CHALMERS

Benchmarks and measures for better fuel efficiency.

How AIS data can be used in operational performance analysis.

Master of Science Thesis in Nordic Master in Maritime Management

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Department of Marine and Shipping Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Goteborg, Sweden, 2012

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ABSTRACT

Shipping will face an escalating competition in the future, as more stringent environmental regulations will lead to significant higher fuel costs. Today, the cost of fuel stands for approximate 35-70% of total operational cost. Fuel efficiency measures are vital in order to stay competitive in the future.

The issue with the study is to examine how AIS data can be used to compare ships against each other with appropriate benchmarks in order to identify measures for better fuel efficiency.

A case study of 44 general cargo ships was carried out with AIS data from 2010-2011. These were two sister groups of 7 700 dwt and 12 700 dwt, with 22 ships in each group. Each group of sister ships were selected from their design and configuration in order to eliminate any design configuration differences in the operational analysis. Disturbance in AIS data was corrected and only voyages with coherent data without time gaps were used in analysis.

Ships in study show on a significant potential of improvement in terms of fuel efficiency. Short periods at high speed increase the average fuel consumption in total. All ships were operated at a significant higher average speed than the best economic speed, i.e. lowest cost per nautical mile. There were also tendencies of differences between the operators, where some operators tend to run their ships at a more fuel-efficient way than others. Capacity utilization analysis indicated a spare of 10-20% before hitting the optimum span, which show that fuel efficiency can be improved by increasing the output of the ships i.e. more cargo. However, the most important fuel efficiency measure is speed reduction, i.e. slow steam. The theoretical no anchoring strategy calculations confirm that there are great possibilities to minimize anchoring time in favour of speed reduction.

Keywords: shipping, ship operation, fuel consumption, fuel efficiency, AIS data analysis, slow steaming, operational performance.

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Gothenburg, May 2012

Johan Wigforss

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GLOSSARY

AIS = Automatic Identification System

Bunker = Ship fuel

Demurrage = Compensation to the ship owner if cargo handling in port takes longer time than agreed upon.

Despatch = Compensation to the charter if cargo handling in port are finished in in advance of what is agreed upon.

Dwt = Deadweight tonnage. A measure of how much a ship can safely carry. It is the sum of cargo, fuel, ballast water, fresh water, stores, and crew.

ECA = Emission Control Area. Environmental sensitive area designated by the IMO.

Economic speed = The speed that gives the lowest cost (shipping cost) per nautical mile.

General cargo ship = Ship that can carry packed items, including containers.

HFO = Heavy Fuel Oil.

IMO = International Maritime Organisation

Liner ship = Ship engaged in systematic liner trade. Runs according to a fixed schedule, just like a buss service.

MARPOL = International Convention for the Prevention of Pollution from ships by the IMO.

MGO = Marine Gas oil.

RoRo ship = Roll-on/Roll-off. Ships designed to carry wheeled cargo.

SECA = Sulphur Emission Control Area. Environmentally sensitive area, with special rules of sulphur content in bunker fuel, designated by the IMO.

Slow steam = Speed reduction of cruising speed.

Tramp ship = Ship engaged in tramp trade, i.e. operated without a fixed schedule. Just like a taxi service.

Transportation work = A unit of freight measured in tonne-km. The output of moving one tonne of cargo one kilometre.

Voyage = A journey from one port to another port. In study, a voyage is defined as the time a ship arrives a port till the time a ship arrives next port.

1 INTRODUCTION

The shipping industry will face an escalating competition from other modes of transport in the future, as shipping companies have to comply with new, more stringent environmental regulations, which will lead to increase of sea transportation cost, due to significant higher fuel price. Efficiency measures are vital for the shipping company and for the industry, in order stay competitive in the future.

1.1 EMISSIONS FROM SHIPPING

Emissions from shipping have become a hot topic during the last years. Emission of sulphur dioxide (SO_2) from shipping is now exceeding the emissions from emission sources on land, including traffic. Nitrogen oxide (NO_x) emissions from shipping are also likely to exceed emissions from land sources in only a few years. (Transportgruppen, 2012)

Emissions to air from shipping affect environment and human health in different ways. SO_2 and NO_x are harmful to the natural environment as they cause acid rain. NO_x and volatile organic compound (VOC) are also helping ozone to be created close to ground, which could be harmful to human health and vegetation. Emissions of NO_x also contribute to eutrophication, which could harm the sensitive balance in the land and marine ecosystem. (Transportgruppen, 2012)

Small particles, that are harmful for human health, are created when SO_2 and NO_x oxides in the atmosphere to sulphur and nitrogen particles that binds to dust and sot. Studies show on increased unhealthy and shortened lifetime of the population near the coastlines around Europe, where shipping is a large source of the environmental emissions. Carbon dioxide (CO_2) and other greenhouse gas emissions from ships contribute to global changes in the climate. (Transportgruppen, 2012)

It is possible to reduce emissions from shipping by technical measures on-board the ship. However, reducing the fuel consumption is the most important measure in order to minimize environmental impact, as emissions are in direct relation to fuel consumption.

1.1.1 REGULATIONS

Shipping is an international business. Regulations to protect the environment must be implemented on highest international level, due to the nature of the business, i.e. ships travel the globe in and out of national waters.

Prevention of pollution of marine environment through ship operations and accidents are covered in the MARPOL convention. The aim with the convention is to prevent and minimise both accidental pollution and pollution from routine ship operation. The convention consists of six annexes, where annex VI cover the prevention of air pollution from ships. It includes limits on sulphur oxide, nitrogen oxide, particulars from exhaust, and emissions of ozone depleting substances. (IMO, 2012)

1.1.2 SULPHUR

The global limit of sulphur content in maritime fuel is today 3.5%. This limit will be reduced over the next years, and by 2020 the limit of sulphur content is 0.5% globally. However, some areas are especially sensitive and have more stringent regulations, i.e. emission control areas (ECA), see Figure 1.1.

Figure 1.1; Existing, and possible future emission control areas. (DNV, 2012)

One example of an ECA is the Baltic Sea, which is a sulphur emission control area (SECA), with more stringent sulphur regulations. The limit of sulphur content in bunker fuel in the SECAs is today 1%. By 2015, the limit will be reduced to 0.1%, see Table 1. (IMO, 2012)

Year	SECA	Globally
Present (2012)	1.0%	3.5%
2015	0.1%	
2020/2025		0.5%

Table 1.1; Present, and upcoming sulphur regulations from the IMO. (IMO, 2012)

The date of global reduction of sulphur limit is not yet set. In 2018, IMO will analyse the global supply and demand of maritime fuel with low sulphur content. New global regulations will come into force in 2020 if the supply meets the demand. However, if there is a shortage in supply, the regulation will come into force by 2025. (IMO, 2012)

1.1.3 NEW REGULATIONS EFFECT ON SHIPPING

A study made by Sjöfartsverket (2009) indicate that the cost of fuel for ships operating in the Baltic Sea will increase with approximately 70%, as a result from the implementation of the new regulations from the IMO, and the use of a fuel type with lower sulphur content, i.e. change from HFO to MGO (Figure 1.2).

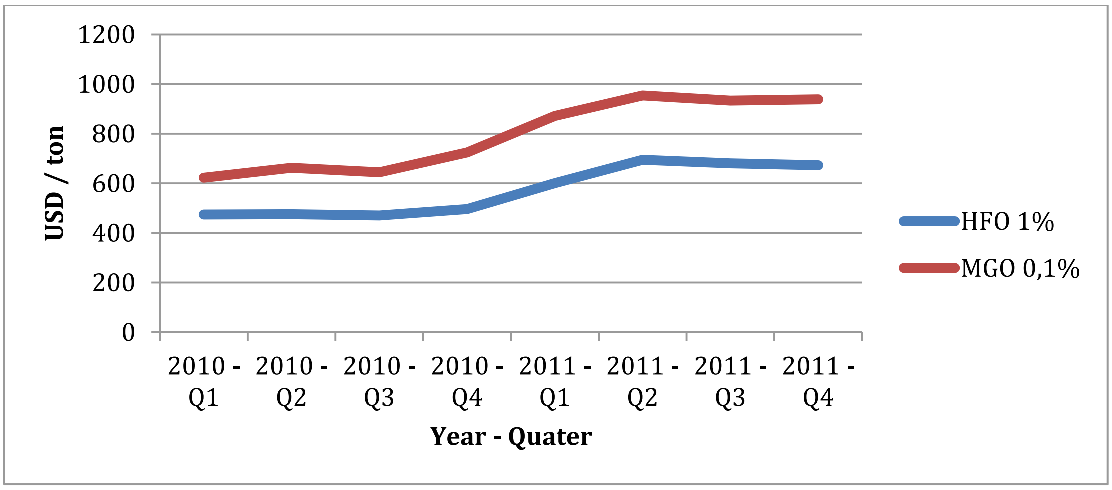

Figure 1.2; HFO and MGO price 2010-2011 in Rotterdam.

Research made by Kalli, Karvonen, & Makkonen (2009) indicate that the increase of fuel cost will increase freight cost of a container on the Baltic Sea with approximately 44-55%, see table 2, as the cost of fuel accounts for between 35% and 70% of a ship's total operational cost (Appendix 1), depending on the type of ship and service.

Sulphur content in fuel	1%	0.5%	0.1%
Container freight rate	4-13%	8-18%	44-55%

Table 1.2; Increase in container freight rates as a consequence of the low sulphur fuel regulations. (Kalli, Karvonen, & Makkonen, 2009)

Shipping companies are required to recover the increase in cost to maintain their level of service, meaning the price of shipping on sea have to be increased. However, recovery of fuel cost from cargo customers are challenging when vessel capacity utilization is not 100%, and trade is not evenly balanced. Cargo owners might seek new ways of transportations if the price increase outweighs the advantages of sea transport. They might accept a small change in freight cost, however, shipping in the Baltic Sea face tough competition from other modes of transport, such as rail and truck.

1.1.4 NEW REGULATIONS EFFECTS ON INDUSTRIES

The expected change in price of freight cause of new stringent environmental regulations will affect the industries in proximity of the emission control areas. Each industry will be affected differently, as there is a difference in import/export and need of sea transport. Estimations for the Finish industries show, that especially forest-, metal-, and chemistry industry will face significant increase in cost, in many cases with as much as 14-30%. (Kalli, Karvonen, & Makkonen, 2009) Similar calculations have been made for the Swedish industries, which show on similar result as in Finland. (Sjöfartsverket, 2009)

The industries will face a tough challenge, as they need to increase their price in order to recover the increase in shipping cost. They are competing on a global market and an increase of price might not be possible, which will lead to smaller marginal. A possible scenario could be movement of industrial production out from the ECA, e.g. Baltic Sea and closer to the market, which will be devastating for the economies around the ECA areas.

1.2 MAXIMISE EFFICIENCY FROM ASSETS

The reduction of fuel consumption trough optimisation of the fleet, use of alternative fuels, or through new technology is a high priority in order to stay competitive in the market even with new regulations. Optimisation in efficiency of existing ships and fleet could help in cutting cost of the operation. Different areas of operation could be improved, for example, voyage planning, weather routing, just in time, ship handling, fleet management, fuel type, etc. The yield of individual measures may be small, but the collective effect across the entire fleet can be significant.

In order to identify and setting targets of improvement within the shipping company and in comparison with others in terms of fuel efficiency, benchmarking is utterly important. The benchmarks must be identifiable and easy to access in order to simplify the analysis and realisation of applicable measures.

The process of constant improvement of fuel efficiency is vital in order to stay competitive in a market with high competition and increasing costs as a result of higher bunker prices.

1.3 PURPOSE

The purpose with the study is to propose benchmarks and measures for better operational efficiency from analysis of AIS data, with main focus on fuel consumption to achieve ship and fleet efficiency.

1.3.1 RESEARCH QUESTIONS

The issue with the study is to examine how AIS data can be used to compare ships against each other with appropriate benchmarks in order to identify measures for better fuel efficiency.

The study will answer two main research questions:

- Is it possible to benchmark ship fuel efficiency from AIS data?
- What benchmarks are useful in comparison with other ships?

These questions are further divided into sub-questions; Reliability of AIS data? Method of AIS data analysis? What are appropriate benchmarks in terms of fuel efficiency in different operational modes (i.e. sea, port, and anchor)? What measures in fuel efficiency improvement could be found from the benchmarks?

1.4 DELIMITATION

The study will limit the segment of study to two sister groups of small general cargo ships of 7 700 dwt and 12 700 dwt, with 22 ships in each group. AIS data from 2010 and 2011 is used in the compilation of operational profiles, where ships with less than 100 days of coherent data has been disregarded in further analysis.

