
GTV	ASD 3110 (7 months)	53	3132	503	1579	53,6%	46,4%	218	0,43	1,46	1,68	€172,96
Antwerp	Rampart 3200	65	3800	2396	3018	50,8%	49,2%	659	0,27	0,62	0,64	€109,99
Antwerp	Armon Design	65	3700	2503	3082	43,9%	56,1%	540	0,22	0,69	0,54	€86,34
Antwerp	Compact Tug Design	86	5200	2482	3204	49,4%	50,6%	757	0,30	0,65	0,64	€121,93
Antwerp	Voith Schneider	45	3100	2099	2721	47,6%	52,4%	651	0,31	0,68	0,62	€124,02
Antwerp	Citranaval Defcar	65	3700	2556	3084	41,6%	58,4%	641	0,25	0,70	0,50	€100,28

Zeebrugge	RT8028	86	5300	1137	2878	66,3%	33,7%	573	0,50	0,85	1,68	€201,64
Zeebrugge	RT8032	84	5295	1167	3017	65,6%	34,4%	500	0,43	0,89	1,70	€171,35
Zeebrugge	Citranaval Defcar	65	3700	1095	2778	66,5%	33,5%	386	0,35	0,83	1,72	€140,99
Zeebrugge	ASD 3213	95	5420	1203	3328	59,7%	40,3%	645	0,54	1,12	1,65	€214,51
Hamburg	ASD 3212	80	5050	926	1916	41,8%	58,2%	293	0,32	1,20	0,86	€126,57
Hamburg	ASD 2810	60	3678	997	1999	40,1%	59,9%	256	0,26	1,20	0,80	€102,71
Hamburg	ATD 2412	70	4200	1033	1952,5	40,1%	59,9%	268	0,26	1,13	0,76	€103,79
Hamburg	Normal ATD	45	2207	938	1779	32,9%	67,1%	265,4	0,28	1,27	0,62	€113,18
Bremerhaven	RT 8032	84	5295	947	2264	40,9%	59,1%	451	0,48	1,41	0,98	€190,77
Bremerhaven	ART 8032	80	5295	1006	1258	83,2%	16,8%	380	0,38	0,21	1,04	€151,09
Bremerhaven	RT 7532	78	4698	928	2585,5	35,0%	65,0%	480	0,52	1,82	0,97	€207,05
Bremerhaven	ATD 2412	70	4200	877	1967	40,4%	59,6%	285	0,33	1,34	0,91	€130,08
Liverpool	ASD 2810	60	3678	794	2380	61,7%	38,3%	288	0,36	1,15	1,85	€145,36
Liverpool	Conv.ASD	39	2000	786	2360	59,8%	40,2%	232	0,30	1,21	1,80	€118,07
Liverpool	Voith Schneider	41-36	2532-3100	748	2218	61,6%	38,4%	345	0,46	1,14	1,83	€184,49
Liverpool	ASD 3110	53	3132	177	605	51,8%	48,2%	70	0,40	1,65	1,77	€158,42
London	ATD 2412	70	4200	560	1302	30,1%	69,9%	239	0,43	1,63	0,70	€170,71
London	Rampart 3200	65	3840	391	1009,3	29,0%	71,0%	183	0,47	1,83	0,75	€187,01
London	ART 8032	80	5295	63	89	46,4%	53,6%	37,7	0,60	0,76	0,66	€239,37
Southampton***	Rampart 3200	65	3840	39	85	30,1%	69,9%	17,9	0,46	1,52	0,66	€183,59
Southampton***	ATD 2412	70	4200	40	92	27,4%	72,6%	15,4	0,39	1,67	0,63	€154,00
Southampton***	ASD 3213	95	5420	38	124	27,1%	72,9%	39,0	1,03	2,38	0,88	€410,53

***The Data for the ports in the table above AND figures below are based in the year 2016 EXCEPT for the new entry port of Southampton where the performance of tugs regarding their fuel cost per job is based in months April & May 2017

7.5 Fuel Cost Analysis of KST for Same Tug Types in various ports 2016

From Table 45, KST is capable to assess efficiently the fuel cost per job for each type. Starting with Rampart 3200 in Europoort, the fuel cost per job was equal to 192,03 € (2016). However, the same tug type in the port of Antwerp, was proven to have fuel costs per job equal to 109,99 € (2016). Figure 126, proves however that the variance percentage among mobilization and demobilization time among the two ports was equal to 5%, leading to a considerably high variance among the fuel consumption between these tugs. At the same time, the fuel cost per job for the ports of London & Southampton is also high, and almost identical as in Europoort case, because of the high percentage of mobilization and demobilization times. Especially in the port of London due to the five different main areas in the port, the tug must proceed in long transit routes though Thames and therefore the mobilization and demobilization for this port is equal to 70%.

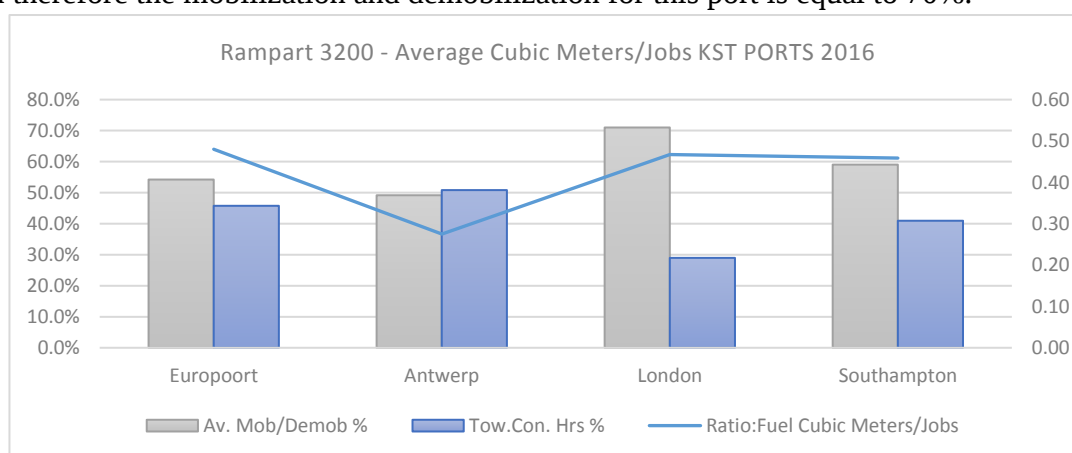


Figure 126: Rampart 3200 average Cubic Meters/Jobs 2016

ASD2810 is the second tug type to be evaluated, since it exists in various ports of operations of KST. Figure 127, shows that this type was proven to operate most efficiently in the port of Hamburg, while it was proven to be also the tug with the lowest fuel cost in Europoort. Therefore, if the amount of jobs to be made annually is also considered, ASD2810 is proven to be the optimum tug for Europoort. At the same time, even if the mobilization and demobilization times among Europoort & Hamburg vary, a significant variance is observed among the towline connection times and the activities that take place among the ports, which influence considerably the fuel cost per job. The same situation occurs also in the port of Liverpool where the towline connection has an average equal to 1,85 hours, and therefore the ASD2810 has the highest fuel cost compared to the port of Hamburg and Europoort. However, ASD2810 was proven to be also one of cheapest tugs in the port of Liverpool, especially compared to Voith Schneider's.

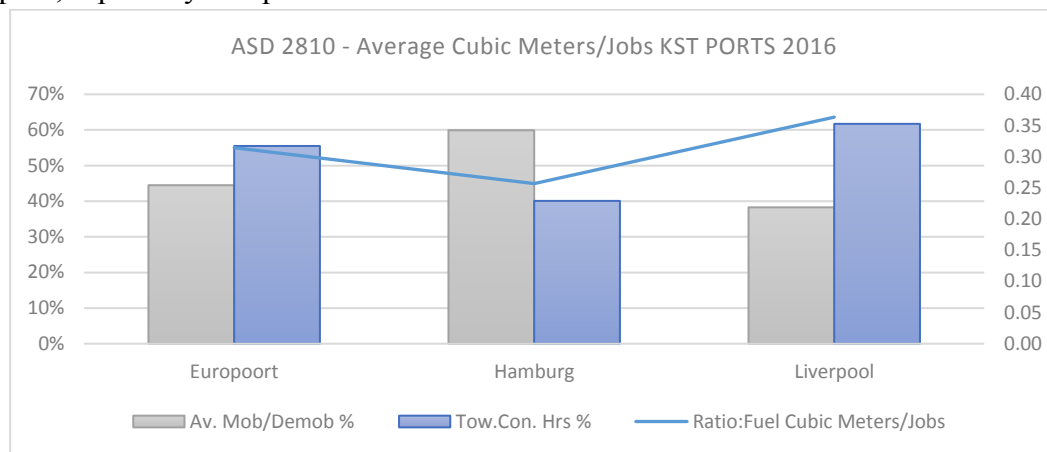
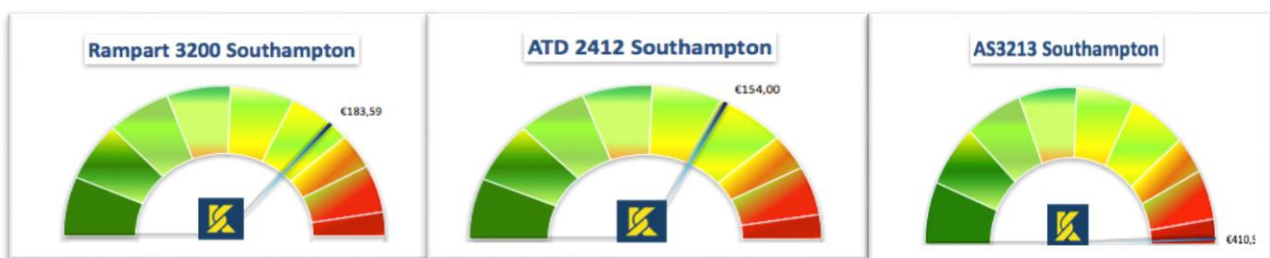


Figure 127: ASD2810 average Cubic Meters/Jobs 2016

Additionally, ASD 3213, is proven to be the most expensive tug for the Europoort, with a total fuel cost per job equal to 238,07 € (2016). On the other hand, for the port of Zeebrugge, the SMIT TIGER, was proven to have a slightly better fuel performance, as a result of the 3 % less mobilization and demobilization time among the two ports, leading to a fuel cost per job equal to 214,51 € (2016). However, for the port of Southampton, the reallocated SMIT TIGER, was proven to suffer from considerably high fuel consumption.



The period based on which it was evaluated was for the months of April & May. By retrieving the main information associated with the consumed cubic meters and the amount of jobs for this period in the port of Southampton, the SMIT TIGER was proven to suffer from a considerably high fuel cost rate equal to 410,53 € (2016) per job. This tremendously high rate occurred due to the amount of jobs and consumed cubic meters which were equal to 38 and 39 respectively, leading to 1,1 cubic meters per job. One of the main reason, capable to explain the high fuel rate is correlated with the escorting duties that take place in the port. As it was already explained in subchapter 5.10.2, all the incoming vessels having length larger or equal to 365 meters require escorting. However, the final decision for escorting is up to pilot discretion, and depends on the type as well as from the class of the vessel.

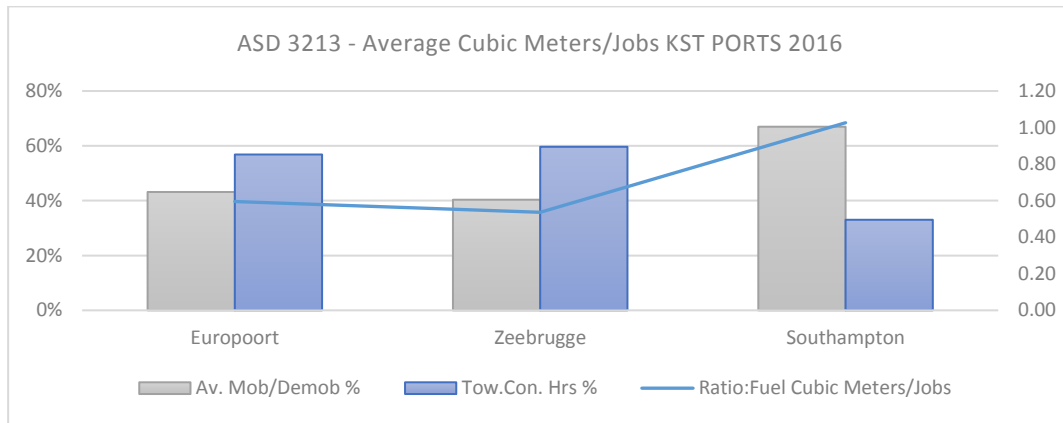


Figure 128: ASD3213 average Cubic Meters/Jobs 2016

In Table 46, three escorting assistances occurred during the period April & May. SMIT TIGER, is the only tug over 70 tons, with escorting notation, and therefore it was the only tug capable to proceed in the requested escorting duties. On the other hand, ZP Boxer, (ATD2412), even if it consists of 70 tons of BP, it is not characterized from escort notation while SD Shark, even if it is characterized from escort notation its total BP is equal to 65 tons. From Table 46, it is evident that the average required time per job was equal to 6 hours. All the vessels in the table below are over or equal to 365 meters, and for these cases pilots decided that escorting was necessary.

Table 46: Escorting Duties for SMIT TIGER in Southampton

Passive Escorting	Assistance	Unmoored	Job Start	Job End	Moored	Vessel Name	Length
	1	16:00	18:40	21:20	21:55	NYK CRANE	265
	2	22:00	01:40	02:45	03:15	NYK BLUE JAY	364,15
	3	09:45	12:41	15:04	16:00	MOL TRIUMPH	400

For the rest assistances in the port of Southampton, SMIT TIGER was proven to have as an average assistance hour equal to 2 hours, while 1 hour as an average is required during Mob/Demob. For this tug type, it was possible to retrieve vital information for defining the correlation among engines rpm and speed vessel. Table 47 shows that at 8 knots, which is an average speed for passive escorting, the fuel consumption, was proven to be 275 liters per hour, while at 5 knots is equal to 140 liters per hour.

Consequently, by considering the first assistance in Table 46, for 2,5 hours the tug will consume as an average 0,7 cubic meters. During the assistance, as it was already discussed, several types of activities can take place under pilot orders and therefore it can be assumed that 0,2 cubic meters will be consumed during this procedure. Finally, the required time for sailing back to the berth, was proven to be 35 minutes. If an average speed during demobilization, is equal to 7 knots, the expected consumed cubic meters will be equal to 0,15. Consequently, the average fuel consumption would be in a range of 1 to 1,2 cubic meters. Due to the significant influence of the human factor, a surplus should be added, equal to 1,05 cubic meters, for satisfying the cases when tug masters are sailing with higher range of speeds. This result justifies the calculated rate of fuel per job for the SMIT TIGER in the port of Southampton which was proven to be equal to 1,1 cubic meters per job. By assuming 400 € per cubic meter, the fuel cost per job would be equal to 410,53 € per job (2016).

Table 47: Free Sailing Characteristics ASD3213

Speed	Engine rpm	Fuel Consumption per hour	Time/ Distance / Consumption over 10 miles
5 kn	670	140 liters	2 hour /10 miles / 280 lt
6 kn	720	200 liters	1 hour 40 / 10 miles / 334 lt
7 kn	770	245 liters	1 hour 25 / 10 miles/ 350 lt

8 kn	800	275 liters	1 hour 15 / 10 miles/ 344 lt
9 kn	830	325 liters	1 hour 07 / 10 miles / 361 lt
10 kn	900	425 liters	1 hour /10 miles /425 lt
11 kn	1009	600 liters	55 min / 10 miles / 545 lt
12 kn	1010	860 liters	50 min / 10 miles / 716 lt
13 kn	1010 (vol)	910 liters	46 min 10 miles / 700 lt
=/- 14,5 kn	1010	1260 liters	869 liters in 10 miles

The next tug type to be evaluated among the various ports is the Normal ATD. This type for the entire year of 2016 was operating in the port of Rotterdam Area & Hamburg. The same situation takes place also for the year of 2017. Starting with the Rotterdam Area, the fuel cost was proven to be higher compared to Hamburg. This can be explained from the high variance among the towline connection times between the two ports, where it is evident that during mobilization & demobilization in the port of Hamburg the tug masters were sailing with the optimum speed (~7 knots).

On the other hand, for the port of Rotterdam, it is shown that higher fuel consumption occurred due to the larger required time for completing a job, while in cases of speed higher than 7 knots during Mob/Demob, higher fuel consumption would occur in between jobs as it also proven in Figure 122, (ZP Chalone/Rotterdam City). The fluctuations in liters per hour which are indicated in the graph especially during demobilization, can verify that the tug was sailing in full speed since it was already late for its next job.

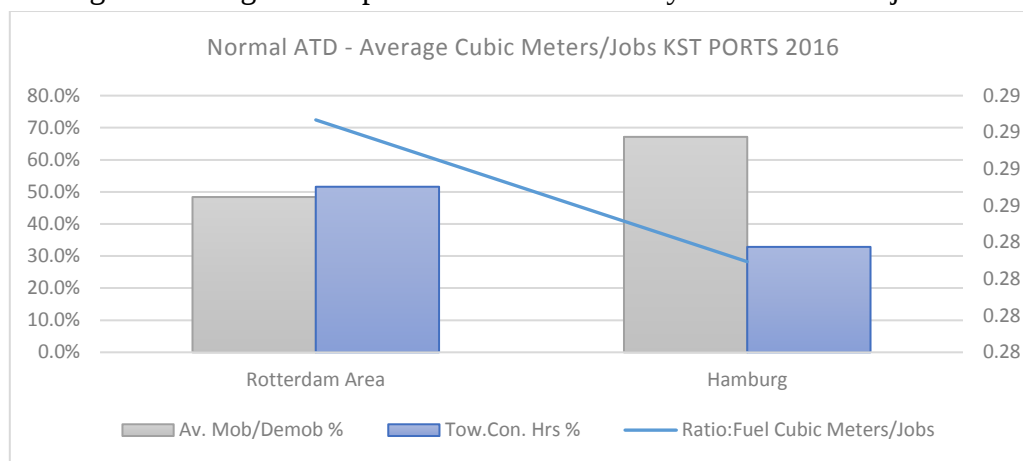


Figure 129: Normal ATD average Cubic Meters/Jobs 2016

The next type to be assessed among the various ports of KST is the Voith Schneider. Figure 130 indicates that the lowest fuel cost for this type was in the port of Antwerp, while slightly higher was the cost in Rotterdam Area. Again, for the port of Antwerp even if the mobilization and demobilization time is high, the tug was proven to sail in its optimum speed, while in combination with the lowest towline connection time for one job, the port of Antwerp was proven to be most the efficient port for Voith's.

On the other hand, Voith Schneider's were proven to have the worst behavior in GTV Area. The main reason for this output refers to the long transit routes among Terneuzen and Ghent, leading to the higher fuel cost values for this type. This also explains the high levels of towline connection for this area. However, the same high towline connection levels are also observed in the case of Liverpool. As it was already explained in subchapter 5,9 it is evident that the port of Liverpool is characterized from high complexity levels. Therefore, the presence of small locks combined with confined areas and narrow passages has as a result high towline

connection times and therefore high fuel costs. Finally, for the Rotterdam Area again the same situation takes place for Normal ATD's. Higher Towline connection levels and increased speed levels during mobilization & demobilization lead to higher fuel cost compared to the port of Antwerp.

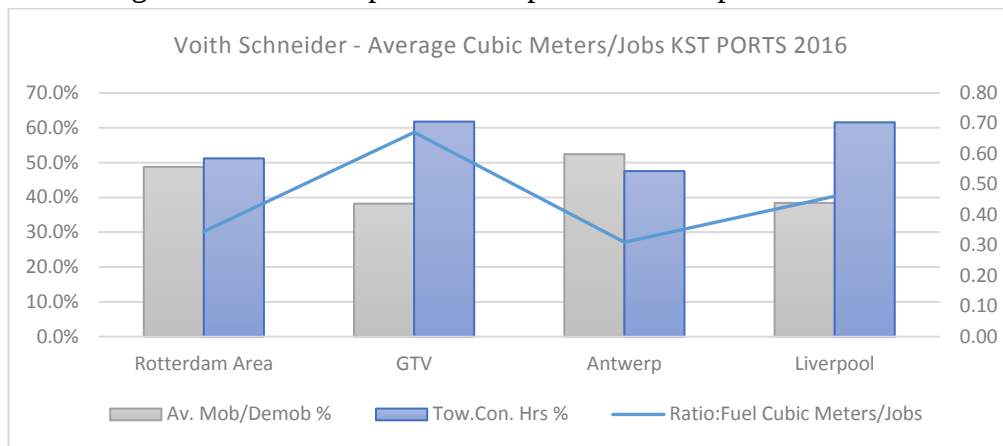


Figure 130: Voith Schneider average Cubic Meters/Jobs 2016

Figure 131, shows all the necessary insights for conventional ASD's among GTV area and Liverpool. For this type, it is proven that lower cost occurs for the port of Liverpool. This result is explained again due to the long transit routes among Terneuzen & Ghent Port. However, the selection of Conventional ASD's for that area was proven to be very efficient, as it is shown in Table 45, with a fuel cost per job equal to 166,77 € (2016), while Voith Schneider's were proven to be the less efficient, with a fuel cost per job equal to 268,33 € (2016).

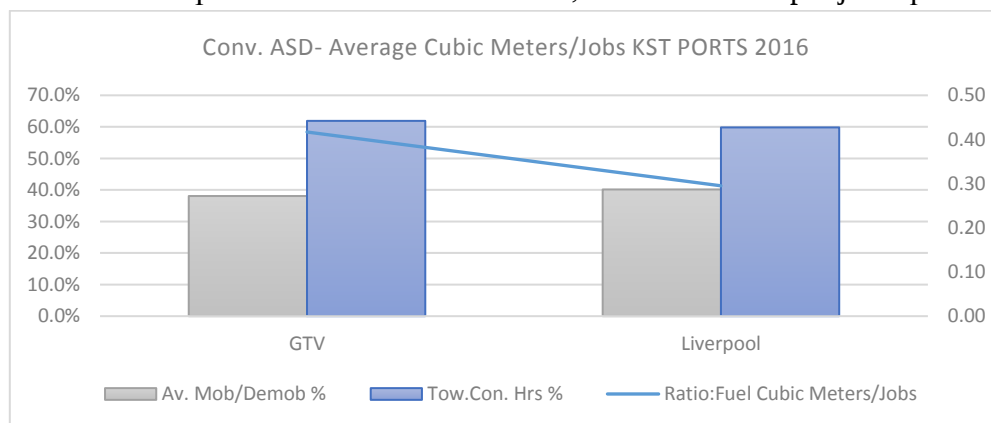


Figure 131: Conv. ASD average Cubic Meters/Jobs 2016

Figure 132, indicates that the most efficient port for the Citranaval Defcar type is the port of Antwerp, while the less efficient port of operation was GTV area. Even if the higher towline connection time is in Zeebrugge, compared to the rest ports due to the presence of lock in that port, this tug type was proven to be very efficient, which is a main advantage for the entire Schelde Area.

The same situation also refers to GTV, as a result of the high towline connection times. However, the speed of the tug, during the transit routes varies considerably, while several times the tugs might sail in the GTV area under high speed for assisting vessels, in cases where fleet capacity is limited. This explains the reason why this type was proven to consist of the highest fuel cost in GTV area.

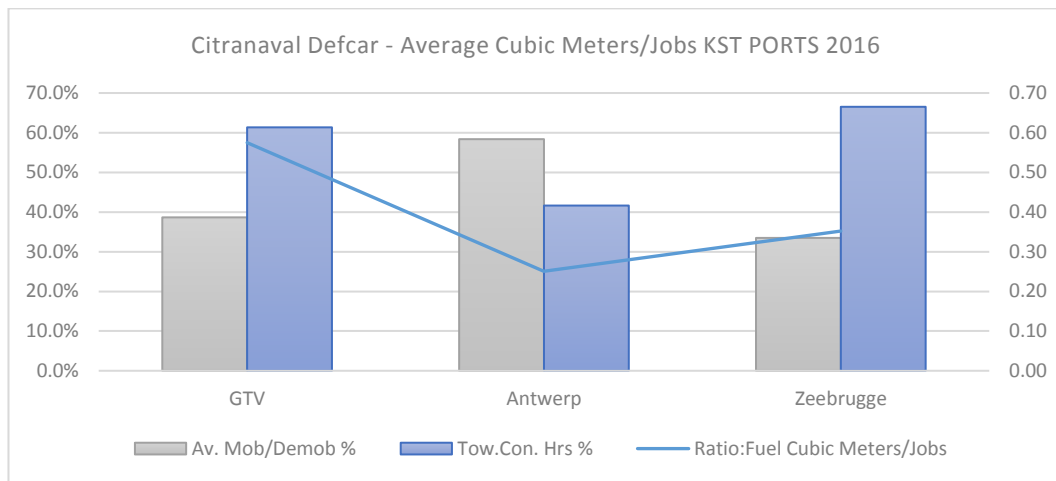


Figure 132: Citranaval Defcar average Cubic Meters/Jobs 2016

Finally, the last types that can be compared in various ports refer to RT 8032 and ATD 2412 twin fin. Starting with RT 8032, RT AMBITION in the port of Zeebrugge was proven to have significantly lower fuel cost compared to RT PETER & ROB in the port of Bremerhaven. This is explained from the entirely different philosophy of locks operational profile among the two ports. In the port of Bremerhaven, there are several possible areas where tugs remain stand-by, while depending on if tugs will assist an incoming or an out coming vessel, as well as due to the crew changes, tugs tend to spend a tremendously high level of their time during Mobilization and Demobilization, as it is shown in Figure 133. This percentage is equal to almost 60%, compared to ~35% in the port of Zeebrugge. To make matters worse, in several cases Rotors, which also consist from 3 engines are sailing at higher speed than 7 knots, for covering distances in the port, while at the same time they are dealing with multiple stand-by moments when operate in & out of the lock, for assisting car carriers.

All these factors lead to significantly higher fuel cost in the port of Bremerhaven. On the other hand, the time spent in the port of Zeebrugge concerning Towline connection is higher while the tug in this port spend less fuel during transit routes, as it is confirmed in the figure below.

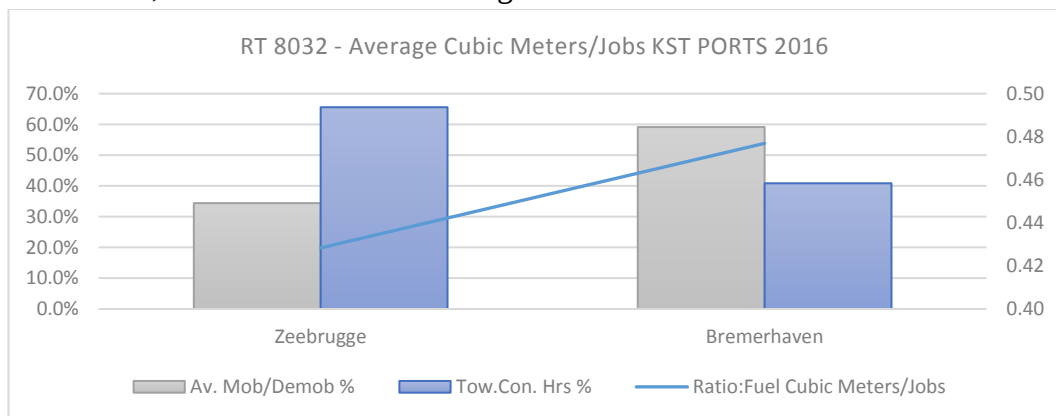


Figure 133: RT8032 average Cubic Meters/Jobs 2016

For ATD 2412, the most efficient port was proven to be Hamburg, with a fuel cost per job equal to 103,79 € (2016), while the most expensive port was the port of London. This is explained from the high levels of Mob/Demob times in the Thames river, as it was already mentioned for the Rampart 3200 in the same port. For the port of Bremerhaven, even if the sailing profile for this type was proven to be identical with Hamburg, apparently the speed during mobilization times was significantly higher. Moreover, the port of Hamburg does not consist from locks, and therefore the required tasks to occur during towline connection will vary

considerably among German ports. Especially, for ZP Bison when operate inside the lock, for handling car-carriers, higher consumption levels are expected. This explains adequately why the fuel cost for this type is raised by 26,29 € (2016) per job in Bremerhaven, compared to Hamburg.

