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M.Sc. IN SHIPPING MANAGEMENT

INVESTIGATING THE RELATIONSHIP BETWEEN VESSELS SPEED AND FUEL PRICES USING AIS DATA

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To my mother

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Abstract

The main purpose of this thesis is to investigate the relationship between the sailing speed that vessels use in regards the fuels prices based on data from the Automatic Identification System (AIS). The speed of vessels affects the fuels consumption and their relationship can be described by a cubic function. Fuels consumption can be decreased up to 23% by decreasing vessel's speed by only one knot. The speed reduction is also expressed as speed optimization from the shipping companies as the best sailing speed for each voyage that must be selected based on the technical parameters of the vessel and the type of voyage. The two main departments that decide the speed of a vessel is the Technical department and the Operations department of shipping company. In order any vessel to sail with lower speed for a long-time many factors have to be considered. Vessels engines are manufactured to run smoothly under certain speed which is indicated by the manufacturer. Sailing in lower speed, outside the boundaries that manufacturer has set, leads to extra maintenance on the engine and several checks that must be added for the crew. Nowadays with the intelligence engines this has been minimized but also exist. In regards our analysis on how the fuel prices affect the vessels speed will be based on the information provided by the AIS from each ship like the ship speed, the ship type, the ship position, the ship IMO, the ship MMSI, etc. In order to extend our analysis extra variables will be used. In the end we will try to evaluate and explain the results of our research and identify extra variables that can be added on our analysis for better results.

Keywords: shipping companies, speed optimization, fuel consumption, Automatic Identification System (AIS), data analysis

Περίληψη

Ο κύριος σκοπός αυτής της εργασίας είναι να διερευνήσει την σχέση ανάμεσα στην ταχύτητα πλεύσης των πλοίων και τις τιμές των καυσίμων στηριζόμενη σε δεδομένα από το Αυτόματο Σύστημα Αναγνώρισης (AIS). Η ταχύτητα των πλοίων επηρεάζει την κατανάλωση των καυσίμων και η σχέση μεταξύ τους περιγράφεται από μια κυβική συνάρτηση. Η κατανάλωση των καυσίμων μπορεί να μειωθεί έως και 23% μειώνοντας την ταχύτητα του πλοίου μόνο κατά ένα κόμβο. Η μείωση της ταχύτητας εκφράζεται επίσης και ως βελτιστοποίηση της ταχύτητας από τις ναυτιλιακές εταιρείες καθώς η καλύτερη ταχύτητα πλεύσης για κάθε ταξίδι θα πρέπει να επιλεγεί βασιζόμενη στις τεχνικές παραμέτρους του πλοίου και στον τύπο του ταξιδιού. Τα δύο βασικότερα τμήματα μιας ναυτιλιακής εταιρείας που επιλέγουν την ταχύτητα πλεύσης του πλοίου είναι το Τεχνικό τμήμα (Technical Department) και το τμήμα Επιχειρήσεων (Operations department). Εάν ένα πλοίο αποφασιστεί να πλεύσει με χαμηλότερη ταχύτητα για ένα μεγάλο χρονικό διάστημα πολλοί παράγοντες πρέπει να ληφθούν υπόψη. Οι μηχανές των πλοίων είναι κατασκευασμένες να λειτουργούν ομαλά κάτω από συγκεκριμένη ταχύτητα η οποία ορίζεται από τον κατασκευαστή της μηχανής. Πλέοντας με χαμηλότερη ταχύτητα, έξω από τα όρια που έχει θέσει ο κατασκευαστής της μηχανής, έχει ως επακόλουθο η μηχανή να χρειάζεται επιπλέον συντήρηση και επιπλέον ελέγχους από το πλήρωμα. Στην σημερινή εποχή, με τις «έξυπνες μηχανές», αυτή η επιπλέον συντήρηση και οι επιπλέον έλεγχοι έχουν μειωθεί αλλά ακόμη υπάρχουν. Σχετικά με την ανάλυση μας για τον τρόπο επηρεασμού της ταχύτητας πλεύσης των πλοίων εν συνάρτησή των τιμών των καυσίμων, θα στηριχτεί στις πληροφορίες από το Αυτόματο Σύστημα Αναγνώρισης (AIS) των πλοίων μερικές εκ των οποίων είναι η ταχύτητας πλεύσης, ο τύπος του πλοίου, το IMO του πλοίου και το MMSI του πλοίου. Περισσότερες μεταβλητές πέραν των παρεχόμενων από το Αυτόματο Σύστημα Αναγνώρισης (AIS) θα χρησιμοποιηθούν για την περαιτέρω επέκταση της ανάλυσης μας. Στο τέλος αυτής της εργασίας θα προσπαθήσουμε να αξιολογήσουμε και να εξηγήσουμε τα αποτελέσματα της ερευνάς μας αναγνωρίζοντας επίσης επιπλέον μεταβλητές που θα μπορούσαν να προστεθούν στην ανάλυσή μας σε μελλοντικό χρόνο για την εξαγωγή καλύτερων αποτελεσμάτων.

Λέξεις κλειδιά: ναυτιλιακές εταιρείες, βελτιστοποίηση ταχύτητας, κατανάλωση καυσίμων, Αυτόματο Σύστημα Αναγνώρισης (AIS), ανάλυση δεδομένων

Contents

Introduction

In the past due to lack of the technologies that are used nowadays all the decisions related to the maritime sector and the shipping industry in general where based on the experience and the point of view of the persons that are related with the industry. In the last years, due to the information technology and the electronic systems that are installed on board of vessels this changed. More and more shipping companies extract conclusions for the next day based on the data gathered from the vessels in relations with the global economic data. In current paper we will analyze the relationship of the speed of vessels with the fuel prices using data from the Automatic Identification System (AIS). More specific we will investigate how the speed of the vessels is affected from the fuel prices for specific dates and how this relationship is affected from extra parameters like the vessel characteristics.

1.Vessel speed optimization

1.1 Introduction

Shipping plays an important role in the global economy, as almost 90% goods traded worldwide are transported by sea. Speed optimization of vessels or speed management has been an attractive topic in the shipping industry for a long time.

A shipping company have a number of departments like Operations department, Technical department, Finance department, Crew/Manning department etc. Two of the main departments that most companies have, the Operations and the Technical, are having a main role on deciding the best sailing speed for vessels. The Operations department has a role on the sailing speed of the vessel as its main goals are to maximize the economic and the safe deployment of the vessel (planning, scheduling, etc.) and to coordinate the needed processes with other departments, vessels, charterers, ports, agents, etc. The Technical department also has a role on the decision of the sailing speed of the vessel as its main responsibilities are to keep the vessel in a seaworthy condition, is responsible for vessel's maintenance and repairs and has an involvement on the new building projects.

The choice of the sailing speed of a vessel is most an operational decision as cannot be above the design speed and also must have a minimum speed in order to ensure safety. The term fleet deployment refers on how best a fleet could be used and the selection of speed is part of the deployment aspects (IMO, n.d.)[4].

Speed selection and speed optimization of a vessel for a specific voyage is a decision that contains the involvement of different departments of a shipping company in relation with external factors such as global economic factors such the price of fuels.

1.2 The cost of running ships

Vessels are one of the most used means for transporting goods around the globe. One of the main reasons that vessels are preferred among other means for transportation is that they can transfer big amounts of goods with a good transportation fee. Shipping companies are competing in giving the better price for transferring a cargo. In order to be competitive in a volatile industry like shipping industry their main goal is to minimize the costs of their running ships in order to have the opportunity in giving better transportation prices to their customer and maximize their profits.

The costs of running vessels may various related to ship type and year build but in general principles can be categorized. Costs can be categorized in Operating costs, Periodic maintenance costs, Voyage costs, Capital costs and Cargo-handling costs. Operating costs are the costs that constitute the expenses involved in the day-to-day running of the ship. Essentially those costs such as crew, stores and maintenance that will be incurred whatever trade the ship is engaged in. The periodic maintenance costs are incurred when the ship is dry-docked for major repairs, usually at the time of its special survey. In older ships this may involve considerable expenses, and it is not generally treated as a part of operating expenses. Voyage costs are all the costs associated with a specific voyage and include such items as fuel, port charges and canal dues. Capital costs express the way that the ship has been financed. Also, they may take the form of dividends to equity or interest and capital payments on debt finance. Last, Cargo-handling costs represent the expense of loading, stowing and discharging cargo that are particularly important in the liner trades. In practice all costs are volatile, depending on external developments such as changes in oil prices and the way the ship's owner manages and finances the business. Figure 1 summarizes the structure of costs.

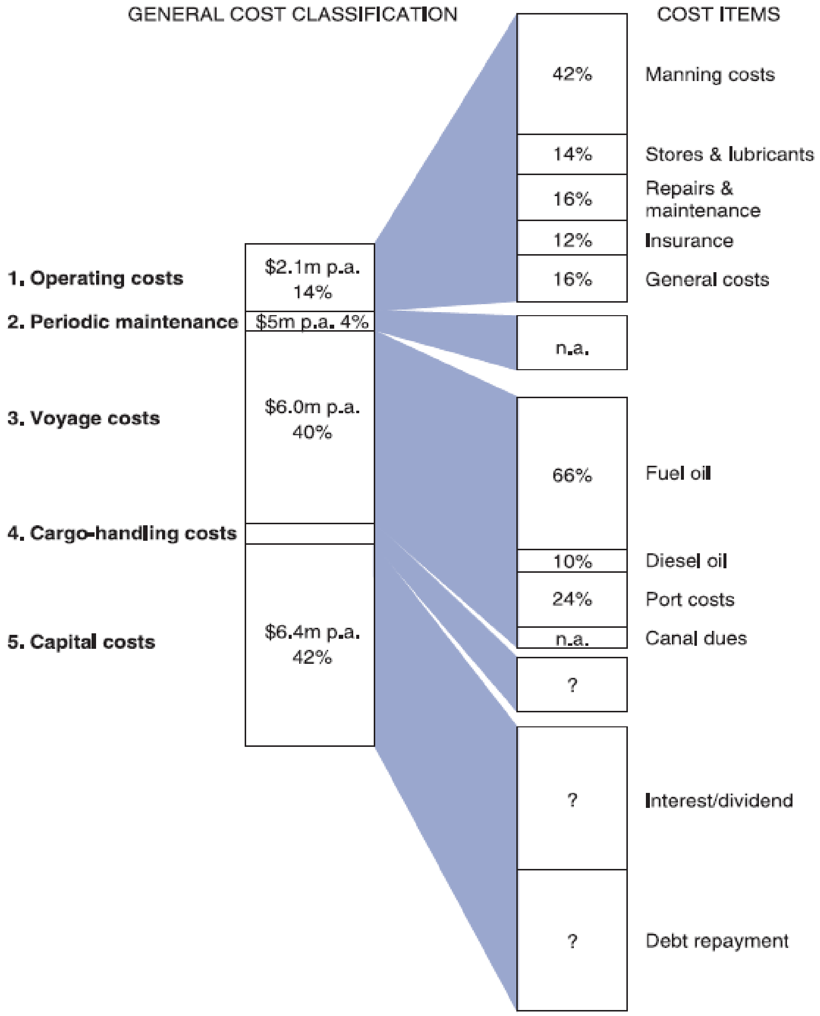

Figure 1: Analysis of the major costs of running a bulk carrier

Source: Compiled by Martin Stopford from various sources

Note: This analysis is for a 10-year-old Capesize bulk carrier under the Liberian flag at 2005 prices. Relative costs depend on many factors that change over time, so this is just a rough guide.

Each box in the diagram lists a major cost category, the variables which determine its value, and the percentage cost for a 10-year-old ship. The four main cost groups that are built up to determine an overall financial performance of the ship are the operating costs (14%), the periodic maintenance (4%), the voyage costs (40%) and the capital costs (42%). Taken together these costs determine the cost of sea transport and they are extremely volatile, as is evident from the trends in fuel, capital and other costs shown in Figure 1.1. Between 1965 and 2007 the ship cost index increased by 5.5% per year, compared with 4.6% for the US consumer price index. However, the ship cost index was far more volatile, driven by the wild swings in fuel and capital costs which together account for close to two–thirds of the total. (Stopford, 2009)[7]

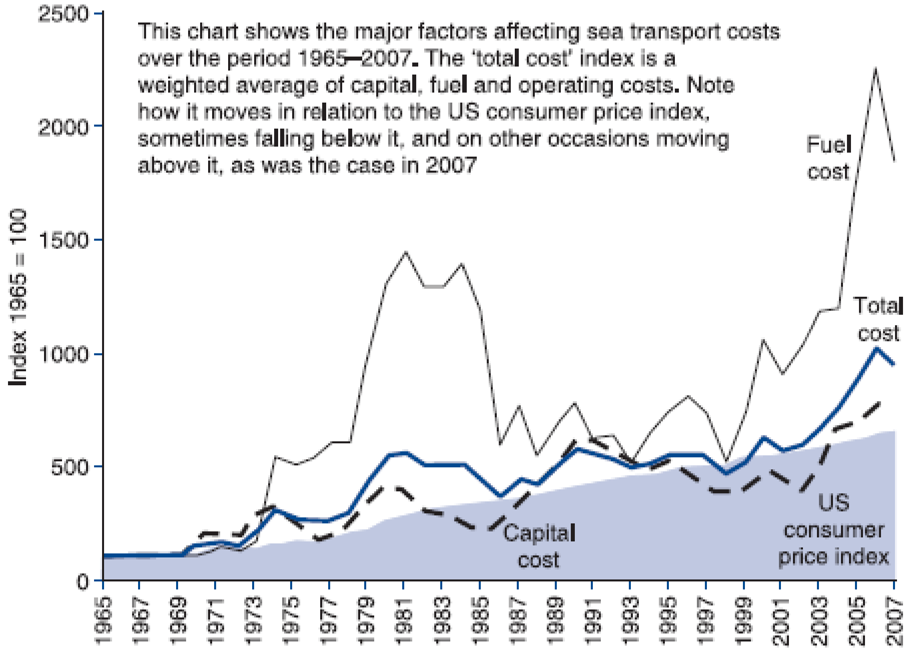

Figure 1.1 Inflation in shipping costs, 1965–2007

Source: Fuel costs based on marine bunker price 380 cSt, Rotterdam; capital costs based on aframax tanker newbuilding price (in $); other costs based on US consumer price index

1.3 <u>Fuel cost</u>

Fuel oil (bunkers) is the single most important item in voyage costs, accounting for 47% of the total. In the early 1970s when oil prices were low, less attention was paid to fuel costs in ship design and many large vessels were fitted with turbines, since the benefits of higher power output and lower maintenance costs outweighed their high fuel consumption. However, when oil prices rose during the 1970s, the whole balance of costs changed. During the period 1970–85, fuel prices increased by 950% (Figure 1.1). Leaving aside changes in the fuel efficiency of vessels, this meant that, if fuel accounted for about 13% of total ship costs in 1970, by 1985 it had increased to 34%, more than any other individual item. As a result, resources were poured into designing more fuel-efficient ships and operating practices were adjusted, so that bunker consumption by the shipping industry fell sharply. In 1986 the price of bunkers fell and the level of interest in this aspect of ship design reduced, but in 2000 bunker prices started to increase again (Figure 1.1) and the importance of fuel costs increased.