Ship sailed distance and fuel consumption are theoretical calculations based on AIS data, result could therefore differ from on-board ship-log recordings. The grouping of ships in tramp/liner traffic is based on analysis of the operational pattern with no confirmation from the operator; reality could show on a different type of traffic or a mix of tramp/liner traffic. Further is the same engine configuration, resistance coefficient, and cargo capacity assumed for each group of sister ships.

1.5 OUTLINE OF THE REPORT

- Introduction
  The study is introduced by giving a background to the problem.

- Theory
  The chapter describes the cost structure of shipping and different measures that can be applied in shipping operation with main focus on efficient energy consumption.

- Methodology
  The chapter describes how the study was carried out, and discusses quantitative and qualitative research, case studies, data collection, and reliability – validity – objectivity.

- Case study
  This chapter describes input data to case study and the compilation of operational profiles for 44 general cargo ships from AIS data.

- Result
  The results of the case study are presented in this chapter. Operational profiles for all ships in study are presented.

- Analyse
  This chapter presents an in-depth analysis and discussion of the operational profiles. Benchmarks of the ships in study are set for each operational mode and measures in terms of fuel efficiency improvement are discussed.

- Conclusion
  Findings from result and analyse are summarized.

- Future study
  Suggestions of future areas of study are given in this chapter.

2 THEORY

The chapter describes the cost structure of shipping and different measures that can be applied in shipping operation with main focus on efficient energy consumption.

2.1 COST STRUCTURE

The cost of shipping is the main key in the decision process of shipping operations. Shipping cost is built up of voyage cost and operating cost. Voyage cost is a variable cost that comes with a particular voyage. Operating cost is a cost that originates from a ship operation. (Stopford, 2005)

- Shipping cost (SC):
  - Voyage cost (VC)
    - Fuel cost (FC)
    - Port dues and service charges (PS)
    - Canal dues (CD)

  - Operating cost (OC)
    - Manning cost (M)
    - Insurance cost (IN)
    - Repair and maintenance cost (RM)
    - Store and lubricant cost (SL)
    - Administration cost (AD)

SC = VC (FC+PS+CD) + OC (M+IN+RM+SL+AD)

(Stopford, 2005)

Voyage cost is made up of fuel cost, port dues and service charges, canal dues. Operating cost is made up of manning cost, insurance cost, repair and maintenance cost, store and lubricant cost, administration cost. Some costs of manning, administration, and store and lubricant can be shared within a shipping company in order to achieve economies of scale. (Venus Lun & Browne , 2009)

2.2 SECTORS OF SHIPPING

Shipping is a highly international business; companies are privately owned and offer a service of transportation within, or between regions. The shipping industry is mainly divided in three different sectors, liner, tramp, and industrial, divided by the type of service and characteristics of the transported cargo. (Stopford, 2005)

2.2.1 LINER SHIPPING

Liner shipping offers a regular service between ports, operated just like a bus service according to a fixed schedule. Cargoes are accepted under a bill-of-lading contract issued by the ship operator to the cargo owner. The cargoes are most often smaller quantities with a high value per tonne that does not by itself fill an entire shipload.

The combination of many small consignments and a regular service put a lot of demand on the administration, which leads to high overhead cost in liner shipping compared to other sectors of shipping. Liner operators are therefore vulnerable to price cutting strategies by other companies operating at the same route. Competition in liner service has generally been regulated by conferences, i.e. agreements between the shipping companies. These are agreed upon in order to stabilize conditions of competition and to set fright rates for all members in the conference. (Stopford, 2005)

2.2.2 TRAMP SHIPPING

Tramp shipping, also commonly referred to as bulk shipping is characterised by shipping of cargo with a low value per ton, often a whole shipload from a single shipper. Tramp service is unlike the liner service not running on a fixed schedule. The cargoes are referred to as spot cargoes where a contract arranged between the ship-owner and shipper, either for a single voyage, i.e. voyage charter or for a period of time, i.e. time charter. (Stopford, 2005)

2.2.3 INDUSTRIAL SHIPPING

When the shipper, i.e. cargo owner is confident of the amount of cargo he need to transport in the future, he might take the role as shipping operator himself. Industrial shipping is most often carried out by large cooperation's that transport own goods or raw material essential to their manufacture and distribution supply chain.

Industrial shipping has however decreased during the recent years in favour of tramp shipping. Companies have shifted towards a stronger focus on their core business, rather than also being a shipping operator. This has led to increase of tramp market, where operators now have more cargo with a constant flow to choose from. (Stopford, 2005)

2.2.4 CHARTER AGREEMENTS

Voyage charter
In a voyage charter, the ship-owner agrees to transport a specific cargo between two ports. The charterer pays the ship-owner per tonne or a lump-sum. The ship-owner pay all cost involved in the transport, excluding stevedoring in port. (Stopford, 2005)

Time charter
In a time charter contract, the ship-owner hands over the operational control to the charterer during a specified time period. The ship-owner still pays the operational cost of the ship, however, the charterer pays the voyage specific costs. (Stopford, 2005)

Bareboat charter
In a bareboat charter, the ship full operational control is handed over to the charterer. The owner is usually an investment company who has no knowledge about ship operations, i.e. the ship is only an investment. The charterer pays both the operating and voyage specific costs. (Stopford, 2005)

2.3 ENERGY EFFICIENCY

Fuel cost is the single most important variable cost. It accounts for approx. 35-70% of the total cost of running a ship (Appendix 1). Building fuel-efficient ship has become more and more important in the shipping industry as oil prices have increased significant over the last decades.

By improving the energy efficiency of a ship, more work can be done with the same energy consumption. Improvement in efficiency can be achieved in both the design and in operation of the ship. Some of the improvements can be retrofitted to existing ships, however the most important factors that are determine the energy efficiency of a ship are closely linked to the specification of the ship and more easily changed in the design and building process of a ship. This means that design improvements in efficiency take some time before they will be implemented and have any affect in the efficiency status of a shipping company, as most ships have a service life of approx. 30 years before they are phased out. The lifetime of ship can change over its lifetime, so can the intended market for the ship, which is important to take into account already in the design process. Larger ships are usually more energy efficient per tonne-km than smaller ships. However, smaller ships can usually achieve a higher utilization, which may result in a better energy efficiency. (IMO, 2009)

It is important to use the right ships in the shipping network. With larger ships, energy efficiency can improve, however when looking on the whole chain, door-to-door, energy efficiency can be improved if smaller ships, i.e. feeder ships, connect with the larger ship in the spread of distribution, as illustrated in Figure 3.1. This because larger ships become more energy inefficient if they have to sail with low capacity utilization. (IMO, 2009)

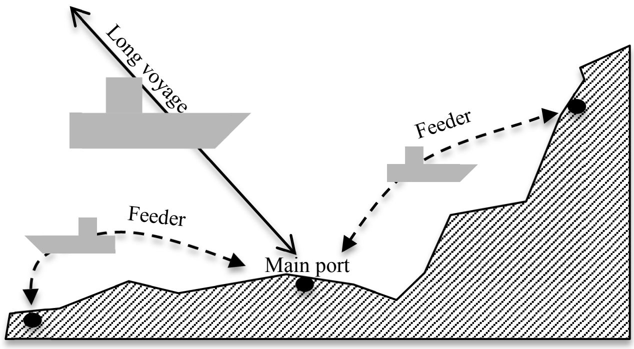

Figure 3.1; Smaller feeder ships connect with large ship in order to achieve energy efficiency in the whole shipping network.

2.4 FUEL CONSUMPTION

The hull resistance through water and type of engine used to propel the ship forward mainly determine the fuel consumption of a ship. A formula for estimating the power consumption is showed below. (IHS Fairplay, 2012)

$$P_{active} = 20\% \times P_{Aux.Gen} + 85\% \times P_{Main} \times \left(\frac{V_{calc}}{94\% \times V_{service}}\right)^{2,5}$$

P_{active} = Total power. (kW)
$P_{Aux.Gen}$ = Auxiliary generator power. (kW)
P_{Main} = Main engine power. (kW)
V_{calc} = Calculated average speed. (Knots)
$V_{service}$ = Ship service speed. (Knots)

The P_{active} consumption formula is used when the ship is under way sailing, i.e. a speed ≥ 0,2 knots. If the ship has a calculated speed < 0,2 knots, i.e. at anchor or at berth in port, a $P_{inactive}$ formula is used.

$$P_{inactive} = P_{Aux.Eng} \times ActivityShare_{VesselType}$$

$P_{inactive}$ = Total power. (kW)
$P_{Aux.Eng}$ = Auxiliary engine power. (kW)
$ActivityShare_{VesselType}$ = % Of Auxiliary engine use in berth or at anchor.

The activity share of the auxiliary engine of a general cargo ship is set to 25%, both at berth and at anchor.
The auxiliary power used while at sea, i.e. speed ≥ 0,2 knots, is set to 0. The auxiliary power needed while at sea is calculated as an additional load on the main engine.
Each ship has a value of fuel consumption in grams per kWh of energy generated by its engine. This value is multiplied with P_{active} to produce total fuel consumption in grams. (IHS Fairplay, 2012)

2.5 ENERGY EFFICIENCY MEASURES

Energy efficiency could be improved by implementing different measures in the operation of a ship. Measures could be carried out both on-board the ship by the crew and by onshore personnel at the shipping company.

2.5.1 OPTIMISATIONS BY THE MASTER.

The master of a ship is in a position where he can optimise the voyage in a way to run efficient, within the limitation from constrains that are set in contractual agreements and scheduling. Except from technical side with ballast and trim optimisation he can also adjust the ship route according to the weather and currents i.e. weather routing and just in time, where he take tide, queues and arrival window into consideration. (IMO, 2009)
The efficiency potential of voyage optimisation measures is very hard to access from a general basis. Each ship and route has its own characteristics of operation, it is therefore important to look into the individual operational procedures in order to define areas of improvement and potential of increased fuel efficiency. (IMO, 2009)

2.5.2 WEATHER ROUTING

In order to optimise the voyage in terms of fuel consumption, safety, comfort, and minimum time under way, the weather routing systems suggest an optimum track for the intended voyage based on the weather forecast, condition of sea, and the design and specifications of the ship. The master can use the pilot chart atlases, the sailing directions, and historical weather data tables to make a preliminary weather routing. A weather routing agency can also assist the master by suggesting an optimal route in compliance with the weather forecast. The agency can then monitor the ship and suggest changes in the route as voyage progress. (Bowditch, 202)

Weather routing is preferable especially if the passage is:

- Long passage, about 1 500 nm or more.
- There is more than one choice of route. The waters are navigational unrestricted.
- Weather (wind, waves, current) is an important factor in the choice of route.

Studies show that efficient weather routing can save approximately 2-4% in fuel consumption. (MARINTEK, 2000) However, weather routing is today a common practice in ship voyage planning, significant increase in fuel consumption savings is therefor hard to achieve.

2.5.3 JUST IN TIME

Shipping has a tradition in operating at a high speed during the sea leg of the voyage, with waiting outside port as a consequence. Arrival just in time when berth is ready has a huge potential in fuel cost savings for the shipping company. However, contractual agreements sometimes favour insufficient operations.

The laytime start as soon as the ship owner sent notice of readiness. The laytime specifies time needed for loading/unloading. The ship owner is entitled to compensation from the charterer i.e. demurrage, if the loading/unloading takes more time than specified in the laytime clause, as illustrated in Figure 3.2.

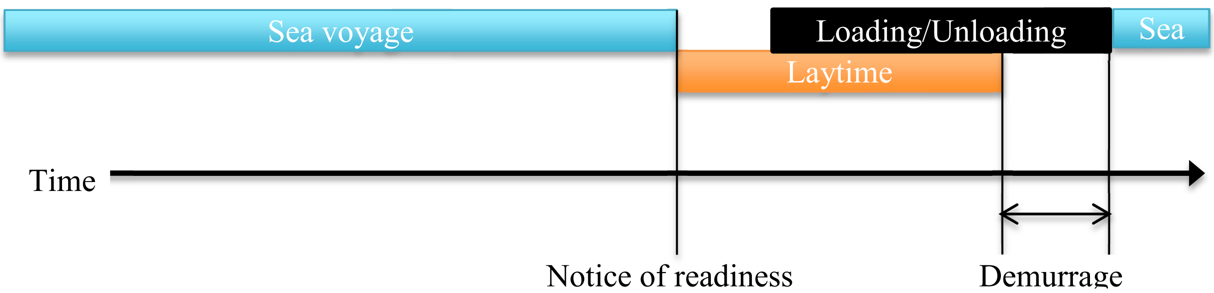

Figure 3.2; Demurrage. Loading/Unloading exceeds the laytime.

The owner should compensate the charterer, normally half of the demurrage rate, i.e. despatch, if the loading/unloading operation is completed in advance of the time specified in the laytime clause, as illustrated in Figure 3.3.