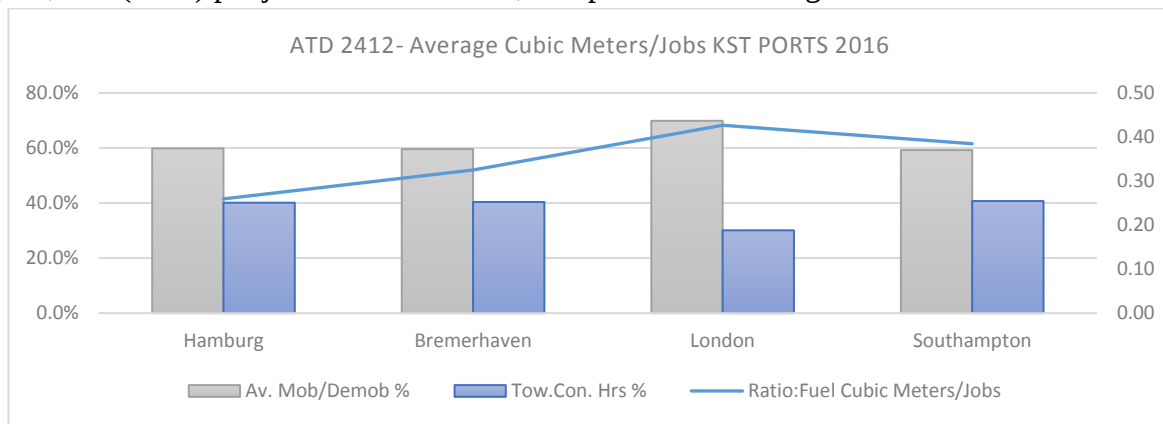


Figure 134: ATD 2412 average Cubic Meters/Jobs 2016

Intermediate Conclusion

Rampart 3200, was proven to operate more efficiently in Antwerp, compared to Europoort, as a result of the different sailing profiles among the ports, which are presented in Figure 126. Moreover, the same type was confirmed to consist from higher fuel cost per job for the ports of London & Southampton, as a result of the high percentage of mobilization and demobilization times. On the other hand, ASD2810 was proven to operate most efficiently in the port of Hamburg, while it was also confirmed to be the tug with the lowest fuel cost in Europoort. For this reason, KST should re-evaluate the planning of 24 hours and block tugs, while ASD2810 could be used more as an ideal solution for 24 hours tug due to the reduced fuel costs per job. This type was also proven to be very efficient in the port of Liverpool, which is characterized from an average towline connection equal to 1,85 hours. On the other hand, ASD 3213, is proven to be the most expensive tug for Europoort, with a slightly better performance in the port of Zeebrugge, as a result of the 3% less mobilization and demobilization time among the two ports, while for the port of Southampton, the same tug type suffered from significantly higher fuel consumption.

Additionally, Voith Schneider's were proven to have the lowest fuel cost in the port of Antwerp, while slightly higher was the cost in Rotterdam Area; while one of the main conclusion that can be made is that Voith Schneider's consist from the lowest fuel cost in the port of Antwerp as a result of the low towline connection time per job. On the other hand, Voith Schneider's were proven to have the worst behavior in GTV Area, due to the long transit routes among Terneuzen & Ghent, while the port of Antwerp was the most efficient area for Citranaval Defcar. Even if the towline connection time is higher in Zeebrugge, this tug type was proven to be very efficient, which is a significant advantage for the entire Schelde Area. On the other hand, RT AMBITION was proven to have significantly lower fuel cost in the port of Zeebrugge compared to RT PETER & ROB in the port of Bremerhaven (both RT8032), because of the different locks configurations and operational profile among the two ports. Moreover, for ATD 2412, the port of Hamburg was confirmed to consist of the lowest fuel cost per job, while the most expensive port was the port of London. This is explained from the high levels of Mob/Demob times in the Thames river. Moreover, the port of Hamburg does not consist from locks, and therefore the required tasks to occur during towline connection will vary considerably among the two German ports. Especially, for ZP Bison when operate inside the lock, in the port of Bremerhaven for handling car-carriers, higher consumption levels are expected to be increased by 26,29 € (2016) per job in Bremerhaven, compared to Hamburg.

7.6 KST Ports Fuel Cost Analysis 2016

After the variances among each tug type are analyzed through subchapter 7.5, the goal of this chapter is to assess the fuel cost per port, as a result of the selected tug types in each region. Figure 135, summarizes the results among the various ports of operations of KST, which are plotted in x-axis. Additionally, the averages of towline & Mob/Demob percentages times are shown, combined with the average towline connection time, together with the average fuel cost per job for all tug types which were selected for each port during 2016. From Figure 135, it is evident that the resulted fuel cost for each port, is aligned with the types as well as the number of tugs to be selected. Therefore, it is obvious that ports with high levels of towline connection times towards a job, are related to higher fuel cost. Starting with Europoort, high fuel cost values are expected, since it consists of five different tug types with various fuel costs. The average for this port is high, mainly due to Rampart 3200 & ASD 3213 which were proven to be the two most expensive tug types. At the same time, the presence of only three tug types in Rotterdam Area with considerably lower fuel costs, combined with lower towline connection times, had as a result lower fuel cost.

The ports in GTV area, Zeebrugge & Liverpool, consist of high fuel costs, which are aligned with high levels of towline connection hours equal to 1.86, 1.69 & 1.82 hr. accordingly. On the other hand, the ports of Antwerp & Hamburg are proven to be the most efficient, consisting of the lowest fuel costs and lowest amount of times for completing an assistance. Finally, for the rest UK ports, significantly high levels of Mobilization times led to high levels of fuel consumption, as a result of the selected types for these areas. Especially for the port of Southampton, the presence of ASD 3213 had the largest influence towards the fuel cost per job for the new entry port.

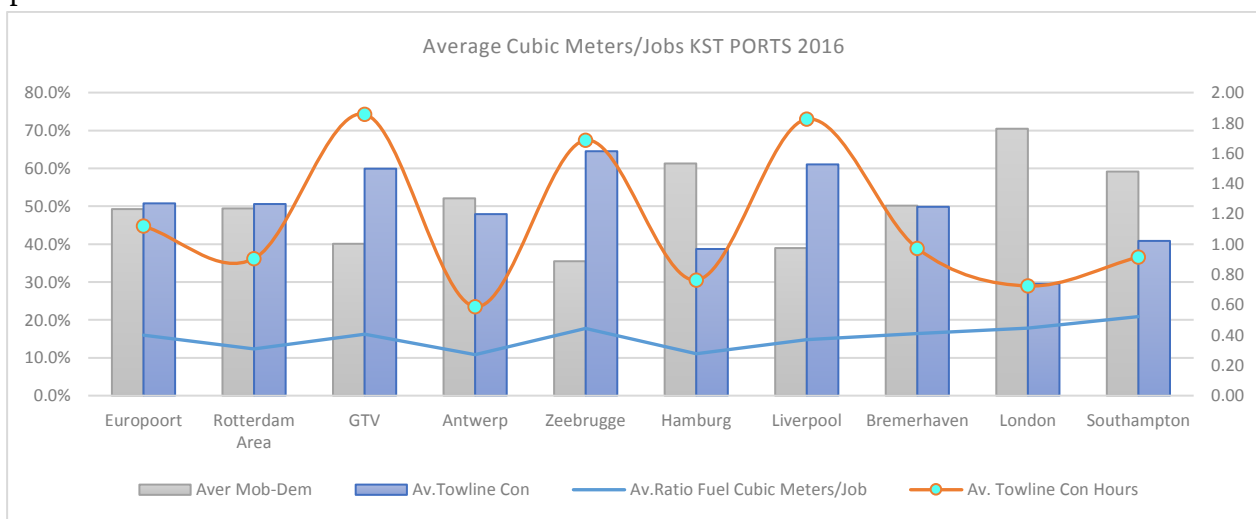


Figure 135: Average Cubic Meters/Jobs KST PORTS 2016

Table 48, shows in detail the information which is plotted in Figure 135. The average ratios of cubic meters per jobs for all the tug types per port for 2016, are plotted with the blue line, while the towline connection hours as an average from all the types are shown from the line with the orange color. The clustered columns for each port, show the difference of towline connection and Mobilization/Demobilization times for each case.

Table 48: Summary of Ports Insights for 2016 (Southampton->2017)

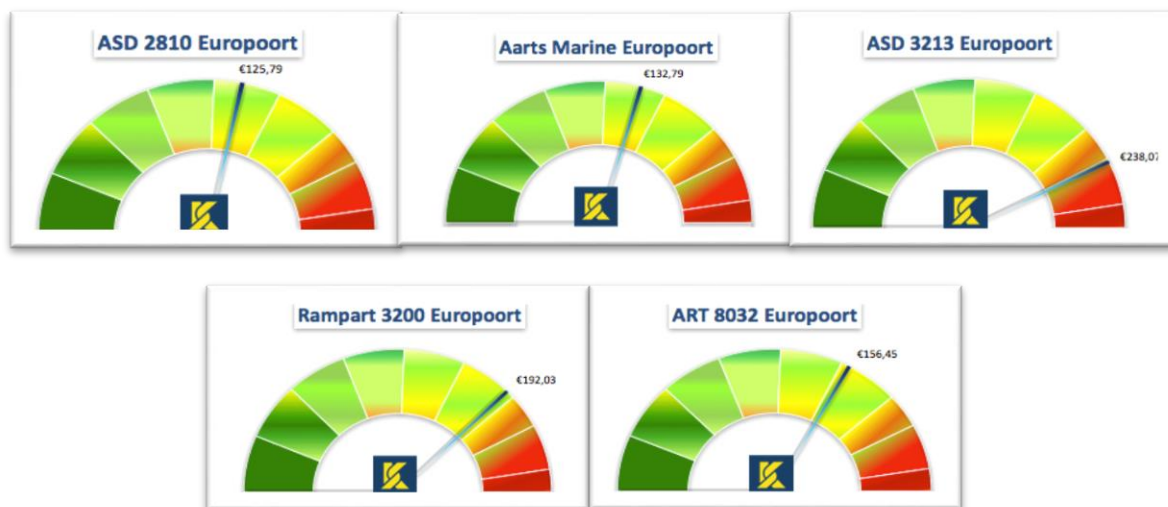
Ports	Jobs	Av. Ratio Cub. Meters/Job	Av. Towline Con	Aver Mob-Dem	Aver Tow.Con Hours	# Of Tugs Per Port
Europoort	1378	0.40	50.8%	49.2%	1.12	13
Rotterdam Area	1387	0.31	50.6%	49.4%	0.90	6
GTV	864	0.40	59.4%	40.6%	1.86	9
Antwerp	2370	0.27	47.9%	52.1%	0.59	9
Zeebrugge	1150	0.44	64.5%	35.5%	1.69	6
Hamburg	974	0.28	38.7%	61.3%	0.76	5
Bremerhaven	939	0.41	49.8%	50.2%	0.97	5
Liverpool	776	0.37	61.0%	39.0%	1.82	6
London	476	0.45	29.5%	70.5%	0.72	2
Southampton	300	0.52	40.8%	59.2%	0.91	3

Tug Types VS Port of Operation

Europoort

Analyzing the tug types which were selected for the Europoort (13 tugs in total during 2016), it is proven that the lowest fuel cost per job was achieved from ASD 2810, with a fuel cost equal to 125,79 € (2016). Slightly higher fuel cost characterizes Aarts Marine (Fairplay 21 & 24), with a fuel cost price equal to 132,79 € (2016), while ART 8032 was proven to have an average price for this port. The hybrid technology for this rotor type, led to lower fuel consumption during mobilization and demobilization.

On the other hand, Rampart 3200 and ASD 3213 were proven to be the most expensive tugs for daily operations, while ASD 3213 tugs (SMIT Cheetah & Panther), consist of a cost equal to 238,07 € (2016); however, these tugs are required in Europoort since they are involved in Heerema projects, which require at least two tugs with minimum BP equal to 85 tons of BP.



On the other hand, the Rampart 3200 tugs (SD Seal & Stingray) which have variance only by five tons, compared to ASD 2810 (65 vs 60 tons), should be reconsidered towards the daily operations in Europoort, since they are proven to be tremendously expensive, with a cost equal to 192,03 € (2016). Figure 136, also confirms that the sailing profiles among the majority of the tug types is identical, except from Rampart 3200 & ART 8032. The reason why Rampart 3200 has higher Mob/Demob. percentage is related with the dispatch planning, and the fact that this type used to operate as a 24-hour tug during 2016. Therefore, depending on the destination of the assisted vessel in the Europoort, this type spent higher percentage during this mode, compared to the rest. Additionally, for ART 8032, this result should not be compared with the rest types, since

tugs from this type sailed multiple times in London for increasing temporarily the capacity requirements in this port. Finally, Figure 135 shows that Europoort is considered as one of the highest in fuel cost ports among the ports of operation of KST. This result occurs due to the various types that operate in a daily basis, consisting from various fuel cost values per job, as has occurred from the dashboard above. Therefore, possible reallocations of tugs in this port under various scenarios, which will be deeply analyzed in chapter 9, could lead to significant fuel cost reductions.

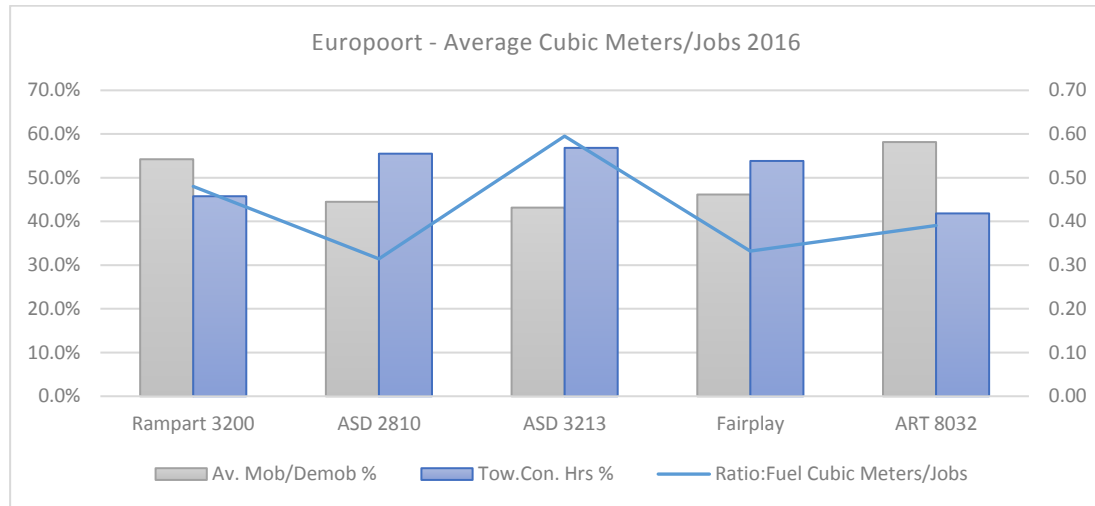


Figure 136: Average Cubic Meters/Jobs for Europoort 2016

Rotterdam City

For Rotterdam City (six tugs in total during 2016), the lowest fuel cost per job was reflected in Normal ATD, with a cost equal to 116,27 € (2016) per job. This result justifies company's decision to use these tug types also as 24 hours' tugs, since it was proven that this type is the most optimum and therefore the most ideal for 24 hours' assistances. Rampart 3000, SD Jacoba, was slightly more expensive with a cost equal to 118,57 € (2016) per job. As it was expected from Figure 137, Voith Schneider's were proven to be the most expensive tug type with a fuel cost equal to 138,25 € (2016) per job. Once again, it is vital to analyze the amount of time spent for each type towards towline connection time and during mobilization & demobilization. Normal ATD & Voith Schneider consist from similar times towards the three phases of Figure 121, while SD Jacoba was confirmed to have significantly higher percentage of mobilization & demobilization times.



However, these results are expected and hence can be explained from the fact that, SD JACOBA, proceeded multiple times in several trips to Europoort from Rotterdam City, for fulfilling the needs for an extra tug in Europoort area. Ex KOTUG tugs, which are located in Rotterdam City, are preferably selected from the dispatchers to operate in Europoort area if necessary, and the reason is that if they have to berth temporarily anywhere in Europoort for proceeding to multiple assistances in cases that extra fleet capacity is required in Europoort, the crew will not be paid extra, as it will happen with ex SMIT tugs, due to the existing multiple CLA's. ZP Chalone, the other ex KOTUG tug, which is also located in Rotterdam City, is more rarely selected

due to the lower BP levels compared to SD JACOBA, and therefore it is not capable to fulfill always the needs of BP in Europoort.

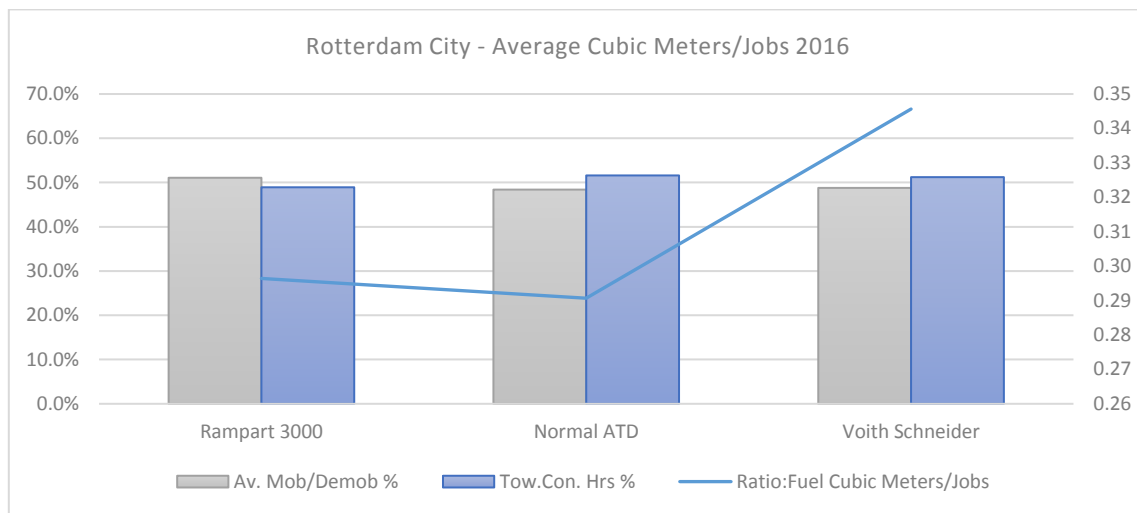


Figure 137: Average Cubic Meters/Jobs for Rotterdam City 2016

GTV

The long distances to be covered especially among Terneuzen & Ghent led to high levels of fuel consumption. Additionally, since the tugs in GTV area (nine tugs in total during 2016) must offer several assistances in the general area including the port of Vlissingen & the chemical plants in Terneuzen, several times tugs are enforced to sail full speed during mobilization & demobilization since the fleet capacity in this area is not enough, leading to high fuel costs per job. By looking the dashboard for GTV area, it is proven that the lowest fuel cost per job refers to conventional tugs. Combi tugs, (Braakman & Terneuzen) were proven to be ideal for this area, which requires pure conventional tugs, making this type the optimum for GTV area. They consist from high effectiveness levels for Bow to Stern operation, when towing “conventionally”, and therefore they are ideal for operating into the channel from Terneuzen to Ghent, with the lowest fuel cost. On the other hand, middle costs characterize the types of Conventional ASD’s and ASD 3110 with 166,77 € (2016) & 172,96 € (2016) respectively, while Citranaval and especially Voith Schneider were proven to be the less efficient type for this area with cost equal to 268,33 € (2016) per job.



Figure 138 proves that the all the types operating in GTV area, except from ASD 3110 which operated in GTV for seven months during 2016, before its departure for the port of Liverpool, were characterized from ~ 62% towline connection time and ~38 % for mobilization & demobilization times. Finally, the GTV area is considered as one of the expensive areas with high fuel costs, as a result of the selected types for that year and the large sailing distances. The same tug types exist also for this year, except from the ASD3110 tug type and therefore it would be wise to reevaluate the behavior of the rest tug types of the company, before proceeding to tug’s reallocations under more efficient scenarios.

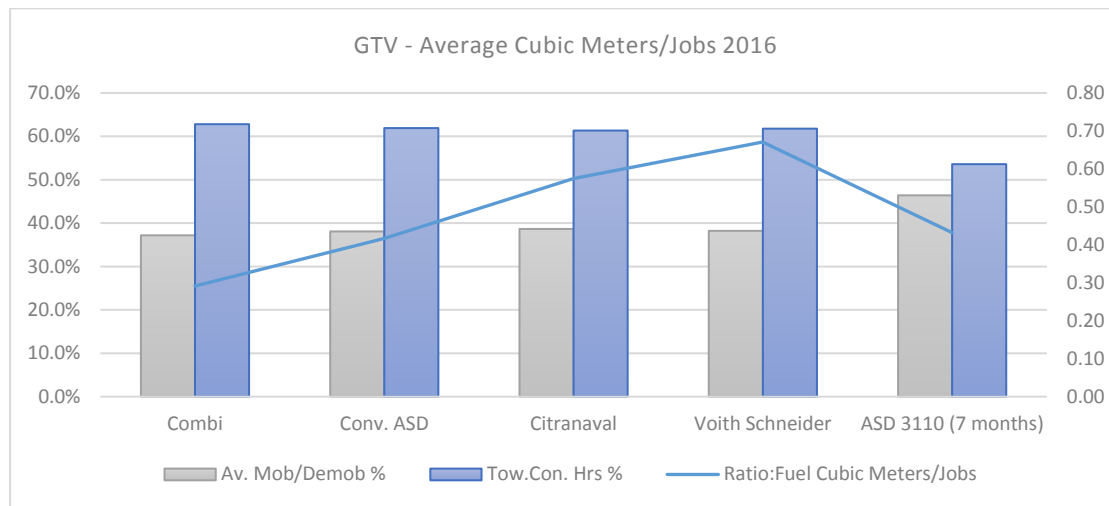


Figure 138: Average Cubic Meters/Jobs for GTV 2016

Antwerp

For the port of Antwerp (nine tugs in total during 2016), the most optimum choice with the lowest fuel cost was proven to be the Armon Design, with a cost equal to 86,34 € (2016) per job. The dashboard for this port however also proves that all the tug types consist from significantly low fuel cost levels, while by comparing the combination of the tug types in the rest ports in Figure 135, it is evident that the port of Antwerp is the lowest port in terms of cubic meters per job, with a score equal to 0,27. Special attention is given to Rampart 3200 which was proven to have 82,04 € less fuel cost compared to the same tugs in Europoort, because of the 5 % less mobilization & demobilization times among the ports. At the same time, Compact Tug Design tugs, UNION HAWK & EAGLE even if are characterized from the highest BP value, compared to rest types in Antwerp, they were proven to have a fuel cost equal to 121,93 €.



Finally, the highest score refers to Voith Schneider, and was equal to 124,02 € per job. The variance among the last two pre-mentioned types, Compact Tug Design (86 tons of BP) & Voith's (45 tons of BP), explains the reason why Voith's with bollard pull in between 40-60 tons, are not preferred from harbor towage companies, as it is shown in Figure 40. The preference of towage companies to enrich their fleet with azimuth propeller tugs instead of Voith's, is mainly due to the demand for higher levels of power, where Voiths demand about 10 % to 20 % more power for delivering the same amount of bollard pull compared to similar azimuth propeller harbor tug, thus higher fuel consumption will occur. (Artyszuk, TYPES AND POWER OF HARBOUR TUGS - THE LATEST TRENDS 2013). In case of KST, for the port of Antwerp the Voith's were proven to have higher fuel cost, compared to tugs with almost double amount of BP. Additionally, by looking

Figure 139, it is confirmed that the tug types have similar profile towards the towline connection times and Mob/Demob. Times, with percentages equal to ~49 % & ~51% respectively.

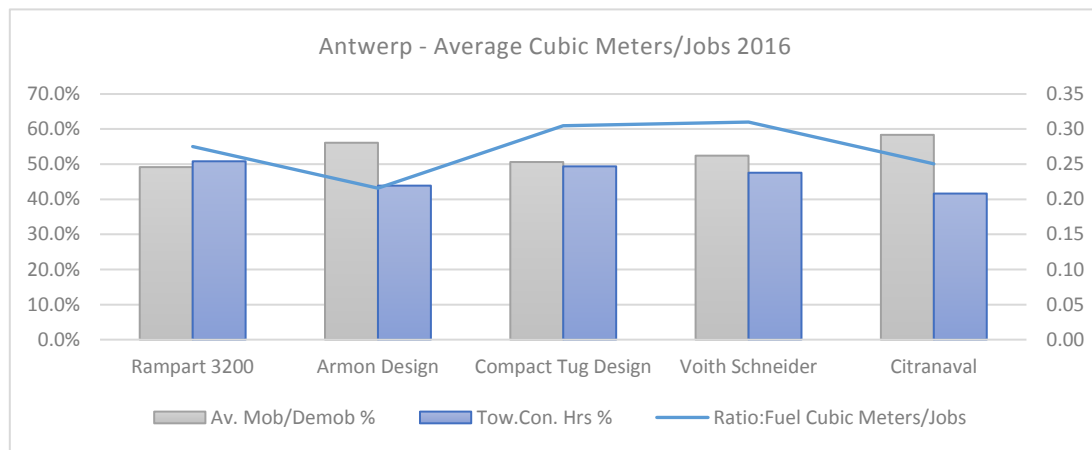


Figure 139: Average Cubic Meters/Jobs for Antwerp 2016

Zeebrugge

For the port of Zeebrugge (six tugs in total during 2016), the most efficient tug type was proven to be the Citranaval Defcar with fuel cost equal to 140,99 € (2016) per job. Additionally, 30,29 € fuel cost per job variance occurred among the two rotor types, RT8028 & RT 8032, while the most expensive tug in this port was confirmed to be the ASD 3213, with a fuel cost equal to 214,51 € (2016) per job. Moreover, Figure 140 indicates that the entire fleet in this port followed the same operational profile and therefore ~65 % was referring to the towline connection, while only ~ 35% for mobilization & demobilization. This can be explained from the configuration of this port, as it was already explained in subchapter 5.5, which analyzed the presence of the lock and the small transit distances. The port of Zeebrugge resulted to have one of the highest fuel cost rate, as it is shown in Table 48, due to the three rotor tugs as well as due to the presence of the SMIT TIGER (ASD 3213). However, the fuel cost of ASD3213 in the port of Zeebrugge, was proven to be 9,89 % less compared to Europoort for the tugs, SMIT CHEETAH & PANTHER.



All these types resulted to have high fuel cost per job results, based on two major reasons as a result of the port complexity. The strong current at the “mouth” of the port enforces the incoming vessels to enter the port with high speed and as a result during towline connection time, tugs are enforced by pilots to operate in full power for offering the maximum braking assistance. This situation refers especially to container vessels, since their terminals are in short distance from the port entrance. On the other hand, for car carriers, there is more time, since they will always berth in the inner port, after the lock. Even if there is more time, for providing braking assistance till the lock, the combination of adverse environmental conditions as well as the type of assisted vessels (car carriers) at the port, make tugs to operate at high rpms for long period in and out of the lock, for offering in the most efficient way the requested ship-handling duties.

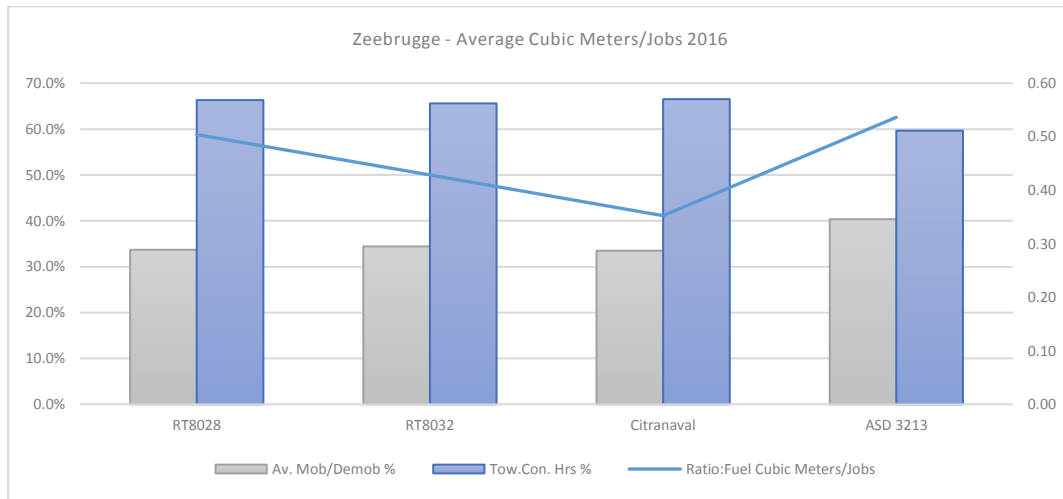
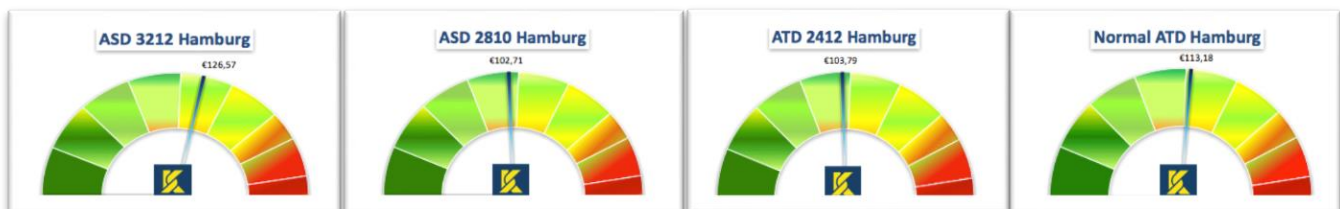


Figure 140: Average Cubic Meters/Jobs for Zeebrugge 2016

Hamburg

During 2016, the port of Hamburg was consisting from four different tug types (five tugs in total during 2016). Starting with ASD3212, SD Dolphin was proven to be the most expensive in terms of fuel cost tug. However, it's cost in general is considered as one of the lowest among all ports, equal to 126,57 € (2016) per job. Moreover, Normal ATD was proven to be 2,57 % lower compared to Normal ATD in Rotterdam City, even if the time spent per activity because of the various sailing profiles for Rotterdam City & Hamburg, was completely different. For the ZP Condon (Hamburg), 65 % of its running hours was spent during Mobilization & Demobilization, while only 35% during towline connection time. On the other hand, the Normal ATD's in Rotterdam City, spent 48,4% towards Mob & Demob. Concerning the next tug type, ATD2412, the fuel cost per job was equal to 103,79 € (2016), while by looking Table 45, it is evident that this type is proven to be one of the most optimum, since it matches perfectly the towage restrictions and regulations among the various container terminals, especially during adverse environmental conditions, with considerably low fuel cost.