The shipping industry's response to these extreme changes in bunker prices provides a good example of how the design of ships responds to changes in costs. Although shipping companies cannot control fuel prices, they have some influence on the level of fuel consumption. Like any other piece of complex machinery, the fuel a ship burns depends on its design and the care with which it is operated. To appreciate the opportunities for improving the fuel efficiency of ships it is necessary to understand how energy is used in the ship. Take, for example, a typical Panamax bulk carrier, illustrated in Figure 1.2.

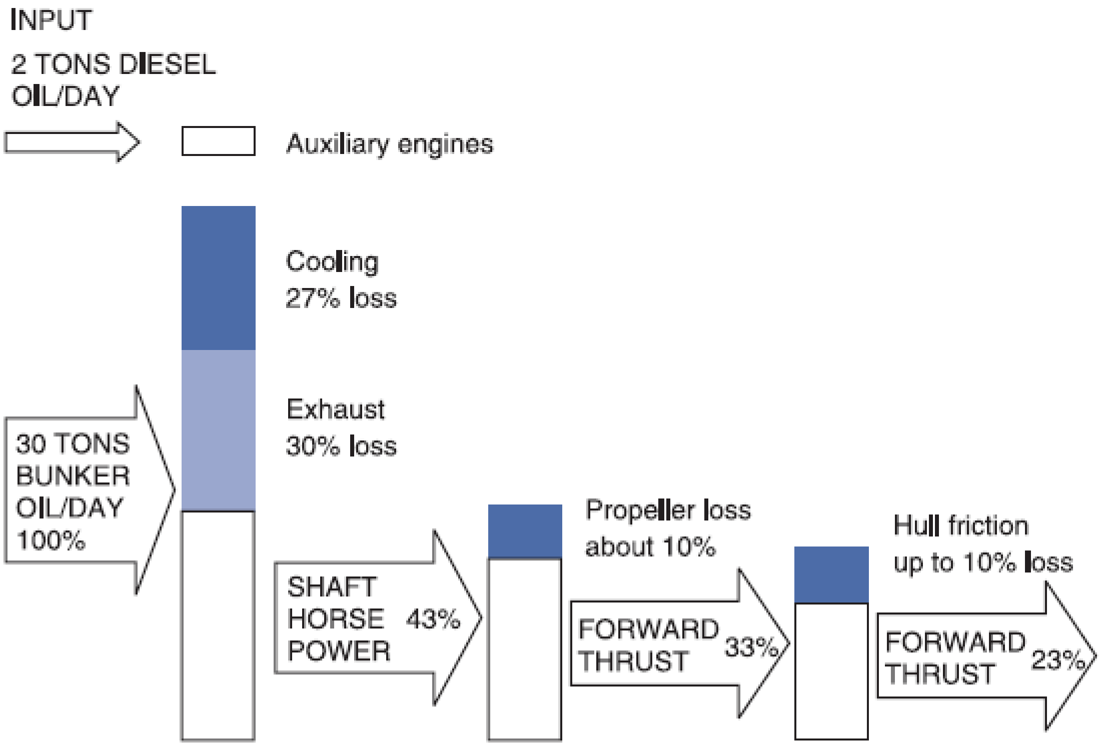

Figure 1.2: Energy losses in typical 1990s built Panamax bulk carrier

Source: (Stopford, 2009)[7]

At a speed of 14 knots it consumes 30 tons of bunker oil and 2 tons of diesel oil in a day. Approximately 27% of this energy is lost in cooling the engine, 30% is lost as exhaust emission, 10% is lost at the propeller, and hull friction accounts for an additional 10%. Only a residual 23% of the energy consumed is actually applied moving the vessel. This simplified view of a complex process it identifies the areas where technical improvements can be made and these are the main engine, the hull and the propeller. The range of the improvement can be identified by the fact that ships built in the 1970s typically consumed 10 tons per day more fuel than ships built in later years to achieve the same speed.

The design of the main engine is the single most important influence on fuel consumption. Following the 1973 oil price rises, and particularly since 1979, there were major improvements in the thermal efficiency of marine diesel engines. Between 1979 and 1983 the efficiency of energy conversion in slow-speed marine diesel engines improved from about 150 grams per brake horsepower per hour to around 127 grams per brake horsepower per hour. In addition, to lower fuel consumption, engine operating speeds were reduced to below 100 rpm, making it possible to use more efficient large-diameter, slow-speed propellers without installing a gear box. The ability to burn low-quality fuel was also improved. In some cases, the fuel savings achieved were quite spectacular. Diesel-powered 300,000 dwt VLCCs built in 2005 consumed 68 tons of bunkers a day at 15 knots, compared with fuel consumption of 130–150 tons per day by turbine-powered vessels built in the 1970s.

Fitting auxiliary equipment also improved the fuel efficiency. This accomplished by installing waste heat systems, which use some of the heat from the exhaust of the main engines to power a boiler that drives the auxiliary engines when the main engine is running, thus saving diesel oil. Another method for using auxiliary equipment is to use generators powered direct from the main engine while the vessel is at sea. In that way the auxiliary power is obtained from the more efficient main engine rather than a small auxiliary engine burning expensive diesel fuel.

In theory, the ship's fuel consumption depends on its hull condition and the speed at which it is operated. When a ship is designed, naval architects optimize the hull and power plant to a prescribed design speed which may be, for example, 15 knots for a bulk carrier or 18 knots for a small container ship. Operation of the vessel at lower speeds results in fuel savings because of the reduced water resistance, which, according to the 'cube rule', will be approximately proportional to the cube of the proportional reduction in speed:

$$F = F^{*}\left(\frac{S}{S^{*}}\right)^{a}$$

where F is the actual fuel consumption (tons/day), S the actual speed, F* the design fuel consumption, and S* the design speed. The exponent a has a value of about 3 for diesel engines and about 2 for steam turbines. This type follows from the cube rule (or square-cube law) which states that when an object undergoes a proportional increase in size, its new surface area is proportional to the square of the multiplier and its new volume is proportional to the cube of the multiplier. The above type in regards vessels speed and fuel consumption express that the level of fuel consumption is very sensitive to speed. For example, for a Panamax bulk carrier a reduction in the operating speed of 16 knots to 11 knots results in a two-thirds saving in the tonnage of fuel burnt per day, as shown in Table 1.

Speed knots	Main engine fuel consumption tons/day
16	44
15	36
14	30
13	24
12	19
11	14

Table 1: How speed affects fuel consumption for a panama bulk carrier

Source: (Stopford, 2009)[7]

For any given speed, fuel consumption depends on hull design and hull smoothness. According to work carried out by British Maritime Technology, a reduction in hull roughness from 300 micrometers to 50 micrometers can save 13% on the fuel bill. Between dry docking, marine growth on the hull of the ship increases its water resistance, reducing the achievable speed by 2 or 3 knots in extreme cases. Even with regular dry docking, as the ship ages its hull becomes less smooth as the hull has been scraped and repainted many times. Self-polishing coatings and anti-fouling, which release a poison to kill marine growth and reduce hull fouling between dry dockings, are now widely used but are expensive to apply and have a limited life.

As a result of these factors there can be a wide inequality between the fuel consumption of vessels of a similar size and speed. For example, the fuel consumption of two Panamax bulk carriers operating at the same speed could differ by 20–30% depending on age, machinery and hull condition. Obviously, the cost importance of this difference in efficiency depends on the price of fuel. (Stopford, 2009)[7]

1.4 Slow steaming

One of the most applied and oldest measures for fuel saving in shipping industry was to reduce the ship speed. This parameter has the greatest effect on ship fuel consumption, which is a cubic function of ship speed as we mentioned on the previous chapter. As a result, reducing ship speed is an effective way to reduce fuel consumption. Speed reduction can result in energy savings up to 23% and decreasing the ship's speed by only 1kn could save more than 5% of the energy consumption (Table 1.1) (Chaal, 2018)[2].

Speed reduction	Saving energy consumption
-0.5 kn	-7%
-1 kn	-11%
-2 kn	-17%
-3 kn	-23%

Table 1.1: Reduction of consumption according to the decrease in speed

So, sailing at the optimal speed for each ship condition is an extremely effective energy efficiency operational measure.

Slow steaming is a process of reducing the speed of cargo/tanker ships on purpose in order to cut down fuel consumption. In slow steaming, a container ship travels at a speed of around 12-19 knots instead of the usual 20-24 knots. This has as a result the reduction of engine power and proportionally the fuel consumption. Slow steaming has successfully helped ship owners in reducing the amount of fuel needed to run ships reducing their costs. Slow steaming has been adopted by majority of companies and ship owners in order to survive in the tough times of rising fuel prices and financial recession. (Sanguri, 2012)[6]

The major benefits of slow steaming have been:

- Higher fuel savings
- Reduction in carbon emissions (CO2, NOx and Sox)
- Improved reliability
- Increased efficiency

Slow steaming is not a regular affair for a marine engineer as they have not been trained for it so efforts have to be made to remove the traditional mindset and reluctance of the engine staff and retrain them. In addition, additional routines and inspections of the Main Engine must be added, which is operating outside its designed optimal range. Marine engineers have always been advised by engine manufacturers that low load operation must be avoided. The engines must be run close to its continuous rating for optimization of all its parameters and allowing the individual components to operate in their designed range. Slow steaming create many concerns for a chief engineer.

Among the basic tasks that a chief engineer has to deal with more tasks must be added in order slow steaming to be supported with the less issues. The issues that may occur from slow steaming are various from the technical perspective. Frequent and thorough scavenge and under piston inspections must be carried out. Cylinder liners must be checked for over lubrication unless a load dependent cylinder lubrication system is suited for slow steaming according to the optimal value of the cylinder lubrication rate that is defined from the manufacturer. Extra attention must be carried out in regards the turbochargers which may be fouled and cause loss of efficiency. Also, the operation of turbochargers outside their designed range produce less air flow leading to more deposits. The carbon deposits on the injectors will be increased influencing their performance. The exhaust gas economizer will be fouled having as result the reduction of capacity along with the increasing of danger of causing fire. The scavenge air pressure will be reduced resulting in improper combustion. Improper atomization of the fuel will be caused as well as impingement. Increased carbon deposits will be caused creating the need for modification to the maintenance intervals. The gas temperatures will be low which may cause low temperature corrosion. The compression pressure may be reduced and must be handled accordingly in that case. Changing the state of the engine at full load after a long period of slow steaming will occur damages and become imminent. The piston ring pack efficiency will be influenced resulting to increase under piston and scavenge deposits. Another critical cause is that the risk of scavenge fires will be increased which will need extra scavenge and under piston area draining. The loss of heat transfer will be caused by slow steaming due to carbon deposits and failure of components due to thermal stresses. Last, reduction in the efficiency of the economizer will be caused creating the need of oil fired boiler to operate which will add to extra cost and maintenance.

Many companies are using the option of slow steaming to save fuel costs at available opportunities. In the bulk carrier market, it is normal to instruct the ship to move at slow or economy speed towards certain destination until the charter is finalized. Sometimes the charters also demand that the vessel should proceed at slow steaming and a relevant clause is inserted in the charter party. Normally, ships have a speed vs consumption table at various RPM in ballast and loaded condition. It is a usual practice that the charterers ask for this data prior to fixing the charter party.

In today’s scenario the charterers may also ask for slow steaming data. In cases when a long anchorage is expected or when the cargo is not time sensitive, it may be profitable to the charterer to run the ship as slowly as possible to save fuel as well as anchoring costs. It is the duty of marine engineers to ensure that the main engine is run properly without compromising the safety and preventing long term damage. Therefore, a correct and safe economical speed per RPM has to be told to the charterers while finalizing the voyage. Many times, in the event of insufficient data as in old ships, a sea trial has to be done to find the eco speed per RPM and fuel consumption. (Sanguri, 2012)[6]

1.4.1 Optimization of Ship's Main Engine

Low speed marine engines are not traditionally suited for constant slow steaming as a result a number of measures need to be taken in case slow steaming operations are adopted without modification. In order to adopt slow steaming checks need to be done, additional maintenance is required and precautions are to be taken so that there are no long-term damages to the machinery.