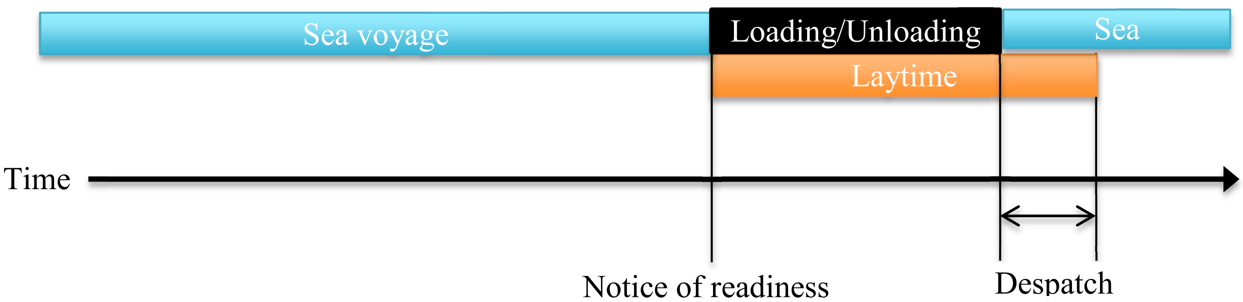

Figure 3.3; Despatch. Loading/Unloading is finished before laytime ends.

The ship-owner wants to send notice of readiness as soon possible within the time frame specified in the contractual agreement, as the demurrage rate could affect his financial result of the contract in a positive way. Owner's motivation of just in time delivery of the ship when berth is ready might be reduced cause of the demurrage possibilities, which could affect the choice of speed and fuel consumption in a negative way as he might choose to operate in a higher speed than what would be necessary for a just in time delivery.

Studies show that just in time arrivals could save approximately 1-5% in fuel consumption. A higher saving may be achieved if the contractual agreement not favours the operator to operate the ship at a higher speed. (IMO, 2009)

2.5.4 TRIM OPTIMISATION

The energy savings by trim optimisation, i.e. optimal position in the water, is very much depending on the type of ship and nature of operation. An optimal position can be translated into fuel consumption savings, as the optimal trim will reduce the resistance through water.

Lockley and Jarabo-Martin (2011) indicate in their report that the potential savings of trim and ballast optimisation could reduce the fuel consumption with approximate 4% compared with ship operation at level trim. However, the study of IMO (2009) indicate significant lower savings, 0-1%, as trim optimisation already is a common practice.

2.6 CHOICE OF SPEED

The optimal speed from an economical point of view is defined by MARINTEK, 2000: *"The speed that maximizes the difference in between income and expenses (per time unit) of the ship"*. However, the optimal speed changes from which view of the different actors in the sea transportation. As Ronen (1982) point out in his research, the owner of the cargo sees the transportation cost in relation to value of the cargo. A cargo with high value could be too expensive to slow steam as the savings in fuel cost might be diminished by the extra cost of an increased lead-time.

The ship owner has to weigh his income and cost against contractual agreements, which could vary from time to time. When the supply of sea transport exceeds the demand, a speed reduction may be the best choice for the ship owner. If the demand of sea transport is higher than the supply, a minimum time strategy is normally chosen. (MARINTEK, 2000)

2.6.1 SLOW STEAMING

Slow steam became a common practice in shipping during the financial crisis in 2008-2009. The demand of shipping fell rapidly at the same time new capacity was delivered due to previous orders made during the financial boom in the years leading up to the financial crisis. Shipping companies started to use slow steaming as a way to reduce cost and to be able to utilize the fleet in a wider extent than the demand. The practice was supposed to fade out when the economy started to grow again and the demand of shipping rose. However, increase in fuel price and more stringent environmental regulations have led to slow steaming as a normal practice in order to adapt to new market conditions, which is showed in the research of Cariou (2011), where he points out that the concept of slow steaming has reduced fuel consumption with approximate 11% in major container trades worldwide during 2008-2010.

With slow steaming you run the ship with approx. 80% of the main engine full power. Which reduce fuel consumption with approx. 40% (Appendix 1).

Timing of fuel injection, adjusting exhaust valves, and exchanging other mechanical components in the engine is vital in order to make sure maintenance cost does not overrun fuel cost savings.

2.6.2 ECONOMIC SPEED

Running the ship at slower speed means significant lower fuel consumption with lower cost as a result. The economic speed of a ship is achieved at the speed that result in the best possible financial result for the shipping company. Several factors are considered when determining the economic speed of a ship.

- Price of bunker.
- Relation of fuel consumption and speed.
- Daily operating cost.
- Operating profit.
- Future employment of the ship.
- The state of the freight market.
- Design speed of the ship.
- Technical ability for the engine to operate at a lower speed.
- Weather conditions.

An easy way to determine the economic speed of a certain ship is to calculate the total voyage costs in relation to speed, as illustrated in Figure 3.4. (Dykstra, 2005) Where the operating cost for each ship category is set as an fixed cost per day, i.e. daily charter rate, and the bunker price a variable, which is the same for all ships (Table 3.1).

	7 700 dwt	**12 700 dwt**
Daily charter rate	4066 USD	5403 USD
Fuel:		
HFO 1% sulphur	570 USD / tonne	
MGO 0.1% sulphur	794 USD / ton	

Table 3.1; Daily charter rate and fuel price.

The economic speed calculations are based on the average charter rates (VHSS, 2012) and fuel prices in Rotterdam (IHS Fairplay, 2012) during the period of study, i.e. 2010-2011. There was a significant steady increase in fuel price over the period, with an increase of 51% of the MGO and 51% of HFO. Charter rates were distributed between 2634 USD/day and 5151 USD/day, respectively 3338 USD/day and 7348 USD/day for the larger ships. The peak period of charter rates occurred in the first quarter of 2011.

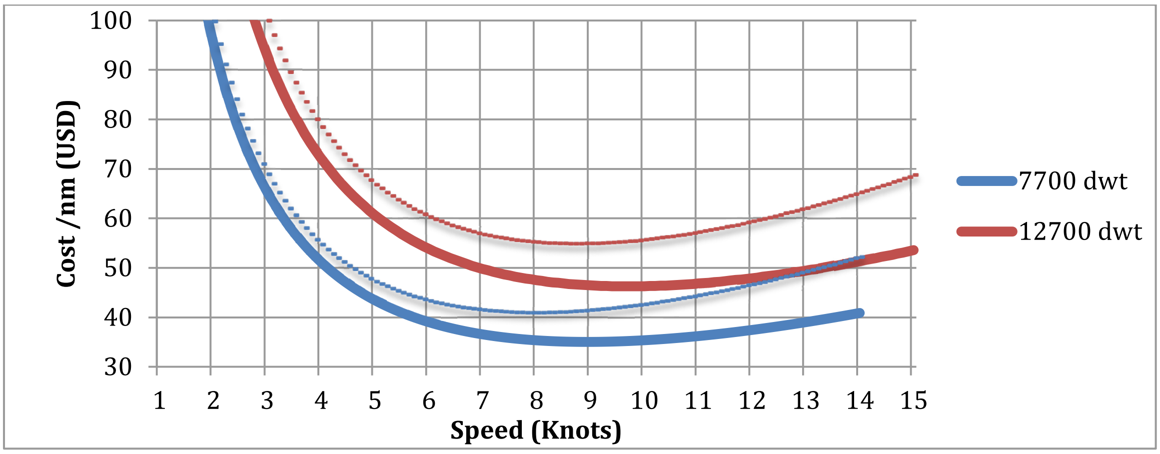

Figure 3.4; Economic speed. Thick line show cost per nautical mile with use of normal bunker fuel (HFO 1%). Dotted lines show cost per nautical mile with low sulphur fuel (MGO 0,1%).

Where the curve of cost per nautical mile reaches its minimum in Figure 3.4 determine the most economic speed, i.e. lowest cost per nautical mile, for the two ship categories examined in this report. (Dykstra, 2005)

	7 700 dwt	**12 700 dwt**
HFO 1%	8.9 knots	9.7 knots
MGO 0,1%	7.8 knots	8.7 knots

Table 3.2; Best economical speed at different fuel prices.

As Figure 3.4 and Table 3.2 show, the best economical speed decreases when the fuel price increases. However, when the charter hire increase, the optimal economical speed increase as the economical speed is a function of the relation between fuel cost and total cost. With higher speed, the fuel cost percentage of the total cost increase. At a speed of 10 knots, the fuel consumption stands for approximately 50% of the total cost.

The economic speed calculation does not take into consideration of other variables than charter hire, bunker price, and fuel consumption. Type of trade, state of market, weather, and technical aspects could also affect the economic speed. The model is also only looking at the economic benefit of the charterer.

The ship owner’s benefit of a reduction in speed stretches beyond the economical speed of the charterer. The economical speed seen from both the ship owner and the charterer’s point of view in a time charter agreement can be expressed as the stakeholder shared benefit. In this economic model the economic benefit is shared equal between the two main stakeholders, i.e. ship owner and charterer. (Klanac, Nikolic, Kovac, & McGregor, 2010)

$$B_{SO}(V) = B_{CH}(V)$$

$$B_{SO}(V) = N_{SS}(V) \times (ACR - C_O) – (ACR - C_O)$$
$$B_{CH}(V) = N_{SS}(V) \times (-ACR - C_{FO}(V)) – (-ACR – C'_{FO})$$

Where:

$N_{SS}(V)$ = Number of ship necessary to transport equal amount of cargo. ($\frac{V_{Service}}{V_{calc}}$)
ACR = Annual charter rate. (365 $\times$ t $\times$ Daily charter rate), (t = commercial use of ship per annum).
$C_{FO}(V)$ = Fuel cost.
C'_{FO} = Fuel cost at service speed.
C_O = Ship-owner operating cost per ship.

	7 700 dwt	12 700 dwt
Daily charter rate (VHSS, 2012)	4066 USD	5403 USD
Operating cost/year	1200000 USD	1500000 USD
t	90%	
Fuel price/tonne HFO 1%	570 USD	
Fuel price/tonne MGO 0.1%	794 USD	

Table 3.3; Costs associated with ship operation.

A shared stakeholder benefit from a speed reduction from full service speed is illustrated in Figure 3.5. Benefit can be achieved by between 5.1-14 knots for the 7 700 dwt ships, and between 5.4-15 knots for the 12 700 dwt ships. The maximum shared benefit of approx. 363000 USD annually is achieved at 8.6 knots for the 7 7000 dwt ships, and approx. 512000 USD at 9.2 knots of speed for the 12 700 dwt ships. These numbers are only achieved given prerequisites in Table 3.3.

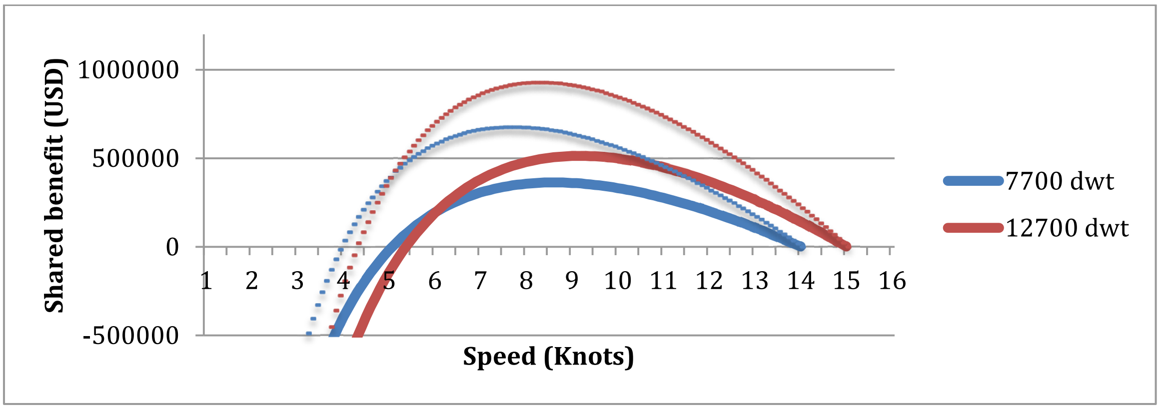

Figure 3.5; Shared stakeholder benefit of a speed reduction from service speed.

An even greater benefit is possible if the ship is running on a low sulphur fuel, i.e. higher fuel cost. The optimal speed for the two ship sizes are approximately 1 knots lower with the use of MGO 0.1% sulphur fuel compared with running on HFO 1% sulphur fuel, as the dotted line in Figure 3.5 illustrate.

3 METHODOLOGY

The following chapter describes how the study was carried out, and discusses quantitative and qualitative research, case studies, data collection, and reliability – validity – objectivity.