Finally, ASD2810 is proven to be the most optimum type for this port, together with Europort. Even if 60 % of its running hours were spent during mobilization/demobilization, tug masters were proven to sail with the optimum speed, 7 knots, frequently among the jobs or towards the berth after job completion. Figure 141, shows for the total of types on the port of Hamburg, the similarities concerning the percentages for towline connection times and Mob/Demob. All types consist of ~60% Mob/Demob times and ~40% of towline connection times. The low percentage during towline connection was also expected since the average time for one job in Hamburg was proven to be equal to 0,76 hr.

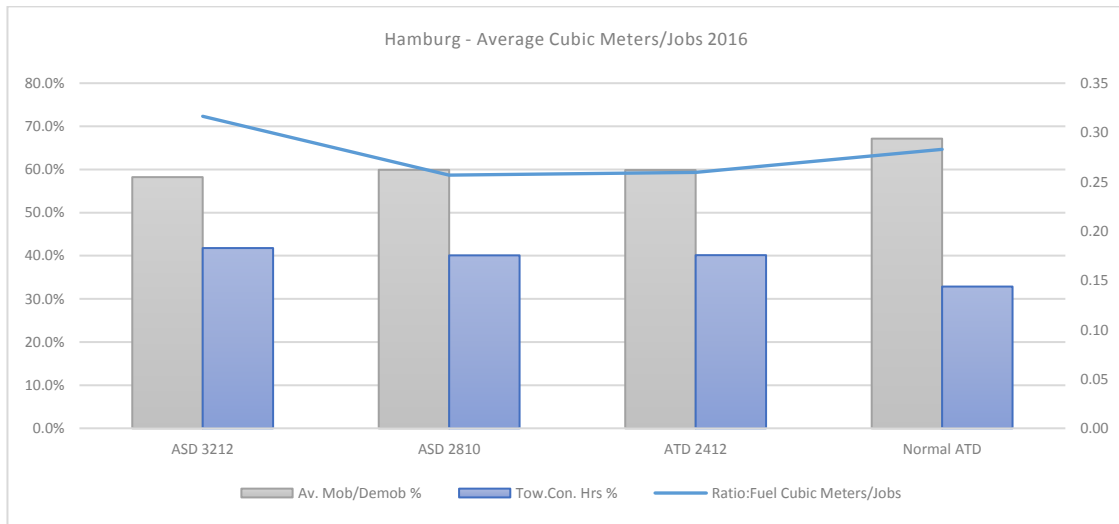
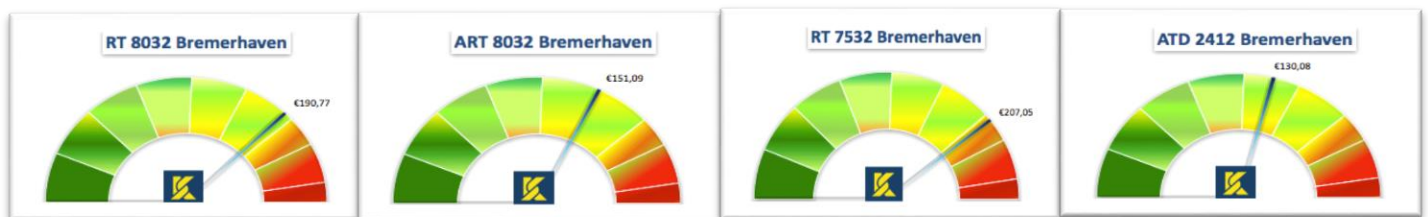


Figure 141: Average Cubic Meters/Jobs for Hamburg 2016

Bremerhaven

The port of Bremerhaven (five tugs in total during 2016), is confirmed to consist from high fuel cost per job, as is it shown in Table 48. The main reason for this result is related with the tug types that used to operate during 2016. The same types are used also during 2017, except from the ATD2412 (ZP Bison).



The rest operational types for the daily towage duties in the port of Bremerhaven are all rotors, and therefore high rates of fuel cost per job are expected, simply due to the combination of tugs with three engines, together with high average time of towline connection (~1 hr.). The harbor towage duties request high levels of awareness and maneuverability due to the presence of two locks. Additionally, since the vessels inside the lock are capable to moor only at the one side, pilots request from tugs to compensate the strong wind levels, which influence the large lateral surfaces of car carriers, by applying full power for long period, on the line; hence rotors are proven to be the most capable types for applying these forces (rotoring). This is the main reason that KST has allocated tug types with high effectiveness levels, capable to deal even with the worst cases scenarios. By looking the dashboard above, as it is expected the type with the lowest fuel cost per job was proven to be the ATD2412 with a rate equal to 130,08 € (2016).

On the other hand, among rotors, the lowest fuel cost per job was achieved from the ART8032, and more specifically from RT EMOTION. As it was already explained in subchapter 3.6 concerning the Hybrid technology, this type is capable to sail under various modes, and hence to achieve even 20 % less fuel consumption compared to the rest rotor types. (MARIN 1999). By comparing the fuel rate per job among the two types RT8032 & ART8032, it is proven that both types have 20% variance at the resulted fuel cost per

job. RT8032 was proven to have a rate equal to 190,77 € (2016), while ART8032 had a fuel cost equal to 151,09 € (2016).

The main reason for this distinction is the ability of the hybrid tug to sail only by using the auxiliary engines/aft main engine for TRANSIT ½, during mobilization & demobilization. Therefore, even if the tasks during towline connection are the same for all the tugs in this port, and hence the fuel consumption during this situation, one the other hand, the fuel cost during mobilization and demobilization for ART during IDLE, TRANSIT ½ modes will be significantly lower; especially in the port of Bremerhaven it is confirmed that most of the times the tug masters are sailing towards the assisted vessel and back to their berth by using TRANSIT 1, with an average speed equal to 6,5 knots. In cases where the current is stronger more power will be required, or in case where tugs are late for meeting the assisted vessel, TRANSIT 2 will be used offering 11,5 knots of speed. For RT7532, the fuel cost per job is proven to be equal to 207,05 € (2016), which is the highest above all in the port of Bremerhaven. As it has been analyzed in subchapter 3.6, concerning the variances in the main principles of rotors, the large levers to be created, because of the higher distances among the towing point location and propulsion units for this type, more power will be required for compensating the resulted levers. (Jansen, Comparison Among RT8032 & ART8032 2017).

However, the presence of RT7532, (RT Innovation & Pioneer) is crucial in the port of Bremerhaven for proceeding in special jobs if necessary. These two tugs are the only tugs consisting from steel wire, while during 2016 they proceeded twice in special jobs for transferring oversized Kasko (120m x 40m) by using Holtenau locks at Kiel from the Neptun Shipyard in Rostock, to Meyer shipyard in Papenburg. Figure 142, proves that all tug types in the port of Bremerhaven follow the same sailing profile, consisting from ~60% mob. /demob, while the rest ~40% belongs to towline connection. The only type that has significant variance from the pre-mentioned percentages is ART8032, and the main reason is due to the IDLE, TRANSIT 1 & 2 modes. The pre-mentioned modes lead to significantly lower running engine hours, belonging almost exclusively to the towline connection hours. This explains adequately the reason why ART8032 offered ~80% of its sailing profile for towline connection time. Finally, it is shown that both mobilization and demobilization times for this port are characterized from high levels. The reason is related with the complexity of this port, where depending on the assisted vessel (incoming VS out-coming), tugs increase their fuel consumption for being stand-by inside the lock, and proceed in swaps among the inner and outer port, depending on the vessel to be assisted.

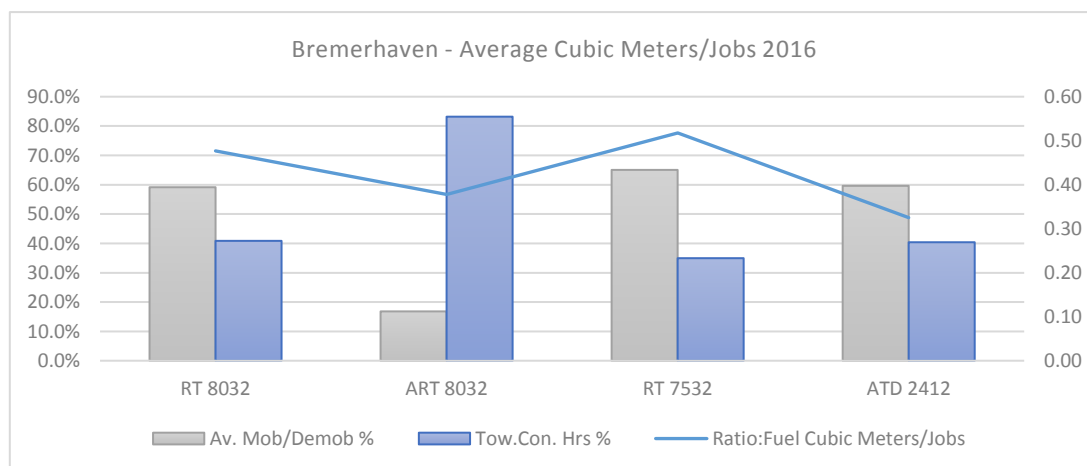


Figure 142: Average Cubic Meters/Jobs for Bremerhaven 2016

Liverpool

The port of Liverpool consists of four different tug types (six tugs in total). Even if the complexity of this port is also high, Liverpool is not consisting entirely from tractors. This is also related with the adopted philosophy in the port of Liverpool, where initially the operations in the narrow locks started by using conventional tugs, while 20 years ago, Voith Schneider's brought a different perspective towards the daily operations by improving considerably the effectiveness levels of towage operations. Apart from Voiths however, this port was never consisting from synchronous ATD's or rotors, while ASD2810 was initially introduced ten years ago. The dashboards below show the fuel cost per job for the three different ASD types, as well as the cost for the Voith Schneider's. The most efficient tug type in terms of fuel cost, was proven to be the conventional ASD, with a rate equal to 118,07 € (2016) per job, while ASD2810 was proven to be 18,77 % more expensive with a rate equal to 145,36 € (2016) per job. ASD3110 was confirmed to be an added value swap from the port of GTV to the port of Liverpool, with an average rate equal to 158,42 € (2016) per job.

Finally, the highest fuel cost per job belongs once again to Voith Schneider's, with a rate equal to 184,99 € (2016). However, the company should not consider to re-allocate the Voiths from the port of Liverpool even if they are characterized from the highest fuel cost per job among the existing types. The combination of several tug types in the port of Liverpool is mandatory, and the main reason for that is the presence of Cammell Lairds shipyard. The shipyard frequently requests tractor tugs, and preferably Voith Schneider's for the removal of the dry-dock gates. Due to the vertical propulsion units, this tug type is considered as the most efficient for this type of operations, since the wash effect does not influence the gate removal.

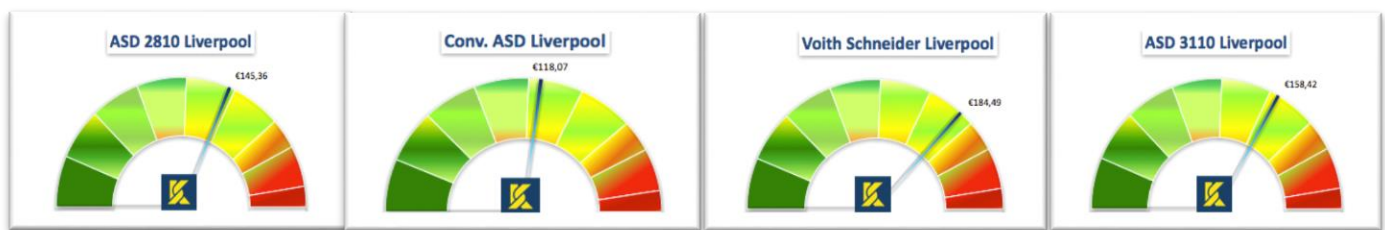


Figure 143 shows the variance among the sailing profiles for the tug types in the port of Liverpool. All the tug types are characterized from the same profile, except from ASD3110 which operated for 7 months during 2016, and therefore its profile is slightly different compared to the rest types. Consequently, it is shown that for the tugs in this port ~62% of their operational profile was spent to towline connection, while ~38% was reflecting mobilization & demobilization.

The high amount of towline connection is justified from the presence of narrow locks in combination of narrow passages and confined areas in this port, leading to an average towline connection time equal to 1,82 hours. Consequently, the large periods of times where tugs are in stand-by mode or in cases where ship handling tasks take place in the inner port and require considerably higher amount of power for controlling efficiently the large bulk carriers in the confined areas, will lead to higher fuel consumption.

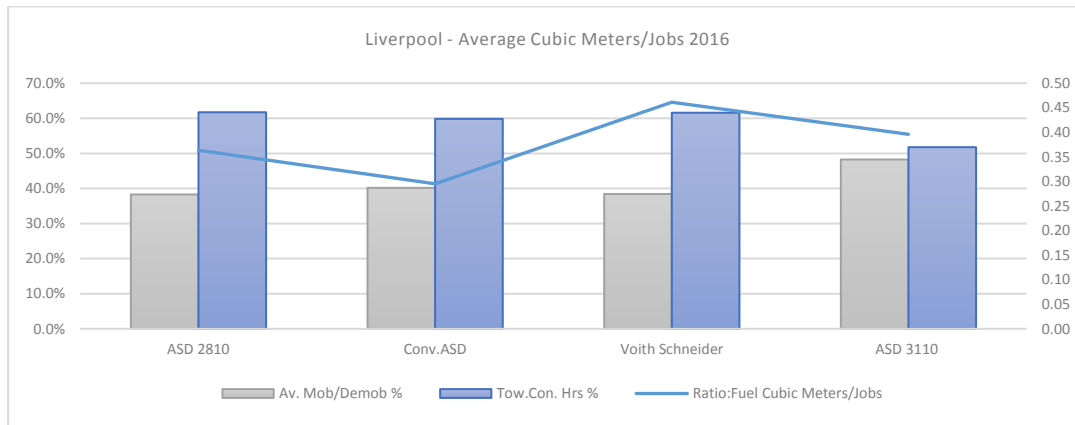


Figure 143: Average Cubic Meters/Jobs for Liverpool 2016

London

The port of London was consisting only from two tug types during 2016. The first tug, ZP Bear which belongs to ATD2412, while SD Shark belongs to Rampart 3200. ZP Bear continues to operate till today in the port of London, while SD Shark has been reallocated to the new entry port of Southampton and is currently replaced from RT Evolution since last April. Figure 144, confirms that both tugs suffered from high amounts of mobilization & demobilization times, as a result of the five main possible areas to operate, offering ship-handling services. Hence both types are proven to consist from a sailing profile consisting from ~70% mobilization & demobilization, while the rest ~30 % belongs to pure towline connection time. Table 48 also shows that the average towline connection time during 2016 was equal to 0,72 hr. By looking the dashboard below, Rampart 3200 was evaluated with a fuel cost equal to 187,01 € per job, while ATD2412 from a rate equal to 180,71 € (2016). Consequently, both types suffered from high rates as a result of the mobilization & demobilization times.



Consequently, KST should re-consider possible reallocations in the port of London with less fuel costs, while during 2017 company decided to reallocate RT Evolution. One of the main goals for reallocating this hybrid tug in the port of London, was related to higher flexibility levels, especially for vessels over 240 meters in London Gateway. Additionally, the contract among Viking cruises & KST, requires two rotors for assisting the cruises in and out of the Thames Barriers.

Finally, the advantages related with the hybrid technology for this type in the port of London, were proven to be poor at least for the months of April & May. The main reason for these results is linked with the strong current in the Thames River. At the same time for cases with short transit distances among the tug and the assisted vessel (~15 to 20 min), tug masters will make use of the hybrid technology rarely, explaining the high fuel cost for this type, during April & May, which was proven to be 220,32 € (2016) per job.

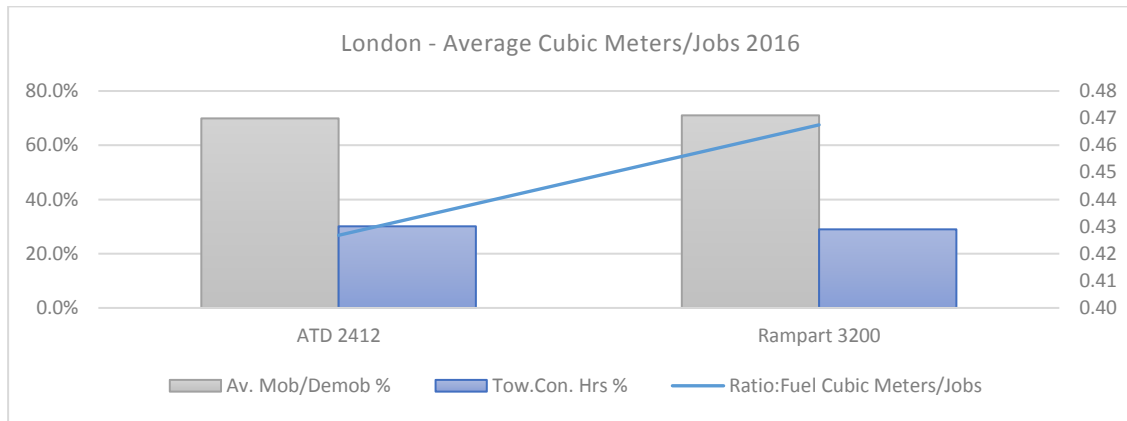


Figure 144: Average Cubic Meters/Jobs for London 2016

Figure 145 presents the behavior of the ART 8032 among the ports of Europoort, Bremerhaven & London. It is evident that this type operated in the most efficient way in the port of Bremerhaven and the main reason is related with the ability of the tug masters to make use of the hybrid technology in the most possible way. In Europoort, since port authorities allow multiple vessels to enter the port at the same time, they tend to create several difficulties to dispatchers planning, while in several cases the fleet capacity is not enough for fulfilling client's needs. Consequently, in most of cases in Europoort, tugs either will be informed late for sailing to a vessel, or they must proceed in multiple jobs in short period of time. In both cases, tugs might be late to assist the client and must sail with high speed while hybrid tugs are not capable to take the advantage and sail with less engines in TRANSIT ½.

On the other hand, for the port of Bremerhaven, dispatchers are dealing with entirely different situation. The location of this port is combined with a tidal river where from the moment vessels enter the river, they will never go upstream for heading back. Therefore, dispatchers are aware of incoming vessels arrival, and hence they are capable to proceed in an efficient planning and notify tugs in advance. This explains also from the weekly reports the reason that RT Emotion was consisting from several idle and Transit 1 hours compared to RT Evolution especially in the port of London, which was proven to have almost zero TRANSIT 1 hours.

Moreover, one significant advantage which allowed the maximum operational profile of hybrid technology, is the presence of locks. The tugs in Bremerhaven must spend a significant amount of their topline connection time in a stand-by mode. This mode applies inside locks where the assisted vessel and tugs wait for the control of sea water level water among the inner and outer port. In this case ART8032 type was proven to be ideal, since tugs can switch to IDLE mode and operate only by using their batteries.

On the other hand, the high current in Thames river, does not allow hybrid tugs to operate in its most efficient way. Therefore, tug masters must increase their power, especially in cases where tug is sailing against the current and therefore they will sail either to TRANSIT 2 or if the distance among tug and assisted vessel is less than 20 minutes, they will proceed directly to ASSIST mode. All the pre-mentioned reasons explain adequately the fuel costs per job for the ART8032, among the ports of Europoort, Bremerhaven & London, which was proven to be 156,45 € (2016), 151,09 € (2016) & 220,32 € (2016) per job respectively.

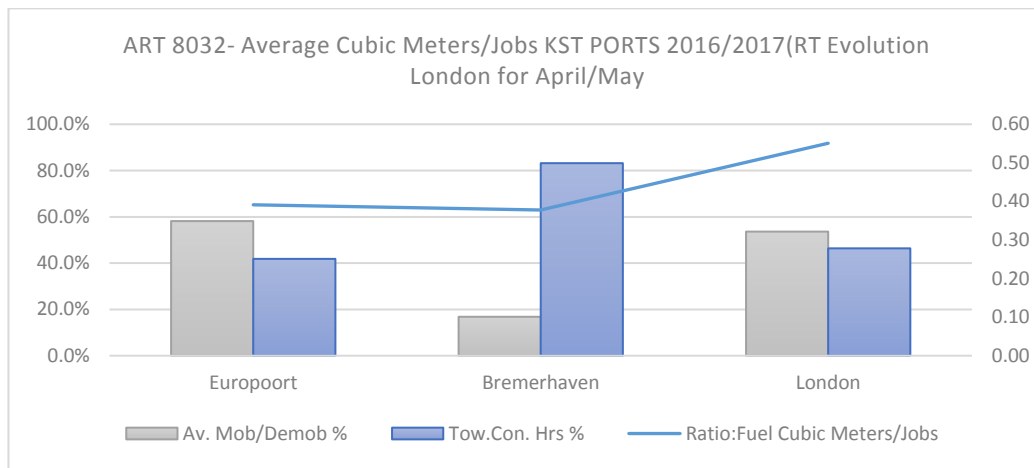


Figure 145 : ART8032 in London, Europoort & Bremerhaven 2016 -2017

After the variances among each tug type which were established through subchapter 7.5, the goal of this chapter was to assess the fuel cost per port, as a result of the selected tug types in each region, while Figure 135, was used for assessing the operational profile of the selected tugs. Moreover, the results regarding the total number of tugs per port, as well as their total fuel consumption for each area, were extensively analyzed and assessed for each tug type, during 2016, while it was proven that the resulted fuel cost, was aligned with the types, as well as the number of tugs to be selected.

The next subchapter aims to establish the strategy to be followed for filling in Table 44 completely. In this matrix, only the cells with orange color were filled in, since for the year 2016 each of the pre-defined tug types was operating in this specific port. For the rest cells, which are characterized from yellow color, the company so far has not a clear indication of the fuel cost per job, and therefore process performance indicators were used for estimating the fuel costs for the entire fleet of KST, regarding all the ports of operations.

7.7 KST Fuel Cost PPI' Fleet in the Various Ports

Strategies for reducing Fuel Consumption

Numerous strategies can take place for reducing the fuel consumption of harbour tugs. As it was already proven in subchapter 7.2, the fuel consumption varies per activity, while the speed factor is high of importance and therefore, continuous monitoring is required. The type of activities based on tugs operational profile, are characterized from massive fluctuations, as it was already proven in Figure 122. Therefore, one added value strategy for monitoring constantly the fuel consumption of a tug, relies on the combination of AIS data, together with the fuel consumption per hour, based on speed tables, for each tug type. This methodology can provide a solid output about the precise number of cubic meters that are consumed for each of the pre-discussed activities. The combination of AIS Data, (Historical Data Overview), with the fuel consumption per hour, is already an adopted technique from several companies worldwide, for calculating the fuel consumption per activity concerning the daily profile of a harbour tug.

The continuous monitoring of the fuel consumption, based on tug's activity and sailing profile is provided, by using flow meters in any type of diesel engine. However, it is also an expensive solution especially for companies with numerous tugs. This system is measuring the fuel flow by providing at the same time in real time conditions the resulted sailing routes. Therefore, these systems provide vital information about the consumed liters per hour, while at the same time they allow the proper correlation among tug's activity and

most importantly the adopted speed for each case. However, no one can guarantee the trustworthiness level of flow meter results, concerning the fuel consumption. Consequently, the performance diagrams from each tug type, as a result of its main engines, and therefore the correlation among engine's rpm with tug speed, can provide essential output, regarding the optimum speed to be followed for each activity, for maintaining the fuel consumption levels as low as possible. (Business 2011).

During the period where the current thesis project took place, none of company's tug was consisting from flow meters, or any other system capable to divide the fuel consumption per activity for each tug and each port during 2016. Moreover, even if a small percentage of tugs was consisting from those systems, again, it would not be wise to extrapolate the retrieved results, by making generic assumptions, since the port characteristics, and hence the sailing profiles per port vary considerably. This is also proven in subchapter 7.5, where the same tug types in various ports were proven to have significant discrepancies, and eventually different fuel cost per job. At the same time, it was impossible to retrieve Historical Data overview for 64 tugs in 12 different ports, by analyzing all the possible routes that were followed, combined with their speed for the entire year of 2016.

Therefore, for the needs of the tool and for providing a good indication of the fuel cost for each of the tug types of KST for the entire number of ports of operations, various indicators based in analogous estimations will be used. The presence of the same tug types in various ports, provided high of importance output, for establishing several metrics, allowing to monitor the behavior of each type in the port of operation. These metrics offered the ability to define the benchmarks, since it was clear to define which tug was proven to be the most efficient during the tugs allocation for 2016, while at the same time, the usage of performance metrics indicators offered the ability to gain a solid average estimation, towards the predicted fuel cost of each tug in each port.

However, the total number of indicators that were used, are not expected to offer 100 % success ratio. The proof is shown already in Figure 122; unless precise systems are installed, all the other methods to be used can only provide a good estimation based on the average behavior of the tugs historical database. However, for the needs of the tool, it was high of importance to proceed in overall evaluation of the various tug types in the port of operation during 2016. By using 130 indicators in total, it was possible to proceed in analogous estimation among the various tug types for all the possible ports of operations, for gaining a good approximation of the fuel cost for every tug in a port, that never sailed before. This method was proven to be one of the most convenient, since limited information was available about the fuel to be consumed for each activity. However, the usage of PPI's can still provide vital insights for the decision-making tool which is extensively analyzed in subchapter 8.2, for determining the best combination of fleet per port leading to high levels of effectiveness towards the daily operations and at the same time to the lowest fuel cost for the entire amount of jobs.

Finally, even if the indicators that are used are not capable to provide 100 % accurate results, still they are capable to provide fair good approximation, while due to the impact of human factor, the trustworthiness level of the predicted indicators regarding all the fuel costs for tugs in new ports, will be evaluated after considering a solid sensitivity analysis. In any case that the user would like to increase or decrease the uncertainty levels of the PPI's, through various simulations, he is capable to make his own selections, by defining the desired uncertainty level, which is extensively analysed in subchapter 8.3.

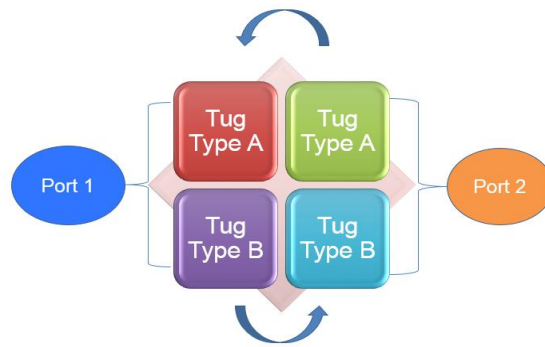


Figure 146: Interface of Indicators for unknown ports

Figure 146, shows the procedure that was followed from the established indicators for the final predicted fuel cost result for the tug types of KST. The comparison was always taking place among two different ports. As it was already proven in subchapter 7.6, the sailing profiles to be followed among all the tug types in the same port will be the same, with only exception rotors with hybrid technology. The reason for that exception is due to the hybrid technology, where less running hours are recorded during mobilization & demobilization, and therefore the final results show that almost the total amount of running hours of those tugs was given for towline connection times. However, this is not always the case, since in ports with high complexity and adverse environmental conditions, there is always the possibility to operate for long period as a conventional rotor tug.