Traditionally main engines are designed to run between 70 % to 85 % load range during continuous operation. The matching and designing of all the auxiliaries rely on this load range operation. The exhaust boiler size (surface area) is set in order to support the exhaust temperature, volume of exhaust gas flow and also the waste heat recovery for this range. Low load operation makes this waste heat recovery system ineffective as a result of less production of steam, which increases the load on the oil-fired boiler. The air cooler size (surface area) is chosen to support the heat load of the air in this operating range. During low load operation the cooling water to the air cooler must be controlled by bypassing the cooler and throttling the water valves in order to maintain optimum scavenge air temperature. An excessive amount of throttling of the water valves reduces the flow velocity of the cooling water thereby increasing the deposit rates of the precipitants, resulting in fouling and contamination of tubes. The turbocharger selection and matching to the main engine is calculated from the enthalpy of the exhaust gas that has to be extracted. Also, the quantity of the scavenge air that needs to be supplied to the cylinders for optimum combustion is another significant criterion. The turbocharger is chosen for the traditional running load range of 70 to 85 %. Low load operations of the main engine result in lower running RPM of the turbocharger and fewer generation of scavenge air. This results in ineffective and incomplete combustion, increased fouling and makes the cleaning measures like dry grit cleaning of the turbine ineffective. The propeller is manufactured to give maximum efficiency for the RPM in this range. Also, lower RPM may affect the propeller efficiency and the Specific fuel oil Consumption (SFOC) is optimized for running in this range. Even though the fuel consumption is lower in totality, the SFOC is higher at part loads as injection and combustion is not proper. The fuel injectors and fuel pumps are designed for this range thus the atomization and penetration could also be effected at low load operation. Other parameters that are affected are the operating parameters and their alarm and monitoring system which are designed for this range. The hydrodynamic lubrication is RPM dependent and the grade of oil and its properties like oiliness are selected for this range. The shaft generators are designed and selected based on this range. Low load operation may make shaft generators unusable.

Closing, for running the main engine below its normal operating range of 70 to 85 % Maximum Continuous Rating (MCR), the whole system needs to be optimized. Generally, it is known that if engine modifications and retrofitting is done on the main engine, then it is safe for slow steaming as well as ultra-slow streaming. Slow steaming up to 50 to 55 % load can be done on most engines without harm in long term if certain precautions are taken. That generally is the point above where the auxiliary blowers cut in. (Sanguri, 2012)[6]

1.4.2 Slow Steaming for Ships: Checks and Precautions

As mentioned in the previous chapter the main engines are designed to run between 75 % to 85% load range during continuous operation. In order to run the ship's engine for slow steaming, a number of precautions need to be taken.

Generally, in traditional marine engines (except intelligent engines) few checks are needed to be made if low load operations are carried out. These checks will be added on the daily inspections program. Frequent scavenge inspection and under piston area inspections must be carried out. The piston rings must be checked for breakage, fouling and lack of springiness. The exhaust boiler must be inspected and cleaned more frequently. Procedures for checking cylinder lubrication rate and inspect liners and piston for over and under lubrication and scuffing have to added. Turbocharger RPM along with the scavenge air pressure need regular checks as any drop in RPM or the scavenge air pressure at same load may indicate fouling of the turbocharger. Regular checks also must be made on the temperature difference of the exhaust gas between the inlet and the outlet of the turbocharger which may indicate fouling of the turbine. The funnel stack temperature after the exhaust gas boiler is also a temperature that must be recorder and checked as any gradual increase in the temperature at same load and decrease in steam pressure may indicate fouling of the exhaust boiler tubes or any sudden increase many indicate a minor fire. Last draining of the air cooler water must be made frequently. (Sanguri, 2012)[6]

1.4.3 Precautions and Maintenance for Slow Steaming of Ships

It is commonly accepted that most breakdowns related to slow steaming occur not during slow steaming itself but when the engine is again operated in the normal range.

In order to avoid any breakdown when the main engine is again put back to normal operating mode, certain technical precautions and routines have to be carried out diligently during slow steaming. Dry washing of the turbine wheel and washing of the compressor must be carried out during the load up. The soot that is deposited on the internal furnace tubes of the Exhaust Gas Boiler must be removed in order to prevent plugging of the gas passes and maintain boiler. This is and additional task that must be carried out during this period. Water condensation in air coolers must be avoided and scavenge air temperature must be kept around 40ºC to 45ºC. Hot well temperature must be maintained using cooling water control of the condenser and directly allowing some condensate to the hot well by bypass valve. Correct cylinder oil feed rate with the correct and higher base number must be used as it is recommended by the manufacturer. Fuel injectors will need better maintenance in better intervals as there is an increased fouling and dripping chances during slow steaming. The low exhaust temperatures may cause corrosion so appropriate measures must be taken in order exhaust temperature after the cylinder not to drop below 250º C. The exhaust gas boiler and extra soot blowing routines must be washed frequently. The fuel in main engine must be of viscosity between 12 to 13 cst. Higher LT (Low temperature) temperature must be maintained in central cooling plants for optimum scavenge temperature. Fresh Water Generator may need to be bypassed to maintain Jacket[1] temperature on some ships. Auxiliary blower must be continuously kept on (in manual mode) to avoid elevated exhaust temperatures after the cut off and before the cut in period. Exhaust temperatures above 450º C can cause hot corrosion and burning of exhaust valves. Last, low load operation can cause non burnt fuel and cylinder oil to be accumulated in the exhaust manifold and may suddenly burn causing subsequent over speeding and damage of the turbocharger when load is increased again. So, carry out frequent exhaust manifold inspections, is necessary. (Sanguri, 2012)[6]

[1] A water jacket is a water-filled casing surrounding a device, typically a metal sheath having intake and outlet vents to allow water to be pumped through and circulated. The flow of water to an external heating or cooling device allows precise temperature control of the device. - https://en.wikipedia.org/wiki/Water_jacket

1.5 Conclusion

Fuel oil is one of the main costs of a running ship and any decrease on this cost will increase the profit of shipping companies. The two main departments in a shipping company that manage the fuel oil (bunkers) of the vessels is the Operation and Technical Department. The Operation department is responsible for coordinating the feed of the vessel with bunkers at the best price with the best quality and Technical is responsible for the engines of the vessel to run smoothly without issues. The Operation department supply the vessel with the bunkers and the Technical "consume" the bunkers in the most efficient way by using it for the engines of the vessel producing the desirable power.

Most of the companies, based on literature, follow a common rule. This rule is related with the consumption of fuel oil and declares that when the fuel prices are high the shipping companies decrease the speed of their vessels in order to decrease the consumption of fuel oil and maximize their profits. Based on the cube rule is a fact that by decreasing the speed of a vessel the fuel consumption will be decreased resulting in very good results regards the fuel consumption.

In maritime the decrease of vessels speed for decreasing the fuel consumption is known a slow steaming. Slow steaming for a long period may cause issues to the vessel's engines and mostly to the main engine. The crew that was responsible for the operation of the main engine, had to add several tasks on daily basis related with the main engine if the vessel was sailing under low steaming. These tasks may change the last years due to the intelligence engines but several of them still exist but may be managed in another way. So, slow steaming adding extra work for the onboard personnel and more procedures are developed in order to cover the safe operation of the vessel under slow steaming.

Fuel oil is a big cost for vessels and slow steaming is one of the oldest methods used by the shipping companies for reducing the fuel oil consumption and maximize their profit.

2. Automatic Identification System (AIS)

2.1 The adoption of AIS

Automatic identification systems (AIS) are designed in order to provide information about the ship to other ships and to coastal authorities automatically. Regulation 19 of SOLAS Chapter V

- Carriage requirements for shipborne navigational systems and equipment - sets out navigational equipment to be carried on board ships, according to ship type. In 2000, IMO adopted a new requirement (as part of a revised new chapter V) for all ships to carry automatic identification systems (AISs) capable of providing information about the ship to other ships and to coastal authorities automatically.

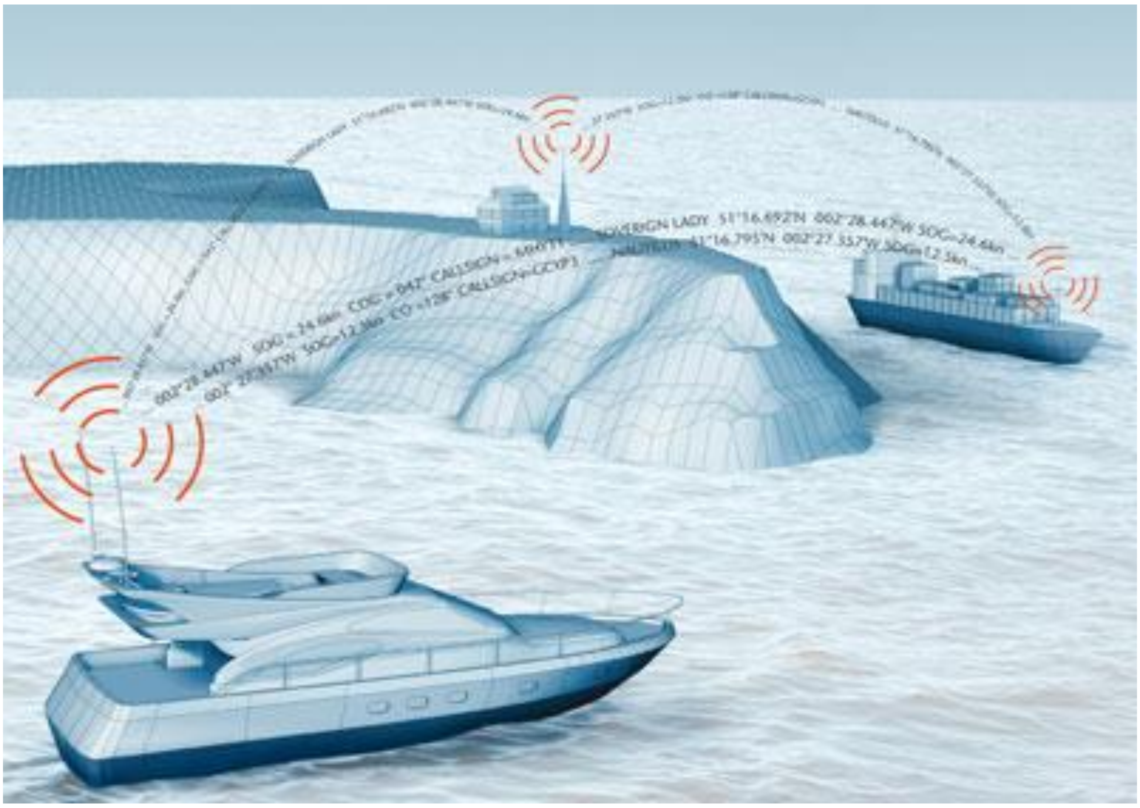

Figure 2: AIS reporting
Source: IMO - Automatic Identification Systems (AIS)

The regulation requires AIS to be fitted aboard all ships of 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages and all passenger ships irrespective of size. The requirement became effective for all ships by 31 December 2004. Ships fitted with AIS shall maintain AIS in operation at all times except where international agreements, rules or standards provide for the protection of navigational information. A flag State may exempt ships from carrying AISs when ships will be taken permanently out of service within two years after the implementation date. Performance standards for AIS were adopted in 1998. The regulation requires that AIS shall provide information - including the ship's identity, type, position, course, speed, navigational status and other safety-related information - automatically to appropriately equipped shore stations, other ships and aircraft. Also, requires that such information must be received automatically with the intention to monitor and track the ships. Last, all the data must be exchanged with shore-based facilities.

The regulation applies to ships built on or after 1 July 2002 and to ships engaged on international voyages constructed before 1 July 2002. In this category belong the passenger ships, not later than 1 July 2003, the tankers, not later than the first survey for safety equipment on or after 1 July 2003 and any ships, other than passenger ships and tankers, of 50,000 gross tonnage and upwards, not later than 1 July 2004. An amendment adopted by the Diplomatic Conference on Maritime Security in December 2002 states that, additionally, ships of 300 gross tonnage and upwards but less than 50,000 gross tonnage, are required to fit AIS not later than the first safety equipment survey after 1 July 2004 or by 31 December 2004, whichever occurs earlier. (The original regulation adopted in 2000 exempted these vessels.) (IMO, n.d.)[5]

2.2 Maritime security - AIS ship data

At its 79th session in December 2004, the Maritime Safety Committee (MSC) agreed that, in relation to the issue of freely available automatic information system (AIS)-generated ship data on the world-wide web, the publication on the world-wide web or elsewhere of AIS data transmitted by ships could be detrimental to the safety and security of ships and port facilities and was undermining the efforts of the Organization and its Member States to enhance the safety of navigation and security in the international maritime transport sector.

The Committee condemned the regrettable publication on the world-wide web, or elsewhere, of AIS data transmitted by ships and urged Member Governments, subject to the provisions of their national laws, to discourage those who make available AIS data to others for publication on the world-wide web, or elsewhere from doing so.

In addition, the Committee condemned those who irresponsibly publish AIS data transmitted by ships on the world-wide web, or elsewhere, particularly if they offer services to the shipping and port industries. (IMO, n.d.)[5]

2.3 AIS equipment

AIS is based on the use of dedicated equipment that should be installed aboard (vessel stations), ashore (base stations) or on dedicated satellites (AIS-SAT). Vessels are equipped with transponders, e.g., stations that send and receive AIS messages. Transponders can either be class A or class B and have an integrated GPS that tracks the movement of the vessel it is installed on. The differences between class A and class B transponders will be presented in the next section. Base stations that are installed ashore are equipped with AIS receivers that receive AIS messages from vessels, but do not transmit. Dedicated satellites are also equipped with AIS receivers and this is very useful for areas with no or low coastal coverage (i.e., with no AIS receiver nearby).