Methodology is a fundamentally approach where framework and different principles are being set up in order to show how the work should proceed. (Höst, Runesson, & Regnell, 2006)

3.1 QUANTITATIVE AND QUALITATIVE RESEARCH

In quantitative research, measurements are made in the data collection process and processed further with statistical methods. The focus in qualitative research is the soft data, e.g. qualitative interviews and interpreted data. (Patel & Davidsson, 2003)
The method of study is chosen in order to gather information needed to carry out the research. (Bell, 1995) A research can consist of a mix of both quantitative and qualitative. The formulation of the problem decides witch research approach to be used. (Patel & Davidsson, 2003)

3.2 CASE STUDIES

Bell (1995) means that case studies are especially suited for single researchers, as case studies give the researcher the opportunity to carry out in depth analysis of a problem in a limited time.

Further describes Silverman (2005) what a case study is:
"The basic idea is that one case (or perhaps a small number of cases) will be studied in detail, using whatever methods seem appropriate. While there may be a variety of specific purposes and research questions, the general objective is to develop as full an understanding of that case as possible"

Case studies are often used in the study of processes and changes, where it is common that different kind of information is gathered in order to give an as detail picture as possible of the case. Most common is the use of interviews, surveys, and observations in the case study to gather information. (Patel & Davidsson, 2003)

3.3 DATA COLLECTION

There are two types of data, primary- and secondary data. The difference between them lies in which purpose data is gathered. Primary data is gathered in the purpose of research and need, while secondary data is gathered in the need of another purpose. (Eriksson & Paul, 2001)
Data collection can be carried out with several different techniques depending on the problem. Interviews, literature, observations, and surveys are examples of methods. The method used, is chosen depending on the purpose with the information.

Literature:

Any kind of materials such as books, brochures, and scientific papers are seen as literature. This material is seen as secondary data, and is used as a theoretical- and analytical frame for the research. (Bell, 1995)

Data collected by others:
Processed material, available statics, index data, and archival data are four different kinds of data collected by others. Höst (2006) means that this data has to be carefully used as it was collected in other purposes than what the study refers to. It is therefore important to have a critical approach to this kind of material to maintain high validity and reliability.

3.4 RELIABILITY, VALIDITY, AND OBJECTIVITY

It is important that the observations made in the study can be repeated in order to attain a high level of reliability. The reliability is depending on the credibility of the measurement instruments. It question if another researcher get the same results with the same measurement instruments. The method should therefore be independent of the researcher in order to achieve high reliability. (Eriksson & Paul, 2001)
Further mean Eriksson & Paul (2001) that the validity is the chosen measure instrument ability to measure what it is intended to measure, and that god validity is attained when the researcher measure what he is intended to measure.
With a low reliability, validity gets low. Good reliability is necessary, but not enough to secure high validity. It is therefore possible to have high reliability with low validity.
The credibility of a study is also depending on the researcher objectivity. Objectivity means the degree of which different values affect the result. The objectivity can be increased if the research clearly describe the study and give the readers an opportunity to create their own view of the result. (Björklund & Paulsson, 2003)

3.5 RESEARCH APPROACH

The aim with this study is to propose measures and benchmarks in operation in order to achieve energy efficient shipping.
A case study of 44 general cargo ships was carried out. These were two sister groups of 7 700 dwt and 12 700 dwt, with 22 ships in each group. Each group of sister ships were selected from their design and configuration in order to eliminate any design configuration differences that could affect the result of the operational analyse.

Both primary and secondary data have been used for the study. The primary data for the case study and analyse was extracted from the IHS Fairplay database, AISLive and Sea-Web. Further were secondary data from literature gathered in order to give the reader a better understanding of the importance of energy efficiency in shipping and to help in the analyse of the case study. Others collected statistical data, such as bunker prices at major ports in year 2010-2011.

The reliability of the study can be considered as high, since the selection of ships were carried out carefully in order to minimize design differences in fuel consumption. The period of 24 months (year 2010, and 2011), also minimize the risk of seasonal differences in analysis. However, the author had no insight in the operator/shipping company strategy of the decision behind the choice of speed and other operational characteristics, several strategy factors could affect the result.

Since the author has no relation to studied ships/companies, the objectivity of the study has been maintained at a high level.

4 CASE STUDY

This chapter describes input data to case study and the compilation of operational profiles for 44 general cargo ships from AIS data.

4.1 AUTOMATIC IDENTIFICATION SYSTEM (AIS)

The AIS system is a ship tracking system that is built up from transponders on ships. A ship carries an electronic device, which transmits and receive single to and from other ships within a certain range. The electronic device consists of a GPS receiver, a computer, and a radio. The GPS send information about the ship position to the computer, which process the data together with other data from the ship and the send this information to other Ships and shore stations equipped with AIS equipment, as illustrated in Figure 4.1.

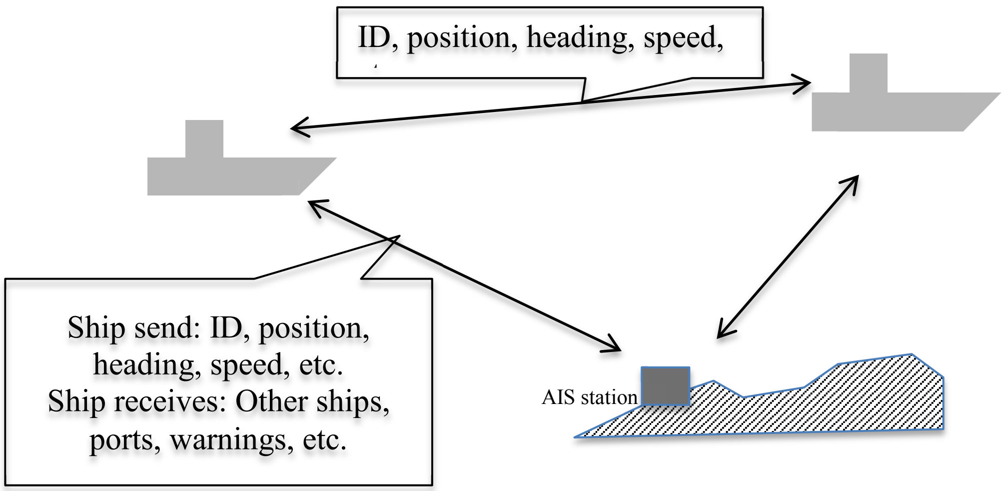

Figure 4.1; AIS system in practice.

The regulation 19 of SOLAS Chapter V from the IMO set the requirements of the navigational equipment to be carried on-board ships. In 2000, IMO adopted a new requirement, which became effective in 31 December 2004, that all ships over 300 gross tonnage engaged on international trade, cargo ships over 500 gross tonnage engaged in domestic trade, and all passenger ships should carry AIS equipment on-board. (IMO, 2012)

The purpose with AIS is to improve the safety and efficiency on sea. The AIS system makes it easier to identify other ships and leaves additional information to the users, which increase the awareness in different situations. The quality of decision-making could be improved for both for the shore-based surveillance activities as well as for the on-board personnel with the use of AIS information together with other navigational systems e.g. radar.

The AIS transmits three types of information from the ship: Static information, which is entered into the system in the installation process and is only updated if vessel change name or if the particulars are changed due to reconstruction. Dynamic information is updated with 2-10sek intervals from the ship sensors connected to the AIS. Voyage specific information, is manually entered by the crew by every voyage or change in operation.

Static information
- MMSI (Maritime Mobile Service Identity)
- Name of ship
- IMO number
- Length and breadth
- Type of Ship
- Position of the AIS antenna

Dynamic information
- Position of the ship (Latitude and Longitude) and GPS accuracy.
- Time (UTC)
- Course over ground (COG)
- Speed over ground (SOG)
- Heading
- Rate of turn

Voyage specific information
- Navigational status (On way using engine, At anchor, Not under command, Restricted ability to manoeuvre, Moored, Restricted by draught, On ground, Engaged in fishing, Under sail)
- Draught
- Dangerous goods
- Destination and estimated time of arrival (ETA)
- Intended route (way-points)
- Short safety related message

(Sjöfartsverket, 2004)

Not all vessels on sea are equipped with AIS equipment; small leisure boats, fishing boats, and shore-based station could lack AIS equipment. The crew of the ship can also turn of the equipment, and the equipment could be inaccurate calibrated. It is therefor important to remember that the AIS system is only a supplement to other navigational information and might not show the whole picture in a situation. The AIS information is only as good as the accuracy in the broadcasted information. (Sjöfartsverket, 2004)

4.1.1 AISLIVE

AISLive is a global AIS network set up by IHS Fairplay to track ship movements in real-time trough an online application. Positions of ships of over 54 000 ships are updated every third minute. The AISLive network of land and satellite antennas covers over 2 500 ports and 100 countries. IHS Fairplay has stored the AIS data once every hour since 2004. This historical data could for example be used to analyse a ship movement pattern and time in particular regions.

Example of AIS data from the IHS Fairplay database:

LRNO	DATE&TIME	LATITUDE	LONGITUDE	HEADING	SOG	VESSEL_STATUS	SOURCE	ZONEID	REGIONID	DRAUGHT	WEEK
9187916	2010-01-01 04.58	35.90972	-5.31345	287	0.1	Anchored	AIS	265	4	6.2	1
9187916	2010-01-01 05.58	35.90846	-5.3151133	359	0.2	Anchored	AIS	265	4	6.2	1
9187916	2010-01-01 06.58	35.91165	-5.31729	82	0.3	Under way using engine	AIS	265	4	6.2	1
9187916	2010-01-01 07.59	35.89511	-5.3061167	278	0	Moored	AIS	264	4	6.2	1
9187916	2010-01-01 09.00	35.89507	-5.3061067	278	0	Moored	AIS	264	4	6.2	1
9187916	2010-01-01 09.58	35.89511	-5.3061017	278	0	Moored	AIS	264	4	6.2	1
9187916	2010-01-01 10.59	35.89508	-5.3061233	278	0	Moored	AIS	264	4	6.2	1
9187916	2010-01-01 11.59	35.8951	-5.3060717	279	0	Moored	AIS	264	4	6.4	1
9187916	2010-01-01 12.59	35.9655	-5.3560383	288	6.4	Under way using engine	AIS		4	6.4	1
9187916	2010-01-01 13.59	35.97303	-5.5625733	260	11.1	Under way using engine	AIS		11	6.4	1

Table 4.1; Example of AIS data.

4.2 Ships in study

44 general cargo ships were selected for the case study (Appendix 2). These were two sister groups, one group of 22 ships with a dwt of approx. 7 700 and a second group of 22 ships with a dwt of approx. 12 700. Within each group of sisters, every ship has the same characteristics i.e. same length, breadth and shape of hull as showed in Table 4.2. This allow comparison of fuel consumption within each sister group, as the resistance and drag coefficients are the same or very close to the same.

	7 700 dwt	12 700 dwt
Length	118,55 meters	138,5 meters
Breadth	15,2 meters	18,1 meters
Draught	6,3 meters	8 meters
TEU 14	300	550
Mcr	3840 kW	5400 kW
Aux. generator	918 kW	2200 kW
Aux. engine	550 kW	1530 kW
Service speed	14 knots	15 knots
Fuel consumption	177 gram / kWh	175 gram / kWh
Fuel consumption Aux. engine	210 gram / kWh	210 gram / kWh

Table 4.2; Ships data.

4.2.1 Fuel consumption

The fuel consumption of the two groups of ships is shown in Table 4.3 at service speed, at berth, and at anchor. Further is fuel consumption illustrated as a function of speed in Figure 4.2.

	7 700 dwt	12 700 dwt
Fuel consumption at $V_{service}$	17 ton/day	24,4 ton/day
Fuel consumption at berth/anchor	0,693 ton/day	1,978 ton/day

Table 4.3; Fuel consumption at service speed and at berth/anchor.

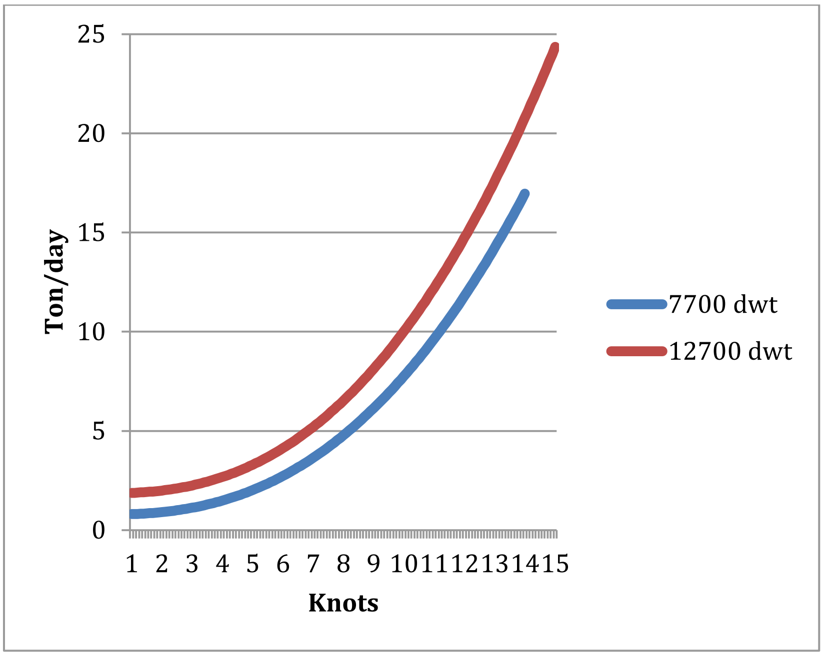

Figure 4.2; Fuel consumption in ton/day at different speeds.