Therefore, it is taken for granted that each new tug from the moment that enters a new port, it will follow the same operational profile of the existing tugs, and hence the same percentages towards mobilization & demobilization, as well as towline connection procedures. The first line of Figure 146, shows that two different PPI's take place as a result of the different ports. These two metrics will vary, since they are entirely aligned with the amount of consumed cubic meters & amount of jobs that took place at each port. The definition of these metrics was already established in subchapter 7.4, for providing a fuel cost overview for the same tug type and for each port.

Therefore, by retrieving an alternative tug type where its ratio is known for one of these two ports, it is possible to retrieve the predicted ratio for the unknown port. The change of percentage among the first tug type can be calculated among the two ports, and therefore since the sailing profile of all tugs in the same port is the same, the unknown tug type is also expected to have the same change of percentage. Numerous indicators, (in total 130), were calculated for defining the predicted values for the unknown fuel costs of the tug types of KST in the various ports, and are summarized in Table 49.

Table 49: Number of Indicators for unknown tug types in ports

Port	Europoort	Rot. Area	GTV	Antwerp	Zeebrugge	Hamburg	Bremerhaven	Liverpool	London	Southampton
Indicators	18	18	14	17	1	13	2	17	12	18

For the port of Zeebrugge & Bremerhaven only 3 indicators were used. The reason for that is explained from the strict regulations that take place in these ports, and therefore it was not necessary to predict the fuel cost values for the entire fleet of KST. Table 50, shows the variances among the tug types, which resulted from the indicators that were used.

The cells with name “Baseline”, show the change of percentage concerning the fuel cost for this specific tug type in each port, while the red cells are empty in cases where each tug type is prohibited to sail in this port.

Table 50: Variances Among Tug Types in the Various Ports

Indicators	Europoort	Rot. Area	GTV	Ant	Zeeb	Ham	Bremer	Liver	Lon	South
Combi	23.9%	32.6%	Baseline	56.4%				8.4%		
Normal ATD	23.5%	Baseline	94.1%	9.3%		2.7%		37.8%		44.4%
Normal ATD	26.8%	2.7%	99.4%	42.6%		Baseline		41.5%		48.4%
ATD 2412	22.5%	2.7%	60.8%	29.9%		Baseline	25.3%	41.5%	64.5%	48.4%
ATD 2412	2.3%	18.0%	28.3%	44.0%		20.2%	Baseline	12.9%	31.2%	18.4%
ATD 2412	25.5%	37.5%	2.2%	57.3%		39.2%		14.0%	Baseline	9.8%
ATD 2412	17.5%	30.8%	8.4%	52.7%		32.6%		4.6%	10.9%	Baseline
Voith Schneider	56.6%	Baseline	94.1%	10.3%				33.4%		49.7%
Voith Schneider	19.3%	48.5%	Baseline	53.8%				31.2%		22.9%
Voith Schneider	17.4%	25.1%	45.4%	32.8%				Baseline		12.2%
Voith Schneider	74.6%	11.5%	116.4%	Baseline				48.8%		66.9%
RT 7532	3.5%	18.0%	46.5%	22.8%		20.2%	Baseline	12.9%	31.2%	18.4%
RT 8032	15.3%	8.7%	63.1%	28.9%	Baseline	11.2%	11.3%	25.7%	46.1%	31.8%
RT 8032	3.5%	18.0%	46.5%	36.1%		20.2%	Baseline	12.9%	31.2%	18.4%
RT8028	24.2%	3.0%	63.1%	28.9%	Baseline	1.4%	11.3%	15.5%	20.9%	91.4%
ART 8032	Baseline	21.9%	24.0%	46.6%		24.9%	3.4%	15.6%	40.8%	14.3%
ART 8032	3.5%	19.1%	28.3%	44.7%		22.3%	Baseline	19.6%	45.8%	18.4%
ART 8032	29.0%	44.5%	12.0%	62.1%		46.7%		17.9%	Baseline	18.8%
Conv. ASD	38.7%	52.1%	Baseline	56.4%				29.2%		7.8%
Conv. ASD	13.5%	32.4%	41.3%	38.4%				Baseline		30.3%
ASD 2810	Baseline	19.0%	31.3%	42.7%		18.3%		15.6%	2.6%	4.4%
ASD 2810	13%	29.9%	14%	50.4%		29.3%		Baseline	15.7%	17.3%
ASD 2810	22%	0.8%	61%	29.9%		Baseline		41.5%	19.3%	17.1%
Citranaval	24%	40.5%	Baseline	56.4%	39%	37.8%		29.2%	25.8%	19.2%
Citranaval	74.6%	36.4%	129.3%	Baseline	40.6%	42.6%		62.3%	70.0%	85.3%
Citranaval	24.2%	3.0%	63.1%	28.9%	Baseline	1.4%		15.5%	20.9%	31.8%
ASD 3110	13%	43.7%	9.2%	50.4%		29.3%		Baseline	15.7%	4.8%
ASD 3110	21%	48.5%	Baseline	54.6%		35.3%		8.4%	22.8%	4.0%
ASD 3212	22%	2.7%	99.4%	18.7%		Baseline		41.5%	19.3%	48.4%
ASD 3213	Baseline	21.9%	31%	42.7%	9.9%	18.3%		4.0%	2.6%	72.4%
ASD 3213	42.0%	54.7%	23.8%	66.8%	47.7%	52.6%		39.7%	43.5%	Baseline
ASD 3213	11.0%	13.3%	45.8%	36.4%	Baseline	9.4%		13.4%	8.1%	91.4%
Fairplay	Baseline	19.0%	31.3%	42.7%		18.3%		15.6%	2.6%	8.4%
Rampart 3200	Baseline	36.1%	31.3%	42.7%	19.5%	18.3%		15.6%	2.6%	4.4%
Rampart 3200	74.6%	11.5%	129.3%	Baseline		40.6%		101.7%	70.0%	66.9%
Rampart 3200	2.7%	34.4%	34.9%	41.2%		16.2%		18.7%	Baseline	2%
Rampart 3200	5%	33.2%	37.4%	40.1%		15.8%		20.9%	1.86%	Baseline
Rampart 3000	28.0%	Baseline	94.1%	10.3%		2.7%		47.9%	24.7%	44.4%
Armon Design	74.6%	11.5%	116.4%	Baseline		42.6%		64.9%	70.0%	66.9%
Compact Tug Design	74.6%	41.4%	129.3%	Baseline		42.6%		64.9%	70.0%	66.9%

Table 51 eventually summarizes the fuel cost for each tug type for every port of operation of KST. The cells with the orange color indicate the known PPI's, based on the current situation for the tugs which are already located in the various ports of operations.

However, in order to provide a solid overview and estimation of the fuel cost per tug type, except from the ports of the current situation, for the tool needs, it was necessary to fill in the cells with the yellow color. This explains adequately the main purpose for using so many indicators for approaching high prediction levels of the unknown fuel costs values, for the entire fleet of KST towards all the possible ports of operations.

Table 51: Price per Cubic Meter Per Tug Type

Fuel Cost / Job / PER TUG TYPE	Europoort	Rot. Area	GTV	Antwerp	Zeebrugge	Hamburg	Bremerhaven	Liverpool	London	Southampton
Combi	€ 88.78	€ 78.53	€ 116.60	€ 50.85				€ 106.80		
Normal ATD	€ 143.54	€ 116.27	€ 225.67	€ 105.42		€ 113.18		€ 160.17		€ 167.92
ATD 2412	€ 127.12	€ 106.63	€ 166.95	€ 72.81		€ 103.79	€ 130.08	€ 146.89	€ 170.71	€ 154.00
Voith Schneider	€ 216.52	€ 138.25	€ 268.33	€ 124.02				€ 184.49		€ 207.01
RT 7532	€ 214.38	€ 169.73	€ 303.29	€ 159.82		€ 165.21	€ 207.05	€ 233.82	€ 271.73	€ 245.13
RT 8032	€ 197.53	€ 156.39	€ 279.45	€ 121.88	€ 171.35	€ 152.23	€ 190.77	€ 215.43	€ 250.37	€ 225.86
RT8028	€ 250.39	€ 195.61	€ 328.85	€ 143.42	€ 201.64	€ 204.45	€ 224.49	€ 232.80	€ 243.85	€ 265.78
ART 8032	€ 156.45	€ 122.22	€ 193.93	€ 83.56		€ 117.44	€ 151.09	€ 180.78	€ 220.32	€ 178.88
Conv. ASD	€ 102.17	€ 79.82	€ 166.77	€ 72.74				€ 118.07		€ 153.84
ASD 2810	€ 125.79	€ 101.89	€ 165.20	€ 72.05		€ 102.71		€ 145.36	€ 122.50	€ 120.26
Citranaval	€ 175.08	€ 136.77	€ 229.93	€ 100.28	€ 140.99	€ 142.95		€ 162.78	€ 170.50	€ 269.81
ASD 3110	€ 137.09	€ 89.11	€ 172.96	€ 78.52		€ 111.94		€ 158.42	€ 133.51	€ 166.08
ASD 3212	€ 155.01	€ 130.03	€ 252.37	€ 102.93		€ 126.57		€ 179.12	€ 150.96	€ 187.79
ASD 3213	€ 238.07	€ 185.98	€ 312.66	€ 136.36	€ 214.51	€ 194.39		€ 247.67	€ 231.85	€ 410.53
Fairplay	€ 132.79	€ 107.56	€ 174.39	€ 76.06		€ 108.42		€ 153.44	€ 129.32	€ 143.91
Rampart 3200	€ 192.03	€ 122.61	€ 252.19	€ 109.99	€ 154.63	€ 156.79		€ 221.90	€ 187.01	€ 183.59
Rampart 3000	€ 151.78	€ 118.57	€ 230.14	€ 106.37		€ 115.42		€ 175.40	€ 147.82	€ 171.25
Armon Design	€ 150.73	€ 96.25	€ 186.80	€ 86.34		€ 123.08		€ 142.37	€ 146.79	€ 144.11
Compact Tug Design	€ 212.88	€ 172.44	€ 279.58	€ 121.93		€ 173.82		€ 201.07	€ 207.32	€ 203.53

Restricted
Known Indicators
PPI's

Validation of Process Performance Indicators for Various Operational Profiles

From Table 41, the process performance indicators for the unknown fuel costs of ASD3110 & Rampart 3200 can be validated, for both operational profiles of Antwerp & GTV area. For the ASD3110, (SMIT BELGIE), the fuel cost per job regarding GTV area, was proven to be equal to 172.96 € (2016). However, this result occurred based on 7 months' sample during 2016, since afterwards the tug was reallocated in the port of Liverpool. However, past company's records for the year of 2013, 2014 & 2015 can provide essential information and at the same time they can validate the trustworthiness levels of the PPI's which are shown in Table 41, regarding the predicted cubic meters to be consumed, based on the number of assistances for each port annually.

The consumed cubic meters for the ASD3110 towards the port of Antwerp during the year of 2013, were proven to be equal to 451,3 m³. If the amount of assistances during 2013, is assumed to be the same with the number of assistances during 2016, (~2370 assistances), with the same operational profile the PPI to occur will be equal to 0.19042 cubic meters per job. Again, by assuming the same amount per cubic meter, (400 €),

the fuel cost will be equal to 76,16877 €/job. The resulted fuel cost is almost identical with the fuel cost in Table 51, which was proven to be for the same area equal to 78,52 €/job.

Moreover, the SMIT BELGIE, for the GTV area for the year of 2015 was proven to consume 383,050 cubic meters. Again, by assuming the same operational profile among the years of 2015 & 2016 in GTV, as well as the same amount of assistances (864 jobs), the PPI is proven to be equal to 0,443344 cubic meters per job. For a fixed price of cubic meter equal to 400 €, the total fuel cost will be equal to 177,337963 € per job. Consequently, the price for this tug type during the year of 2016 is verified to be almost identical compared to the year of 2015.

The last tug type which was also used during 2014 for one year in GTV area, refers to Rampart 3200. The Union Grizzly was confirmed to consume 564,491 cubic meters, while the followed sailing profile was the same compared to the rest tug types in this area. If the same operational profile compared to the rest tug types in this area is considered, as well as the same amount of assistances during 2014 (864 jobs), it is concluded that with a fixed price per cubic meter equal to 400 €, the fuel cost per job for this tug type would be equal to 261,3384 €/job. The resulted cost is almost identical with the cost to be shown in Table 41, which is equal to 252,19 € per job. Consequently, it can be confirmed that the PPI's that were used for all the unknown values of the tug types in the various ports of operations of KST, are characterized from high trustworthiness levels.

KST FLEET - Cubic Meters Per Job Per Port Per Type NL & GHENT

Starting with the ports of the Netherlands & Ghent, the known fuel cost per job for the current situation is clearly indicated in Figure 147. The blue clustered columns show the fuel costs per tug type in the port of Rotterdam, while the bars with the red template shows the fuel costs for the current situation. ASD3213 was proven to be the most expensive tug type for the port of Rotterdam with 238,07 € per job. The second most expensive tug was proven to be the Rampart 3200 with a total fuel cost equal to 192.03 € while ART8032 was proven to have much lower fuel cost price equal to 156.45 €. The lowest tug types were Fairplay and ASD2810, which was proven to be the most efficient tug in the port of Rotterdam.

If it is also taken into consideration the amount of jobs that take place in this port (average in Europoort ~1378), in case where KST is planning to increase the fleet capacity in this port and 60 tons of BP is fulfilling the extra required towage needs, ASD2810 would be ideal, as well as an exceptional option for 24 hours' tug. Moreover, in cases where extra needs of BP are required one efficient solution would be to reallocate one of the ATD's 2412 in Europoort.

On the other hand, Rampart 3200 was proven to be significantly more expensive for this port and hence, one of the scenarios in the tool to be analysed in chapter 9, will evaluate the cost reduction results if any of the tug of this type is reallocated. Additionally, for the Big Cat Class – ASD 3213, even if it was proven to be the most expensive tug type in the port of Rotterdam, KST probably should check the possibilities for reallocating any of these two tugs of this type, due to special contracts with companies, where the minimum towage requirements state that 2x85 tons are required.

However, in the current situation the only two tugs that are capable to fulfil this requirement are, SMIT CHEETAH & SMIT PANTHER. Hence, if company would ever consider proceeding in replacing one of these

two tugs with a tug type with less fuel cost, it is also important that new entry tug would be capable to comply with client needs.

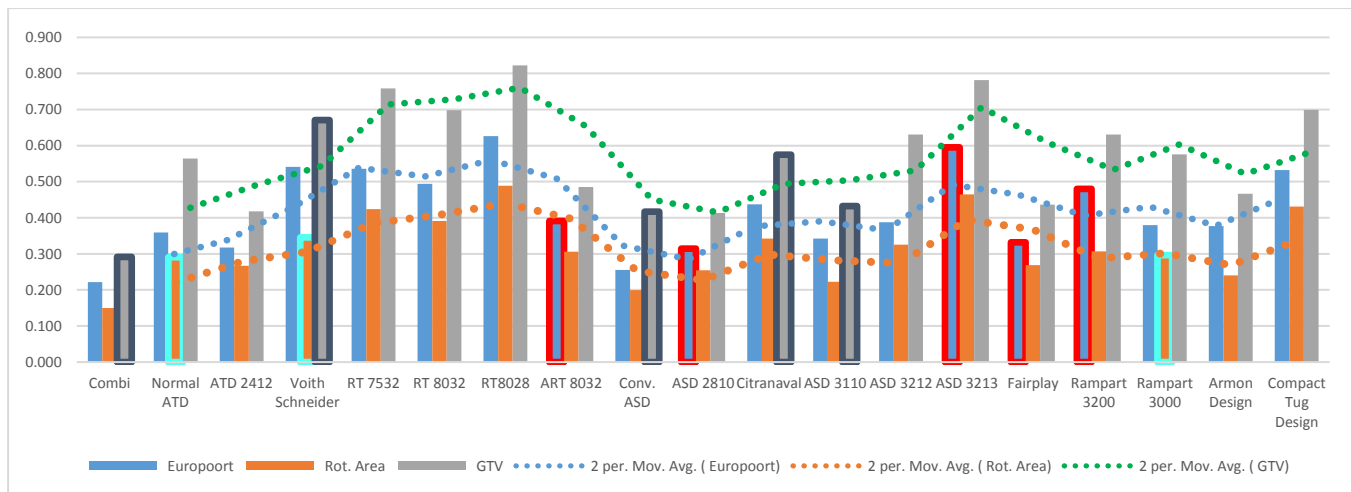


Figure 147: Known & Predicted Cubic Meters Per Job for KST Fleet in NL & Ghent

Figure 148, shows that the only tug type over 85 tons of BP is the Compact Tug Design. However, this type was proven to very efficient in the port of Antwerp and therefore the company should not consider proceeding in this reallocation. For medium range BP tugs, the fuel cost in the port it is expected to be among 0.4 -0.6 cubic meters per job, while Voith's and non-Hybrid Rotors are not considered as an optimum choice for the sailing profile of this port.

For Rotterdam City, Normal ATD & Rampart 3000 were proven to have the lowest fuel cost per job, while the highest cost occurred for Voith's and was equal to 138,25 €/job. For this area, the average BP of the current types is around 50 tons and therefore, if the fleet capacity must be increased, "middle range" azimuth stern drive tugs, in terms of BP would be ideal, as it justified in Figure 149. As far as is concerned the rest tug types to be reallocated in the port of Rotterdam, most Azimuth Stern Drive tugs will have an average fuel consumption equal to 0.3-0.35 cubic meters per job.

Tug with high amount of BP or rotors are not necessary for this area, and therefore should not be considered at all as possible reallocations. Finally, Voith Schneider's are proven to have relatively low fuel cost compared to the rest ports and therefore it would be wise to continue the daily operations in port of Rotterdam, even as 24-hour tugs.

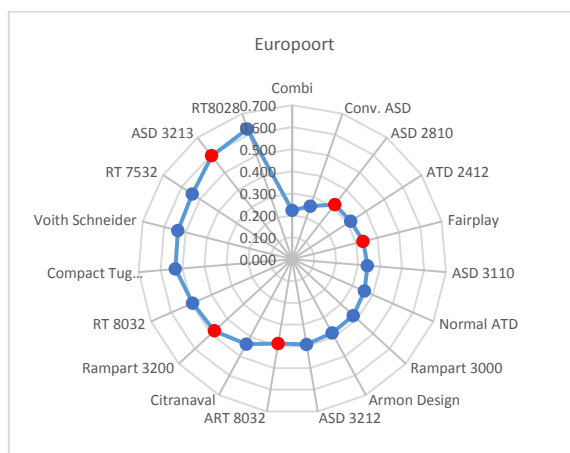


Figure 148: Fuel Radar for KST Fleet in Europoort

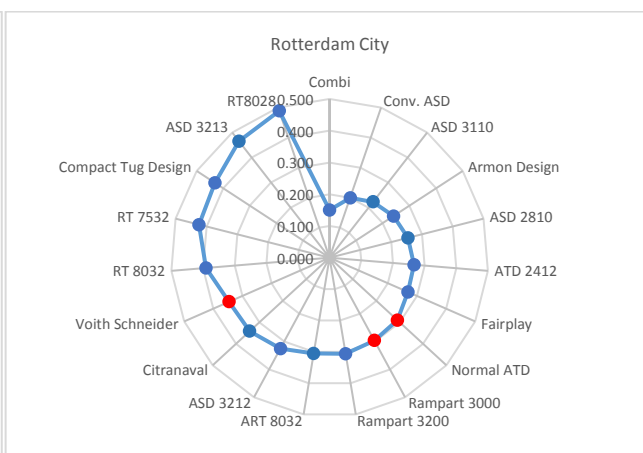


Figure 149: Fuel Radar for KST Fleet in Rotterdam City

For GTV area, the most efficient tug type was proven to be the combi tug. The two conventional tugs are ideal, capable to sail “conventionally” all the way through the canal from Terneuzen to Ghent, with an average fuel cost per job equal to 116.60€. Conventional ASD’s were also proven to have sufficient levels of fuel efficiency, and therefore company should maintain both types in GTV area.

On the other hand, for Citranaal Defcar category, with higher amount of BP, which is required for Terneuzen Lock in cases of assisted vessels with width larger or equal to 32 m, the fuel cost per job was proven to be double, compared to Combi’s, with a cost equal to 229.93 €. For the same amount, ASD2810 would be the most efficient selection of tug type as is it is also proven in Figure 150, with an expected fuel cost per job equal to 165.20 €.

ASD3110 was also proven to be characterized from relatively higher fuel cost levels, equal to 172.96 € per job, while the decision for reallocating this type in Liverpool, led to fuel savings for the company. Finally, the worst efficiency levels refer to Voith’s, (fuel cost: 268.33 €/job). Consequently, KST should re-evaluate the presence of this type in GTV area, due to the large mobilization & demobilisation periods, because of the trips among Terneuzen & Ghent, which also make less efficient the rotor’s presence for this area.

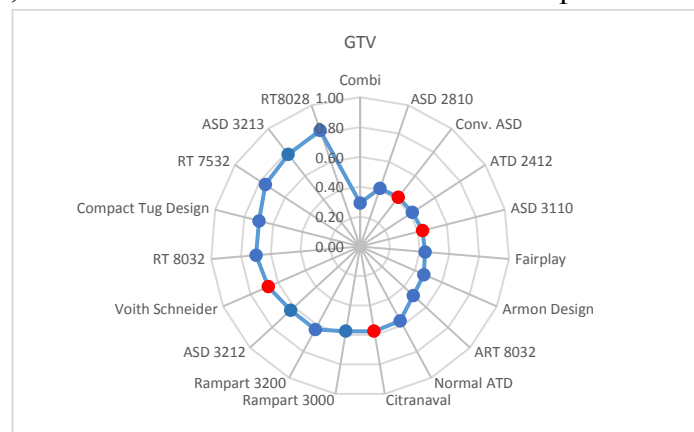


Figure 150: Fuel Radar for KST Fleet in GTV

KST FLEET - Cubic Meters Per Port Per Type BE

The port of Antwerp, together with the port of Hamburg, were proven to be the lowest in terms of fuel cost ports of operation of KST, while every tug type, which is currently located in this port is characterized from a fuel cost lower than 125 € per job, which is also confirmed in Figure 152. The same characteristics refer to the rest tug types for the port of Antwerp, except from rotors which are expected to have an average cost of 150 €/job.

However, rotors should not be considered, simply due to low complexity levels towards the daily operations. Even if the port is characterized from locks, azimuth stern drive tugs match perfectly the daily needs, without requiring tractor tugs with improved effectiveness levels, while the most efficient tug was proven to be the Armon Design with a total fuel cost equal to 86.34 €/job. Based on the same BP category, in case where KST would like to increase the fleet capacity, one of the best solutions would be to select ASD2810, which is expected to have a fuel cost equal to 72.05 €, as it is shown in Figure 151.

Combi tugs are expected to have even lower cost, however they are considered as ideal for the port of Antwerp mainly due to limitation towards Bow to Bow operations, while this type is operating most efficiently in GTV area. One of the most important observation for the port of Antwerp, is substantially lower fuel cost for

Rampart 3200, which belongs again to the middle category of azimuth stern drive tugs. In that perspective, SD SEAL/SD STINGRAY, should be deeply considered for being reallocated in the port of Antwerp from Europort.

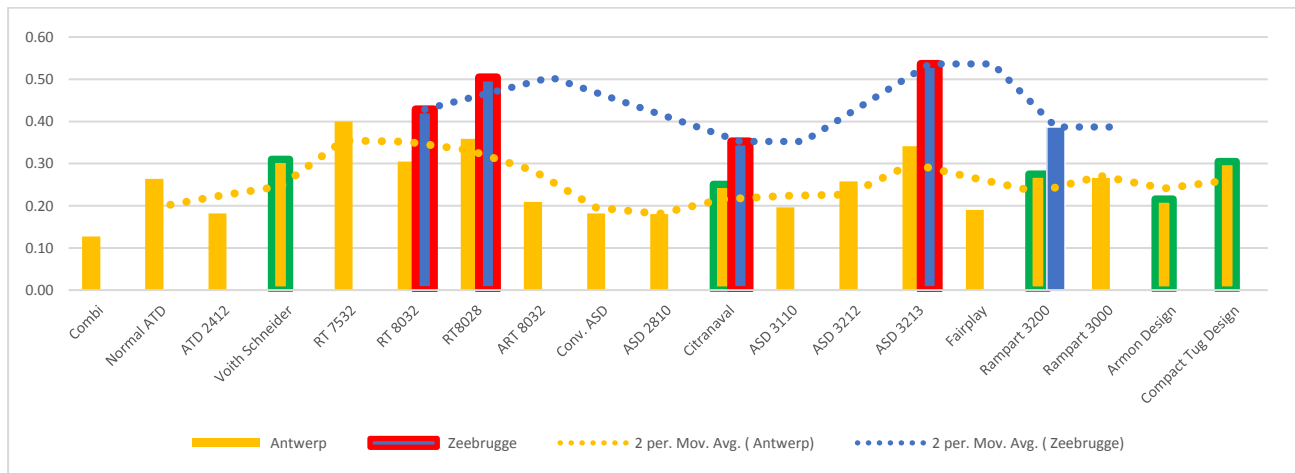


Figure 151: Known & Predicted Cubic Meters Per Job for KST Fleet in BE

For Rampart 3200, the fuel cost for the port of Antwerp was proven to be equal to 109.99€ per job, while the same type in Europort had a cost equal to 192,93 € per job. Furthermore, Voith Schneider's for this port have similar costs with Rotterdam Area, and meaningfully less compared to GTV. Finally, Compact Tug Design Types were proven to have the highest fuel cost per job as a result of the 86 tons of BP. Both tugs from this type, should continue to operate in this port due to the considerably low fuel cost which was proven to be equal to 121,93 € per job.

For the port of Zeebrugge, the total of the tug types which are capable to sail there are already known in terms in fuel cost, except from Rampart 3200. In case that Rampart 3200 is reallocated to this port, is expected to have an average fuel cost equal to 154,63 € per job, which is close to Citranaval Defcar costs. For Citranaval Defcar, the fuel cost per job was proven to be the lowest among all the types, and 40 € more per job compared to Antwerp. At the same time, reasonable values occurred for the two rotor types with average fuel cost per job equal to 200 € per job. On the other hand, ASD3213 was also verified to be the most expensive type with a cost equal to 214.51 € per job.

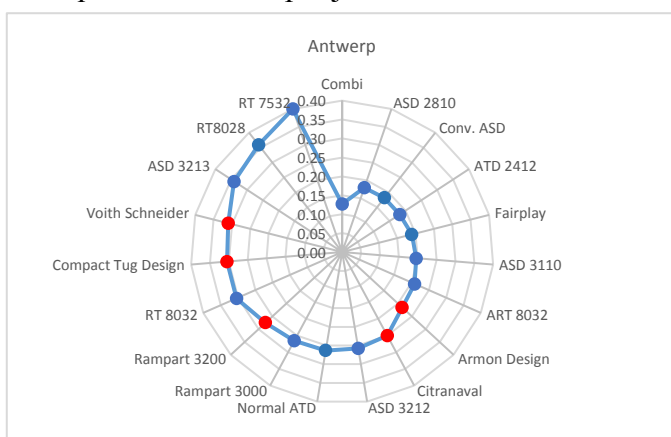


Figure 152: Fuel Radar for KST Fleet in Antwerp

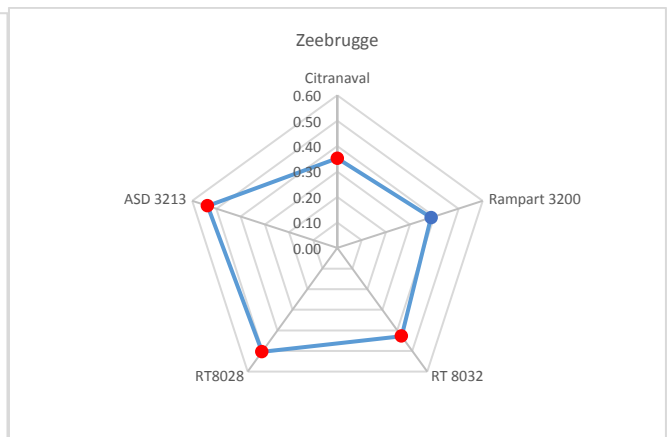


Figure 153: Fuel Radar for KST Fleet in Zeebrugge

KST FLEET - Cubic Meters Per Port Per Type GE

For the port of Hamburg, the state of art tug types was proven to be ATD 2412 and ASD2810 with almost identical fuel costs equal to 103.79 € & 102.71 € per job respectively. Normal ATD was proven to be slightly more expensive, while ASD3212 was verified to be also efficient with a fuel cost equal to 126.57 € per job. In cases where KST reallocate a rotor in the port of Hamburg, the average fuel cost is expected to have a cost equal to 170 €/job, while in cases that tugs with higher amount of BP are required i.e. ASD3213, the average cost is expected to be 190 €/job, as it is shown in Figure 155. However, there is no any actual reason for reallocating any of the rotors in this port, due to the low complexity levels without locks presence or narrow passages with confined areas.