Since 2004, the International Maritime Organization (IMO) requires that all commercial vessels over 300 Gross Tonnage (GT) travelling internationally to carry a Class A AIS transponder aboard. Vessels that do meet these requirements (e.g., smaller vessels, pleasure crafts, etc.) can be equipped with Class B AIS transponders. This requirement of IMO followed the 2002 SOLAS (Safety of Life at Sea) agreement's relative mandate.

AIS transponders use two dedicated VHF channels, AIS-1 (161.975 Mhz) and AIS-2 (162.025 Mhz). Class A transponders implement the Self Organizing Time Division Multiple Access (SOTDMA) protocol. The SOTDMA protocol is based on the division of time in slots. More specifically, a second is divided into 2250 slots, which means that base stations can receive at most one transmission every 26.67 ms. Each vessel should reserve a dedicated time slot in order to transmit an AIS message so that no other vessel transmits at the same time.

Class B transponders use the CSTDMA (Carrier Sense Time Division Multiple Access) protocol which interweaves with Class A transmissions by giving priority to SOTDMA transmissions. (Artikis & Zissis, 2020)

2.4 AIS messages

AIS messages are distinguished on the following two categories: dynamic and static. Dynamic messages contain positional data about voyages. Static messages contain information related to vessel characteristics. The information (e.g., flag) changes less frequently than the respective information included in static messages. The information contained in both types of AIS messages is described below.

2.4.1 Dynamic AIS messages

The dynamic AIS messages contain multiple attributes which give us multiple information. Maritime Mobile Service Identity Number (MMSI) of the vessel is broadcasted through the AIS dynamic messages along with the rate of turn, speed over ground, position coordinates, course over ground, heading, UTC seconds, AIS navigational status.

The MMSI is an identification number for each vessel station. However, it is not a unique identifier. Rate of Turn field contains data regarding the angle that the vessel turns right or left per minute. The values of this field range from 0 to 720 degrees. Speed over ground is the speed of the ship with respect to the ground. The value range of this attribute is from 0 to 102 knots (0.1-knot resolution). Position Coordinates field contains the latitude and the longitude of the position of the vessel. Course over Ground (COG) describes the direction of motion with respect to the ground that a vessel has moved relative to the magnetic north pole or geographic north pole. The values are degrees up to 0.1^o relative to true north. Heading describes the direction that a vessel is pointed at any time relative to the magnetic north pole or geographic north pole and takes values from 0 to 359 degrees. UTC seconds is the second part of the timestamp when the subject datapacket was generated (in UTC time). AIS Navigational status field represents the navigational status of the vessel and it is completed manually by the crew. Some of the different types of navigational status that can be reported in an AIS message are Under way using engine, Anchored, Not under command etc (Table 3.2). Some of the values of navigational status are reserved for future use. For example, there is a placeholder for future amendment of navigational status for ships carrying dangerous goods (DG), harmful substances (HS), marine pollutants (MP) or IMO hazard or pollutant categories, high-speed craft (HSC), and wing in ground (WIG). (Artikis & Zissis, 2020)[1]

2.4.2 Static AIS messages

Static information is provided by a subject vessel's crew and is transmitted every 6 minutes regardless of the vessel's movement status. The static AIS messages contain the fields International Maritime Organization number (IMO), Call Sign, Name, Type, Dimensions, Location of the positioning system's antenna on-board the vessel, Type of positioning system, Draught, Destination and Estimated time of arrival (ETA).

International Maritime Organization number (IMO) is a 9-digit number that uniquely identifies the vessel. Please note that this is not the same as the MMSI. The IMO number is assigned by IHS

Maritime (Information Handling Services) when the vessel was constructed[2]. The MMSI can change, for example when the owner changes. Only propelled, seagoing vessels of 100 gross tons and above are assigned an IMO number. Call Sign is the international radio call sign assigned to the vessel by her country of registry. Name is the name of the vessel. The type of the vessel based on specific codes as we will see. Dimensions are the dimensions of the ship in meters. More specifically, this field refers to: (a) dimension to bow, (b) dimension to stern, (c) dimension to port (left side of the vessel when facing the bow), and (d) dimension to starboard (i.e., right side of the vessel when facing the bow). The location of the positioning system's antenna on-board the vessel is the position of the AIS antenna on board the vessel. The type of positioning system (GPS, DGPS, Loran-C) define the type of the system used for positioning. Differential GPS (DGPS) is a positioning system that performs positional corrections to GPS, providing more accurate positioning data. Loran-C (Long-range navigation) is a hyperbolic radio navigation system that allows a receiver to determine its position by listening to low frequency radio signals transmitted by fixed land-based radio beacons. Although Loran-C system is old, it can be used as backup system to the GPS, since GPS can be spoofed or jammed. Draught is the term which refers to the vertical distance between the waterline and the bottom of the hull (keel), with the thickness of the hull included and the value of this field is measured in meters. The destination field is the destination of the vessel as completed manually by the crew of the subject vessel (free text). The estimated time of arrival (ETA) is a UTC timestamp completed manually by the crew indicating the estimated time of arrival at destination.

[2] https://ihsmarkit.com/products/imo-ship-company.html

Data	Class A (receive)	Class B (send)	Class B (receive)
Call Sign	Yes	Yes	Yes
IMO	Yes	No	No
Length and beam	Yes	Yes	Yes
Antenna location	Yes	Yes	Yes
Draught	Yes	No	No
Cargo information	Yes	Yes	Yes
Destination	Yes	No	No
Estimated Time of Arrival	Yes	No	No
Time	Yes	Yes	Yes
Ship's position	Yes	Yes	Yes
Course Over Ground	Yes	Yes	Yes
Speed Over Ground	Yes	Yes	Yes
Gyro heading	Yes	Yes	Yes
Rate of turn	Yes	No	No
Navigational status	Yes	No	No
Safety message	Yes	No	Yes

Table 2: Attributes of AIS messages exchanged using Class A and Class B

Source: (Artikis & Zissis, 2020)

Ship's dynamic conditions	Reporting rate
Anchored/Moored	3 minutes
0-14 knots	10 seconds
0-14 knots and changing course	3.33 seconds
14-23 knots	6 seconds
14-23 knots and changing course	2 seconds
Faster than 23 knots	2 seconds
Faster than 23 knots and changing course	2 seconds

Table 2.1: Class A systems

Source: (Artikis & Zissis, 2020)

There are some differences exchanged between vessels with class A and class B transponders, as shown in Table 2. For example, most of the vessels for which it is not mandatory to have class A transponders do not have an IMO, so this attribute is not used in messages sent from class B transponders. Rate of turn, navigational status, destination and ETA reports are also attributes that are not used in Class B AIS messages.

Ship's dynamic conditions	Reporting rate
0-2 knots	3 minutes
Above 2 knots	30 seconds

Table 2.3: Class B systems

Source: (Artikis & Zissis, 2020)

Special conditions	Reporting rate
Search and Rescue (SAR) aircraft	10 seconds
Aids to navigation	3 minutes
AIS base station	10 seconds or 3.33 second

Table 2.4 Other AIS sources

Source: (Artikis & Zissis, 2020)

Also, vessels with class B transponders do not transmit but are able to receive AIS messages related to safety. Tables 2.2, 2.3, and 2.4 describe the reporting rates of vessels with class A and class B transponders. The AIS reporting rates of vessels depend on their navigational status (e.g., whether they are underway using engine or moored), their speed and course changes, and whether they are equipped with class A or class B transponders. Both class A and class B vessels that are anchored/moored or move very slow (up to 2 knots) send AIS messages every 3 minutes. Class B vessels with speed more than 2 knots send messages every 30 seconds, while class A have higher reporting rate that increases as the vessel accelerates and/or it is changing course. For example, a class A vessel that navigates with speed up to 14 knots needs to send AIS messages every 10 seconds. (Artikis & Zissis, 2020)[1]

2.5 Example dataset

We provide example AIS messages through sample data of a dataset that is publicly available[3]. Table 2.5 shows a sample of static AIS messages that contains the following attributes: MMSI, IMO, Call sign, Name, Type (the code corresponding to the vessel type), Dimension to bow, Dimension to stern, Dimension to port, Dimension to Starboard, Estimated arrival time (ETA), Draught, Destination, and the timestamp when the AIS message was received by an AIS receiver (e.g., terrestrial, satellite, or an AIS transceiver installed aboard the vessel). It is apparent from the

ipp[3] https://zenodo.org/record/1167595#.XQtPIY9RUuU table that some fields may be missing in some messages (e.g., destination in messages 2 and 4), or invalid in other (e.g., draught reported in messages 2 and 4). Table 2.6 depicts sample dynamic AIS messages from the same dataset. The dynamic messages contain the following attributes: MMSI, the code that corresponds to the navigational status of the vessel, the rate of turn, the speed over ground, the course over ground, the heading, the location of the vessel (longitude and latitude dimensions), and the timestamp.

MMSI	304091000	228037600	228064900	227705102
IMO	9509255	0	8304816	262144
Call sign	V2GU5	FIHX	FITO	FGD5860
Ship name	HC JETTE-MARIT	AEROUANT BREIZH	VN SAPEUR	BINDY
Ship type	70	30	51	60
To bow	130	6	21	9
To stern	30	9	54	26
To starboard	18	5	10	5
To port	6	2	6	4
ETA	04-09 20:00	00-00 24:60	29-09 12:00	00-00 24:60
Draught	10.1	0	5.9	0
Destination	BREST		RADE DE BREST	
Time	1443650423	1443650457	1443650471	1443650474

Table 2.5 Example of static AIS messages

Source: (Artikis & Zissis, 2020)

MMSI	245257000	227705102	228131600	228051000	227574020
Navigational Status	0	15	15	0	15
Rate of Turn	0	-127	-127	-127	-127
Speed Over Ground	0.1	0	8.5	0	0.1
Course Over Ground	13.1	262.7	263.7	295	248.6
Heading	36	511	511	511	511
Longitude	-4.4657183	-4.4965715	-4.644325	-4.4851084	-4.4954414
Latitude	48.38249	48.38242	48.092247	48.38132	48.38366
Time	1443650402	1443650403	1443650404	1443650405	1443650406

Table 2.6 Example of dynamic AIS messages

Source: (Artikis & Zissis, 2020)

2.6 AIS Processing Difficulties and Challenges

The Automatic Identification System was initially designed to allow vessels to provide ship information automatically to other ships in the vicinity and to maritime authorities. The aim was to assist vessel's officers on the watch and coastal authorities to track maritime traffic and thus, reduce collision risk and improve the overall safety at sea. With the vast proliferation of vessel tracking systems, AIS has been used for vessel tracking services at a global scale. Such systems collect streams of AIS messages transmitted from the world's fleet and provide global ship tracking intelligence services such as those of MarineTraffic[4]. Figure 2.1 illustrates the density map of vessel traffic and highlights one of the capabilities the AIS tracking systems can offer.

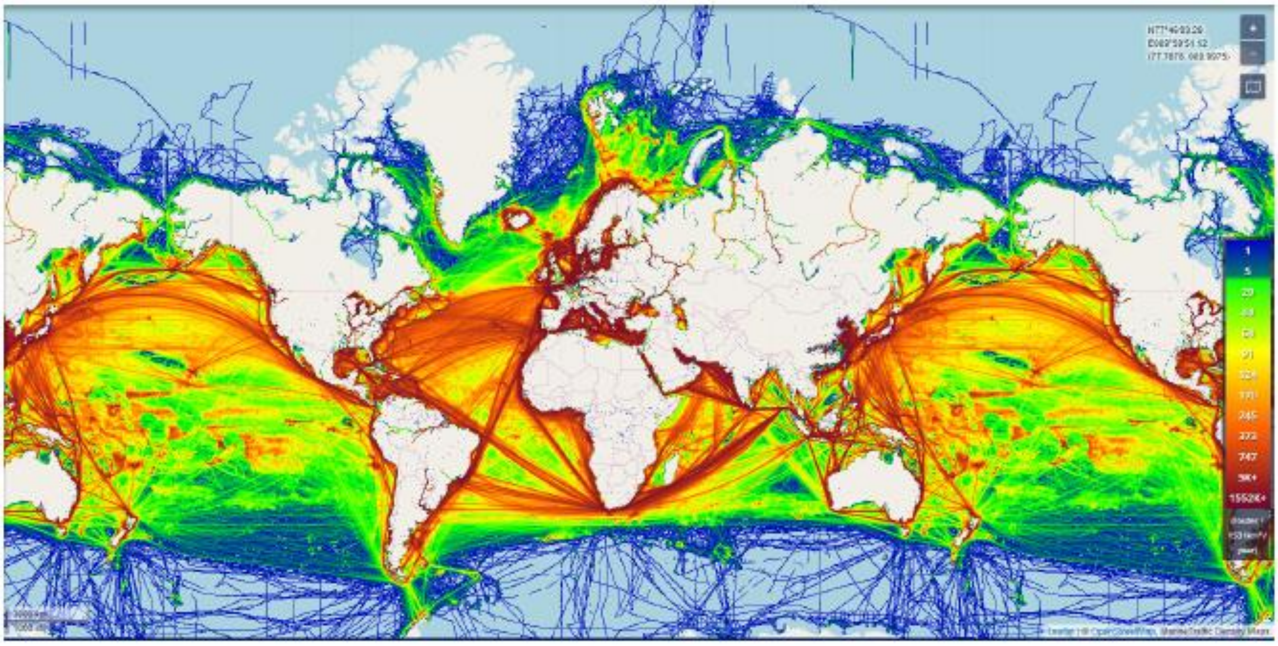

Figure 2.1: Density maps layer of MarineTraffic's services.

However, since the initial purpose of the AIS communication system was not tracking vessels and their activities globally, some inherent characteristics of the communication protocol raise technical challenges that should be addressed to offer consistent and reliable information.