4.2.2 HYDROSTATIC DATA

Hydrostatic data of the two ship sizes help to determine the amount of cargo on-board at the time of a given AIS recording with draught data. The deadweight is a measure of how much a ship can carry. It sums up the weight of cargo, fuel, fresh water, ballast water, provisions, passengers, and crew.

7 700 dwt			12 700 dwt		
Draught	tonne / cm	Deadweight	Draught	tonne /cm	Deadweight
3,0	14,36	0	No data available		
3,5	14,53	773			
4,0	14,74	1456			
4,5	14,96	2199			
5,0	15,23	2955			
5,5	15,56	3727			
6,0	15,88	4516			
6,5	16,17	5316			
7,0	16,39	6132			

Table 4.4; Tonne of deadweight to change draught. (Bodewes Shipyards bv, 2012)

4.3 AIS DATA

AIS data were extracted from the IHS Fairplay database for all ships during the period 2010-01-01 to 2011-12-31. The tracking of each ship was plotted onto a map in order to determine area of operation and in order to visualize the correctness of the AIS data.

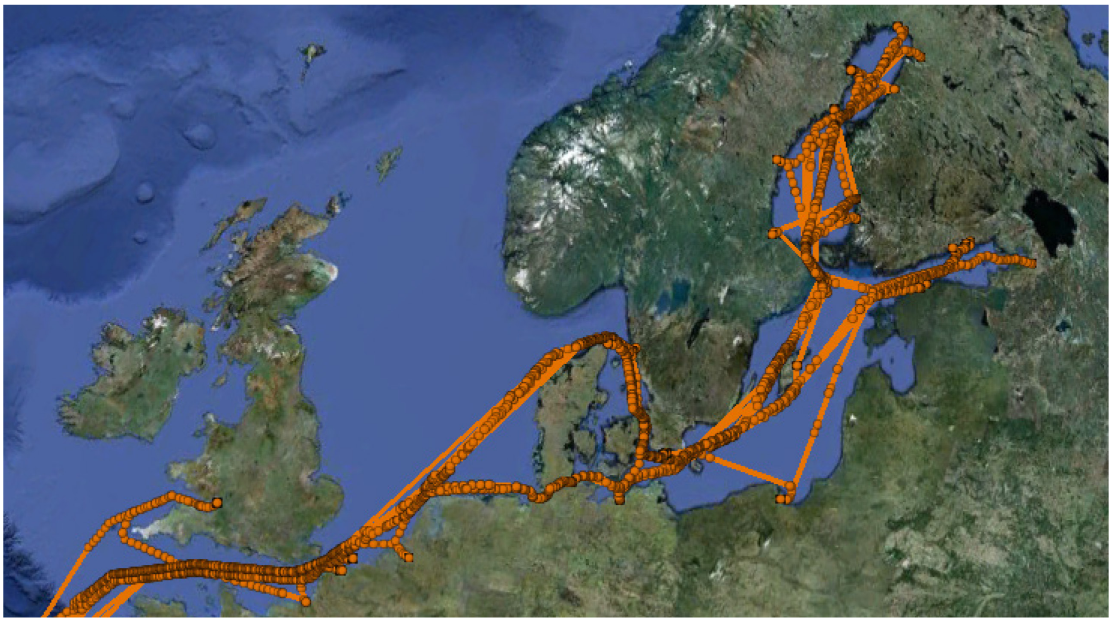

Figure 4.3; Example of ship's visualization of track on map.

The AIS data included some faulty recordings of data due to disturbance in transmission. The visualization of the tracks showed on faulty recording where coordinates have been misplaced in the data. These were manually corrected in the data and track was controlled in visualization.

AIS recordings with duration from previous recording of less than 10 minutes were deleted, as they generally were displaced coordinates.

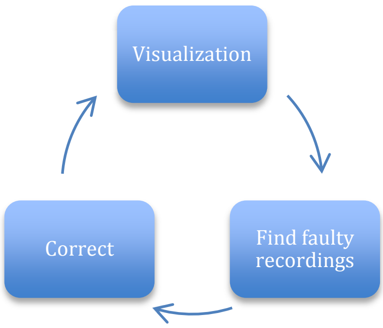

Figure 4.4; Working process of AIS data correction.

The AIS data included SOG (speed over ground), however this data is automatically transferred from the Ship GPS to the ship AIS equipment at the time when AIS data is transferred. It does not show on the actual SOG since the last update. Actual average speed since pervious update was manually calculated based on the distance between coordinates and duration from previous recording in order to be able to correctly calculate the fuel consumption of the ship. The AIS data were also missing two weeks, week 15 in 2010 and week 4 in 2011. Duration and distance after each of these weeks were set to 0 in order to minimize the risk of faulty data in analysis.

The spherical law of cosines is used to calculate the distance between two coordinates, as planet earth is spherical.

Distance = ACOS(SIN(lat1)*SIN(lat2)+COS(lat1)*COS(lat2)*COS(lon2-lon1))*6371

However, Microsoft access, which was used in this study for data analysis do not recognize arc cosines. The formula was therefor modified for the use in Microsoft access:

Distance = Atn(Sqr(1-(Sin([latt1])*Sin([latt2])+Cos([latt1])*Cos([latt2])*Cos([long2]-[long1]))^2)/(Sin([latt1])*Sin([latt2])+Cos([latt1])*Cos([latt2])*Cos([long2]-[long1])))*6371/1.852)

LRNO	DATE&TIME	LATITUDE	LONGITUDE	HEADING	SOG	VESSEL_STATUS	SOURCE	ZONEID	REGIONID	DRAUGHT	WEEK	Calc_Distance	Calc_ AvgSpeed
9187916	2010-01-01 04.58	35.90972	-5.31345	287	0.1	Anchored	AIS	265	4	6.2	1	0.009120706	0.009111923
9187916	2010-01-01 05.58	35.90846	-5.3151133	359	0.2	Anchored	AIS	265	4	6.2	1	0.110885502	0.110882422
9187916	2010-01-01 06.58	35.91165	-5.31729	82	0.3	Under way using engine	AIS	265	4	6.2	1	0.219006259	0.218809695
9187916	2010-01-01 07.59	35.89511	-5.3061167	278	0	Moored	AIS	264	4	6.2	1	1.13201705	1.104508648
9187916	2010-01-01 09.00	35.89507	-5.3061067	278	0	Moored	AIS	264	4	6.2	1	0	0
9187916	2010-01-01 09.58	35.89511	-5.3061017	278	0	Moored	AIS	264	4	6.2	1	0	0
9187916	2010-01-01 10.59	35.89508	-5.3061233	278	0	Moored	AIS	264	4	6.2	1	0	0
9187916	2010-01-01 11.59	35.8951	-5.3060717	279	0	Moored	AIS	264	4	6.4	1	0	0
9187916	2010-01-01 12.59	35.9655	-5.3560383	288	6.4	Under way using engine	AIS		4	6.4	1	4.875603598	4.886802521
9187916	2010-01-01 13.59	35.97303	-5.5625733	260	11.1	Under way using engine	AIS		11	6.4	1	10.04625945	9.967873198

Table 4.5; Extract from AIS data with distance and speed manually calculated.

The calculated distance and average speed was added to the data as illustrated in Table 4.5.

The ship operational status at each AIS recording was corrected with updated data given from IHS Fairplay, where operational status was divided into three different statuses; "Under way using engine", "Moored", "Anchored".

Ports were added to the AIS data by comparison of the zone id with IHS Fairplay database of ports. In the cases where operational status was set "Moored" and no zone id was given, port name was set to "Unknown-"name of region".

Further was transportation work for each AIS recording calculated. Transportation work is a measure of how much cargo the ship have transported, measured in tonne-kilometre. The transportation work was calculated with the use of hydrostatic data, see Table 4.4, where the corresponding deadweight of AIS recording draught was multiplied with distance travelled since previous AIS recording.

A list of voyages for all ships was created. Each voyages started when operational status changed to "Moored" from either "Under way using engine" or "Anchored", as illustrated in Figure 4.6. Only voyages with coherent AIS data were used in analysis. Voyages including AIS recordings with duration from previous recordings of more than 48 hours were deleted.

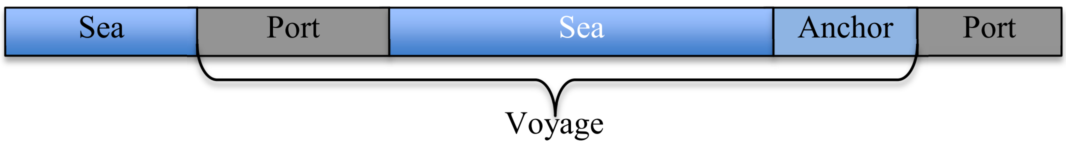

Figure 4.5; Definition of voyage in study.

The list of voyages summarizes for each voyage, the time, distance, freight transport, and fuel consumption at sea, at anchor, and in port. The draught was also assed from the AIS data, which indicated if the voyage included a loading or unloading procedure and time spent in different draught modes.

4.3.1 Confidence and uncertainty of data

Input	Source	Confidence	Comment
Ships particulars data	Fairplay database	High	
Ships machinery data	Fairplay database, ship-owner websites	Moderate /High	Some minor individual differences might be found.

			All ships are however assumed to have the same configuration in the calculations.
Ship service speed	Fairplay database, ship-owner websites	Moderate	Same as above
Distance, Speed	AISLive	Moderate	Distance is calculated as a straight line between AIS recordings. Accuracy could be affected if there is a landmass between the AIS recordings, i.e. shortest way. Randomly check of distances show on a low inaccuracy during the two-year period.
Ship status	AISLive, analysis	Moderate / High	The ship status, i.e. "Under way", "Moored", "Anchored" where corrected with updated data from IHS Fairplay.
Draught data	AISLive	Low/Moderate	The crew of the ship updates draught manually. Ships in study showed on good regularity of updates. However, the recordings sometimes indicated a delay in draught update after a port call.

Table 4.6; Confidence and uncertainty of AIS data.

5 RESULT

The results of the case study are presented in this chapter. Operational profiles for all ships in study are presented.

5.1 OPERATIONAL PROFILES

Operators are listed in Table 5.1. Each operator was given a corresponding number in order to simplify further analysis. In total, there are 18 different operators, 10 operators for the 7 700 dwt ships and 8 operators for the 12 700 dwt ships.

7 700 dwt		12 700 dwt	
Nr	Operator	Nr	Operator
1	Feederlines BV	11	BBC Chartering & Logistic GmbH
2	Universal Africa Lines NV	12	OXL NV
3	Flinter Shipping BV	13	Clipper Projects A/S
4	Harren & Partner Ship Mgmt	14	SE Shipping Lines Pte Ltd
5	Hermann Buss GmbH & Cie KG	15	Marlow Navigation Co Ltd
6	Navesco SA	16	BD-Shisnavo GmbH & Co
7	Onego Shipping & Chartering BV	17	Jutha Phakakrong Shipping
8	Scan-Trans Chartering KS	18	Nordana Lina A/S
9	Strahlmann E Reederei eK		
10	Transatlantic Rederi AB		

Table 5.1; List of operators.

Operational profiles compiled from AIS data 2010-2011 of the ships in study are listed in Table 5.2, where each ship has been given an individual number in order to simply further analysis. The column, Time days, show total time of ship in analysis, the reason this figure is significant lower than 365*2=730 can be derived from the cleaning of AIS recordings. All voyages where there was a gap somewhere in the AIS recordings with over 48 hours were deleted, in order to increase the level of correctness of analysis.