Moreover, SD Dolphin in terms of BP is fulfilling adequately the needs for braking assistances as a stern tug, as well as towards the escorting needs for the port of Hamburg, while together with its escort notation, is capable to offer escorting duties continuously.

For the port of Bremerhaven, the most efficient tug type was proven to be the ATD 2412, with a fuel cost equal to 130.08 €/job. This tug type proved its high effectiveness levels during the complex needs of the car carriers in the locks of Bremerhaven, while even if it suffered from high stand-by towline connection times inside the locks, its fuel efficiency was maintained in tremendously high levels. Even if this tug type is reallocated, it is considered as one of the most efficient selections in case that KST decides to increase its fleet capacity.

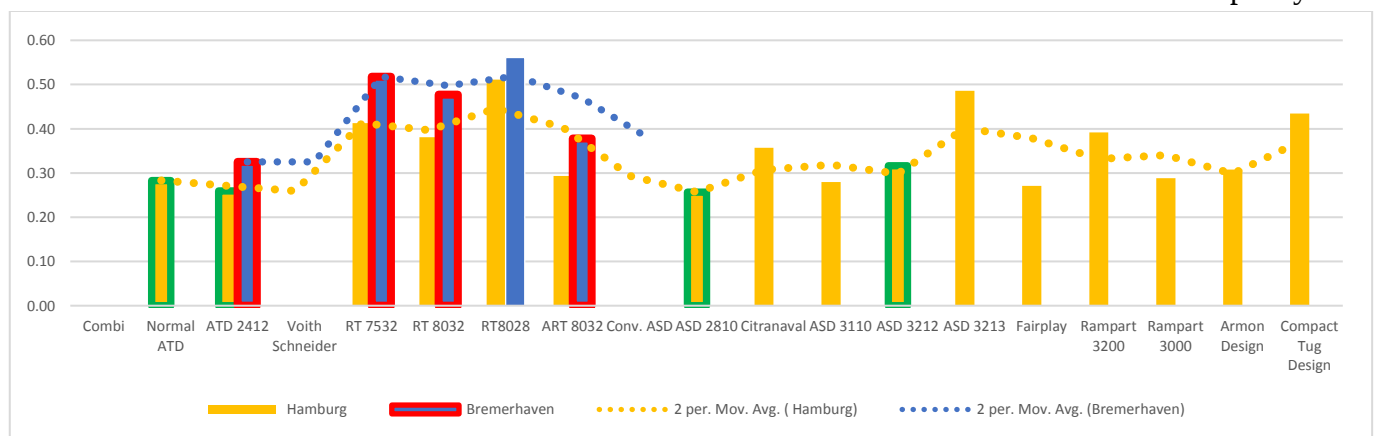


Figure 154: Known & Predicted Cubic Meters Per Job for KST Fleet in GE

Figure 156 also shows that the hybrid technology of RT Emotion fits entirely the complex needs of this port. RT Emotion (ART 8032) was characterized from a cost equal to 151.09 € per job, while due to the port configuration and efficient dispatch planning, this tug type is capable to use in the most efficient way its hybrid technology by using IDLE or TRANSIT ½ during mobilization & demobilization, as well as during the stand-by times inside locks. Consequently, one possible scenario could be the reallocation of RT Evolution in the port of Bremerhaven.

Finally, the rotor types, RT7532 & RT8032, were proven to have 17 € variance, while the fuel cost for RT8032 was 190.77€/job. Figure 156, shows that the only tug type which could sail in the port of Bremerhaven except from the types of the current situation is RT8028. The cost for this type is expected to be 35 € more per job. Additionally, this reallocation should never be considered from KST, since both tugs of RT8028, consist of FiFi 1 notation and therefore their presence is mandatory due to LNG terminal in the port of Zeebrugge.

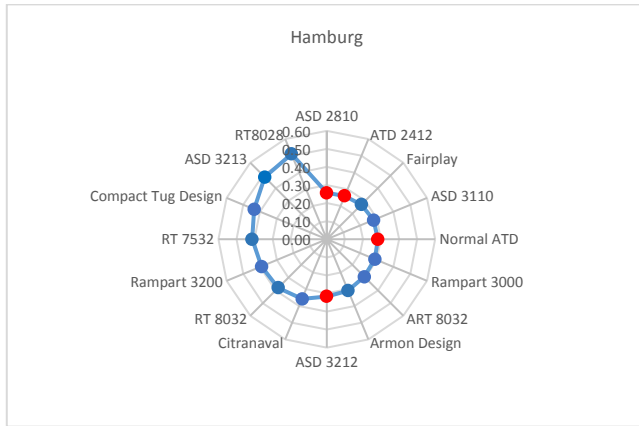


Figure 155: Fuel Radar for KST Fleet in Hamburg

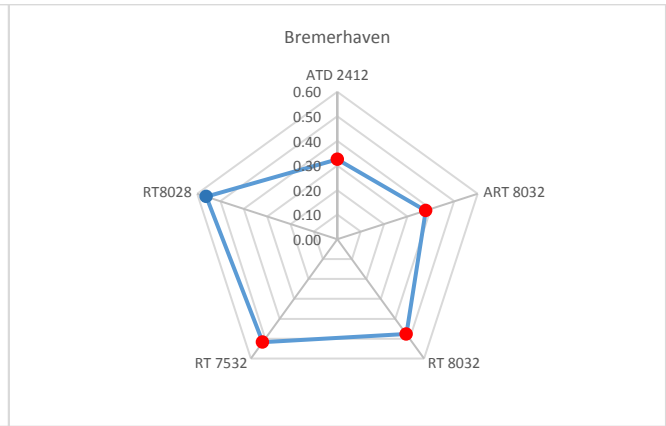


Figure 156: Fuel Radar for KST Fleet in Bremerhaven

KST FLEET - Cubic Meters Per Port Per Type UK

The port of Liverpool was characterized from high levels of fuel costs for the current tug types, while due to complexity of this port, special attention is required for all the possible reallocations. The small locks, in combination with narrow passages and confined areas lead to high fuel costs even for the tug types which were proven to be significantly lower in ports with lower levels of stand-by times, without the presence of locks or other confined areas.

Starting with ASD2810, Table 50 shows that it is less efficient by 13 %, with a total cost equal to 145.36 € per job, while the tug with less cost was the ZEEBRUGGE which belongs to Conventional ASD's, with a cost equal to 118,07 €. Middle ranges ASD's as SMIT BELGIE (ASD3110), were proven to have less costs compared to GTV, while the most expensive type once again is the Voith Schneider with fuel cost equal to 184.49 €/job.

Rotor tugs should not be considered as an efficient alternative, since Figure 158, shows that they are expected to consist from average costs from costs higher than 230 €/job. Moreover, KST should consider maintaining a fleet with medium range of BP in the port of Liverpool, due to smaller size of vessels compared to Europort or Antwerp. In the port of Liverpool, a tug with maximum BP amount of 60 to 65 tons would be totally capable to fulfill the required harbor towage duties.

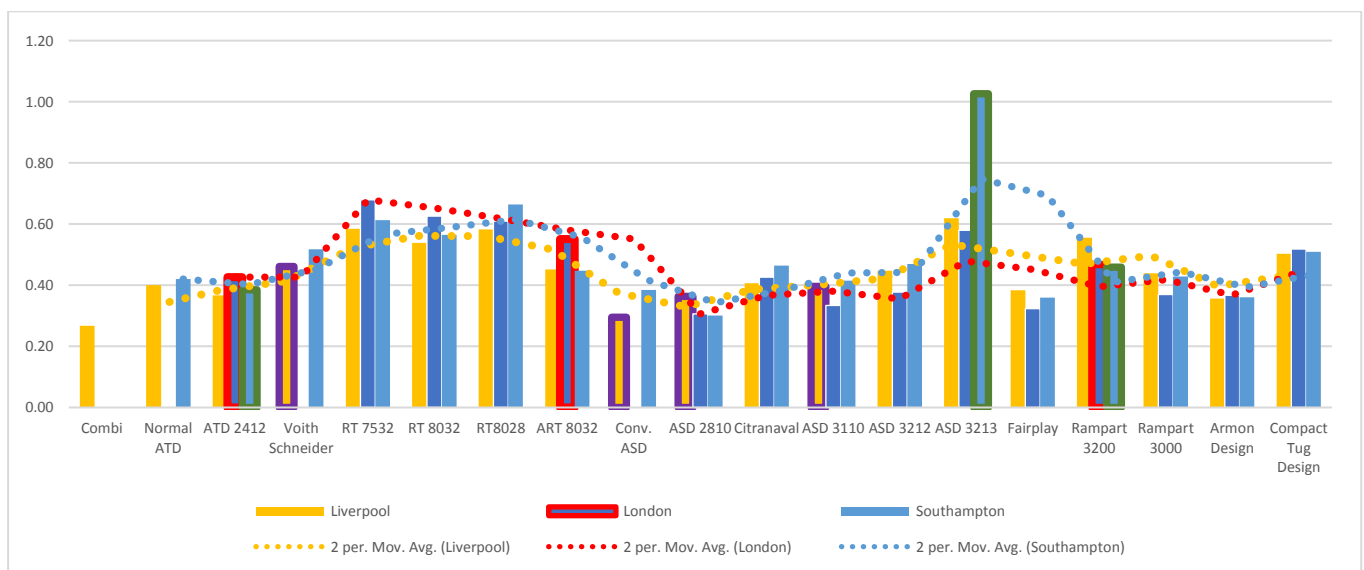


Figure 157: Known & Predicted Cubic Meters Per Job for KST Fleet in UK

For the port of London, only three tug types are known as it is indicated in Figure 159. The type with the less fuel cost was ATD2412, with a cost equal to 170.71€ per job, while slightly more expensive was confirmed to be SD Shark (Rampart 3200) with a cost equal to 187.01 € per job. On the other hand, the reallocation of RT Evolution, ART8032, was proven to be 40,8 % compared to the cost of this type in Europoort and by 45,8 % compared to cost of RT Emotion in Bremerhaven, as it is shown in Table 51. The main reason for this high cost, is related with the unavailability for this type to make efficient use of its hybrid technology, due to the high speed of current in Thames river.

Additionally, based on tug master's insights, in cases of assistances with short mobilization distances, the hybrid advantages of this tug will not be used at all, and eventually the tug will operate as a pure conventional tug. The combination of the pre-mentioned reasons eventually led to a fuel cost for the RT Evolution to be equal to 220.32 €/job.

Moreover, Figure 159 also proves that from the entire fleet of KST, the ATD2412 is proven to be one of the most efficient while ASD2810 is expected to be the most efficient it terms of fuel cost. However, based on the flexibility of KST in the port of London, two rotors are required especially during spring and summer period, for assisting cruise ships in Thames Barriers. Therefore, the company should consider reallocating the hybrid rotor tug to a port which would allow to make use of its hybrid technology, with larger amount of jobs, for achieving higher cost reduction.

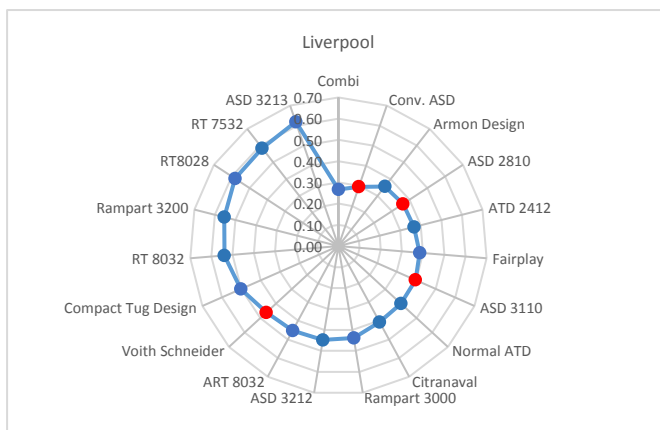


Figure 158: Fuel Radar for KST Fleet in Liverpool

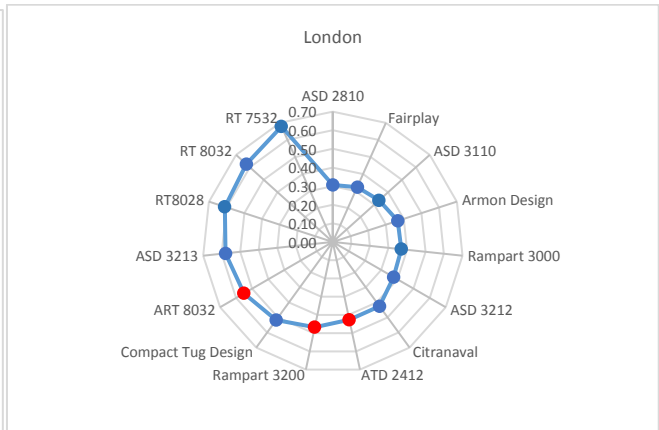


Figure 159: Fuel Radar for KST Fleet in London

Finally, the last port to be discussed is the new entry port of Southampton. Since the company started operating in this port last April, the period for assessing the fuel cost analysis of the tugs is relatively small. Therefore, the results in Figure 160, are only capable to provide an indication of tugs fuel cost analysis for the three different tug types which were selected to operate in the new entry port.

Starting with the ATD2412, its fuel cost was verified to be the lowest and was equal to 154 €/job. Based on Table 50, the fuel cost of this tug type was improved by 10,9%, compared to London, and 32,6% worse than Hamburg. The second tug type, Rampart 3200 was characterized from highest fuel cost equal to 183.59 €, which is 5% less, compared to the same type in Europoort, and 40.1% more in the port of Antwerp.

On the other hand, Figure 160 shows a tremendously high variance among the two pre-mentioned tug types and ASD3213. Based on the retrieved data regarding the amount of jobs & consumed cubic meters for the period of April/May, SMIT TIGER was proven to be by far expensive. The tug was involved multiple times in escorting duties, each with a total duration of 6 hours, while several other assistances had an average

duration of 3 hours, leading to high levels of fuel consumption. The high result of this tug type is one extra proof, that continuous fuel monitoring in combination with the speed per activity is required for defining properly the distributions of fuel consumption. At the same time, it is evident that human factor in towage industry is probably one of the major factor for a solid evaluation in terms of fuel cost per tug type for each port.

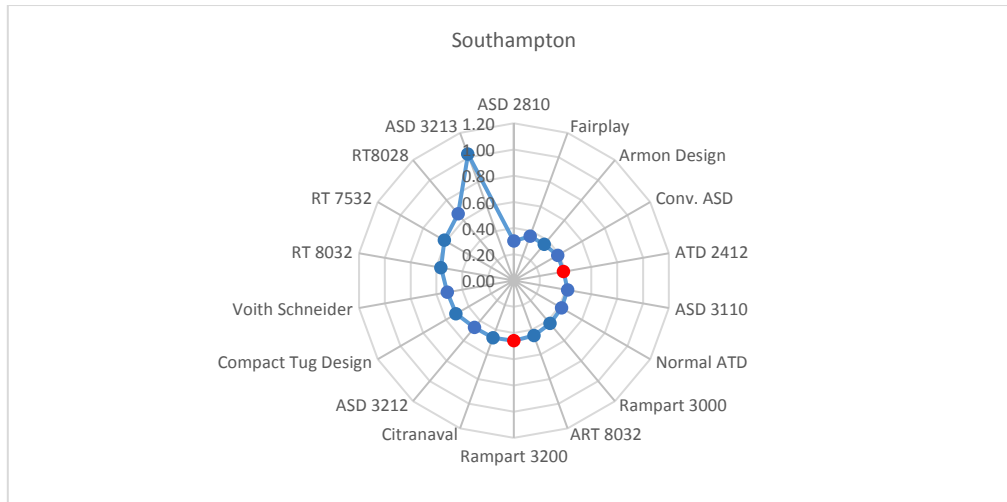


Figure 160: Fuel Radar for KST Fleet in Southampton

7.8 Chapter Conclusion

The subject of this chapter was to establish the method to be followed for providing a trustworthy indication towards the costs for KST fleet in the various ports. This part of the thesis will be used for the tool function, which is analyzed in chapter 8, offering the ability to the user for assessing all the possible tugs combinations to occur. The user will be able to verify and compare not only the effectiveness of the selected tugs, but at the same time the costs per job for each simulated scenario. Since the focus for the expenses to occur through the tool, refer exclusively to fuel costs, tool's main goal, is to indicate which tug types combination is characterized from the highest effectiveness level, together with the lowest fuel cost regarding the amount of assistances per port.

During this project, it was not possible to monitor the speed of its tug type per job for each area and for the entire year of 2016. Moreover, the correlation of fuel consumption graphs for all the tug types, in a range of speed, requires significant amount of time, while for providing a good approximation on the fuel costs, process performance indicators were used, for approaching a fair indication of the fuel distribution based on the activities per tug type. After establishing the variances among each tug type, the goal was to assess the fuel cost per port, as a result of the selected tug types in each region, while Figure 135, was used for assessing the operational profile of the selected tugs. The tug types with the lowest fuel costs per job were discussed, while the comparison among the same tug types in several ports, proved the most optimum port of operation for achieving the highest fuel savings.

The tug type Rampart 3200, was proven to operate more efficiently in Antwerp, compared to Europoort, while higher fuel costs occurred in London & Southampton, as a result of the mobilization and demobilization times. On the other hand, ASD2810 was proven to operate most efficiently in Hamburg, while this type has the lowest fuel cost in Europoort. This type was also proven to be very efficient in Liverpool, which is characterized from an average towline connection equal to 1,85 hours. For ASD 3213, it was proven to be the most expensive tug in Europoort, with a slightly better performance in the port of Zeebrugge, because of the 3% less mobilization

and demobilization time, while for the port of Southampton, it suffered from significantly higher fuel consumption. Regarding tractors, Voith Schneider's were proven to have the lowest fuel cost in the port of Antwerp, while slightly higher costs occurred in Rotterdam Area. On the other hand, high costs occurred in GTV, due to the long transit routes among Terneuzen & Ghent. Among rotors, RT8032 was proven to have significantly lower fuel cost in the port of Zeebrugge compared to Bremerhaven, as a result of the various locks configurations and operational profile. Moreover, ATD 2412 had the lowest fuel cost per job in Hamburg, and the highest cost in the port of London, mainly due to the high levels of Mob/Demob times in the Thames river.

The strategy that was followed, for estimating the fuel costs for the entire fleet of KST, among the various ports, was related with several process performance indicators that were used based in analogous estimations. The presence of the same tug types among some ports, provided high of importance output, for establishing several metrics. These metrics offered the ability to define the benchmarks, since it was clear to define which tug was proven to be the most efficient during the tugs allocation for 2016; PPI's offered also the ability to gain a solid average estimation, towards the predicted fuel cost of each tug in each port.

Even if the indicators that are used are not capable to provide 100 % accurate results, still they are capable to provide fair good approximation, while due to the tremendously high impact of human factor, the trustworthiness level of the predicted indicators will be evaluated under various uncertainty percentage levels (sensitivity analysis) in chapter 9. In any case that the user would like to increase or decrease the uncertainty levels of the PPI's, through various simulations, he will be capable to make his own selections, by defining the desired uncertainty level, which is analysed in subchapter 9.2.

The next chapter aims to establish the new tool of KST for assessing the operational profile of the entire fleet, for defining the optimum tugs combination for each port, capable to guarantee high effectiveness results, together with the lowest fuel costs per job, under multiple scenarios. The sophisticated tool was established though excel while the following chapter aims to determine its main coefficients, as well as the procedure that is followed for simulating one scenario. The results towards several swaps to occur after multiple simulation will be discussed in chapter 9.

8

KST Fleet Assessment Tool

This chapter aims to assess the effectiveness results and the resulted variances as well as the fuel costs for the selected tugs in various ports, under multiple scenarios. Therefore, a well-established tool through excel, aims to confirm the optimum tug reallocations in the ports of operations of KST, for achieving both high levels of effectiveness, together with the lowest fuel costs per assistance, based on the amount of assistances that take place at each port, under all the possible scenarios to be decided from each user perspective. Moreover, this chapter aims to define the main coefficients of the tool, while afterwards four scenarios are simulated for determining the optimum tug combinations for all the ports of operations of KST.

8.1 Tool Overview

The scenarios simulation through the tool regarding KST fleet should take place in a user-friendly environment. For this reason, the tool is built in a way that allows the user, to have a solid overview in total for all the ports of operations of KST and all the possible tugs to be selected, as it is shown in the main commands window in Figure 161.

The first to be mentioned denotes the selections for each port. The capacity for each area occurs after a long discussion among the operations managers in KST, for making sure that the fleet capacity for each area is satisfying client's needs, offering at the same time the highest flexibility levels without violating the restrictions and regulations of each case. Therefore, the number of tugs to be selected through the tool is predefined, while this number is possible to be increased or decreased at a later phase, without requiring significant amount of time.

The demonstration of proceeding in a scenario simulation, will start from Europoort. The user is capable to select each tug through a list, while this list shows directly in alphabetical order all the available tugs. The list is built in a way, where after checking if the main characteristics of each of the KST tugs comply with the restrictions & regulations of each area, then the tug is saved, and eventually the tugs which are capable to sail are clearly indicated. Figure 161, shows all the tugs which are selected for all the ports of operations of KST, based on the current situation.

For Europoort, the first tug which is selected is SD SEAL. The user by clicking on the button for selecting the first tug in Europoort (except SD SEAL, which is already selected) can scroll down and select a new tug, based on his preferences. In any case, where the user selects a tug which is already selected in another port, the establishment of conditional formatting of the tool will show with purple colour that this selection cannot proceed, since the same tug has been selected twice. The same procedure must take place for all the ports of operations, for defining the tugs to be selected for each case; when the selections are made, the user is then

capable to save his selection as a new scenario in the “New Scenario Name”, by clicking manually the Save New button. Additionally, if the user wants to clear automatically all the fields for each port, he can just click on “Clear Input” button, and the macro will automatically erase all the information for each port.

After all the new scenarios are established, the user is also capable to retrieve the information from any of the pre-saved scenarios. Therefore, by clicking on the “Change Scenario”, a list will appear with all the saved scenarios. The user is then capable to click on any of the saved scenarios, and afterwards by clicking on the button “Load”, the desired scenario will be automatically loaded. This button is tremendously important, in cases where users are willing to proceed in some modifications towards the saved scenarios, by making alternative swaps among tugs & ports. After all the changes are done, the user is then capable to click on the button “Overwrite” and save again the same scenario with the same or different name but this time with the new selections.

Finally, the user is capable to load an old scenario and in any case, he would like to delete it, then by clicking on “Delete” button, the tool asks confirmation for proceeding to the requested action. If the user clicks on “YES” button, then the loaded scenario is deleted permanently. The tool is made in a way that each user is capable to generate unlimited new scenarios and proceed in various modifications in old scenarios continuously. Afterwards, as it will be explained later in this subchapter the user is capable to compare the decisions for each scenario for verifying which of all the simulated scenarios fits in the most efficient way to the daily operations of KST.

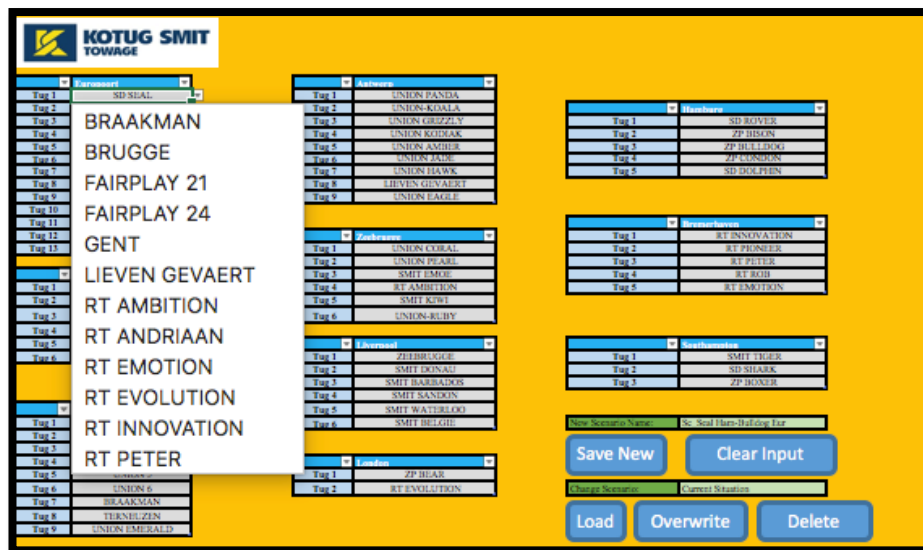


Figure 161: Tool interface

As soon as the user proceeds on the desired tugs selections for each port, he is then capable to verify the flexibility of his selections for all the ports of KST. After defining the regulations/requirements for each port, for determining tug's availability to sail or not, the tool also shows the flexibility of the selected tugs for each scenario for evaluating tugs combinations, for each of the established scenarios.

One main advantage of the sophisticated tool is shown in Figure 162, and indicates if the tugs selection for each scenario complies with the maximum requirements per port. For example, in the port of Zeebrugge the main rule to be evaluated is related with the total amount of BP regarding the tugs to be selected. Even if the user, can select only tugs equal or larger than 60 tons of BP, all with FiFi 1 notation, it is also crucial to verify

Afterwards the operations managers can take the decision for reallocating a tug in a port which might decrease partially the flexibility in cases where specific merchant vessels require harbor assistance under adverse environmental conditions. Therefore, KST should re-consider to re-allocate a tug in cases where some rules are violated rarely within a year, and substantial fuel savings can occur. On the other hand, for cases where the combination of tugs in this port is not capable to offer towage assistances under every possible scenario, the company can compare the fuel savings, together with the charter costs for hiring a tug from a competitor. For this reason, it is high of importance to evaluate the tug's selections, and therefore the percentage of flexibility for each port, for determining the most optimum scenario.

Figure 162: Flexibility Control Panel

Group A: Car Carriers - Containers										Group B: Bulk Carriers - Tankers															
SO SEAL		SO STRIMURY		FAIRPLAY 21		FAIRPLAY 24		SMIT ELBE		SMIT SCHELDE		SMIT TENIC		SMIT PANTHER		SMIT ERDO		AT AMBACHAN		SMIT CHESTAN		SMIT HUDSON		SO REBEL	
ETL Group A	87.45		82.45		76.75		76.75		73.55		73.55		73.45		63.55		73.45		82.45		83.45		73.45		73.45
ETL Group B	87.45		82.45		76.75		76.75		73.55		73.55		73.45		63.55		73.45		82.45		83.45		73.45		73.45
Localship	1152.03		1152.03		1152.79		1152.79		1125.79		1125.79		1125.79		62.38.07		1125.79		1156.45		62.38.07		1125.79		1125.79
SHAN SHAN		UNION 7		UNION 7		UNION 7		UNION 5		UNION 5		UNION 5		UNION 5		UNION 5		UNION 5		UNION 5		UNION 5		UNION 5	
ETL Group A	73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55
ETL Group B	73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55
Localship	73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55
UNION 8		AT ANNASTASIA		UNION 8		UNION 8		UNION 5		UNION 5		UNION 5		UNION 5		UNION 5		UNION 5		UNION 5		UNION 5		UNION 5	
ETL Group A	73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55
ETL Group B	73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55
Localship	73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55
UNION PANDA		UNION KIDDA		UNION KIDDA		UNION KIDDA		UNION KIDDA		UNION KIDDA		UNION KIDDA		UNION KIDDA		UNION KIDDA		UNION KIDDA		UNION KIDDA		UNION KIDDA		UNION KIDDA	
ETL Group A	73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55
ETL Group B	73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55
Localship	73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55
UNION CATAL		UNION FLEET		UNION FLEET		UNION FLEET		UNION FLEET		UNION FLEET		UNION FLEET		UNION FLEET		UNION FLEET		UNION FLEET		UNION FLEET		UNION FLEET		UNION FLEET	
ETL Group A	73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55
ETL Group B	73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55		73.55
Localship	73.55																								

169

At this point, and after the main selections for the current scenario are made, the user is now capable to have a solid summary of the total effectiveness results of the selected tugs per port, as well as the total amount of fuel costs for the selections of this scenario. Figure 164, shows the effectiveness results for each port for both groups of the vessels to be assisted. The results for both groups occurred from the average of the effectiveness results from the selected tugs, while the fuel cost per port is the total amount of costs that KST will pay for the selected tugs per assistance. It is evident that the amount of fuel cost is entirely dependent from the type of tugs to be selected, as well as from the number of tugs for each area.