Dynamic AIS messages include the MMSI and IMO fields. The IMO number is a unique identifier for ships, registered ship owners and management companies that cannot be modified but is not mandatory for all the vessels. In fact, SOLAS regulation XI/3 made IMO number mandatory

[4] https://www.marinetraffic.com/

for all cargo vessels that are at least 300 Gross Tons (GT) and passenger vessels of at least 100 GT. Vessels solely engaged in fishing, ships without mechanical means of propulsion and pleasure yachts are just some examples of vessel types that are not obliged to have an IMO number. On the other hand, MMSI is a nine-digit number that is mandatory for all the vessels, but it is not a unique identifier (i.e., it can be modified under certain circumstances). According to ITU,4 the first 3 digits of any MMSI number are called Maritime Identification Digits (MID) and indicate the respective vessel's flag. Thus, when a vessel owner decides to change the flag under which the vessel will sail, her MID will be updated and consequently her MMSI will change. The absence of a global unique ship id for all the vessels of the world fleet, dictates the necessity to parse the received AIS data, clean the stream from messages with invalid MMSI identifiers and assign a unique id to the rest of them before proceeding with any further processing.

Some of the information included in AIS messages are manually inserted by the vessel's crew. The reported destination and the Estimated Time of Arrival (ETA) are typical examples of inconsistent and unreliable information reported through AIS. For instance, a passenger vessel that is performing the same itinerary with multiple stops every day, may not change the destination for each stop and report only the final destination from the beginning of the voyage. Furthermore, “Piraeu”, “Piraeus Port”, “Piraeus Anchorage”, “Pir”, “P” are all acceptable values in the reported destination of a vessel travelling to the port of Piraeus. String similarity metrics can be used to deduce the correct destination. Similarly, the ETA field is also prone to errors as it may not correspond to the time needed to reach the next port but the time needed to reach the final destination. Manually inserted information is not reliable and data processing of AIS stream would provide more accurate results.

According to the AIS communication protocol the reporting intervals are fluctuating and depend on the vessel's behavior (e.g., speed, rate of turn). This decision was taken so as to avoid throttling the system with too many messages that would lead to packet collision and message re-transmission, but at the same time transmit frequent messages when moving with high speed or changing course so as to notify in time other vessels in the vicinity. From the data provider perspective, the reception rate is the same as the vessel's transmission rate when the vessel is in range of a terrestrial station (which is approximately 50 km), but can be significantly lower when the vessel is sailing at open seas. In such case the satellites are used for monitoring and the update interval may range from few minutes up to several hours, depending on the satellite availability. All these lead to non-uniform distribution of collected data with significant communication gaps in some cases that may lead to inaccurate trajectory construction.

It may occur that a vessel is transmitting erroneous information due to sensors' faulty operation. To discard such messages from the AIS data stream, feasibility analysis is essential to evaluate whether a vessel position is valid based on the vessel's past positions.

The only time-related information included in AIS messages is the seconds field of the UTC timestamp at which the AIS message was generated. This is sufficient information for the vessels in the surrounding area, but when it comes to ship tracking data providers that store AIS messages for historical analysis, each message should be time referenced. This is usually done by assigning the UNIX epoch (i.e., seconds elapsed since 01/01/1970) the moment each message is collected in base station. When the messages are aggregated in a central entity from the receivers, processing is needed to avoid duplicate messages (i.e., messages that were received from more than one station). Furthermore, it is likely that the messages arrive with a variable delay. This may be caused by network delay or due to collecting data from various sources (terrestrial stations or satellite-AIS stations) that may be out of synch. Message re-ordering or accepting messages with a delay in the stream system would tackle such issue. (Artikis & Zissis, 2020)[1]

3. Maritime Data Processing

3.1 Methodology and variables

In this section, we will describe the chosen variables for our multiple regression framework and our expectations related to their impact on vessels speeds. Using a set of multiple regression models, we expand the traditional analysis of speed determinants, from only macroeconomic variables to also include technical constraints and ship specific variables.

A few words for the multiple regression. Multiple regression generally explains the relationship between multiple independent variables and one dependent variable. A dependent variable is modeled as a function of several independent variables with corresponding coefficients, along with the constant term. Multiple regression requires two or more independent variables, and this is why it is called multiple regression. The multiple regression equation explained above takes the following form:

$$y = b_1x_1 + b_2x_2 + \dots + b_nx_n + c$$

Here, b_i's (i=1,2…n) are the regression coefficients, which represent the value at which the dependent variable changes when the independent variable changes.

On our case the *dependent variable* is the average speed of vessel. The average speed of each vessel will be calculated by adding the speed of each vessel per day according to the messages that had send and divide it with the number of messages. This information will be gathered from the AIS dynamic messages table excluding records based on the restrictions that we will set and we will explain later. Speed is expressed in knots.

The *independent variables* will be the bunkers price, the length of the vessel, the beam of the vessel, the YOB (Year of Build) and the DWT (Dead Weight Tons) of the vessel. The available information related to bunker prices is the bunker price every Friday on different ports. The bunker port that is closely to the area that are data cover and for which we have the bunker prices is the port of Rotterdam so we will use the bunker prices of this port for our analysis. Also, on the port of Rotterdam the current period where two different types of HSFO fuels available, HSFO 180cst (centistokes) and HSFO 380cst (centistokes). The 60% of the world bunker trade is in HFO380cst while HFO180cst and other grades account for about 30%, with the remaining 10% of world trade being in marine diesel oil[5]. Based on this we will use the most used type of HSFO fuel, the HSFO 380cst, assuming that all the vessels in our sample data load fuels from the port of Rotterdam type of HSFO 380cst. Vessel's length will be calculated from the AIS static data as the sum of columns to_bow and to_stern. Also, we will compare the length value with the length value that it is provided for each vessel from the BALTICSHIPPING.COM[6] and we will conclude on the value that we will use. Vessel's beam will be calculated from the AIS static data as the sum of columns to_port and to_starboard. Also, we will compare the length value with the length value that it is provided for each vessel from the BALTICSHIPPING.COM and we will conclude on the value that we will use. The year of build of each vessel on our sample data will be fetched from the BALTICSHIPPING.COM. The fetched year of build will be based on the IMO number of each vessel that is provided through the AIS static messages. Each vessel's DWT will be fetched from the BALTICSHIPPING.COM based on the IMO number of each vessel that is provided through the AIS static messages.

To explain the determinants of the average speed Vi, observed for messages i in our panel dataset, we test various specifications of a multiple linear regression model using combinations of the above variables. For instance, in the case of all variables, the model could be

$$V_i = a_0 + a_1 Pb_i + a_2 Le_i + a_3 Be_i + a_4 YOB_i + a_5 DWT_i + c$$

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[5] Mr.Tsouknidis presentation for the course of Shipping Financial Management

[6] https://www.balticshipping.com/

where **Pb** is the bunker price for the specific period, **Le** the length of the vessel, **Be** the beam of the vessel, **YOB** the year of build of the vessel, **DWT** the dead weight tons of the vessel and **c** the model's error term (also known as the residuals).

From the results of our analysis we will determine their relation based on the R-squared and coefficient of each independent variable with our dependent variable and the relation of all the independent variables along with our dependent variable.

R-squared is a measure in statistics of how close the data are to the fitted regression line. It is also known as the coefficient of determination, or the coefficient of multiple determinations for multiple regression. It is the percentage of the response variable variation that is explained by a linear model.

$$\text{R} - \text{squared} = \frac{\text{Explained variation}}{\text{Total variation}}$$

R-squared is always between 0 and 100%. 0% means the model explains none of the variability of the response data around its mean.100% indicates that the model. Generally, the higher the R-squared, the better the model fits the data.

The t statistic is the coefficient divided by its standard error. The standard error is an estimate of the standard deviation of the coefficient, the amount of it varies across cases. It can be thought of as a measure of the precision with which the regression coefficient is measured. If a coefficient is large compared to its standard error, then it is probably different from 0.

Our main target on this analysis is the relation of speed and the bunker prices and the way that the bunker prices affect the speed of the vessels. Also, we will analyze the speed relation by adding more independent variables like the length of the vessel, the beam of the vessel, the YOB (Year of Build) and the DWT (Dead Weight Tons).

3.2 AIS data analysis

The provided AIS data are covering a period of 6 months from 2015-10-01 00:00:00 UTC until 2016-03-31 23:59:59 UTC and coverage area with longitude between -10.00 and 0.00 and latitude between 45.00 and 51.00 (area of English Channel).

In order to export the preferred variables from the dataset that we analyzed on the previous chapter we have to join the data of static AIS messages along with the data of dynamic AIS messages. Our basic source will be the dynamic AIS messages which contain vessels speed data about voyages and we will join these data with the static AIS messages which will give us the required information of the vessels.

We will set some restrictions related with the vessels that exist in our AIS messages. The vessels that will be selected will be either cargo vessels or tanker vessels. Also, the navigational status of the vessels must be “Under way using engine” (codes: 0, 8) in order to exclude from our sample, the vessels that were at anchor or moored etc. Also, we excluded the vessels that their MMSI number couldn’t be found on the AIS static messages as we won’t be able to get the extra vessels information from the table of the AIS static messages like the IMO number which will help us to find the extra information. Another observation related with the AIS dynamic messages was the speed that each vessel was broadcasting. We identified that a set of vessels on the category of cargo and tanker where reporting speed more than 25 knots (ex. 102.5, 32) as a result we excluded all these vessels from our analysis getting as correct the maximum speed of 25 knots.

Bunkers price is one of the independent variables that we will use on our model. It is very important for our analysis the relation of the bunker price with each vessel’s speed. Below, in Figure 3 is a graph showing the bunker price of HFO380cst in the port of Rotterdam for the period of 6 months for which we have AIS data.

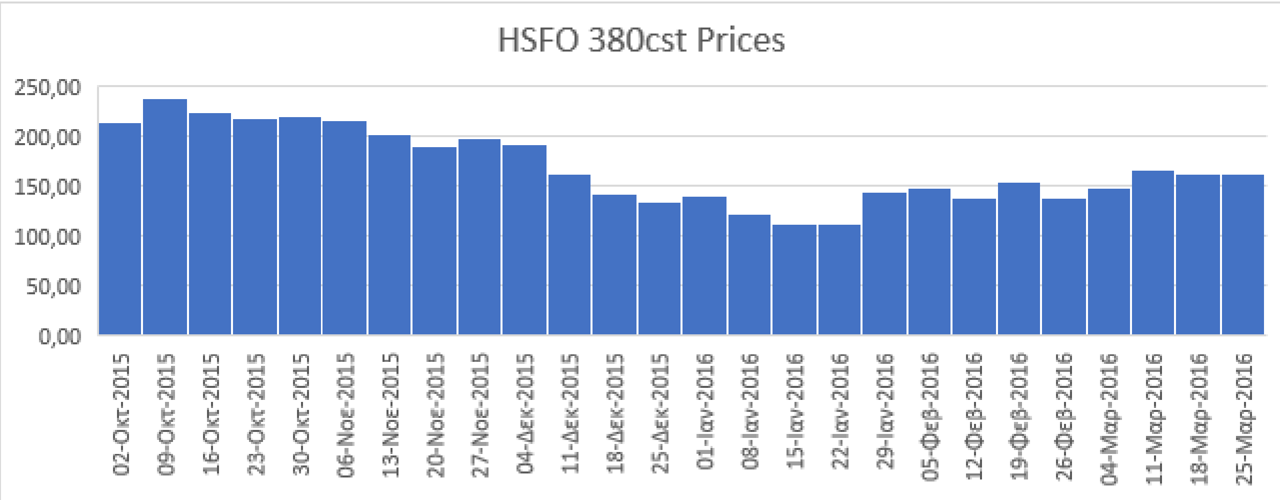

Figure 3: HSFO 380cst Prices

In the Figure 3 we observe that the value of HSFO 380cst on the port of Rotterdam decreased over the 6 months period (2015/10/01 – 2016/03/31). Through our analysis we will try to identify the existence of any relation between the average speed of the vessels and the bunker prices for the current period. As we observe on Figure 3 the values of bunker prices that we have are for each Friday for the period of the 6 months that will make the analysis. This restriction on the provided data for the bunker prices force us to calculate the average speed per day and compare it with the value of the bunkers at the end of the week. For example, we calculate the average speed of a vessel for each day for the week starting 2015-10-02 (Friday) to 2015-10-09 (Friday) and we get the bunker price for Friday / 2015-10-02 for each day of the week. We select the value of bunkers of 2015-10-02 because we want to identify if the speed of the vessels changes during the upcoming week (2015/10/02 – 2015/10/09) in relation with the value at the beginning of the week.

In regards the length and the beam of the vessels that was reported through the AIS messages we noticed some differences in relation with the length and beam that was recovered from the BALTICSHIPPING.COM database. Our decision related with these two variables was to keep as the right values the values that fetched from the BALTICSHIPPING.COM database as after a comparison of a set of values with a third database (MarineTraffic[7]) we found more accurate the values from the BALTICSHIPPING.COM.

3.2.1 Applying restrictions to the AIS data

In order to apply all the restriction mentioned on the previous chapter we had to exclude the non-applicable records from the AIS data.

Firstly, we had to exclude all the records from the AIS dynamic messages that the ship type code was not in the range of 70 to 89 as the cargo and tanker vessels have the ship id in the range 70 to 89 as the below table indicates (Table 3).