7 700 dwt										
Nr	NAME	Time days	% sea	% moored	% anchored	Avg Speed	Fuel tonne/h	Avg Voy. Sea (days)	Op. Nr.	Liner /Tramp
1	VARNADIEP	184	57%	32%	12%	10.47	0.39	3.7	1	Liner
2	VRIESENDIEP	172	53%	38%	10%	10.39	0.40	3.7	1	Liner
3	VOSSDIEP	219	69%	24%	6%	10.12	0.36	4.7	1	Liner
4	VEERSEDIEP	120	51%	31%	17%	9.60	0.35	3.5	1	Liner
5	VELSERDIEP	129	56%	37%	7%	10.87	0.43	3.9	1	Liner
6	VIKINGDIEP	262	58%	32%	11%	10.81	0.43	4.4	1	Liner
7	VECHTDIEP	154	46%	39%	15%	9.95	0.36	3.5	1	Liner

8	VLIEDIEP	213	45%	45%	9%	9.80	0.34	3.8	1	Liner
9	NORDLAND	413	62%	37%	1%	11.59	0.51	2.4	1	Liner
10	WISAFOREST	448	63%	36%	1%	11.55	0.50	2.5	1	Liner
11	VASADIEP	210	55%	38%	6%	9.76	0.35	3.2	1	Liner
12	UAL CYPRUS	226	65%	25%	10%	11.36	0.47	4.6	2	Liner
13	FLINTERLAND	307	59%	24%	17%	10.50	0.42	6.8	3	Tramp
14	PAZ COLOMBIA	101	51%	34%	16%	10.03	0.36	3.4	4	Tramp
15	HERMANN SCAN	186	66%	19%	15%	11.12	0.43	6.0	5	Tramp
16	PENSILVANIA	135	49%	28%	23%	9.61	0.36	4.1	6	Tramp
17	VLISTDIEP	136	48%	44%	8%	11.41	0.47	2.7	7	Tramp
18	HARTWIG SCAN	232	65%	22%	13%	10.67	0.43	6.4	8	Tramp
19	HANSEN SCAN	268	59%	22%	19%	10.63	0.39	6.2	8	Tramp
20	LIFTER	257	60%	29%	11%	11.20	0.47	4.3	9	Tramp
21	TRANSCAPRICORN	238	53%	34%	12%	10.21	0.40	2.6	10	Tramp
22	TRANSANDROMEDA	273	55%	35%	10%	11.01	0.47	2.7	10	Tramp
12 700 dwt										
Nr	**NAME**	**Time days**	**% sea**	**% moored**	**% anchored**	**Avg Speed**	**tonne/h**	**Avg Voy. Sea (days)**	**Op. Nr.**	
23	BBC GEORGIA	216	57%	31%	11%	11.21	0.59	3.3	11	Liner
24	BBC VERMONT	101	50%	35%	15%	10.52	0.50	3.0	11	Liner
25	BBC ALASKA	236	56%	27%	17%	11.94	0.64	4.4	11	Liner
26	BBC MARYLAND	262	61%	25%	14%	12.07	0.69	5.5	11	Liner
27	BBC FLORIDA	316	64%	25%	11%	12.21	0.68	5.0	11	Liner
28	BBC DELAWARE	293	70%	25%	5%	11.35	0.55	5.2	11	Liner
29	BBC ZARATE	245	59%	31%	10%	11.75	0.61	3.3	11	Liner
30	BBC MAINE	350	59%	31%	10%	11.75	0.63	3.8	11	Liner
31	BBC MONTANA	281	63%	26%	12%	11.00	0.53	4.5	11	Liner
32	BRATTINGSBORG	120	51%	37%	12%	11.44	0.64	3.2	12	Liner
33	CLIPPER ANGELA	186	51%	31%	18%	12.65	0.68	5.9	13	Tramp
34	SE PACIFICA	372	64%	25%	11%	10.97	0.53	6.0	14	Tramp
35	SE PELAGICA	341	54%	36%	11%	11.36	0.57	5.5	14	Tramp
36	SE PANTHEA	470	71%	19%	9%	11.89	0.60	7.0	14	Tramp
37	SE POTENTIA	246	57%	30%	13%	11.46	0.59	4.4	14	Tramp
38	ROSARIO	84	33%	51%	8%	11.01	0.53	2.2	15	
39	MARSELISBORG	69	51%	18%	4%	12.70	0.73	4.9	16	
40	FREDENSBORG	97	51%	29%	38%	12.58	0.76	2.9	17	
41	ELSBORG	46	59%	40%	2%	12.01	0.62	5.4	18	
42	ELLENSBORG	35	79%	16%	5%	10.98	0.50	7.0	18	
43	JANNES H	No data available								
44	AGGERSBORG	No data available								

Table 5.2: Operational profiles.

7 ships in the 12 700 dwt group, i.e. number 38-44 are not further analysed in study. Their total time in analysis fell below 100 days. 100 days was set as a limit in order to minimise special conditions of a certain voyage.

The type of traffic ship has been occupied in during the period of study is showed in last column of Table 5.2. This parameter has been set from analysis of the ship operational pattern; both from visual track analysis and from analysis of port call regularity.

Table 5.3 and Table 5.4 shows minimum, maximum, and average time spent as percentage of total voyage time, i.e. sea+port+anchor.

	7 700 dwt					
	Sea		Port		Anchor	
Min	45%		19%		1%	
Max	69%		45%		23%	
Average	57%		32%		11%	
	Liner			Tramp		
	Sea	Port	Anchor	Sea	Port	Anchor
Average	57%	35%	9%	57%	29%	14%

Table 5.3; 7 700 dwt, Min, max, and average percentage of time spent in each operational mode.

In the group of 7 700 dwt ships, the average time in port was 32%. The difference between the ship that spent the longest time in port (45%) and the ship that spent the least time in port (19%) was 26%. The average time at anchor was 11%, with a difference of 22% between the ship that spent the most time at anchor (23%) and the ship that spent the least time at anchor (1%).

The average time spent at anchor is higher for the tramp ships (14%) compared with the liner ships (9%), while the liner ships spent an average 5% more time in port than the tramp ships.

	12 700 dwt					
	Sea		Port		Anchor	
Min	50%		19%		5%	
Max	71%		37%		18%	
Average	59%		29%		12%	
	Liner			Tramp		
	Sea	Port	Anchor	Sea	Port	Anchor
Average	59%	29%	12%	60%	28%	12%

Table 5.4; 12 700 dwt, Min, max, and average percentage of time spent in each operational mode.

In the group of 12 700 dwt ships, the average time in port was 29%. The difference between the ship that spent the longest time in port (37%) and the ship that spent the least time in port (19%) was 18%. The average time at anchor was 12%, with a difference of 13% between the ship that spent the most time at anchor (18%) and the ship that spent the least time at anchor (5%). Only small or none difference can be found in the distribution between the operational modes when comparing the 12 700 dwt liner ships against the tramp ships.

5.2 Fuel consumption

Fuel consumption is calculated from each individual AIS recording and summarized for all voyages of each ship. The results are showed in Figure 5.1 and Figure 5.2. The differences in fuel consumption derive from the choice of speed during the sea leg of the voyage. These are theoretical calculations of fuel consumption; actual fuel consumption could show on a different result. However, the fuel consumption formula used in study (4.2.1 Fuel consumption) has showed on a very reliable result in comparison with actual fuel consumption measured on board ships. (IHS Fairplay, 2012)

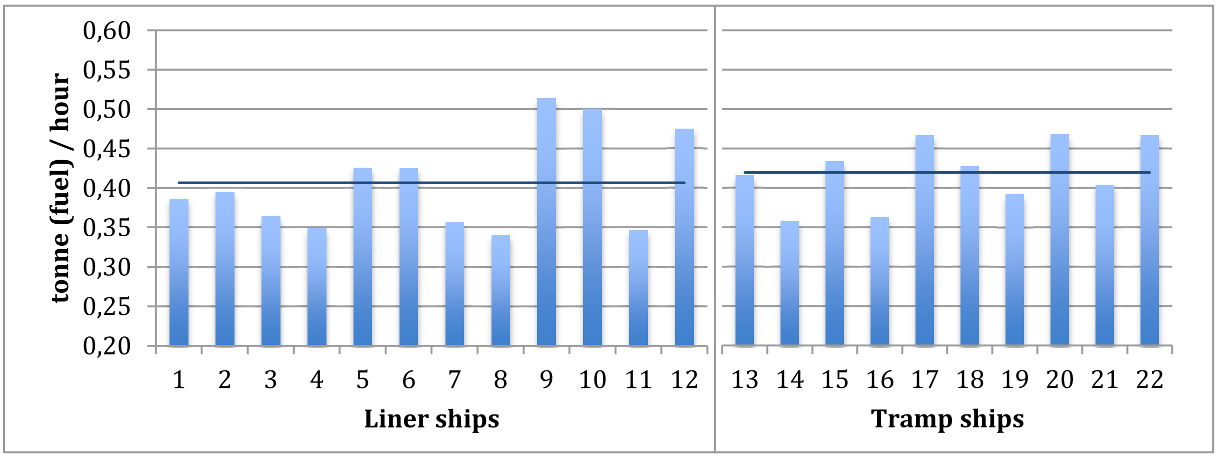

Figure 5.1; 7 700 dwt, fuel consumption per hour.

The 7 700 dwt ship with lowest fuel consumption was ship 8 (Vliediep) with 0.34 tonne/h, 33% less than the ship with the highest fuel consumption, ship 9 (Nordland). The average fuel consumption of the 7 700 dwt ships was 41 tonne/h.

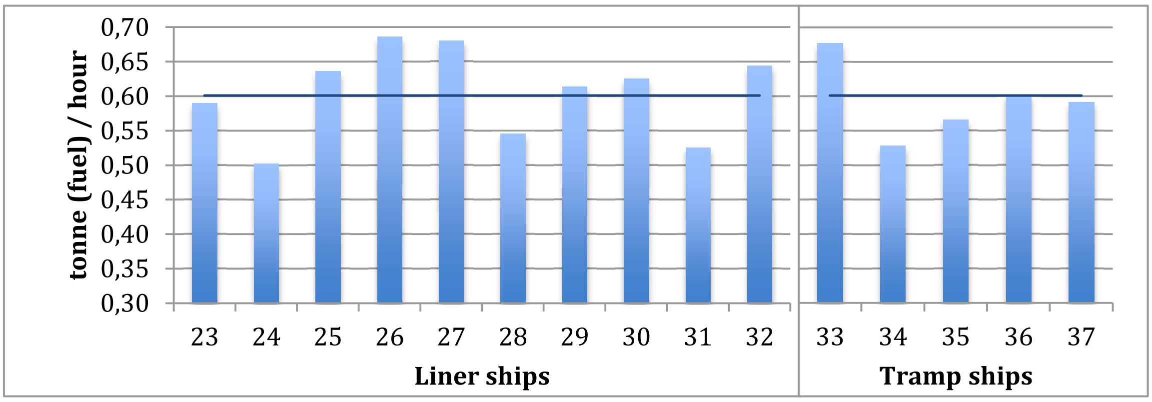

Figure 5.2; 12 700 dwt, fuel consumption per hour.

Ship 24 (BBC Vermont), had the lowest fuel consumption per hour of the 12 700 dwt ships with 0.50 tonne /h, 27.5 % less than the ship with highest fuel consumption per hour, ship 26 (BBC Maryland). The average was 0.6 tonne/h.

No general difference in either group between liner and tramp ships could be found. The group of 7 700 dwt show a correlation between length of voyage and fuel consumption per hour, where an average of shorter voyages give a higher fuel consumption. However, the group of 12 700 dwt ships show on the contrary relation between length of voyage and fuel consumption.

5.3 TRANSPORTATION WORK

Transportation work shows how many tonne-kilometre each ship has carried out. As each ship has an unequal total time of analyse in the study, a measure of tonne-km per hour is used in order to compare the ships against each other. Figure 5.3 shows all 7 700 dwt ships transportation work per hour.

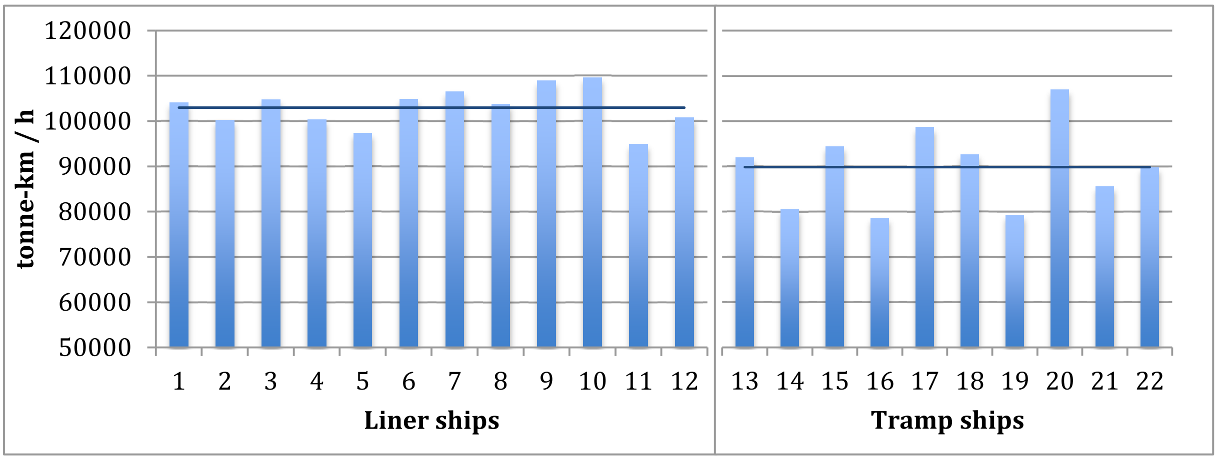

Figure 5.3; 7 700 dwt, transportation work per hour.