Figure 164: Current Scenario Dashboard

KST Overview Of Operations			
Europoort			
Eff: Group A	☐	79.4%	
Eff: Group B	☐	78.5%	
EuroJob			12,036.95
Rotterdam Area			
Eff: Group A	☐	69.1%	
Eff: Group B	☐	69.1%	
EuroJob			1743.89
GTV			
Eff: Group A	☐	66.1%	
Eff: Group B	☐	66.0%	
EuroJob			11,565.34
Antwerp			
Eff: Group A	☐	71.8%	
Eff: Group B	☐	72.0%	
EuroJob			1980.52
Zeebrugge			
Eff: Group A	☐	82.1%	
Eff: Group B	☐	82.0%	
EuroJob			1997.58
Hamburg			
Eff: Group A	☐	79.9%	
Eff: Group B	☐	78.7%	
EuroJob			1550.04
Bremerhaven			
Eff: Group A	☐	94.1%	
Eff: Group B	☐	94.0%	
EuroJob			1946.72
Liverpool			
Eff: Group A	☐	70.2%	
Eff: Group B	☐	70.1%	
EuroJob			1936.17
London			
Eff: Group A	☐	88.9%	
Eff: Group B	☐	87.7%	
EuroJob			1391.03
Southampton			
Eff: Group A	☐	83.4%	
Eff: Group B	☐	82.8%	
EuroJob			1748.12

However, the tool should be constructed in such a way for offering a general overview and comparison among the multiple scenarios. The main objective of KST was to come up with a tool entirely capable to achieve cost reduction and therefore it was more than required to show the total amount of costs for all the simulated scenarios, for comparing the consequences among each scenario and hence the reduction or increase of the costs.

Figure 165, shows the final overview for all scenarios which are created from the user. In a separate sheet in the tool, with the name “PVT”, the user is capable to have the general overview of all the selections which were made under the various scenarios. At the top left side, all the ports are indicated, while by clicking on each port, the selected tugs are shown, while on the top of the table, the row with the yellow line shows the exact results for each scenario concerning the effectiveness results & fuel costs for each scenario. The graphs show in detail the effectiveness results for each port and for the selected tugs (blue clustered column for Group A & orange clustered columns for Group B). Therefore, the user is capable to check and evaluate the variances for each case as a result of the various tug’s selections.

At the end of each scenario and after all the ports are shown, the total number of fuel costs will occur. The result has occurred after retrieving the average number of jobs, based on 2016 database per port, and by assuming that the price per cubic meter per port is fixed and equal to 400 €. However, the price per cubic meter and per area, is possible to vary considerably, and therefore, the user is also capable to alter the cubic meter price for every port, for proceeding in the desired scenarios simulation. However, for the scope of this project it is assumed that the prices remain the same in order to have a solid assessment for all the possible tug selection, with the same criteria.

Finally, the user is capable to check the results regarding the total fuel costs for all the simulated scenarios in the figure with the grey background, as it is shown in Figure 165. In this case, the blue clustered column shows the result for the current situation while all the rest columns, show the final fuel costs for the rest simulated scenarios.

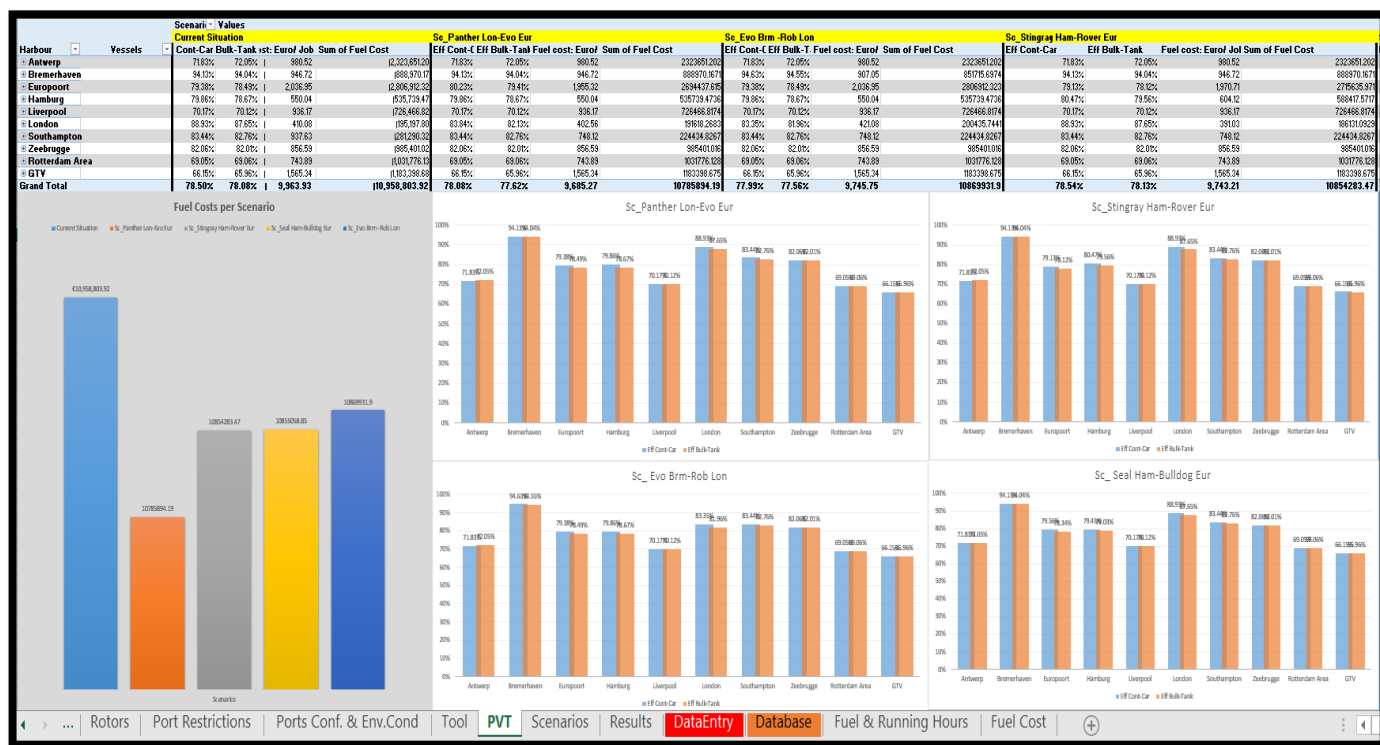


Figure 165: Final Overview Dashboard of all Loaded Scenarios

8.2 Tool Analysis Coefficients

As it shown in Figure 166, four main coefficients are established in the tool, for measuring the effectiveness results for each selected tug, as well as the total fuel costs for each simulated scenario. The first part (KST Fleet Effectiveness), refers to the daily operations as it was explained extensively in subchapters 3.6 & 4.3. The results for each tug and for each possible type of operation are directly sustained in the DATA ENTRY sheet. The effectiveness results for each tug type vary, as a result of the resulted types of operations for each category, with the maximum number to be in total equal to 8.

The first four results refer to Group A Towline Connection types of operations (Bow to Bow, Bow to Stern, Stern to Bow & Stern to Stern), while the rest four results refers also to the same possible types of operations and this time for Group B. This information is then aligned with the second part of Figure 166, (Ports of Operations), as a result of the port configuration and the related market trends, which were established in chapter 5, and hence the effectiveness results for each tug will be again stored in the DATA ENTRY sheet.

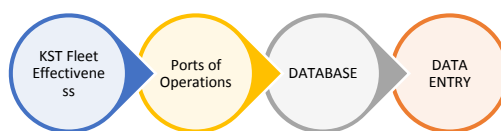


Figure 166: Tool Analysis Coefficients

The effectiveness results for each tug and for each port will vary, based on the port configuration, consisting from locks and their dimensions, as well as from confined areas and narrows passages, while the role of environmental conditions is also crucial. This explains adequately the reason that AHP method is used to align the user tug selection with the desired port of operation under numerous scenarios. However, the number of criteria among the twelve ports of operations varies, and therefore the weight factors concerning the

effectiveness of tugs will also vary. Finally, the last part of Figure 166, DATABASE, refers to a general matrix which summarizes the tugs names, which are capable to sail in each port after all the related towage restrictions & regulations are analysed.

8.3 KST Tool Framework Analysis

After the main four coefficients are discussed during sub-chapter 8.2, this subchapter evaluates the core of the tool, for retrieving, calculating and providing in the most user-friendly way the results for all the possible simulated scenarios. The first complexity for the construction of a sophisticated tool was related with the various criteria for each port, while the tool should be smart enough, for recognizing on which port each tug was assigned, and therefore to retrieve the information for the resulted criteria and for each case.

			Tug Portfolio		
Port	Tug List	Tug Name	BP	Model	Type
Europoort	Tug 1	SD SEAL	65.26	ASD	Rampart 3200
Europoort	Tug 2	SD STINGRAY	65.26	ASD	Rampart 3200
Europoort	Tug 3	FAIRPLAY 21	55	ASD	Aarts Marine
Europoort	Tug 4	FAIRPLAY 24	55	ASD	Aarts Marine
Europoort	Tug 5	SMIT ELBE	57	ASD	ASD 2810
Europoort	Tug 6	SMIT SCHELDE	59	ASD	ASD 2810
Europoort	Tug 7	SMIT SEINE	60	ASD	ASD 2810
Europoort	Tug 8	SMIT PANTHER	95	ASD	ASD 3213
Europoort	Tug 9	SMIT EBRO	60	ASD	ASD 2810
Europoort	Tug 10	RT ANDRIAAN	84	Rotor	RT 8032
Europoort	Tug 11	SMIT CHEETAH	95	ASD	ASD 3213
Europoort	Tug 12	SMIT HUDSON	60	ASD	ASD 2810
Europoort	Tug 13	SD REBEL	60	ASD	ASD 2810
Rotterdam Area	Tug 1	THAMESBANK	45	ATD	Normal ATD
Rotterdam Area	Tug 2	UNION 11	45	Voith	Voith Schneider
Rotterdam Area	Tug 3	UNION 7	45	Voith	Voith Schneider
Rotterdam Area	Tug 4	SD JACOBA	52	ASD	Rampart 3000
Rotterdam Area	Tug 5	ZP CHALONE	45	ATD	Normal ATD
Rotterdam Area	Tug 6	TEXELBANK	45	ATD	Normal ATD

Figure 167: Index & Match of Tug Portfolio

The second complexity of the tool was referring to the recognition of the selected tugs from user perspective, which would be totally different during the implementation of the various scenarios. Hence, the tool should identify and then match the selected tugs for each port. After the recognitions are established, the tool should then retrieve the effectiveness results for all the selected tugs, with their correspondent ports, as a result of the specific port configurations for each case.

Figure 167, indicates how the information is retrieved for the port of Rotterdam, regarding both areas of Europoort and Rotterdam City. In the “Tug Name” column, the selected tugs are automatically saved based on user selections from the general commands center, which is shown in Figure 161. The same situation will then take place also for columns “BP”, “Model” & “Type”. Based on tug’s name, which is selected from the user, the tool communicates automatically with its “DATAENTRY” sheet, and retrieve the related information concerning the bollard pull, the model, and type of the selected tug.

The type as well as the model of each tug are necessary for the conditional formatting which is shown in Figure 162. For example, in case of London, the tool should check if at least two of the selected tugs are Rotors, for verifying if the user’s selections comply or violate KST established rules for this port. Afterwards the tool should be capable to retrieve the rest information regarding the towline effectiveness results for each tug, and for both group of vessels to be assisted.

Towline Connection						
Group A				Group B		
Towline.B-T-B-Group A	Towline.B-T-S-Group	Towline.S-T-B-Group	Towline.S-T-S-Group A	Towline.B-T-B-Group B	Towline.B-T-S-Group B	Towline.S-T-B-Group B
88.7%	N/A	82.7%	N/A	88.7%	N/A	86.0%
88.7%	N/A	82.7%	N/A	88.7%	N/A	86.0%
73.0%	N/A	72.0%	N/A	63.0%	N/A	68.5%
73.0%	N/A	72.0%	N/A	63.0%	N/A	68.5%
82.0%	81.1%	81.1%	N/A	82.0%	81.0%	81.1%
82.0%	81.1%	81.1%	N/A	82.0%	81.0%	81.1%
82.0%	81.1%	81.1%	N/A	82.0%	81.0%	81.1%
88.3%	80.3%	90.0%	N/A	88.3%	78.7%	88.3%
82.0%	81.1%	81.1%	N/A	82.0%	81.0%	81.1%
N/A	84.3%	80.2%	77.8%	N/A	84.3%	79.8%
88.3%	80.3%	90.0%	N/A	88.3%	78.7%	88.3%
82.0%	81.1%	81.1%	N/A	82.0%	81.0%	81.1%
82.0%	81.1%	81.1%	N/A	82.0%	81.0%	81.1%
N/A	76.0%	N/A	59.3%	N/A	76.0%	N/A
N/A	71.5%	N/A	59.3%	N/A	70.3%	N/A
N/A	71.5%	N/A	59.3%	N/A	70.3%	N/A
70.0%	N/A	81.0%	N/A	70.0%	N/A	81.0%
N/A	76.0%	N/A	59.3%	N/A	76.0%	N/A
N/A	76.0%	N/A	59.3%	N/A	76.0%	N/A

Figure 168: Index & Match effectiveness results of selected tugs Part A

The tool based on the tug name recognition, which has already occurred and shown in Figure 167, is then capable to retrieve all the rest linked information for the selected tug. For this reason, as it is shown for example for the first tug in Europoort in Figure 168, (“SD SEAL”), the information to be retrieved indicate 88,7% effectiveness result for Bow-to-Bow operation regarding Group A, and 82,7 % for Stern to Bow Operation towards Group B. For Bow to Stern & Stern to Stern types of operations, the tool provides as an answer “N/A”, since this tug is not capable to offer these two types of operations, and therefore it will be evaluated only for two out four types of operations. The same situation will take place towards the effectiveness results for Group B, as it is indicated in the following columns in Figure 168.

Lock Efficiency			Confined Spaces		Environmental Conditions		
Efficiency Locks Bremerhaven	Efficiency Locks Terneuzen	Efficiency Locks Liverpool	Confined Areas Bremer	Confined Areas Liverpool	Environmental Conditions	Euro/Job Europoort	Euro/Job Rotterdam A
FALSE	FALSE	FALSE	FALSE	FALSE	67.5%	€ 192.03	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	67.5%	€ 192.03	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	61.7%	€ 132.79	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	61.7%	€ 132.79	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	70.7%	€ 125.79	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	70.7%	€ 125.79	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	70.7%	€ 125.79	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	66.7%	€ 238.07	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	70.7%	€ 125.79	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	66.7%	€ 238.07	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	70.7%	€ 125.79	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	70.7%	€ 125.79	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	56.7%	FALSE	€ 116.27
FALSE	FALSE	FALSE	FALSE	FALSE	60.0%	FALSE	€ 138.25
FALSE	FALSE	FALSE	FALSE	FALSE	60.0%	FALSE	€ 138.25
FALSE	FALSE	FALSE	FALSE	FALSE	66.7%	FALSE	€ 118.57
FALSE	FALSE	FALSE	FALSE	FALSE	56.7%	FALSE	€ 116.27
FALSE	FALSE	FALSE	FALSE	FALSE	56.7%	FALSE	€ 116.27

Figure 169: Index & Match Effectiveness Results of selected tugs Part B

The next steps to take place in the tool refer to the data to be retrieved regarding tugs effectiveness levels for locks, confined spaces & environmental conditions. The tool is built in a way which allows to retrieve the related information concerning the selected tug for each port as it is shown in Figure 169. By selecting randomly as first tug in Europoort, “SD SEAL”, the tool output is “FALSE”, since the selected tug is placed in a port without the presence of locks. At the same time, this port is not characterized from confined areas while based on the environmental conditions for Europoort, it is evaluated with a result based on subchapter 5.11, which in case of “SD SEAL” and for Europoort case, it was proven to be equal to 67,5 %.

At this phase and after all the related information is retrieved for each tug and its correspondent port, the tool should then proceed in the final calculation of the effectiveness results for each tug, based on the total criteria number for each port. This is the phase where AHP proves its importance for the calculation of the total results per tug. Figure 170 illustrates a small part of the calculations among the selected tugs and the number of criteria

for the assigned ports. Therefore, as an example it is shown that the port of Bremerhaven consists of four criteria; the selected tugs for this port, RT PIONEER, RT INNOVATION, RT PETER, RT ROB & RT EMOTION, will be evaluated through AHP method, with the weight factors to occur after four criteria are considered in total. The same situation will take place also for the port of Liverpool, however the weight factors will vary, since the port configuration in combination with the environmental conditions in this port will also vary, leading to different weight factors, while the total results for the selected tugs in this port will vary not only as a result of the tug type, but at the same time from the higher complexity of this port, which will alter the establishment of the weight factors.

On the other hand, for GTV area three number of criteria are considered, and therefore different weight factors are expected. Finally, in cases i.e. of Europoort & Hamburg the number of criteria will be even more reduced, leading once again to alternative weight factors. Therefore, it is evident, that each time depending on user's selections, the tool should be able to retrieve the proper information for each of the selected port, and at the same time to calculate properly the results towards the over-all effectiveness results, for each tug for both Groups A & B.

AHP - Multicriteria Analysis Group A

Bremerhaven	4 Criteria	Weight Factors	RT INNOVATION	RT PIONEER	RT PETER	RT ROB	RT EMOTION	Weight Factors
		Tug Type Score	75.0%	75.0%	80.0%	80.0%	82.0%	0.18
		Locks	90.0%	90.0%	100.0%	100.0%	100.0%	0.48
		Confined Areas	100.0%	100.0%	100.0%	100.0%	100.0%	0.29
		Environmental Conditions	85.0%	85.0%	88.0%	88.0%	96.0%	0.05

Liverpool	4 Criteria	Weight Factors	ZEEBRUGGE	SMT DONAU	SMT BARBADOS	SMT SANDON	SMT WATERLOO	SMT BELGIE	Weight Factors
		Tug Type Score	73.8%	81.4%	81.4%	85.4%	85.4%	80.0%	0.17
		Locks	65.0%	65.0%	65.0%	80.0%	80.0%	65.0%	0.57
		Confined Areas	70.0%	70.0%	70.0%	70.0%	60.0%	70.0%	0.19
		Environmental Conditions	68%	71%	71%	60%	60%	67%	0.07

GTV	3 Criteria	Weight Factors	UNION S	ST ANNASTRAND	GENT	BRUGGE	UNION S	UNION E	BRAAKMAN	TERNEUZEN	UNION EMERALD	Weight Factors
		Tug Type Score	80.0%	73.8%	73.8%	73.8%	73.8%	73.8%	83.8%	83.8%	76.8%	0.29
		Locks	80.0%	65.0%	65.0%	65.0%	65.0%	65.0%	60.0%	60.0%	65.0%	0.61
		Environmental Conditions	68.0%	68.2%	68.2%	68.2%	68.2%	68.2%	20.0%	20.0%	60.0%	0.10
		Weight Factors	UNION CORAL	UNION PEARL	SMT EMIDE	RT AMBITION	SMT KIVI	UNION RUBY	Weight Factors			

Zeebrugge	3 Criteria	Weight Factors	UNION CORAL	UNION PEARL	SMT EMIDE	RT AMBITION	SMT KIVI	UNION RUBY	Weight Factors	
		Tug Type Score	76.8%	76.8%	83.3%	80.8%	83.3%	76.8%	0.31	
		Locks	65.0%	65.0%	95.0%	100.0%	95.0%	65.0%	0.57	
		Environmental Conditions	60.0%	60.0%	90.0%	88.0%	90.0%	60.0%	0.11	
		Weight Factors	UNION PANDA	UNION KOALA	UNION GRIZZLY	UNION KODIAK	UNION AMBER	UNION JADE	UNION HAWK	LIEVEN GEVAERT

Antwerp	3 Criteria	Weight Factors	UNION PANDA	UNION KOALA	UNION GRIZZLY	UNION KODIAK	UNION AMBER	UNION JADE	UNION HAWK	LIEVEN GEVAERT	UNION EAGLE	Weight Factors
		Tug Type Score	85.7%	85.7%	85.7%	85.7%	74.3%	74.3%	83.3%	65.4%	83.3%	0.31
		Locks	65.0%	65.0%	65.0%	65.0%	70.0%	70.0%	65.0%	80.0%	65.0%	0.57
		Environmental Conditions	67.5%	67.5%	67.5%	67.5%	75.0%	75.0%	70.0%	60.0%	70.0%	0.11
		Weight Factors	UNION CORAL	UNION PEARL	SMT EMIDE	RT AMBITION	SMT KIVI	UNION RUBY	Weight Factors			

Figure 170: Calculation of Weighting Criteria based on selected tugs through AHP

Similar figures as the one which is shown in Figure 170, are used in the tool for the calculation of tugs effectiveness results for both Groups A & B and for all the ports of operations of KST. The following two figures aims to explain more efficiently how the selection lists per port are established into the tool interface as it shown in Figure 161. Starting with Figure 171, the first row presents all the ports of operations of KST. Each port consists of certain tug names, which are automatically linked with the lists to be shown in Figure 161. Each of the tug is afterwards checked towards the related towage regulations & restrictions for each area, while by writing a specific formula, the tool is then capable to create a list in alphabetical order for adding one by one every tug from KST fleet, which is capable to sail at each area.

During the period when this thesis project was made, the fleet capacity of KST was equal to 64 tugs. Therefore, from Figure 171, it can be confirmed that in the port of Rotterdam (Europoort & Rotterdam City), as well as in GTV area, the entire fleet of KST is capable to sail, and this explains the reason that for these ports the entire fleet is registered. The same situation will take place in the ports of Antwerp and Liverpool.

However, in cases of Zeebrugge or Bremerhaven, the number of tugs which are capable to sail is significantly lower, explaining adequately the shorter lists for both ports. For the ports where limited number of tugs is

Finally, in the left column, the user can check the saved scenarios. In this case, four different scenarios are already simulated. Last but not least, in any case that KST fleet is increased, then by adding all the correlated main characteristic of the tug in the “DATANETRY” sheet, the tool will be entirely able to check and verify all the possible ports where the new tug(s) are capable to sail. Consequently, the formulas which are already saved for each port, will proceed in this evaluation and will increase the list per port, only in cases where the tug is allowed.

[illegible]

Figure 171: Database for allowed tugs per port

At this point, the tool has already retrieved the average number of jobs for the entire year of 2016, while it is also skilled to provide the final fuel costs for one assistance for each scenario. Afterwards the final calculation of fuel costs for one year is calculated and hence a pivot table is created, offering direct and compact assessment for all the saved scenarios which are indicated in Figure 165.

The user has the flexibility to adjust the information which are shown either in rows or columns while at the same time, he can evaluate the result either per area or per port. On the first row, and with yellow colour, the saved scenarios are clearly indicated. Then by clicking on each port, the user is capable to assess the variances among the tugs selections, for all the simulated scenarios, while by comparing all the figures below the PVT table, the user is capable to assess the variances for each scenario.

Finally, the most important information to be retrieved, is the combination of a simulated scenario which offers high effectiveness levels and at the same time the lowest possible fuel costs. Additionally, the tool is built in a way for proving whether KST is capable to reduce slightly the effectiveness levels in some ports, by proceeding to tugs reallocations, which are capable to guarantee significant fuel costs reductions.

Scenario	Harbour	Vessels	Eff. Group A	Eff. Group B	Cost/Job	Jobs	Fuel Cost
Current Situation	Europoort	SD SEAL, SD STINGRAY, FAIRPLAY 21, FAIRPLAY 24, SMT ELBE, SMT SCHELDE, SMT SEINE, SMT PANTHER, SMT EBRO, RT ANDRIAAN, SI	79.38%	78.49%	2,036.95	1,378.00	12,806,912.32
Current Situation	Rotterdam Area	THAMESBANK, UNION 11, UNION 7, SD JACOBBA, ZP CHALONE, TEXELBANK	69.05%	69.06%	743.89	1,387.00	11,031,776.13
Current Situation	GTV	UNION 8, ST ANNASTRAND, GENT, BRUGGE, UNION 5, UNION 6, BRAAKMAN, TERNEUZEN, UNION EMERALD	66.16%	65.96%	1,565.34	756.00	11,163,286.68
Current Situation	Antwerp	UNION PANDA, UNION KODAL, UNION GRIZZLY, UNION KODAK, UNION AMBER, UNION JADE, UNION HAWK, LIEVEN GEVAERT, UNION EAGLE	71.63%	72.15%	980.52	2,353.81	12,323,651.29
Current Situation	Zeebrugge	UNION CORAL, UNION PEARL, SMT EMCE, RT ANIBITION, SMT KIWI, UNION RUBY	82.08%	82.09%	856.59	1,150.38	1,065,401.02
Current Situation	Hamburg	SD ROVER, ZP BISON, ZP BULLDOG, ZP CONDON, SD DOLPHIN	79.86%	78.67%	950.04	974.00	1,535,739.47
Current Situation	Bremerhaven	RT INNOVATION, RT PIONEER, RT PETER, RT ROB, RT EMOTION	94.13%	94.04%	946.72	939.00	1,088,970.17
Current Situation	London	ZP BEAR, RT EVOLUTION	88.93%	87.65%	410.08	476.00	1,951,818.27
Current Situation	Southampton	SMT TIGER, SD SHARK, ZP BOXER	83.44%	82.76%	937.63	300.00	1,281,290.32
Current Situation	Liverpool	ZEEBRUGGE, SMT DONAU, SMT BARBADOS, SMT SANDON, SMT WATERLOO, SMT BELGIE	70.17%	70.12%	936.17	776.00	1,726,466.62
Sc. Panther Lon-Evo EU Europoort	Europoort	SD SEAL, SD STINGRAY, FAIRPLAY 21, FAIRPLAY 24, SMT ELBE, SMT SCHELDE, SMT SEINE, RT EVOLUTION, SMT EBRO, RT ANDRIAAN, SI	80.23%	79.41%	1,955.32	1,378.00	12,694,437.61
Sc. Panther Lon-Evo EU Rotterdam Area	Rotterdam Area	THAMESBANK, UNION 11, UNION 7, SD JACOBBA, ZP CHALONE, TEXELBANK	69.05%	69.06%	743.89	1,387.00	11,031,776.13
Sc. Panther Lon-Evo EU GTV	GTV	UNION 8, ST ANNASTRAND, GENT, BRUGGE, UNION 5, UNION 6, BRAAKMAN, TERNEUZEN, UNION EMERALD	66.16%	65.96%	1,565.34	756.00	11,163,286.68
Sc. Panther Lon-Evo EU Antwerp	Antwerp	UNION PANDA, UNION KODAL, UNION GRIZZLY, UNION KODAK, UNION AMBER, UNION JADE, UNION HAWK, LIEVEN GEVAERT, UNION EAGLE	71.63%	72.15%	980.52	2,353.81	12,323,651.29
Sc. Panther Lon-Evo EU Zeebrugge	Zeebrugge	UNION CORAL, UNION PEARL, SMT EMCE, RT ANIBITION, SMT KIWI, UNION RUBY	82.08%	82.09%	856.59	1,150.38	1,065,401.02
Sc. Panther Lon-Evo EU Hamburg	Hamburg	SD ROVER, ZP BISON, ZP BULLDOG, ZP CONDON, SD DOLPHIN	79.86%	78.67%	950.04	974.00	1,535,739.47
Sc. Panther Lon-Evo EU Bremerhaven	Bremerhaven	RT INNOVATION, RT PIONEER, RT PETER, RT ROB, RT EMOTION	94.13%	94.04%	946.72	939.00	1,088,970.17
Sc. Panther Lon-Evo EU London	London	ZP BEAR, SMT PANTHER	83.84%	82.13%	402.56	476.00	1,916,181.27
Sc. Panther Lon-Evo EU Southampton	Southampton	SMT TIGER, SD SHARK, ZP BOXER	83.44%	82.76%	748.12	300.00	1,224,434.83
Sc. Panther Lon-Evo EU Liverpool	Liverpool	ZEEBRUGGE, SMT DONAU, SMT BARBADOS, SMT SANDON, SMT WATERLOO, SMT BELGIE	70.17%	70.12%	936.17	776.00	1,726,466.62

Figure 172: Summary of Selected tugs per port based on the simulated scenarios

The next subchapter aims to investigate multiple scenarios and assess the results after numerous simulations of tugs reallocations take place, among the various ports of operations of KST. Now that the main concept of the tool is extensively analysed, the reader will be fully capable to understand the results to occur from the tool simulations. Each scenario will be discussed towards its effectiveness results, as well as concerning its resulted fuel costs for each case.

8.4 Reallocation Analysis-Scenarios Results

This subchapter aims to simulate various tugs reallocations under defined scenarios with a primary goal to prove which tugs reallocations are capable to guarantee the maximum cost reductions in terms of fuel in KST. Multiple simulations will take place, while emphasis will be given in ports with high fuel rates costs as it can be seen in Figure 135. The reason behind the high fuel rates costs in various ports, is mainly dependent from two major parameters. The first reason is related with the tug types to be selected, while the second parameter linked with higher weight factor, is related with the amount of jobs to take place in each port. Consequently, emphasis to be given in ports with the most assistances, as it was proven from 2016 results in Table 48.