[7] https://www.marinetraffic.com/

Ship Type Code min	Ship Type Code max	Type Name	AIS Type
10	19	Reserved	Unspecified
20	28	Wing In Grnd	Wing in Grnd
29	29	SAR Aircraft	Search and Rescue
30	30	Fishing	Fishing
31	31	Tug	Tug
32	32	Tug	Tug
33	33	Dredger	Special Craft
34	34	Dive Vessel	Special Craft
35	35	Military Ops	Special Craft
36	36	Sailing Vessel	Sailing Vessel
37	37	Pleasure Craft	Pleasure Craft
38	38	Reserved	Unspecified
39	39	Reserved	Unspecified
40	49	High-Speed Craft	High-Speed Craft
50	50	Pilot Vessel	Special Craft
51	51	SAR	Search and Rescue
52	52	Tug	Tug
53	53	Port Tender	Special Craft
54	54	Anti-Pollution	Special Craft
55	55	Law Enforce	Special Craft
56	56	Local Vessel	Special Craft
57	57	Local Vessel	Special Craft
58	58	Medical Trans	Special Craft
59	59	Special Craft	Special Craft
60	69	Passenger	Passenger
70	70	Cargo	Cargo
71	71	Cargo - Hazard A (Major)	Cargo
72	72	Cargo - Hazard B	Cargo
73	73	Cargo - Hazard C (Minor)	Cargo
74	74	Cargo - Hazard D (Recognizable)	Cargo
75	79	Cargo	Cargo
80	80	Tanker	Tanker
81	81	Tanker - Hazard A (Major)	Tanker
82	82	Tanker - Hazard B	Tanker
83	83	Tanker - Hazard C (Minor)	Tanker
84	84	Tanker - Hazard D (Recognizable)	Tanker
85	89	Tanker	Tanker
90	99	Other	Other

Table 3: Ship Type Codes

Next, we excluded the vessels with navigational status different to 0 or 8 based on the below table. We are interesting for the vessels that are under way in order to get their speed, when these vessels are using their engines and being on a trip. By adding this limitation we excluded vessels that may be anchored, moored or even towed by a tag boat.

Navigational Status Code	Code Meaning
0	under way using engine
1	at anchor
2	not under command
3	restricted maneuverability
4	constrained by her draught

5	moored
6	aground
7	engaged in fishing
8	under way sailing
9	reserved for future amendment of navigational status for ships carrying DG, HS, or MP, or IMO hazard or pollutant category C, high speed craft (HSC)
10	reserved for future amendment of navigational status for ships carrying dangerous goods (DG), harmful substances (HS) or marine pollutants (MP), or IMO hazard or pollutant category A, wing in grand (WIG)
11	reserved for future use
12	reserved for future use
13	reserved for future use
14	AIS-SART (active)
15	not defined = default (also used by AIS-SART under test)

Table 3.1 Navigational Status Codes

In regards the variables length and beam of the vessel, firstly we calculated the length of the vessel based on the AIS static messages as the sum of the fields “To bow” and “To starboard” and the beam as the sum of the fields “To port” and “To Starboard”. Then we fetched the length and the beam of each vessel from the BALTICSHIPPING.COM database and we isolate the records where the length and beam were different between the two sources. Checking a sample from all these values from the MarineTraffic database, available through the internet, we concluded that the data from the BALTICSHIPPING.COM database where more accurate in relation with the AIS data, as a result we used the values of length and beam fetched from the BALTICSHIPPING.COM database.

In the end, after applying all the above restrictions on the AIS messages, the records of data that remained for our analysis were 2.212.013 records, which are the messages that were broadcasted from 2.722 cargo or tanker vessels for the period 2015-10-01 00:00:00 UTC until 2016-03-31 23:59:59 UTC.

Last, for each vessel we fetched from the BALTICSHIPPING.COM database the year of build (YOB) and the dead weight tons (DWT) for using them to our model.

3.3 Data Analysis Results

In the previous chapters we analyzed the variables that will be used, the restrictions that we applied on the AIS data and why these restrictions are applied. Also, we explained the way that we set up our restrictions. In this chapter we will proceed with presenting the results of our model and identify if any relationship exists between the average speed of the vessels and the other variables.

Table 3.2: Speed models with vessels and vessels specific variables

Dependent Variable: Speed	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Constant	10.4	10.92	-124.78	7.88	8.04	13.5
	(48.16)	(211.37)	(-10.10)	(90.05)	(89.01)	(1.3)
	0.000	0.000	0.000	0.000	0.000	0.190
Bunkers Price	0.007					0.0039
	(1.15)					(1.22)
	0.150					0.130
DWT		2.49E-05				-5.07E-05
		(28.5)				(-29.15)
		0.000				0.000
YOB			0.06			-0.004
			(11.05)			(-0.89)
			0.000			0.36
Length				0.02		0.036
				(49.21)		(21.58)
				0.000		0.03

Beam					0.15	0.103
					(45.68)	(8.36)
					0.000	0.000
R^2	0.72%	12.37%	2.06%	29.5%	26.5%	39%

t-values in parenthesis with coefficients above and p-values below

Table 3.2 express the relation of each independent variable with the average speed along with the relation of all independent variables with the average speed. Each column defines a unique static model based on each independent variable and column (6) the static model with all the independent variables. The analysis will isolate and test each independent variable and then will examine all variable together.

3.3.1 Bunkers Price

Table 2.3 indicate that variable “bunkers price” is not statistically significant (p=0.15>0.05) and so bunkers price could not affect the speed. In addition, based on table 2.3, the positive coefficient indicates that as the value of the bunker price increases, the mean of the speed also tends to increase (a1 =0.007). Specifically, the coefficient of bunker price is 0.007 (t-stat =1.15) for the static model (1) with an R^2 at 0.72%. The value of 0.72% for R^2 indicates that only 0.72% of the average speed values can be explained from the values of bunker prices based on our model. As observed, the coefficient of the variable bunker price is not statistically significant at any reasonable confidence level. This is something that was not expected based on common sense as the bunker price is one of the main factors for the decision of the sailing speed of a vessel and follows the rule that the higher the bunkers price the lower the average speed of the vessels. In order to try to explain better this tendency we will try to find the tendency of other variables the period that we analyze which may affect this pattern of bunkers price and averaged speed.

One of the major factors that affects the vessels speed is the freight value. In periods that the freights are high and the demand for vessels is high it is observed an increase on vessels speed independent of the bunkers prices in order the shipowners to take advantage of the high freight rates increasing their profits. Freight rates are playing an important role on the shipping industry as is one of the main factors that affects the profits of losses of a shipping company. In many occasions low freight rates oblige shipping companies to agreed for a cargo transfer for which the operation expenses along with the voyage expenses to be more that the agreed price of transfer.

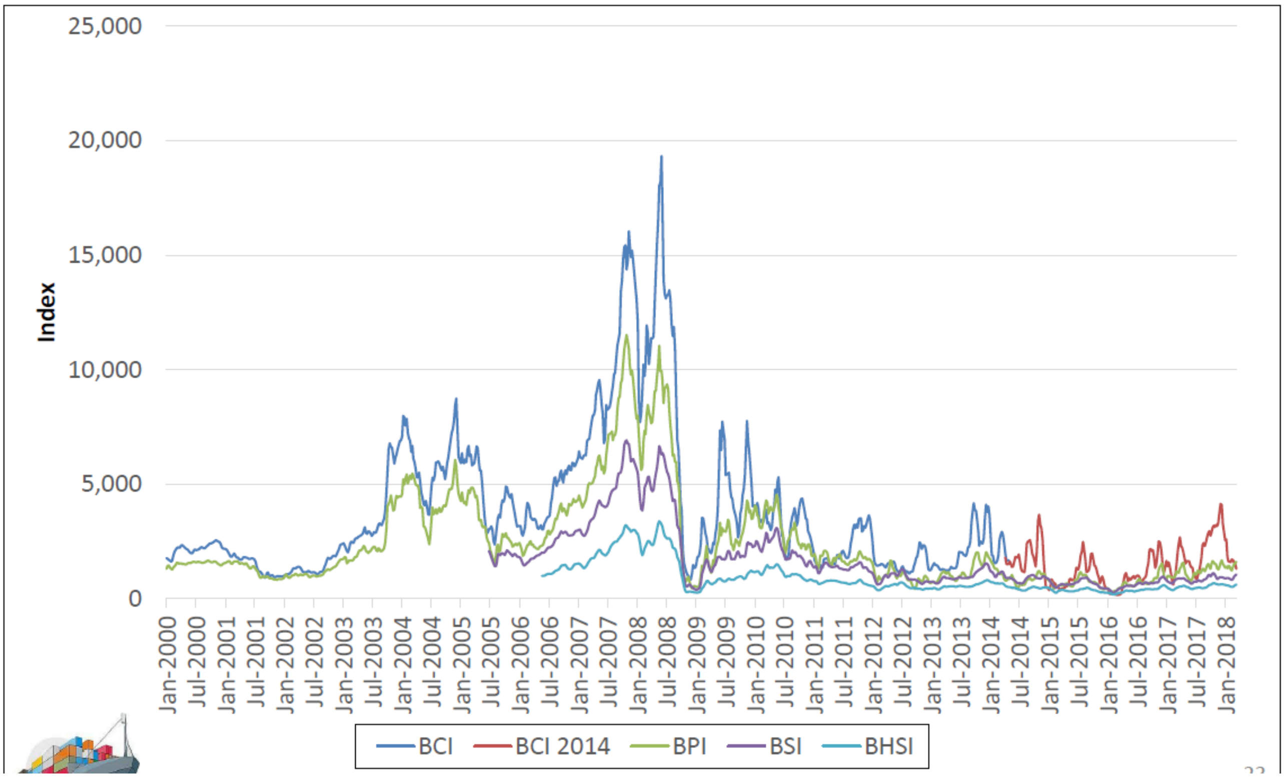

Figure 3.1: Baltic Exchange freight rate indices (dry bulk)

Source: Clarksons SIN

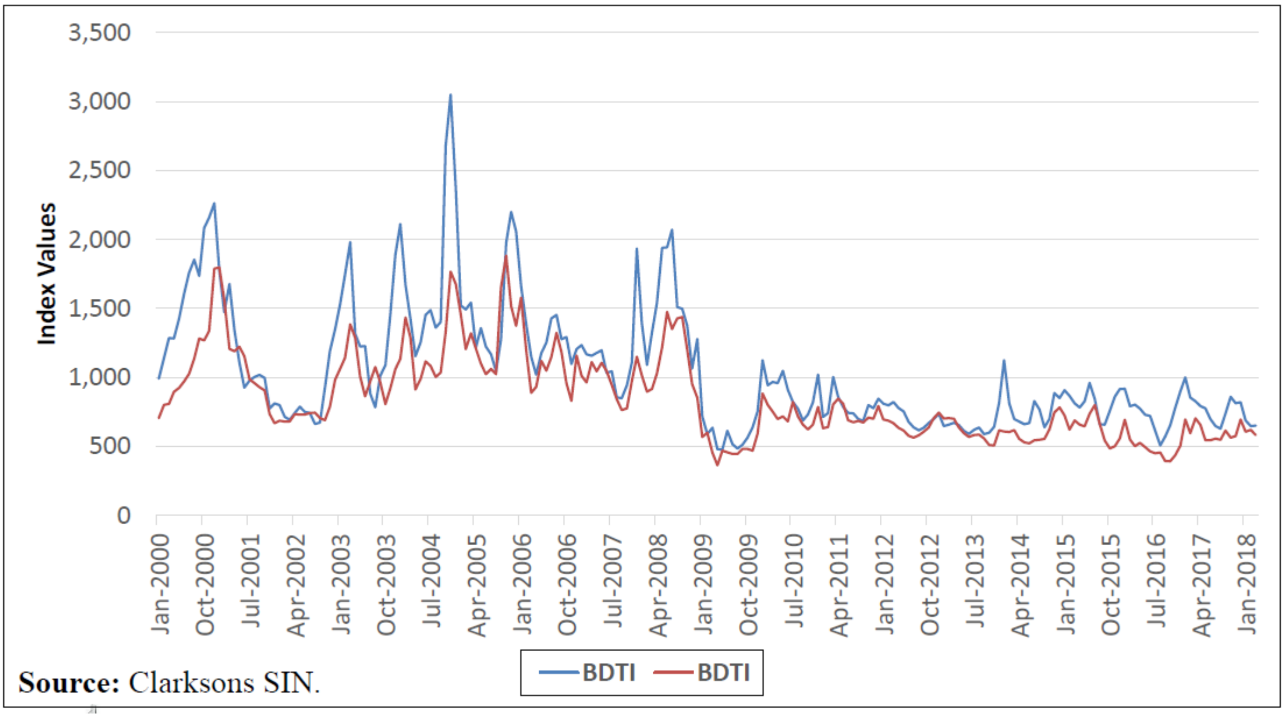

Figure 3.2: Baltic Exchange freight rate indices (tankers)

Based on Figures 3.1 and 3.2 the period from October of 2015 until March of 2016 which is the period that we made the analysis for, we observe that the rates on both bry bulk and tankers market are low. Current period the freight rates for both markets are decreasing, expecting the average speed of vessels to decrease also. Bunker prices also have a decrease this period based on Figure 2.1. From December 2015 until March 2016 the bunker prices for fuel HSFO 380cst are under 160$/ton. The fact that bunker prices on that period are also low may be the reason that the vessels speed is increasing. Our model may express the increase in speed when the bunker prices increase as the bunker prices for the period that we analyze are on low historical levels with fluctuations in a range of lower prices. This is identified from the Figure 3.3. In this figure we observe that the bunker prices at 2015 are at historical low levels related with 5 previous years. So, an increase in bunker prices may affect positive the speed as the increase is very low related with the fuels price the last 5 years.