The average of the 7 700 group where 97 008 tonne-km/h. The best performing ship was ship 10 (Nordland), which had done approx. 39% more transportation work than the lowest performing ship, 16 (Pensilvana). There is also a significant difference between the liner and the tramp ships. Liner ships have an average of 102 988 tonne-km/h, 13% more than the average of the ships occupied in tramp traffic.

Hydrostatic data was not available for the study for the 12 700 dwt ship. Transportation work calculations have therefor not been carried out.

6 ANALYSE

This chapter presents an in-depth analysis and discussion of the operational profiles. Benchmarks of the ships in study are set for each operational mode and measures in terms of fuel efficiency improvement are discussed.

6.1 SPEED

Choice of speed is the most important parameter in the terms of energy efficiency. The distribution of speed is showed in Figure 6.1, and Figure 6.2. The lines in the diagrams correspond to the percentage of time each ship has spent in each speed.

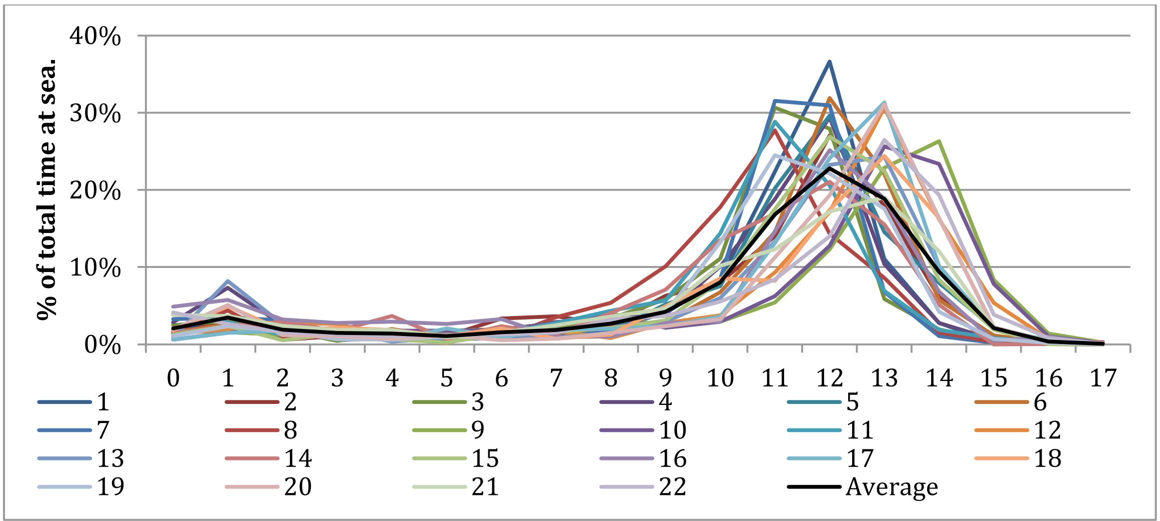

Figure 6.1; Speed distribution of the 7 700 dwt ships.

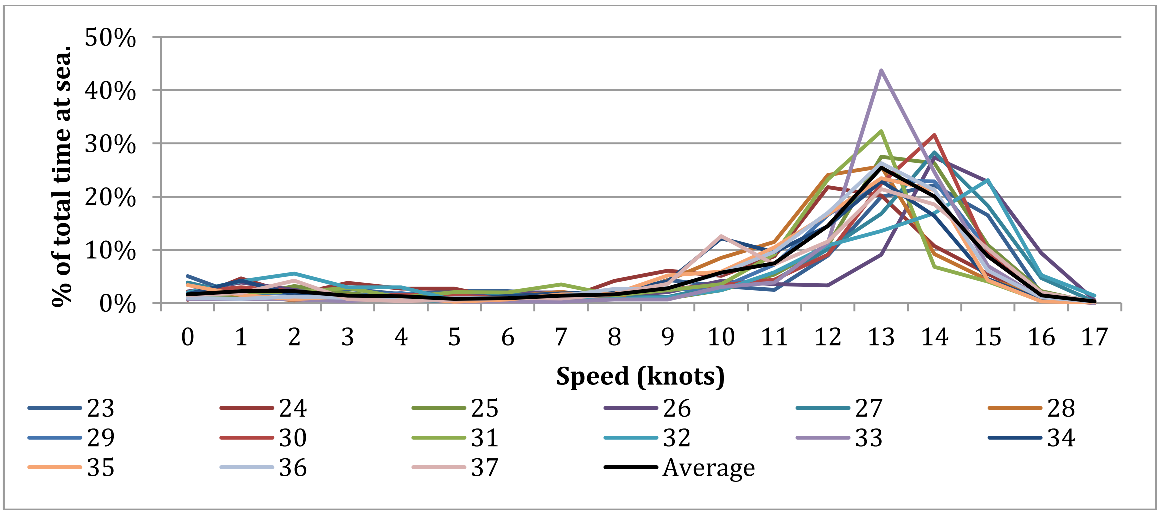

Figure 6.2; Speed distribution of the 12 700 ships.

The fuel consumption of each ship is in direct relation to their distribution of speed. As showed in Figure 6.1, the ship with the best performance of fuel consumption per hour (Table 5.2), ship 8 (Vliediep) is also the ship with the lowest peak of speed in the speed distribution diagram. And the ship with the highest fuel consumption per hour, ship 10 (Wisaforest), is the ship with the highest peak of speed and most time of all ships at a speed at or close to the maximum of 14 knots. Minimizing the time spent in higher speed can reduce fuel consumption.

The average speed of the ship with or without cargo could be different depending on the type of traffic ship is occupied in. Ships in systematic liner traffic run according to a schedule, pre set from the speed of the ship, and the chose of speed normally remains the same from voyage to voyage. The ships in tramp traffic normally adjust their speed after the contractual agreements, where the laytime and the possibility of extra earning through demurrage could tempt the choice of a higher speed, despite higher fuel consumption. Figure 6.3 and Figure 6.4 show the average speed of the sea leg of the voyage before loading of cargo compared with before unloading of cargo.

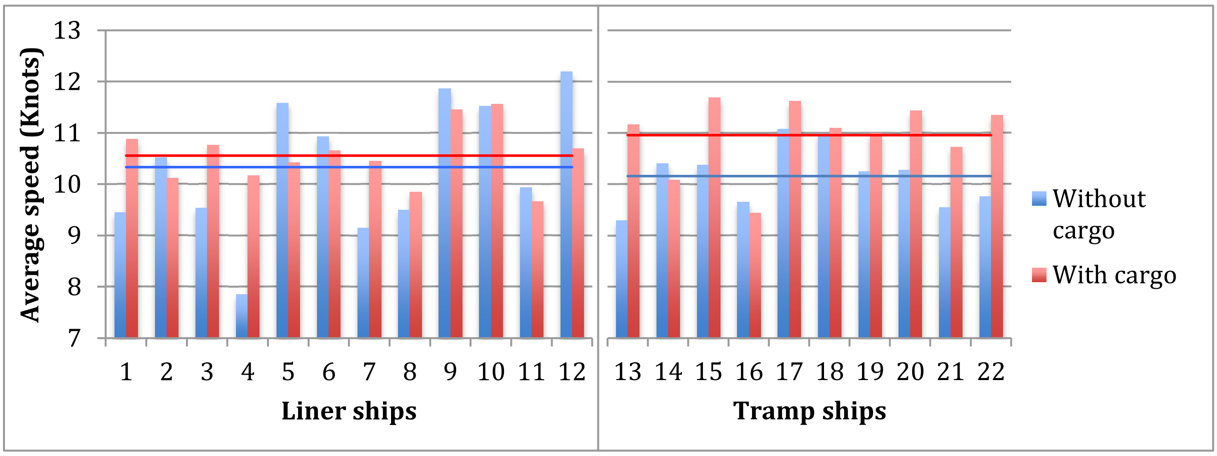

Figure 6.3; 7 700 dwt, average speed without and with cargo on-board.

The average speed is 5% (0.48 knots) higher before unloading than before loading of cargo in Figure 6.3. However the average speed for the tramp ships is 8% higher with cargo on-board, compared with the difference of only 2% for the liner ships.

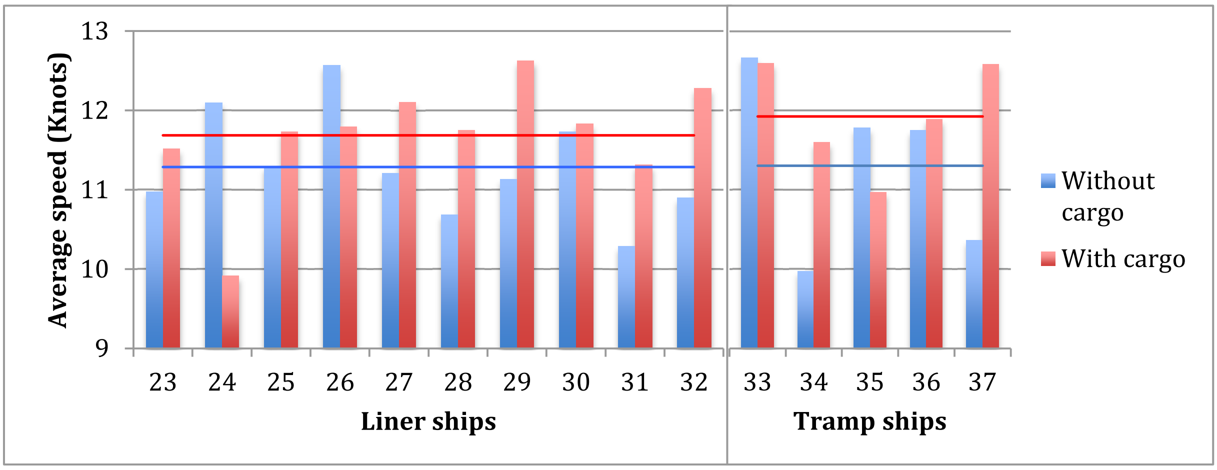

Figure 6.4; 12 700 dwt, average speed without and with cargo on-board.

The average speed in Figure 6.4 is 4% (0.47 knots) higher before unloading than before loading of cargo for the 12 700 dwt ships. The difference in speed with cargo compared to without cargo is 4% for the liner ships and 5% for the tramp ships.

6.1.1 POTENTIAL SAVINGS OF SPEED REDUCTION

The ships average speed is significant higher than the best economic speed (see chapter 3.6.2). The economic speed gives the lowest cost per nautical mile. Contractual agreements and individual conditions of a trade could change the most favourable speed. Neither does the economical model take into consideration the potential of extra earning i.e. more voyages by running the ship at a higher speed.

	7 700 dwt		12 700 dwt	
HFO 1% sulphur				
Calculated avg. speed	10.58 knots	9 374 USD/day	11.57 knots	13 168 USD/day
Economic speed	8.6 knots	7 476 USD/day	9.7 knots	10 769 USD/day
Potential saving		20 %		18%
MGO 0,1% sulphur				
Calculated avg. speed	10.58 knots	10 918 USD/day	11.57 knots	16 225 USD/day
Economic speed	7.8 knots	7 675 USD/day	8.7 knots	11 657 USD/day
Potential saving		30%		28%

Table 6.1; Potential savings in cost per day.

There is a substantial potential in cost reduction by running the ship at a slower speed, as presented in Table 6.1, where cost per day is calculated from the cost per nautical mile, see Appendix 1 - Economic speed. The potential is most likely to increase from 20% to 30% as more stringent environmental regulations will lead to higher bunker prices, i.e. change to 0,1% sulphur fuel.

6.1.2 OPERATOR DIFFERENCES

A higher speed means higher fuel consumption. However, when observing over time, as in this study, a higher average speed does not necessarily mean higher fuel consumption, as illustrated in Figure 6.5 and Figure 6.6. As previous analysis showed, the distribution of speed over time is what determines the fuel consumption.