Figure 173 aims to provide a solid overview regarding the total amount of fuel costs per port annually, as well as regarding the fuel cost per assistance for all the selected tugs, during the year of 2016. From the figure below, it is evident that the two most expensive areas in terms of annual fuel costs, are Europoort & Antwerp. For both areas, the amount of assistances during 2016 was significantly high, where Europoort was proven to consist of 1378 assistances, while the port of Antwerp was proven to consist of 2370 assistances.

By assuming as a fixed number 400 € per cubic meter, it is then clear that the total fuel cost for the selected tugs in Europoort during 2016 was equal to 2,806,912 €, while for the port of Antwerp the total fuel costs, for the same year were equal to 2,323,651 €. Consequently, one of the main scenarios to be implemented though the tool, is related with the possible fuel costs reduction in Europoort, mainly due to the presence of the two Big Cat Class tugs, ASD3213 together with the Rampart 3200, which were proven to be the two major reasons, which led the overall fuel cost in this area to increase vividly.

The second area to be investigated is GTV area. By looking Figure 173, the fuel cost for one assistance for the selected tugs during last year, was proven to be equal to 1565.34 € (2016). The selection of both Citranaval Defcar & especially of Voith Schneider led to a huge increase on the result, and therefore their presence for this area should be reconsidered. The next port to be re-evaluated is the port of London, where RT Evolution during 2017, was proven to be less efficient compared to the behaviour of the same tug type in the ports of Europoort and Bremerhaven. In Figure 173, the fuel cost per assistance for both tugs RT Evolution & ZP Bear,

is proven to be equal to 391.03 €, while during the entire year, the expected fuel costs are expected to be equal to 186,131 €. For the rest ports in UK, Liverpool & Southampton, excessive attention should be given for the presence of SMIT TIGER in the port of Southampton which was proven to suffer from fuel cost per assistance equal to 410 €, while all tugs together in the new entry port led to a total fuel cost per assistance equal to 748.12 € (2017).

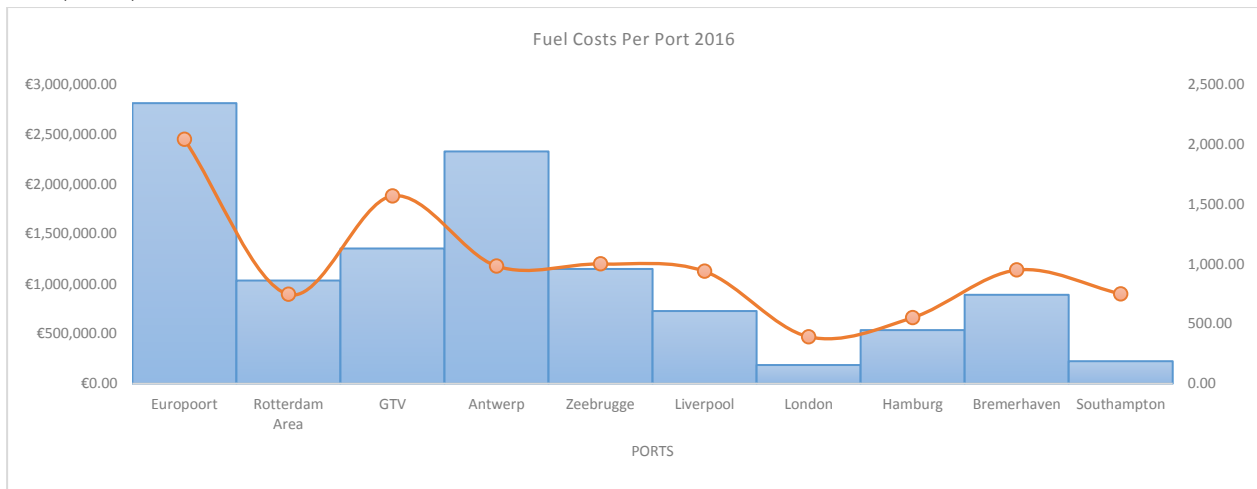


Figure 173: Fuel Costs Per Port during 2016 – Current Situation

Figure 173, summarizes the annual fuel costs per port for the current situation of KST. The results have been generated, by using the known data for the year of 2016, and therefore the average number of assistances per port to be considered, will occur by using the number of assistances during 2016.

The fuel costs per port are entirely linked with two main parameters, for defining the final cost. The first parameter refers to the selected tug types, while the second parameter refers to the number of tugs to operate in each port. Hence, from the figure above it is evident that the port of Rotterdam and the port of Antwerp are the two most expensive ports of KST, since both Europoort & Rotterdam City are proven to have annual costs equal to 3,838,688.45€. On the other hand, even if the port of Antwerp was proven to have the lowest fuel costs per job, the total cost is high due to the high average amount of assistances, which was confirmed to be equal to 2370, explaining the result of 2,323,651.20 € in total.

For the rest areas of Figure 7.3, the fuel costs are significantly lower compared to the two major pre-discussed ports. GTV area was proven to be the third most expensive area, with fuel costs equal to 1,352,455.63€. The number of tugs in the port of Rotterdam is equal to 19, while the port of Antwerp as well GTV area have in total 18 tugs. On the other hand, the port of Zeebrugge consists of 5 tugs with a total fuel cost equal to 1,147,588.09 €. Finally, the ports of Germany & UK consist from lower fuel costs.

Both German ports were proven to consist from fuel costs equal to 888,907.17 € & 535,739.47 €. Regarding the ports in UK the highest fuel costs refer to the port of Liverpool with a total amount equal to 726,466.82€, while ports of London & Southampton consist from 186,131.09 € & 224,434.83 € similarly. For the port of Southampton, the fuel cost to occur annually, were calculated by extrapolating the amount of assistances that took place during the months of April & May. Consequently, it is expected that the fuel cost minimization should start from the busiest ports with the highest fuel costs results, as it is shown in Figure 173, while the tool is capable to do all the possible combinations for satisfying user's selections.

For this reason, the selected ports to be analysed in the following chapter, include the port of Rotterdam & Antwerp, as well as GTV area & London. The user is capable to proceed in different ports selections for evaluating if the new selections reduce the fuel costs results of the current situation.

8.5 Sensitivity Analysis

One of the main complexities was related with the presence of several indicators that should be used in parallel for defining the total fuel cost per port, for all the possible tug combinations to be decided. Therefore, the tool should be constructed in a way, capable to recognize if the selected tugs for each scenario are based on known or unknown data, and therefore each user is capable to define the level of uncertainty for each new scenario to be established. The mathematical equation below shows the calculations to take place in the background, for defining the final fuel cost for each scenario and each port.

$$y' = y * (1 + x)^a$$

y': Total Fuel Cost per Tug for the selected port

y: Initial Fuel Cost per Tug for the selected port

x: uncertainly levels, defined by the user

a: 0 for known indicators / 1 for unknown indicators

The tool is capable to identify the tug name and afterwards to retrieve the fuel cost for this type in the discussed port, based on the indicators which were discussed in subchapter 7.4. However, since the known and mainly the unknown data regarding the fuel cost, is dealing with the enormous influence of human factor error, the tool was constructed in the most user-friendly way, and therefore it allows users to preselect the uncertainty level, as it is shown in Figure 174, (below the Load/Overwrite & Delete button). Eventually, the user will be able to assess the range of minimum and maximum fuel cost for his decisions and therefore, he will be able to decide if the margin among the minimum and maximum costs is adequate for proceeding to a possible swap or not.

Figure 174 presents the tool interface for making the tug selections per port. The figure presents the selected tugs as well as the capacity per port, as it is defined from KST, while these selections are saved as “Current Situation” through the tool. After all the selections are made, the user clicks on “Save New” button for saving his selections, while the tool is afterwards responsible to save the defined selections and to provide a solid feedback.

KOTUG SMIT TOWAGE

Europoort

Tug 1	SD SEAL
Tug 2	SD STINGRAY
Tug 3	FARPLAY 21
Tug 4	FARPLAY 24
Tug 5	SMIT ELBE
Tug 6	SMIT SCHELDE
Tug 7	SMIT EDE
Tug 8	SMIT PANTHER
Tug 9	SMIT EBRD
Tug 10	RT ADRIAAN
Tug 11	SMIT CHEETAH
Tug 12	SMIT HUDSON
Tug 13	SD REBEL

Rotterdam Area

Tug 1	THAMESBANK
Tug 2	UNION 11
Tug 3	UNION 7
Tug 4	SD JACOB
Tug 5	2P CHALONE
Tug 6	TEDEBANK

OIV

Tug 1	UNION 5
Tug 2	ST ANNASTRAND
Tug 3	BENT
Tug 4	BRIDGE
Tug 5	UNION 5
Tug 6	UNION 5
Tug 7	BRANKMAN
Tug 8	TERNEIJZEN
Tug 9	UNION EMERALD

Antwerp

Tug 1	UNION PANDA
Tug 2	UNION CORAL
Tug 3	UNION GREZLY
Tug 4	UNION PEARL
Tug 5	UNION AMBER
Tug 6	UNION JADE
Tug 7	UNION NAVIS
Tug 8	UNION GEVAERT
Tug 9	UNION EAGLE

Zeebrugge

Tug 1	UNION CORAL
Tug 2	UNION PEARL
Tug 3	SMIT EDE
Tug 4	RT AMBITION
Tug 5	SMIT EDE
Tug 6	UNION EDE

Liverpool

Tug 1	2P BRIDGE
Tug 2	SMIT DOMAU
Tug 3	SMIT BARBODS
Tug 4	SMIT SANCOS
Tug 5	SMIT WATERLOO
Tug 6	SMIT ELBE

London

Tug 1	2P BEAR
Tug 2	RT EVOLUTION

Hamburg

Tug 1	SD ROVER
Tug 2	2P BEAR
Tug 3	2P BULLDOG
Tug 4	2P CONDON
Tug 5	SD DOLPHIN

Bremerhaven

Tug 1	RT EMOTION
Tug 2	RT PIONEER
Tug 3	RT PETER
Tug 4	RT FUS
Tug 5	RT EMOTION

Save New **Clear Input** **Load, Update, Delete** **Auto**

Port Allocation Table

Port	Tug Type	Count	Uncertainty Level
London Flates	2 Rotors	2	TRUE
London Flates	Port	1	TRUE
London Flates	Port	1	TRUE
OTV Flates	Port	1	TRUE
Bremerhaven Flates	10 with	10	TRUE

Enter Uncertainty Level **Maximum Improvement** 25,000.00

Figure 174: Tool Interface with Uncertainty Level Definition

For the scope of this thesis project, was decided to proceed in four scenarios, by investigating eight possible reallocations. Each scenario to be analyzed will include 10%, as well as 20% uncertainty level for verifying if the company will be capable to achieve fuel cost reduction or losses. Consequently, subchapter 8.5.1, aims to assess the results under 10 % uncertainty, while subchapter 8.5.2, will present the fuel costs results under 20% uncertainty levels. Finally, subchapter 8.8 aims to evaluate the effectiveness results variances regarding the daily operations, for each scenario with the new tugs combination for each port.

Starting with the port of Rotterdam, and more specifically for the Europoort, as it is already explained in subchapter 7.6, the tug type with the highest fuel consumption was proven to be the ASD 3213, and more specifically the tugs, SMIT CHEETAH & SMIT PANTHER. At the same time is verified that the average amount of jobs in Europoort, was proven to be equal to 1378 during 2016. Therefore, it would be tremendously important for KST and its daily operations, to search for alternatives for replacing one of this two tugs, and possibly reallocate them in a less busy port with lower amount of assistances annually. Additionally, the company would like to consider a possible return of RT EVOLUTION, in Europoort for making better use of its hybrid system. As it was also proven, RT EVOLUTION operates with lower fuel costs in Europoort compared to the port of London, and therefore this reallocation is high of importance. However before assessing the fuel cost for RT EVOLUTION in Europoort & SMIT PANTHER to London, KST must ensure that none of the established regulations in each port is violated, while at the same time it is crucial to confirm that the flexibility for each port is still preserved in high levels. The same procedure must be followed for the rest scenarios to take place, which is mandatory for keeping its clients continuously satisfied.

One second scenario to be established again among the ports of Europoort & London, refers to RT EVOLUTION and SD STINGRAY. This scenario was decided to take place, in cases where special projects in Europoort cannot be carried out from SMIT CHEETAH & RT ADRIAAN, where this rotor tug consists of 84 tons. It is quite often phenomena that KST should meet regulations which demand 2x85 minimum BP, and hence both tugs SMIT CHETAH & SMIT PANTHER are the only capable tugs to comply, since they consist from 90+ tons of BP. Rampart 3200 were proven to be the second most expensive tug type in Europoort and therefore the company could also assess a possible reallocation either for SD SEAL or SD STINGRAY, since both are currently sailing in Europoort.

The next ports to be considered for achieving possible fuel cost reductions refer to the port of Antwerp, Liverpool, as well as GTV area. Even if the port of Antwerp was proven to consist from significantly low fuel cost per job for the selected tug types, still KST can decrease its fuel costs due to significantly high number of assistances. For this reason, the third scenario to be discussed refers to a possible swap among the SMIT BELGIE which is currently located in the port of Liverpool and LIEVEN GEVAERT, which is in the port of Antwerp. Voith Schneider's were proven to be the most expensive tug type in the port of Antwerp, while ASD3110 was consisting from significantly lower fuel costs per job. At the same time, even if the Voith Schneider is more expensive per job, compared to ASD3110 also for the port of Liverpool, again the significantly lower amount of assistance in the latter port (776), are expected to lead in major fuel cost reductions.

Finally, one last scenario (fourth) will include again SMIT BELGIE, but this time it will be considered for a possible reallocation towards GTV area, while UNION 8 (Voith), will be reallocated in the port of Liverpool. As it was already analysed the long transit routes among Terneuzen & Ghent, demand efficient tug types and Voith's without any doubt are characterized from low levels of efficiency, in terms of fuel costs. All the pre-mentioned scenarios for the possible swaps among the tugs will be further analysed in the following subchapters, for two different levels of uncertainties, while their results will be extensively discussed.

Figure 175, shows the overview of the tool in a pivot table, which summarizes the effectiveness results per port, under the new tug combination, as well as the gain in fuel cost compared to the current situation. The total amount of fuel cost to occur for each case is discussed, while the user is capable to define the price per cubic meter for each of the ports; however, in this case the comparison among the ports will occur after considering a fixed price.

Depth (number of swaps)	Scenario	Harbour	Vessels	Average of Eff. Group A	Average of Eff. Group B	Sum of EuroJ	Sum of Jobs	Sum of Min Fuel	Sum of Fuel Cost	Sum of Max Fuel	Sum of gain to current situation
Manual	Union 8 to Liv & Belgie to GTV 20%			78.5%	78.1%	9,827.05	10,614.19	11,003,937.00	11,161,953.98	11,231,574.25	62,171.77
	Union 8 to Liv & Belgie to GTV 10%			78.5%	78.1%	9,827.05	10,614.19	11,130,308.13	11,161,953.98	11,195,764.00	62,171.77
	Union 8 to Liv & Belgie to GTV			78.5%	78.1%	9,827.05	10,614.19	11,161,953.88	11,161,953.98	11,161,953.88	62,171.77
	Lieven to Liv & Belgie to Ant 20%			78.6%	78.1%	9,876.93	10,614.19	11,072,416.13	11,136,540.87	11,213,491.25	87,584.88
	Lieven to Liv & Belgie to Ant 10%			78.6%	78.1%	9,876.93	10,614.19	11,101,563.75	11,136,540.87	11,175,016.25	87,584.88
	Lieven to Liv & Belgie to Ant			78.6%	78.1%	9,876.93	10,614.19	11,136,541.00	11,136,540.87	11,136,541.00	87,584.88
	Evo to Eur & Stingray to Lon 20%			78.1%	77.7%	9,827.46	10,614.19	11,126,129.61	11,159,240.14	11,189,972.48	64,885.62
	Evo to Eur & Stingray to Lon 10%			78.1%	77.7%	9,827.46	10,614.19	11,141,179.73	11,159,240.14	11,179,106.23	64,885.62
	Evo to Eur & Stingray to Lon			78.1%	77.7%	9,827.46	10,614.19	11,159,239.98	11,159,240.14	11,159,239.98	64,885.62
	Evo to Eur & Pan to Lon 20%			78.1%	77.6%	9,826.26	10,614.19	11,065,534.95	11,117,138.22	11,178,342.53	106,387.53
	Evo to Eur & Pan to Lon 10%			78.1%	77.6%	9,826.26	10,614.19	11,089,045.95	11,117,138.22	11,148,040.45	106,387.53
	Evo to Eur & Pan to Lon			78.1%	77.6%	9,826.26	10,614.19	11,117,138.38	11,117,138.22	11,117,138.38	106,387.53
	Current Situation			78.5%	78.1%	9,886.19	10,614.19	11,224,125.69	11,224,125.75	11,224,125.69	-
Grand Total				78.33%	77.91%	127,963.47	137984.4375	144,629,213.77	144,548,745.38	145,320,906.38	964,889.40

Figure 175: Results Overview among the four scenarios

8.5.1 4 Scenarios Results with 10% Uncertainty

Starting with the current situation, the total amount of fuel costs for all the ports of KST, is equal to 11,224,125.69 €. Figure 176 shows the variances of the total fuel costs among the current situation and the pre-discussed scenarios. The clustered columns with the green colour indicate the price of the fuel cost for each of the discussed scenario, while both blue and yellow lines, show the margins for each case, when 10% of uncertainty level is taken into consideration. The indicated price per scenario consists from a maximum, as well as a minimum value, and therefore the user is capable to compare if the fuel savings even under the worst-case scenario are still lower than the current fuel costs, in order to guarantee the success of the swap.

Regarding the first swap (UNION 8 to Liverpool & SMIT BELGIE to GTV), it is expected to lead in a total fuel cost equal to 11,161,953.98 €, while Figure 177 shows that the expected reduction will be equal to 62,171.87 €. For this swap, it is confirmed that the fuel cost reduction to occur will be the same even after

considering 10 or 20% of uncertainty. This is explained from the selected tugs to be reallocated among the port of Liverpool & GTV area. Both tug types consist from indicators with known data and hence the tool shows identical prices. The tool was capable to recognize and retrieve the required information, for each tug type, while the same situation will also take place for the swap among RT EVOLUTION & SD STINGRAY (3rd swap).

Both tug types consist from known indicators for Europoort and for the port of London. For the entire year of 2016, RT EVOLUTION was sailing in Europoort, while SD SEAL & SD STINGRAY are identical with SD SHARK, which used to operate in the port of London, and therefore it is again possible for the tool to investigate if the resulted fuel costs to occur are based on known data and for both tug types. Figure 176, shows that the expected fuel costs in cases where this swap takes place will be equal to 11,159,240.14 €, while the cost reduction among the two tug types will be equal to 64,885.77 €, without any variance even under 10% uncertainty, as it is shown in Figure 177.

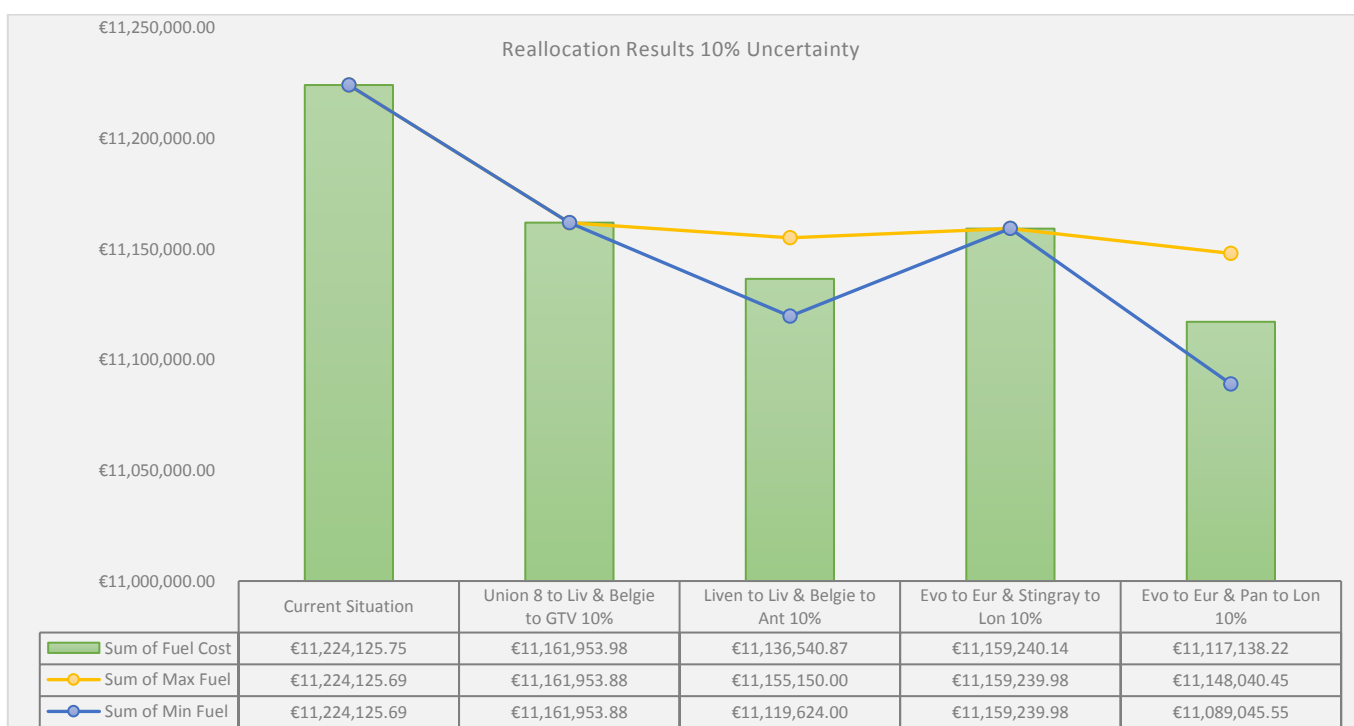


Figure 176: Reallocation Fuel Costs Results with 10% Uncertainty

On the other hand, for the rest two swaps the results will vary under 10% uncertainty. As it is already shown in subchapter 7.6 in the port of Antwerp the most expensive tug type was proven to be the Voith Schneider. Consequently, the second swap, suggests LIEVEN GEVAERT to be reallocated in the port of Liverpool, and SMIT BELGIE to return in the port of Antwerp. Since the average number of assistances for this port is relatively high, it would be wise to assess if it is possible to reduce the fuel costs in this port by reallocating the only Voith Schneider which is currently sailing in the port of Antwerp. SMIT BELGIE as it is already explained in subchapter 7.7, used to operate in the port of Antwerp during 2013.

Even if the data towards the consumed cubic meters are registered in company's records, it is not possible to retrieve information regarding the precise amount of assistances on which this tug was involved, and therefore the same amount of assistances during 2016 (2370) will be used. Therefore, for this case the uncertainty levels will be used for eliminating possible small errors. The new total fuel cost in case where this swap takes place,

will lead to a total amount equal to 11,136,540.87 €, and therefore from Figure 177 it is verified that the cost reduction will be equal to 87,584.75 €. After considering 10% of uncertainty levels, the total reduction then will be 68,975.69 €. However, there is also possibility the cost to be further increased and eventually the maximum cost reduction, is expected to be equal to 104,501.69 €.

Regarding the 4th swap, the resulted fuel savings are expected to be even higher, and refers to SMIT PANTHER & RT EVOLUTION, among the ports of Rotterdam & London. The operation of the hybrid tug ART8032, was proven to be more efficient in Europoort, compared to the port of London, and therefore KST should consider as a possible reallocation for this tug. At the same time, the SMIT CHEETAH & SMIT PANTHER were proven to be the two most expensive tugs in Europoort, and therefore one suggestion capable to reduce the fuel, could be to reallocate SMIT PANTHER to the port of London and RT EVOLUTION in the port of Rotterdam. The fuel cost reduction for this swap is confirmed to be equal to 11,117,138.22 € as it is shown in Figure 176, while Figure 177 verifies that the entire reduction is expected to be equal to 106,987.38 €.

Uncertainty levels of 10 & 20% are also considered for this possible swap, since the ASD3213 BIG CAT CLASS, SMIT PANTHER, has never sailed in the past in the port of London. On the other hand, the presence of RT EVOLUTION in Europoort is known. Consequently, the tool is then capable to recognize and retrieve the requested information in between these two tug types, while if 10% of uncertainty is considered the maximum fuel cost reduction to be achieved, is expected to be equal to 135,080.14 €, while the minimum cost reduction is expected to be 76,085.23 €.

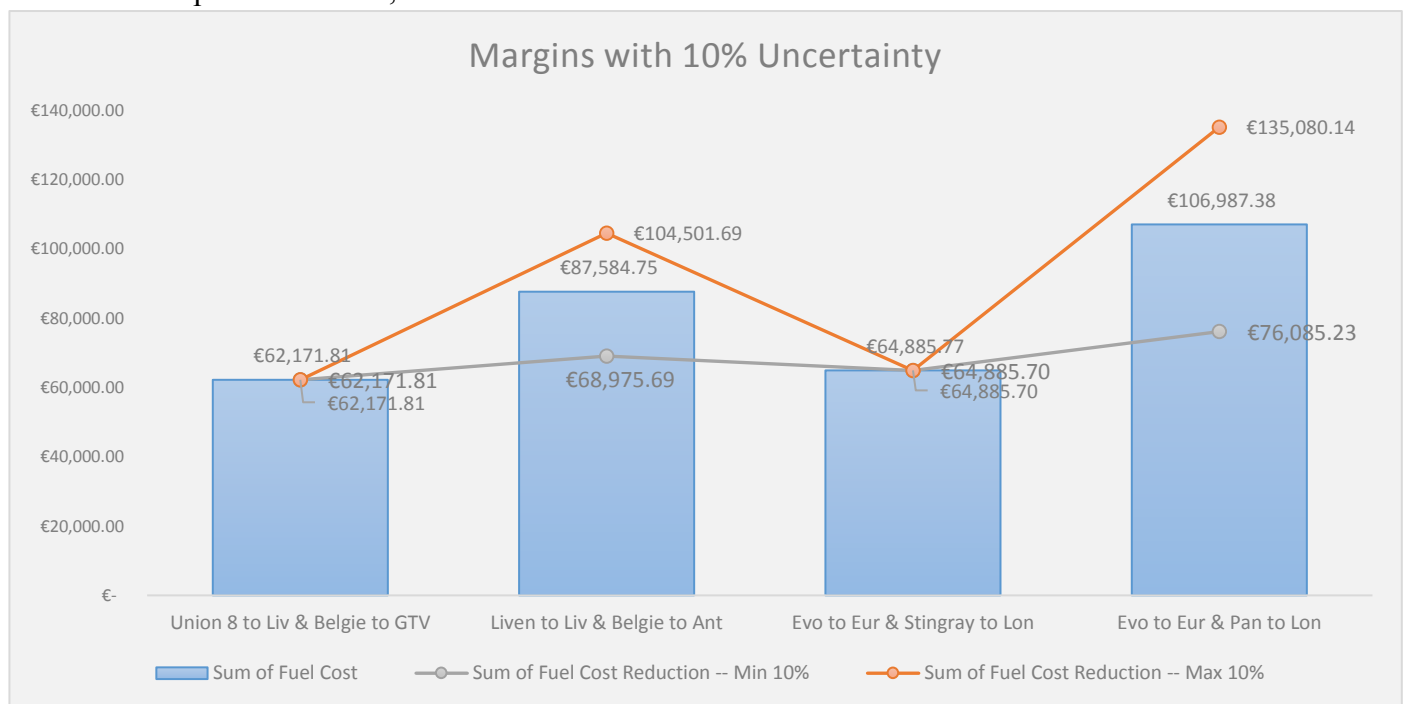


Figure 177: Fuel Costs Reduction Margins with 10% Uncertainty

8.5.2 4 Scenarios Results with 20% Uncertainty

In this subchapter, the pre-defined swaps will be discussed again towards the expected fuel costs reduction, however this time the uncertainty level will be equal to 20%, while Figure 178 shows the variances of the total fuel costs among the current situation and the pre-discussed scenarios after considering the new uncertainty level.

The higher level of uncertainty is necessary for evaluating if the minimum fuel cost reduction is lower compared to the cost of the current situation, even when the worst-case scenario of the lowest fuel cost reduction occurs, in order to guarantee the success of the swap. Starting again with the swaps (UNION 8 to Liverpool & SMIT BELGIE to GTV) and (SD STINGRAY to London & RT EVOLUTION to Europoort), the fuel costs to occur will be the same without considering the 20% uncertainty level. On the other hand, the blue and yellow lines regarding the margins of the fuel cost for the second (LIEVEN to Antwerp & SMIT BELGIE to GTV) and fourth swap (SMIT PANTHER to London & RT EVOLUTION to Europoort) will vary. Figure 178, shows that the margins for the second scenario, will be among 11,173,758.75 € and 11,105,525.50 € for the maximum and the minimum total fuel cost respectively.