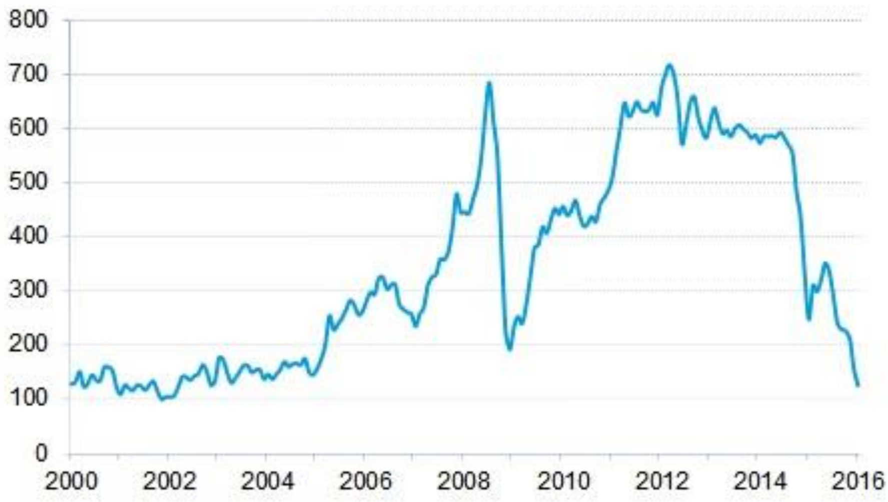

Figure 3.3: Monthly average bunker prices, 2000-January 2016, Rotterdam IFO380 ($/tonne)
Source: Drewry Maritime Advisors (www.drewry.co.uk/consultancy)

3.3.2 DWT – Dead Weight Tons

Table 2.3 indicate that variable "DWT" is statistically significant (p=0.000<0.05) and so DWT of a vessel could affect the speed. In addition, based on table 2.3, the positive coefficient indicates that as the value of the DWT increases, the mean of the speed also tends to increase (a_5 =2.49E-05). In regards the relationship of DWT and the average speed, our model (static model (2)) produced a coefficient of DWT 2.49E-05 (t-stat = 28.5) with an R^2 at 12.37%. The value of 12.37% for R^2 indicates that only 12.37% of the average speed values can be explained from the values of bunker prices based on our model. Also, in this relationship on our model it is not common sense the average speed to be greater for vessels with greater DWT for container ships. On this relationship are also other factors that can define this relationship like the Year of Build of the vessel related with the max speed that can reach and the state of vessel, if it is loaded or unloaded.

In regards the YOB of the vessel is a variable that will is added on our model and we will see later on how will influence the average speed by its own and in combination with the other variables. The state of the vessel is also an important variable that can affect the relationship of average speed and DWT as a loaded vessel sail with different speed in regards an unloaded vessel. In this respect freight rates also define the sailing speed of a loaded and an unloaded vessel, with higher freight rates vessels tend to sail faster either loaded or unloaded and slower when freight rates are lower. Based on this it is obvious how each variable relates with the others and in which level.

3.3.3 YOB – Year of Build

Table 2.3 indicate that variable “YOB” is statistically significant ($p=0.000<0.05$) and so DWT of a vessel could affect the speed. In addition, based on table 2.3, the positive coefficient indicates that as the value of the YOB increases, the mean of the speed also tends to increase (a_4 $=0.006$). YOB is another independent variable that was added in our model (static model (3)) for which we observe that produced a coefficient of YOB 0.06 (t-stat = 11.05) with an R2 at 2.06%. So, based on our model the average speed of the vessels is increasing when the YOB is increasing with a 2.06% accuracy. This result has a logical base as the newer build vessels are using edge technology which allowing them to increase their speed and accordingly their average speed.

YOB is another variable on our model that can be related with the DWT and the average speed of the vessels as the older vessels have limitations in regards the speed that can achieve and more specific older vessels with more DWT can achieve lower speeds than new building vessels with the same DWT.

3.3.4 Vessel Length

Table 2.3 indicate that variable “Length” is statistically significant ($p=0.000<0.05$) and so Length of a vessel could affect the speed. In addition, based on table 2.3, the positive coefficient indicates that as the value of the Length increases, the mean of the speed also tends to increase (a_2 $=0.02$). The coefficient of length in relation with the average speed is 0.02 (t-stat = 49.21) with and

R^2 at 29.5%. Based on these results the average speed of the vessels is increasing when the length of the vessel is increasing with a 29.5% accuracy based on the values of our sample. The length factor of a vessel is a factor that has to do with the evolution of the vessels related with the size through the time as bigger ships are manufactured.

Length is also a variable that is related with the YOB and the DWT as in nowadays bigger vessels are build with more DWT as a result the length of vessels to increase through the years. The size of the vessels doesn't necessarily mean and a decreasing on the average speed as again the evolution of technology help to increase the maximum speed of vessels along with their size. As we can see on the below Figure 3.3 the DWT for most of the vessels increased through time as a result the length to be increased.

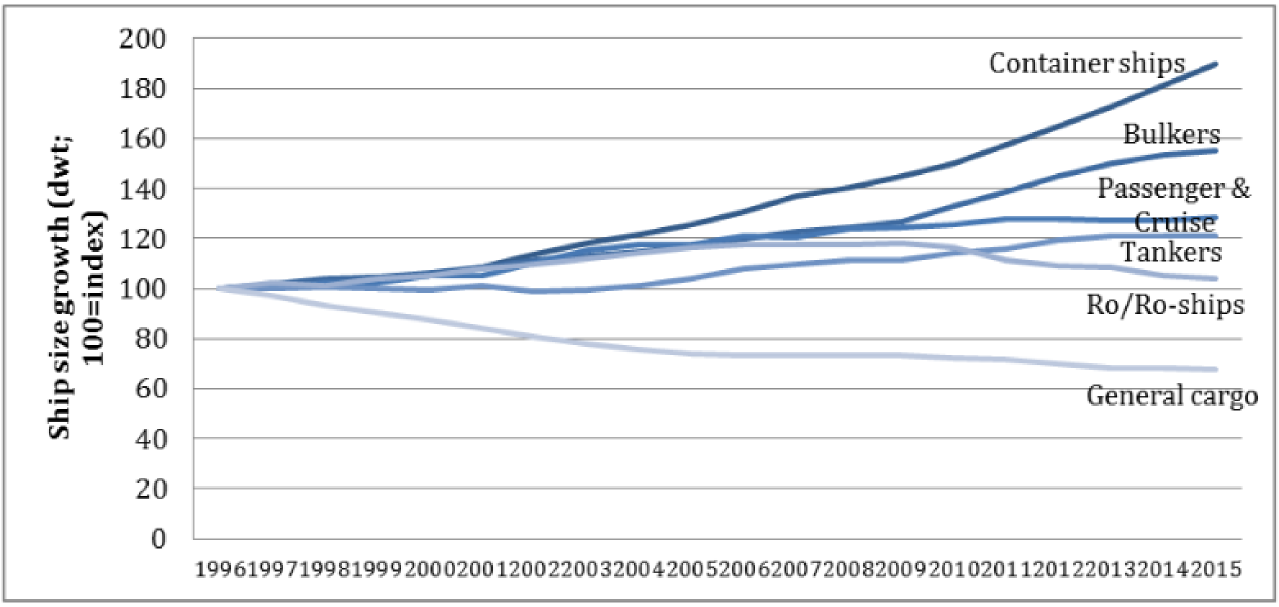

Figure 3.4: Ship size development of various ship types 1996-2015

Source: https://www.itf-oecd.org/sites/default/files/docs/15cspa_mega-ships.pdf

3.3.5 Vessel Beam

Table 2.3 indicate that variable "Beam" is statistically significant (p=0.000<0.05) and so Length of a vessel could affect the speed. In addition, based on table 2.3, the positive coefficient indicates that as the value of the Length increases, the mean of the speed also tends to increase (a_3 =0.15). Beam of vessels is also an independent variable that was added on our model (5). The coefficient of length in relation with the average speed is 0.15 (t-stat = 45.68) with and R^2 at 26.5%. Based on these results the average speed of the vessels is increasing when the beam of the vessel is increasing with a 26.5% accuracy based on the values of our sample. The beam factor of a vessel is a factor that has to do with the evolution of the vessels related with the size through the time as bigger ships are manufactured.

Beam is also a variable that is related with the YOB and the DWT as in nowadays bigger vessels are built with more DWT as a result the beam of vessels to increase through the years. The size of the vessels doesn’t necessarily mean and a decreasing on the average speed as again the evolution of technology help to increase the maximum speed of vessels along with their size. As we can see on Figure 3.3 the DWT for most of the vessels increased through time as a result the beam to be increased.

3.3.6 Review of our model in relation with all variables

We analyzed the relationship of each independent value that we have added on our model with the average speed and we tried to explain the results. The last analysis is based on the explanation of the average speed of vessels in relationship with all the independent variables (model (6)).

Dependent Variable: Speed	**p-value**
Constant	
Bunkers Price	0.130
DWT	0.000
YOB	0.330
Length	0.000
Beam	0.000

Table 3.3: P-values of all the independent variables

Our model generates an R^2 of 39% which is the higher among the individual relationship of each independent variable with the average speed. The value of 39% for R^2 indicates that only 39% of the average speed values can be explained from the values of the independent variables which still remains low but higher that the computed R^2 for each independent variable in accordance with the dependent variable (average speed). This is a sign that are model can be edited by adding more independent variables which will help in increasing its efficiency. Table 3.3 indicate that variables YOB and bunkers price are not statistically significant and do not affect average speed, including all variables in the model. Thus, new model tested with 3 independent variables (Table 3.4).

Dependent Variable: Speed	p-value	coefficient
Constant		
DWT	0.000	0,00005
Length	0.000	0.0368
Beam	0.000	0.1032

Table 3.4: P-Values of all independent variables except YOB

Table 3.4 shows that DWT, length and beam influences average speed. The new R^2 does not change. In conclusion only DWT, Length and Beam play important role to speed.

DWT affects the average speed in a decreasing way whereas previously (Table 3.2) we had an increasing on average speed when the DWT value was increased. The coefficient of DWT is -5.08458E-05 which indicates that if the DWT increase for 1 ton the average speed will be decreased by -5.08458E -05 knots which is generally better than increasing by 2.49E-05 knots (Table 2.3). This may rely on the fact that larger vessels is normal to sail with lower speed due to their size but on the other hand bigger vessels designed the last years in order to cover the bigger demand along with the of evolution technology has also the ability to sail faster with lower fuel consumption.

Length still affects speed in the same way but with a different coefficient of 0.0368. So, the average speed continues increasing as the vessel’s length is increasing with a different relationship. If the length increases for 1 meter the average speed will be increased by 0.0368 knots having a different increasing rate related to previous results (Table 2.3) that would be increased by 0.06 knots (4).

Beam still affects speed in the same way but with a different coefficient of 0.103. So, the average speed continues increasing as the vessels beam is increasing with a different relationship. If the beam increases for 1 meter the average speed will be increased by 0.1032 knots having a different increasing rate related to previous results (Table 2.3) that were resulting on an increase of 0.15 knots per meter increase on beam (4).

Adding all the selected independent variables to our model we identify that the way that some variables affects the average speed change and gives us a better accuracy. Opposite results also on the way that some of them affects the average speed are observed and this is something that is related with the way that each variable affects the other.

3.4 Conclusion

The analysis of the relationship of the average speed of vessels in regards the bunkers price, the length of the vessel, the beam of the vessel, the YOB (Year of Build) of the vessel and the DWT (Dead Weight Tons) of the vessel gave us results that are almost opposite to the theory based on the literature.

The estimation or the tendency of the average speed that vessels sail in different periods is very complicated and difficult to be proved. The speed that each vessel will sail depends on many factors from which many cannot easily be measured or identified in order to be added on models. Modeling any procedure in the maritime sector and more specifically the sailing speed of vessels it cannot be based only on data related to vessel's specific technical data or economic data.

Maritime is a sector that can be affected from many factors like natural disasters, social reasons, medical reasons like a worldwide pandemic etc. With the technological evolution the last years we have managed to create complicated models for statistically predicting the market of shipping other times with success and others without. In maritime the human element is still playing an important role as a result the management decisions in shipping companies are not always calculated as are based in a high percent on human decisions guided not from logical assumptions on data but from empirical experiences.

4. Conclusion

Our main concern on this paper was to identify and explain the relation of the sailing speed of vessels in regards the bunker prices. In order to do so we proceeded with analyzing the AIS data from vessels for a current period along with the bunker prices this period.

Based on our model and using the linear regression analysis we observed that the average speed of vessels was increasing when the bunker prices are increased. The accuracy of our model for the average speed and the bunkers price is 0.72% (Table 3.1). The relation between the speed and bunkers price exist but based on our sample of data only 0.72% can be explained. So, in order to validate better our model, more data will be needed in order to have better results and these data can be from different time period and different geographic area. In future research based in the same idea is better to have more AIS data from the same geographic area that we analyzed and data from other geographic areas.

In regards the exported relationship between the speed and bunkers price from our model is not the expected one. Our model indicates that the average speed of vessels is increasing when the bunker prices are increased, something that is contradicted to the theory that the shipping companies decrease their vessels speed when bunker prices are high. In order to extend our model, we added several independent variables related to vessels characteristics. By adding on our model, the length of the vessel, the beam of the vessel, the year of build of the vessel and the dead weight tons of the vessel the accuracy of our model increased to 39% (Table 3.1). Analyzing this result, we observe that the more parameters we add on our model the more accurate is the results of our model. So, in future extensions of the selected model more independent variables can be added.

The value of freight rates for the current period is a very significant variable that affect the vessels speed. The shipping companies are increasing their fleet speed if the freight rates are high in order to complete each voyage as soon as possible. This allow the shipping companies to commit more voyages where the freight rates are high in order to increase their profit as more voyages with high freight rates will result to more profits. In this respect we have to note that many times the time that can be gained from each voyage is around one or two days and not more than that as in many charter parties the day of arrival to the destination may defined. This off course can be changed in periods of height freights and ship owners avoid charter parties with defined arrival dates or negotiate in a different way on the terms. In the period of our sample of data, the freight rates are in history low levels (Figure 3.1, 3.2) decreasing further. So, the freight rates for current period is a parameter that shows us that the increase of vessel speed this period it cannot be explained from the freight rates as the freight rates are very low.