Consequently, it is evident that even under 20% of uncertainty levels the second swap is capable to generate significant fuel cost reduction for KST equal to 0,4487% compared to the current situation. Conversely, in the case of the minimum fuel cost, the fuel cost will be improved by 1,05664%.

Last but not least, the fourth scenario will consist from larger margins in between the minimum and maximum fuel cost to be achieved, while Figure 178 shows that the expected amounts will be equal to 11,178,942.53 € for the maximum fuel cost and 11,065,634.95 € for the minimum cost accordingly. For this case, the changes of percentages will be 0,4025 % & 1,412 % respectively.

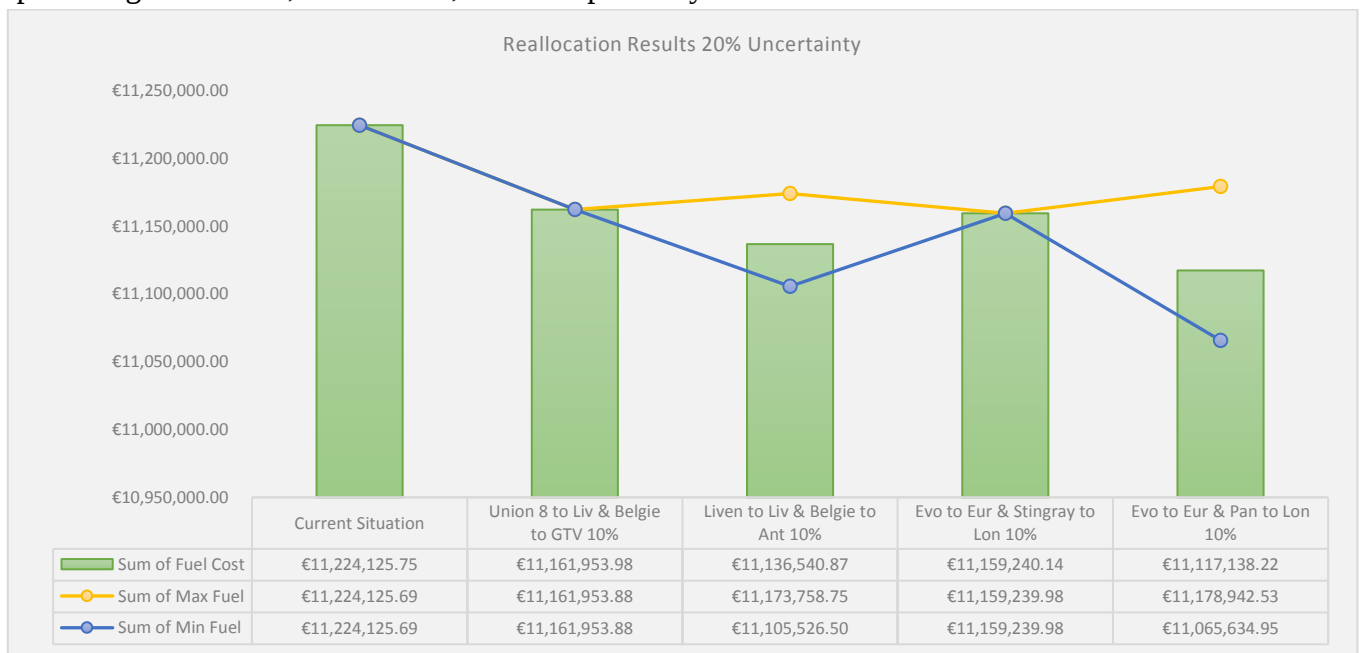


Figure 178: Reallocation Fuel Costs Results with 20% Uncertainty

Figure 179 shows the fuel costs to occur for each of the pre-discussed swaps, also after considering 20% of uncertainty levels for the two out of the four swaps. Starting with the first and third swap, the company is expected to proceed in 62,171.81 € and 64,885.70 € fuel cost reductions responsively. On the other hand, the second swap is expected to lead in cost reduction equal to 87,855.01 €, while with 20% uncertainty the maximum fuel reduction can be equal to 118,599.19 €. Finally, the highest cost reduction is expected towards the fourth swap, while the amount to occur will be equal to 106,987.69 €. However, after considering the uncertainty levels of 20%, the maximum fuel cost reduction can be equal to 158,490.73 €.

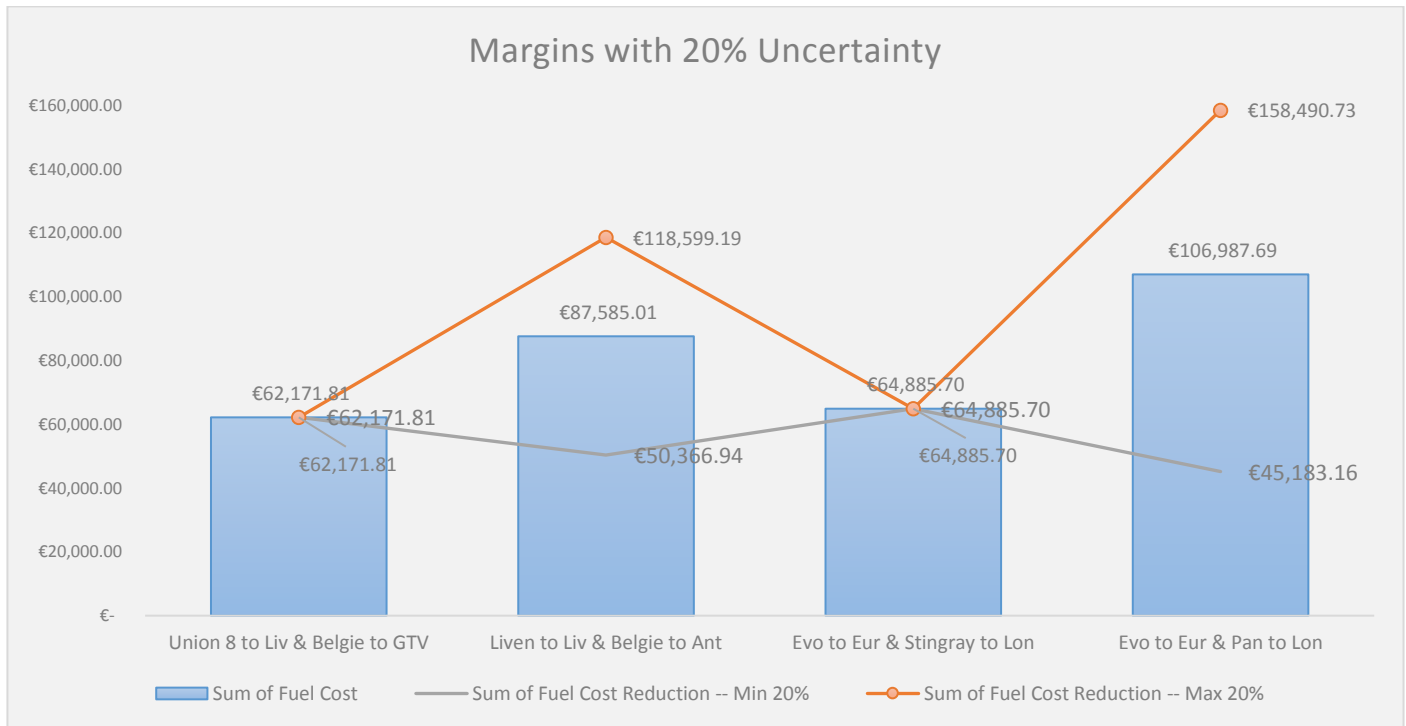


Figure 179: Fuel Costs Reduction Margins with 20% Uncertainty

8.8 Swaps VS Daily Operations Effectiveness

This subchapter aims to evaluate the effectiveness results towards the daily operations for each swap, compared with the current situation. The average effectiveness result for the current situation concerning Group A will be equal to 78,5%, while for Group B equal to 78,1%.

In both cases regarding the first and second swap, the port of Liverpool will consist from an extra Voith Schneider, where it will have higher effectiveness results, during the operations in the narrow locks of Liverpool (especially during Bow to Stern operations), compared to SMIT BELGIE, which belongs to azimuth stern drive tugs, while the effectiveness results are expected to be increased by 1,66 % for Group A & by 1,93 % for Group B.

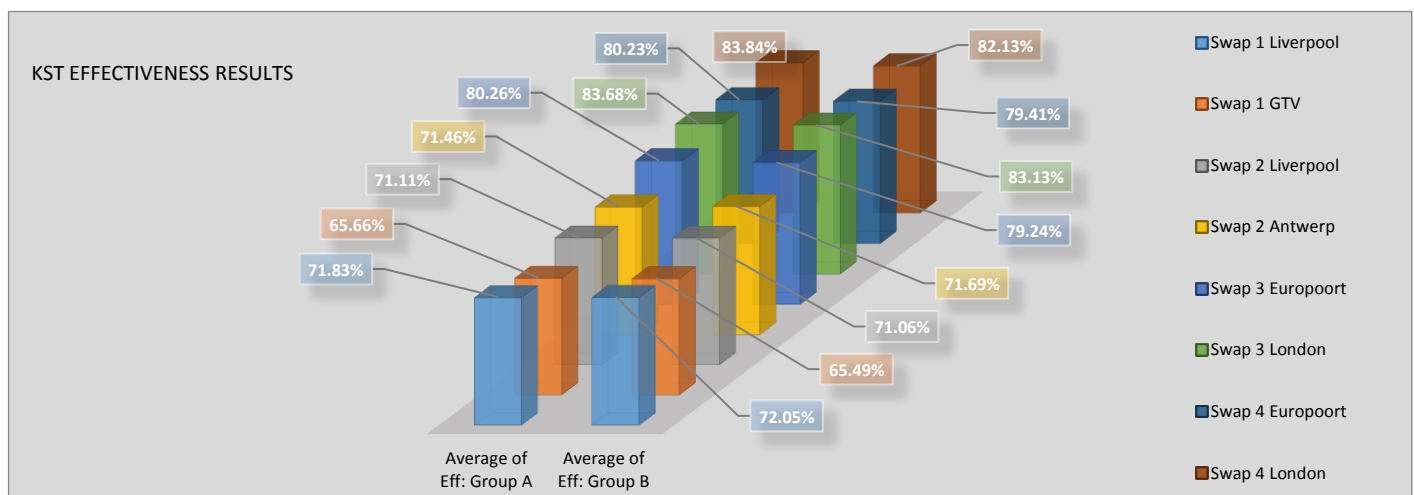


Figure 180: Effectiveness Results of Daily Operations for each Swap

For GTV area the presence of SMIT BELGIE is expected to lead in slight decrease by 0,5 % for both groups. For SMIT BELGIE it is crucial to verify that the tug will be capable to proceed also in Bow to Bow operations,

which are “mandatory” for the port of Antwerp. In general, the change of effectiveness results among the various ports towards the possible swaps are expected to be low, since the number of tugs to be reallocated is relatively small. The same results are also expected towards the second swap.

The effectiveness results in the port of Liverpool are similar, since LIEVEN is also a Voith Schneider, and therefore the effectiveness in this port is again improved as an average by 1,795 %. Moreover, the port of Antwerp will consist only by 0,365% effectiveness reduction for both groups, and the main reason for this minor decrease is related with the significantly larger locks in this port, which offer higher flexibility and convenience during the daily towage operations.

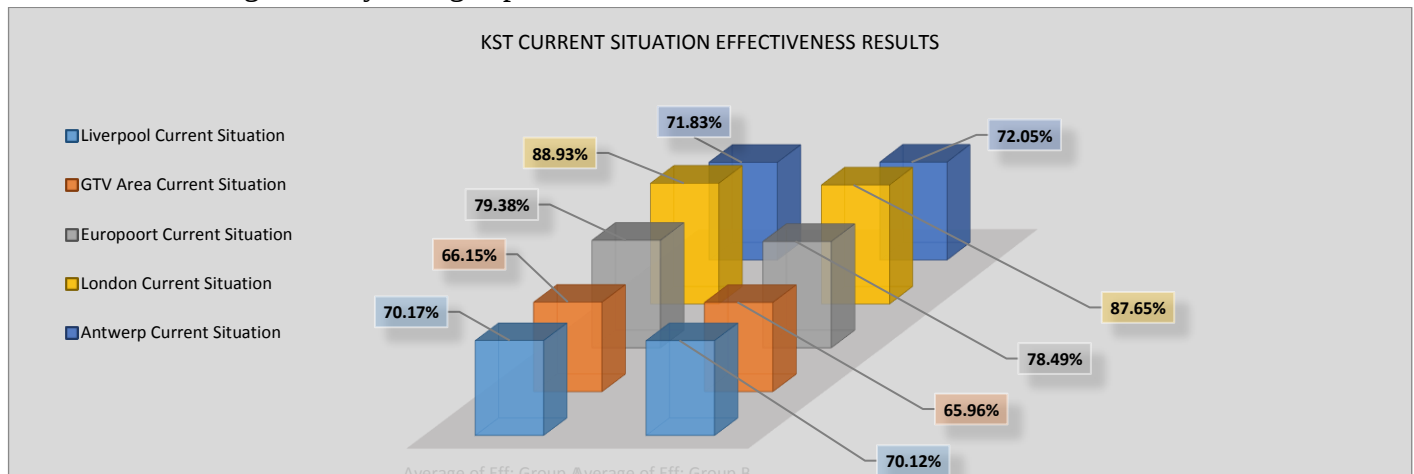


Figure 181: KST Current Situation Effectiveness Results towards Daily Operations

On the other hand, the rest two scenarios (third and fourth), are excepted to consist from larger variances towards the effectiveness results, especially for the port of London. The main reason is related with the number of tugs which is equal to two, compared to Europoort which consists from thirteen. Therefore, in the case where the SD STINGRAY is reallocated to the port of London, the effectiveness results will be equal to 83,68% for Group A & 83,13 % for Group B. However, as it is shown in Figure 185, these results are reduced by 5,25% and 4,52 % for Group A and Group B accordingly, compared with the current situation where RT EVOLUTION is in London.

The change of effectiveness results in the Europoort will be significantly lower, and eventually will lead to a slight improvement equal to 1% for both groups of assisted vessels. Lastly, concerning the fourth swap, the improvement in Europoort is characterized from the same effectiveness results. However, the port of London will be characterized from a decrease towards its effectiveness equal to 5,09 % for Group A and by 5,52% for Group B.

8.9 Verification & Validation of KST Tool Results

In general, every model by its nature is characterized as more intellectual compared to the system which tends to represent. In that perspective, the meaning of a well-built system is more a subjective opinion, while tool’s accuracy is linked with the quality of the results to be extracted. Regarding the term of verification, the main question to be answered refers to the followed process for determining if KST tool establishment as well as its input define efficiently developer’s conceptual description, while the term validation refers to the followed process for defining if tool’s resulted output is close to reality.

Regarding the term of verification, as it shown in Figure 166, four main coefficients were established through the tool in Excel, for measuring the effectiveness results, as well as the total fuel costs for each simulated scenario, while the results for each tug and type of operation were directly sustained in a compact database.

Moreover, since the scenarios simulation through the tool should take place in a user-friendly environment, the tool was built in a way that allows the user, to have a solid overview in total for all the ports of operations of KST, as it was shown in the main commands window in Figure 161. Additionally, the tool offers the ability to evaluate the results in a general dashboard overview, as it was shown in Figure 163 regarding the effectiveness results and fuel cost per tug and per port. The tool is also capable to notify in advance the user, if the desired selections are the most efficient or not, compared to the rest selections. For this reason, specific conditional formatting criteria is established, offering the ability to replace one of the already selected options, for increasing the effectiveness results, combined with the lowest fuel costs.

Various tugs reallocations were simulated, under defined scenarios with a primary goal to prove which tugs reallocations are capable to guarantee the maximum cost reductions in terms of fuel in KST, while emphasis was given in ports with high fuel rates costs. Due to the several indicators that were used for defining the total fuel cost per port, the tool was constructed in a way, capable to recognize if the selected tugs for each scenario are based on known or unknown data; this is the reason that the user is capable to define the level of uncertainty for each new simulated scenario, and eventually to assess the range of minimum and maximum fuel cost. Consequently, it can be confirmed that the new KST tool fulfils the verification needs by satisfying adequately the objective of the thesis project.

On the other hand, the validation of the tool's output is feasible to be assessed only after proceeding towards to one of the suggested swaps. After one of the suggested swaps take place, the next step is to monitor the operational profile for defining the precise fuel costs per activity of each tug in the new port of operation. Based on past company's records for the year of 2013, 2014 & 2015 essential information can be retrieved for validating the trustworthiness levels of the PPI's which are shown in Table 41. However, the only PPI's that could be validated based on the available data towards the unknown fuel costs, refer to the types ASD3110 & Rampart 3200, among the ports Antwerp & GTV area.

For the ASD3110, the fuel cost per job in GTV area was proven to be equal to 172.96 € (2016). The consumed cubic meters for the ASD3110 towards in Antwerp during 2013, were proven to be equal to 451,3. If the amount of assistances, is assumed to be the same with the number of assistances during 2016, (~2370 assistances), with the same operational profile, the PPI to occur will be equal to 0.19042 cubic meters per job. Again, by assuming the same amount per cubic meter, (400 €), the fuel cost will be equal to 76,16877 €/job. The resulted fuel cost is almost identical with the fuel cost in Table 51, which was proven to be for the same area, equal to 78,52 €/job.

Moreover, for ASD3110 in GTV area during 2015, the fuel consumption was proven to be 383,050 cubic meters. Again, by assuming the same operational profile among the years of 2015 & 2016 in GTV, as well as the same amount of assistances (864 jobs), the PPI is proven to be equal to 0,443344 cubic meters per job. For a fixed price of cubic meter equal to 400 €, the total fuel cost will be equal to 177,337963 € per job. Consequently, the price for this tug type during the year of 2016 is validated to be almost identical compared to the year of 2015.

The last tug type which was also used during 2014 for one year in GTV area, refers to Rampart 3200. The Union Grizzly was confirmed to consume 564,491 cubic meters, while the followed sailing profile was the same compared to the rest tug types in this area. If the same operational profile compared to the rest tug types in this area is considered, together with the same amount of assistances during 2014 (864 jobs), it is concluded that with a fixed price per cubic meter equal to 400 €, the fuel cost per job for this tug type would be equal to 261,3384 €/job. The resulted cost is almost identical with the cost to be shown in Table 41, which is equal to 252,19 € per job.

Consequently, it can be confirmed that the PPI's that were used for all the unknown values of the tug types in the various ports of operations of KST, which are shown with yellow color in Table 41, can lead to fuel savings which are characterized from high trustworthiness levels.

8.10 Chapter Conclusion

The main goal of chapter 8 was to discuss the tool development, for assessing the effectiveness results and the resulted variances, as well as the fuel costs for the selected tugs in various ports, under multiple scenarios. For the scope of this thesis project, due to time limitation, four scenarios were established, by investigating eight possible reallocations, while each scenario was analyzed after including 10%, as well as 20% uncertainty level for verifying if the company will be capable to achieve fuel cost reduction or losses.

The first scenario was referring to a possible reallocation of one out of the two ASD3213, in a less busier port, combined with a possible return of RT EVOLUTION, for a better use of its hybrid system; in total, this swap would be possible to lead in maximum annual fuel savings equal to 158,493.73 €. The second scenario was referring to a possible swap among RT EVOLUTION and SD STINGRAY. Rampart 3200 was proven to be the second most expensive tug type in Europoort and therefore KST could also assess a possible reallocation either for SD SEAL or SD STINGRAY. The maximum annual fuel savings for this scenario can be equal to 64,885.70 €. On the other hand, regarding the third scenario, a possible swap among the SMIT BELGIE and LIEVEN GEVAERT, can lead to maximum annual fuel savings equal to 118,599.19 €, while for the fourth scenario the annual maximum fuel savings can be equal to 62,171.81 €.

Finally, through section 8.8, the effectiveness results variances regarding the daily operations, were evaluated. The effectiveness results regarding the first and the second swap for the port of Liverpool are expected to be increased by 1,66 % for Group A & by 1,93 % for Group B, while for Antwerp will be decreased by 0,365% for both groups. On the other hand, for GTV area, the presence of ASD3110 is expected to lead in slight decrease by 0,5 % for both groups. For the third swap, the effectiveness results will be reduced by 5,25% and 4,52 % for Group A and Group B accordingly, while the change of effectiveness results in the Europoort will be significantly lower. Lastly, concerning the fourth swap, the port of London will be characterized from an average decrease equal to towards its effectiveness equal to 5,305 % for both groups.

The main conclusions for each of the four simulated scenarios, as well as future recommendation regarding KST tool will be discussed in chapter 9.

KST Strategic Plans - Conclusions

The main goal of this chapter is to establish a unique business plan based on the future strategies of KST, by assessing the optimum swaps combination, regarding the four scenarios which were already analysed in chapter 8, for re-evaluating KST Fleet Overview in Corporate level. Figure 182, summarizes the total fuel cost reduction to be achieved by combining various swaps.

9.1 Optimum Scenario

The optimum scenario for KST for achieving considerably high fuel savings refers to swaps 2 & 4. The reallocation of LIEVEN GEVAERT in the port of Liverpool and SMIT BELGIE in the port of Antwerp, will lead in fuel savings equal to 87,585.01 €, while the reallocation of RT EVOLUTION to Europoort and SMIT PANTHER to London, will lead to fuel savings equal to 106,987.69 €. Both reallocations will lead KST to proceed in fuel savings equal to 194,572.7 €. Additionally, the fleet effectiveness results in case where swaps 2&4 take place, will lead to a minor decrease of 5% while the rest ports will either increase or decrease slightly their effectiveness results by 1%. Therefore, the tool was capable to prove that by reducing slightly the effectiveness results among some ports, it is possible to achieve significantly high fuel savings. On the other hand, in terms of flexibility among these 2 swaps, KST will not be influenced considerably. In Europoort the only cases requiring special attention refer to some special projects (harbour towage duties), where the company is requested to provide minimum assistance, by using 2 tugs each consisting of minimum 85 tons of BP.

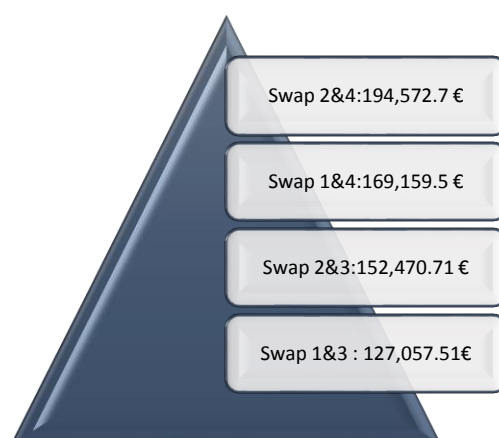


Figure 182: Fuel Savings without uncertainty levels

However, KST is capable to proceed in a re-agreement, for providing the same types of services by using one tug consisting of +90 tons of BP, while the second tug to be used is RT ADRIAAN, with a total amount of BP equal to 84 tons. The difference in terms of BP among RT ADRIAAN and the minimum requested bollard

pull is only one ton, and therefore it would be possible to proceed in this reallocation easily. On the other hand, the reallocations of LIEVEN GEVAERT in the port of Liverpool as well as the SMIT BELGIE to Antwerp, will not cause any violation on the rules, and therefore the company is capable to proceed directly.

9.2 Analysis of Less Optimum Scenarios

Apart from the optimum scenario with total fuel savings equal to 194,572.7 € by combining swaps 2&4, KST is also capable to achieve considerably high fuel reductions, by proceeding in less optimum scenarios, which combine various swaps. Figure 182 shows that the less optimum scenario refers to the combination of swaps 1&4, with a total amount of saving equal to 169,159.5 €. The major reduction also for this scenario is mainly due to the fourth swap, which shows that SMIT PANTHER will reduce the fuel costs in Europoort considerably. The next scenario with total savings equal to 152,470.71 €, refers to swaps 2&3, where the replacement of the Voith Schneider in the port of Antwerp with an azimuth stern drive tug, is the major coefficient capable to guarantee high levels of fuel cost reduction. Last but not least, the lowest fuel reduction is equal to 127,057.31 €, while the swaps to take place during the last scenario, are characterized from almost equal savings.

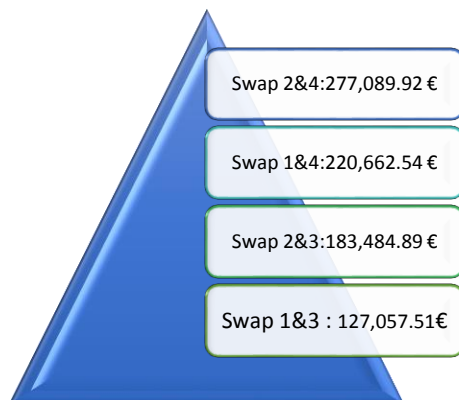


Figure 183: Maximum Fuel Savings with 20% Uncertainty

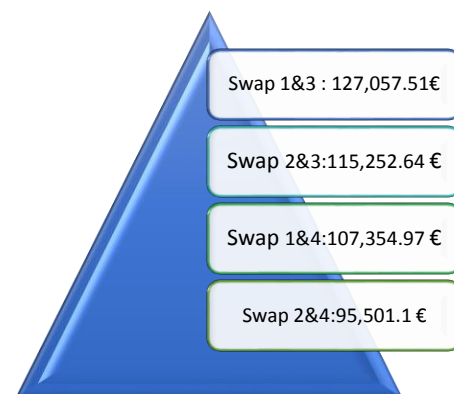


Figure 184: Minimum Fuel Savings with 20% Uncertainty

The next figures to be discussed, refer to maximum and minimum fuel savings concerning the optimum scenario, as well as the less optimum scenarios, whereas both Figure 183 & 184, are established after considering the same uncertainty level equal to 20%. Starting with Figure 183 and the optimum scenario, in case where KST proceed to the implementation of swaps 2&4, it is possible to achieve fuel savings equal to 277,089.92 €. On the other hand, the minimum fuel savings to occur for these swaps, are expected to be equal to 95,501.1 €. Consequently, KST will proceed to tremendously high fuel cost reduction, as it is proven through the tool.

Regarding swaps 1&4, KST could also expect high maximum fuel savings, equal to 220,662.54 €. The minimum savings for this swap are expected to be equal to 107,354.97 €. Scenarios 3 & 4 are proven to lead in lower fuel savings, where swaps 2&3 are expected to result maximum savings equal to 183,484 €, and minimum savings equal to 115,252.64 €, while the lowest and less risky swaps are proven to be swaps 1&3, consisting from the same amount of savings without considering any uncertainty level; In both cases of minimum and maximum savings KST should expect the same amount, equal to 127,057.51 €.

9.3 Future Recommendations – Auto Solver

The scope of this thesis project was to proceed in the construction of a unique tool capable to assess all the possible scenarios to be created manually from the user, for determining the optimum tug's combinations in the various ports of operation of KST. As it was already discussed and proven through chapters 8 & 9, the tool can prove if minor increases or decreases towards tugs effectiveness in each port, can lead to remarkable fuel savings, while ideally the tool should be constructed in a way which would offer the ability to run automatically and generate the most efficient tugs combinations, for achieving the highest possible fuel cost reductions.



Figure 185: KST Tool consisting from Auto Solver

However, during the period when the thesis project took place, it was nearly impossible to proceed in the construction of an automatic procedure-solver for generating the best scenarios, and therefore it is recommended to proceed in further accomplishments, capable to guarantee the automatic functionality of the tool. Figure 185 offers an idea of how the tool should be ideally. One of the main criteria for the automatic scenarios generation, refer to the evaluation of multiple rules per port, where the macros evaluate and eventually present the optimum swaps to take place among all the ports. For this reason, it is not only important to include the regulations and restrictions for each port, as they are established from the port authority, but at the same time it is necessary to construct generic rules as a result of the daily operations for each case, regarding the minimum number and BP for each tug type. At the same time, the evaluation of the established extra rules requires the tool to proceed in multiple simulations, for evaluating and understanding adequately the output to occur.

The next major element refers to the fuel costs indicators regarding the tug types that never sailed in some ports. It is recommended that extra research should take place towards the fuel costs, which will eventually lead to more accurate calculations concerning the fuel savings. At the same time, the improvement towards the fuel monitoring among the tug types of KST in the various ports will eliminate the need for including uncertainty levels, since the implementation of the information to be used for each case will have occurred from real data and not from indications.

Additional research is also required in the effectiveness results towards the daily operations. One major recommendation could be the close cooperation among various shipyards i.e. DAMEN, for retrieving essential information concerning KST harbour tugs effectiveness, under several types of operations and speeds. The results to be collected though the TUG simulator could provide tremendously important information, regarding the behaviour of tugs when operating as a forward or stern tug or during escorting, while at the same time they will provide the ability to proceed in an extra validation towards the resulted effectiveness of KST fleet. By adding all the above recommendations, the existing tool could be entirely qualified to optimize the daily operations of KST in the most efficient way.

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