In regards the bunkers prices that we used on our analysis we used the prices for the fuel oil HSFO 380cst from the port of Rotterdam. We made the assumption based on the data that we have, that cover the area around the English Channel, that the vessels passing through the area will load fuels on the Port of Rotterdam as is the nearest port for which we had fuel prices for that period. This assumption may be in the wrong way as it is very possible many of the ships that end or start their voyage around English Channel or just pass from that area to use other nearby ports for bunkering. This is depending on the planning of each voyage from each company along with the bunker prices for each port. In order to be more accurate in the respect of the bunker prices we must had more data related to the voyage that each ship is doing (source/destination) as for more of the voyages, shipping companies use known ports for bunkering. In that respect we could export from our sample vessels that is not very possible to get bunkers on the port of Rotterdam in relation with the data that indicates are the ports that vessels use for bunkering on a specific voyage. Better will be if we had data where each vessel load with fuel for this period for this area along with the type of fuel that loaded. Also, our analysis could be extended further if we had the values for all the bunker prices on all ports near the English Channel which could be related with the port that each vessel loaded with fuels and that could be related with the average speed of each vessel.

In regards the other variables that we used on our model, the length, the beam and the DWT are variables that have to do with the vessel’s size. Vessels with bigger sizes may sail with lower speed than vessels with smaller sizes. This is not the rule as again this is related with may other factors. One factor, that we also added on our model, is the year of build of vessel. Newer vessels have the ability to sail faster with less fuels than the older ones. Older vessels also need more maintenance if they sail with speed less than the range that the manufacturer propose. Also, newer vessels with bigger capacity may sail faster than older vessels with smaller capacity (DWT). In order to be more accurate related the vessels size and the maximum and minimum speed that they use we must have the relevant information that will be based on their year of build along with their size in order to add them in our model in a sufficient way. So, the bunker price may not affect the speed of vessels as for newer vessels the sailing speed for the lowest fuel consumption may the maximum speed of older vessels.

Vessel capacity (DWT) is the maximum weight that a vessel can carry. An important factor that can be added in our model is the loading state of the vessel. Speed of sailing for vessels defer if the vessels are full loaded, partly loaded or not loaded at all (ballast). This is very important as the vessels of our sample may sail loaded or partly loaded for their destination in order to unload to one of the ports nearby the area that are data cover or just passing from the area with destination a nearby port. These vessels may sail with a different speed from vessels that are sailing without cargo (ballast) heading for a port where they will load cargo. This speed of vessels may be related with the terms of the charter party. If for example the ship owner has a deal with a cargo owner to be on a specific port on a specific date and the time is pressing him, he may increase the speed of his vessel in order to avoid any claims which mean extra expenses. This also may be related with the low freight rates of that period. Freight rates are getting lower when the demand for cargo transferring is lower that the availability of the vessels. In this respect shipowners may speed up to be on a port for loading if the cargos are not so much in order not to lose the opportunity of getting the voyage.

Another important factor that must be considered is the weather. The weather has an important role in the speed selection of the vessel. In bad weather the vessel must maintain a certain speed in order to navigate safely. So, the decision for a vessel in sailing in lower speed must be considered in relation with the weather conditions. In this respect a decision from the company side for reducing speed for a vessel in order to decrease the consumption of fuels must be in accordance with the weather conditions in order the vessel to navigate safely. Weather conditions is fact that can be added on our model and influence the relation between vessels speed and fuel prices.

As we observe the factors that affect the vessels speed are many and with many dimensions. It is difficult enough all these parameters to be included in an analysis, but not impossible. The most important in an analysis are the data in which the analysis will be made. Then is the quantification of the data related to logical assumptions in order to be used on the analysis. Last, is the update of the model through time covering any change. It is important extra parameters that may affect any analysis to be identified through time in order any model that is used to be as close to the target.

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ANNEX

Script for fetching vessels information from BALTICSHIPPING.com

```
<?php

$e = '';
try {
    $conn = new PDO("mysql:host=localhost; dbname=vessels", 'root', '');
} catch (PDOException $e) {
    $e->getMessage();
    if ($e != '') {

        echo "[" . date("Y-m-d H:i:s") . "] [ERROR] Unable to connect to local
mysql database (setel).\n";
        exit();

    }

}

$query = "SELECT distinct(imonumber) as imo from nari_dynamic;";

$result_select = $conn->query($query);

if ($result_select === false){

    echo "Cannot execute select query : ".$query.". Error  : ".implode("|",
$conn->errorInfo());
    exit();

}

while( $row = $result_select->fetch(PDO::FETCH_ASSOC) ){

    $imo = $row['imo'];

    $cmd = 'curl "https://www.balticshipping.com/" -H "User-Agent: Mozilla/5.0
(Windows NT 10.0; Win64; x64; rv:79.0) Gecko/20100101 Firefox/79.0" -H "Accept:
*/*" -H "Accept-Language: en-US,en;q=0.5" --compressed -H "Content-Type: appli-
cation/x-www-form-urlencoded; charset=UTF-8" -H "X-Access-Token: " -H "Origin:
https://www.balticshipping.com" -H "Connection: keep-alive" -H "Referer:
https://www.balticshipping.com/vessels" -H "Cookie:
_ga=GA1.2.167522255.1598980278; _hjTLDTest=1; _hjid=95cee61b-700d-451f-b026-
9390301b9df7; id=null; key=null; level=null; _gid=GA1.2.524906786.1599576310;
_gat_UA-88708763-1=1; _hjAbsoluteSessionInProgress=0" --data-raw "re-
quest"%"5B0"%"5D"%"5Bmodule"%"5D=ships&request"%"5B0"%"5D"%"5Baction"%"5D=list&r
equest"%"5B0"%"5D"%"5Bid"%"5D=0&request"%"5B0"%"5D"%"5Bdata"%"5D"%"5B0"%"5D"%"5B
name"%"5D=search_id&request"%"5B0"%"5D"%"5Bdata"%"5D"%"5B0"%"5D"%"5Bvalue"%"5D=0
&request"%"5B0"%"5D"%"5Bdata"%"5D"%"5B1"%"5D"%"5Bname"%"5D=name&request"%"5B0"%"
5D"%"5Bdata"%"5D"%"5B1"%"5D"%"5Bvalue"%"5D=&request"%"5B0"%"5D"%"5Bdata"%"5D"%"5
B2"%"5D"%"5Bname"%"5D=imo&request"%"5B0"%"5D"%"5Bdata"%"5D"%"5B2"%"5D"%"5Bvalue"
%"5D=';
    $cmd .=
$imo.'&request"%"5B0"%"5D"%"5Bdata"%"5D"%"5B3"%"5D"%"5Bname"%"5D=page&request"%"
5B0"%"5D"%"5Bdata"%"5D"%"5B3"%"5D"%"5Bvalue"%"5D=0&request"%"5B0"%"5D"%"5Bsort"%
"5D=&request"%"5B0"%"5D"%"5Blimit"%"5D=9&request"%"5B0"%"5D"%"5Bstamp"%"5D=0&req
uest"%"5B1"%"5D"%"5Bmodule"%"5D=top_stat&request"%"5B1"%"5D"%"5Baction"%"5D=list
&request"%"5B1"%"5D"%"5Bid"%"5D=0&request"%"5B1"%"5D"%"5Bdata"%"5D=&request"%"5B
1"%"5D"%"5Bsort"%"5D=&request"%"5B1"%"5D"%"5Blimit"%"5D=&request"%"5B1"%"5D"%"5B
stamp"%"5D=0"';
```

```
    $output = shell_exec($cmd);

    $result = json_decode($output, true);

    $result2 = $result['data']['request'];

    if( $result2[0]['ships_found'] == 1 ) {
        $result3 = $result2[0]['ships'];
        $ship_data = $result3[0]['data'];

    }

    $sql_update = 'update nari_dynamic
                    set year_build = '.gmdate("Y", $ship_data['year_build']).',
                    dwt = '.$ship_data['dwt'].',
                    kw = '.$ship_data['kw'].',
                    draught = '.$ship_data['draft'].',
                    length_1 =  '.$ship_data['length'].',
                    beam_1 =  '.$ship_data['breadth'].'
                    where imonumber = '.$imo.' and id > 0';

    $result_update = $conn->query($sql_update);

    if ($result_update === false){

        echo "Cannot execute update query : ".$sql_update.". Error  :
".implode("|", $conn->errorInfo());
        exit();

    }


}


?>
```

Script for exporting results final results

```
<?php

$e = '';
try {
    $conn = new PDO("mysql:host=localhost; dbname=vessels", 'root', '');
} catch (PDOException $e) {
    $e->getMessage();
    if ($e != '') {

        echo "[" . date("Y-m-d H:i:s") . "] [ERROR] Unable to connect to local
mysql database (setel).\n";
        exit();

    }

}

$dates = array(
    '2015-10-02',
    '2015-10-09',
```

```
    '2015-10-16',
    '2015-10-23',
    '2015-10-30',
    '2015-11-06',
    '2015-11-13',
    '2015-11-20',
    '2015-11-27',
    '2015-12-04',
    '2015-12-11',
    '2015-12-18',
    '2015-12-25',
    '2016-01-01',
    '2016-01-08',
    '2016-01-15',
    '2016-01-22',
    '2016-01-29',
    '2016-02-05',
    '2016-02-12',
    '2016-02-19',
    '2016-02-26',
    '2016-03-04',
    '2016-03-11',
    '2016-03-18',
    '2016-03-25'
);

$fuel_prices = array(

    '2015-10-02' => array('HSFO_180cst' => 316, 'HSFO_380cst' => 214),
    '2015-10-09' => array('HSFO_180cst' => 330, 'HSFO_380cst' => 237),
    '2015-10-16' => array('HSFO_180cst' => 280, 'HSFO_380cst' => 224),
    '2015-10-23' => array('HSFO_180cst' => 258, 'HSFO_380cst' => 217),
    '2015-10-30' => array('HSFO_180cst' => 263, 'HSFO_380cst' => 220.50),
    '2015-11-06' => array('HSFO_180cst' => 263, 'HSFO_380cst' => 215.50),
    '2015-11-13' => array('HSFO_180cst' => 262, 'HSFO_380cst' => 201.50),
    '2015-11-20' => array('HSFO_180cst' => 249, 'HSFO_380cst' => 190),
    '2015-11-27' => array('HSFO_180cst' => 243, 'HSFO_380cst' => 197),
    '2015-12-04' => array('HSFO_180cst' => 236, 'HSFO_380cst' => 192),
    '2015-12-11' => array('HSFO_180cst' => 222, 'HSFO_380cst' => 162),
    '2015-12-18' => array('HSFO_180cst' => 206, 'HSFO_380cst' => 141),
    '2015-12-25' => array('HSFO_180cst' => 182, 'HSFO_380cst' => 133.50),
    '2016-01-01' => array('HSFO_180cst' => 182, 'HSFO_380cst' => 140),
    '2016-01-08' => array('HSFO_180cst' => 156, 'HSFO_380cst' => 121),
    '2016-01-15' => array('HSFO_180cst' => 136, 'HSFO_380cst' => 112.50),
    '2016-01-22' => array('HSFO_180cst' => 130, 'HSFO_380cst' => 112),
    '2016-01-29' => array('HSFO_180cst' => 156, 'HSFO_380cst' => 144),
    '2016-02-05' => array('HSFO_180cst' => 183, 'HSFO_380cst' => 147.50),
    '2016-02-12' => array('HSFO_180cst' => 163, 'HSFO_380cst' => 137.50),
    '2016-02-19' => array('HSFO_180cst' => 168, 'HSFO_380cst' => 154),
    '2016-02-26' => array('HSFO_180cst' => 168, 'HSFO_380cst' => 137),
    '2016-03-04' => array('HSFO_180cst' => 171, 'HSFO_380cst' => 147.50),
    '2016-03-11' => array('HSFO_180cst' => 191, 'HSFO_380cst' => 166),
    '2016-03-18' => array('HSFO_180cst' => 169, 'HSFO_380cst' => 161),
    '2016-03-25' => array('HSFO_180cst' => 179, 'HSFO_380cst' => 161.50)

);


$file = fopen("analysis_results.csv","w");

fputcsv($file, array('Range', 'Date', 'IMO', 'AverageSpeed', 'Length', 'Beam',
'YOB', 'DWT', 'Bunker Price'));
```

```
for (  $i = 1; $i < count($dates); ++$i ){
    $query = "SELECT
                '".$dates[$i-1]." TO ".$dates[$i]."',
                '".$dates[$i-1]."' as Date,
                imonumber as IMO,
                ROUND(sum(speedoverground)/count(speedoverground), 2) as 'Aver-
ageSpeed',
                length_1 as Length,
                beam_1 as Beam,
                year_build as YOB,
                dwt as DWT,
                '".$fuel_prices[$dates[$i-1]]['HSFO_380cst']."' as 'Bunker
Price'
                FROM vessels.nari_dynamic
                where
                     navigationalstatus in (0,8) and
                    ( date(t_date) >= '".$dates[$i-1]."' and date(t_date) <
'".$dates[$i]."' )
                    and (shiptype > 69 and shiptype < 90)
                group by imonumber;";


    $result = $conn->query($query);

    if ($result === false){

        echo "Cannot execute select query : ".$query.". Error  : ".implode("|",
$conn->errorInfo());
        exit();

    }


    while( $row = $result->fetch(PDO::FETCH_ASSOC)){

        fputcsv($file, $row);

    }

}

fclose($file);

$conn = null;

?>
```