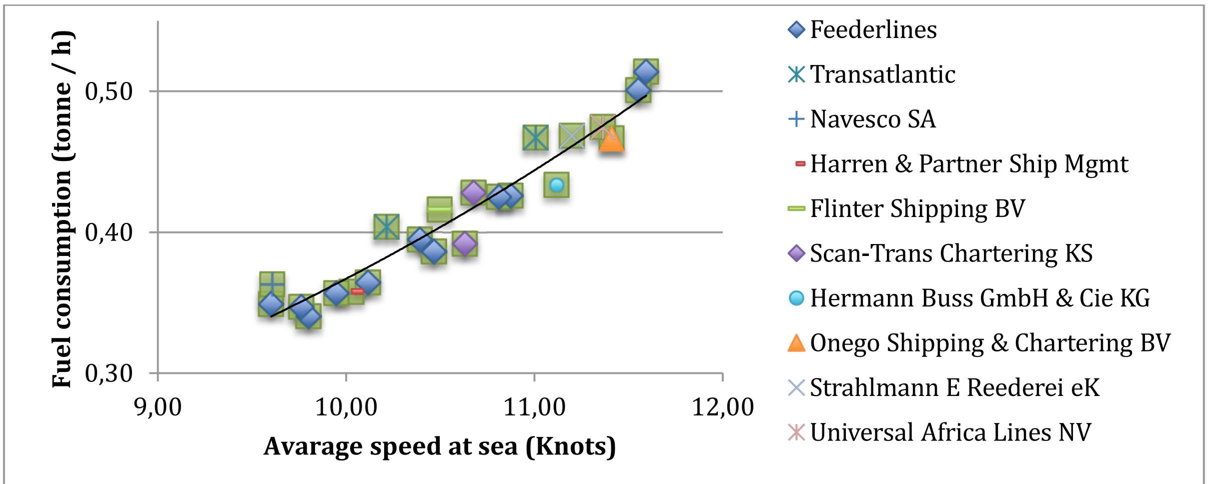

Figure 6.5; 7 700 dwt, fuel consumption vs. average speed.

The further to the right in the diagram of Figure 6.5, the higher average speed during the period of study. The higher up in the diagram, the higher fuel consumption. The reason why a ship could achieve lower fuel consumption at a higher average speed can be derived from the fuel consumption diagram (Figure 4.2), which shows an exponential increase in fuel consumption at higher speed. A few voyages or part time of a voyage at high speed increases the fuel consumption significant.

There are a few differences between the operators of the 7 700 dwt ships. The two Transatlantic operated ships (21 and 22) stand out significant from the rest. Their fuel consumption per hour is approximately 5% higher then the average fuel consumption at the same speed. A comparison of the Transatlantic ships with the best performing ships, operated by Scan- Trans chartering (ship 19) and Hermann Buss (ship 15), shows on an additional potential of 5% in reduction in fuel consumption per hour.

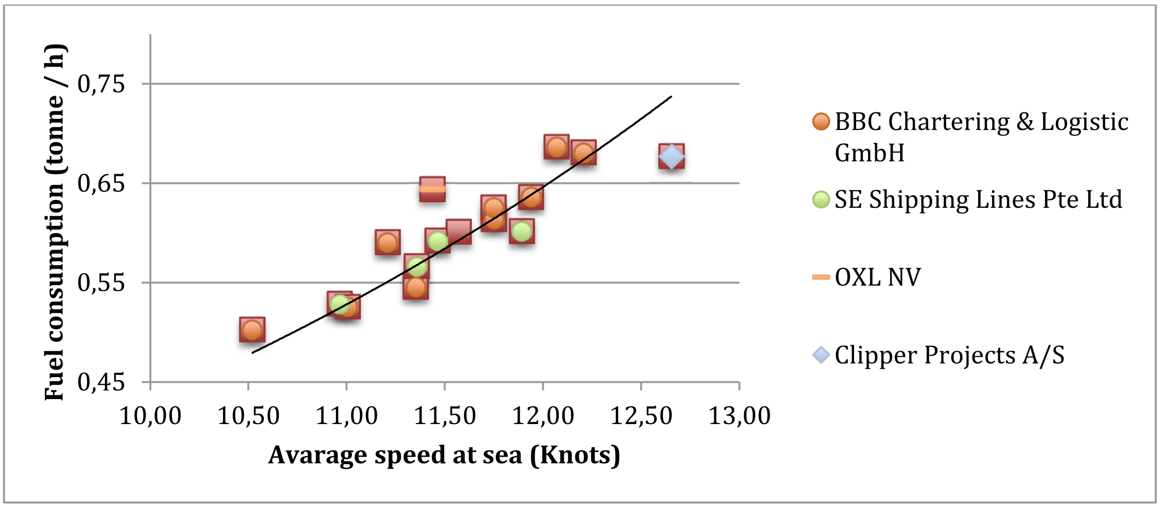

Figure 6.6; 12 700 dwt, fuel consumption vs. average speed.

OXL NV (ship 32) had approx. 7% higher fuel consumption per hour than the average of the 12 700 dwt ships. The Clipper Projects operated ship (ship 33) was the best performing ship with approx. 6% lower fuel consumption than the average.

A correlation between length of voyage and fuel consumption performance was found. In both groups, the ships with the best performance, i.e. lowest fuel consumption compared to average speed, were also the ships with a higher percentage of longer voyages. Reversely, the ships with higher percentage of shorter voyages were also the ships with the highest fuel consumption.

From analysis, the optimal in terms of fuel consumption is to keep the speed as low as possible and constant (Figure 6.7). As an example; if the ship sailing on a route that consist of several sea legs, it will be better to operate the ship at the same speed on all sea legs of the route, than operating the ship at a reduced speed at one leg and increased speed on another leg, even though the total time and average speed would be the same.

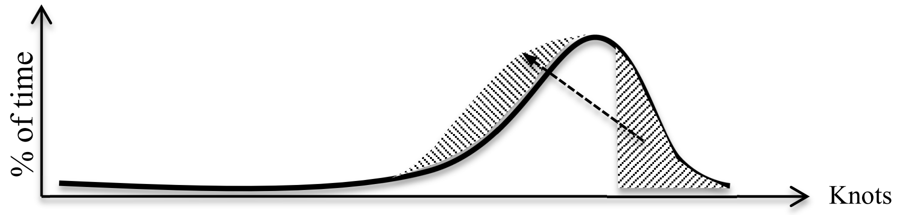

Figure 6.7; Choosing a slower speed will reduce fuel consumption.

However, the profitability of a ship is also a function of its potential earning. A constant speed for a ship in tramp traffic could reduce the possibilities to carry additional spot cargoes and reduce the final result, even though the reduced fuel consumption.

6.2 PORT

There were big spreads in distribution of the result when comparing the time in port per voyage among the ships. However, this difference could be a result of a single port call, significantly longer then the majority of the port calls made by the ship. This was confirmed when a comparison with the time in port, excluding the calls with a significant longer port time, as illustrated in Figure 6.8 and Figure 6.9.

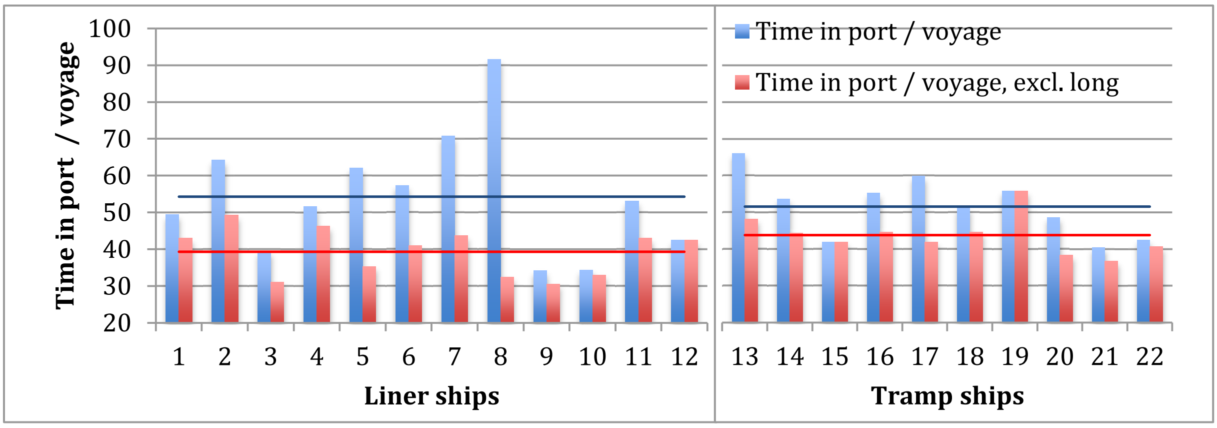

Figure 6.8; 7 700 dwt, Time in port per voyage.

The ship with the least port time of the 7 700 dwt ships was ship 9 (Nordland), with an average of 31 hours per voyage.

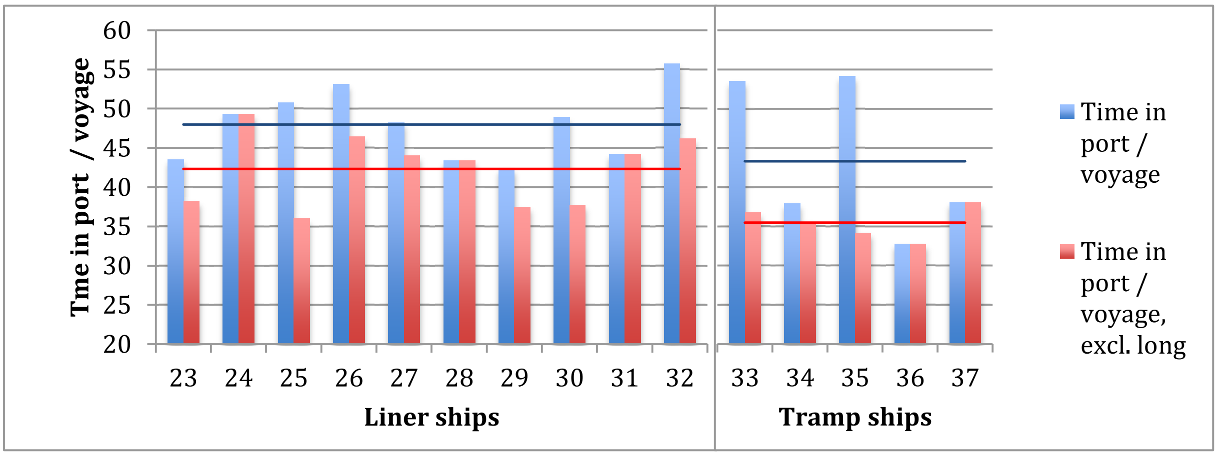

Figure 6.9; 12 700 dwt, time in port per voyage.

The ship with the shortest time in port per voyage among the 12 700 dwt ships was ship 24 (BBC Vermont), with 38 hours per voyage. The group of 12 700 had an average of 8.5% longer time in port than the smaller ships. However, the larger ships have approximate 65% more cargo capacity than the smaller ships, 12 700 dwt compared with 7 700 dwt, an average not more than 8.5% longer time in port show that the time in port not only depend on the ship cargo capacity and cargo handling.

The relationship between time in port and amount of cargo loaded/unloading was examined in Figure 6.10 and Figure 6.11. The analysis shows that there might be a correlation. However, the result of analysis is too widely spread in distribution to draw any conclusions of the analysis.

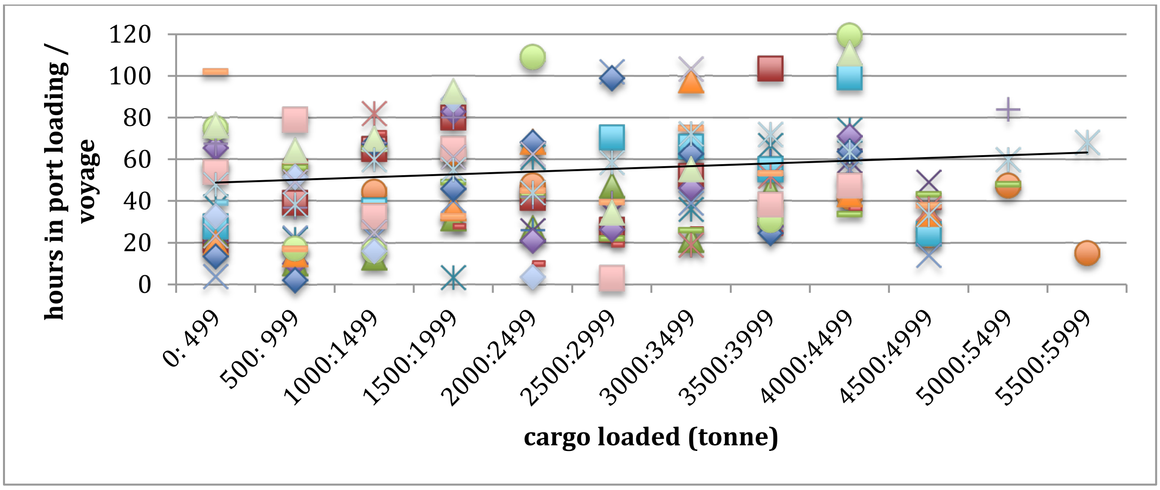

Figure 6.10; 7 700 dwt, hours in port with loading operation

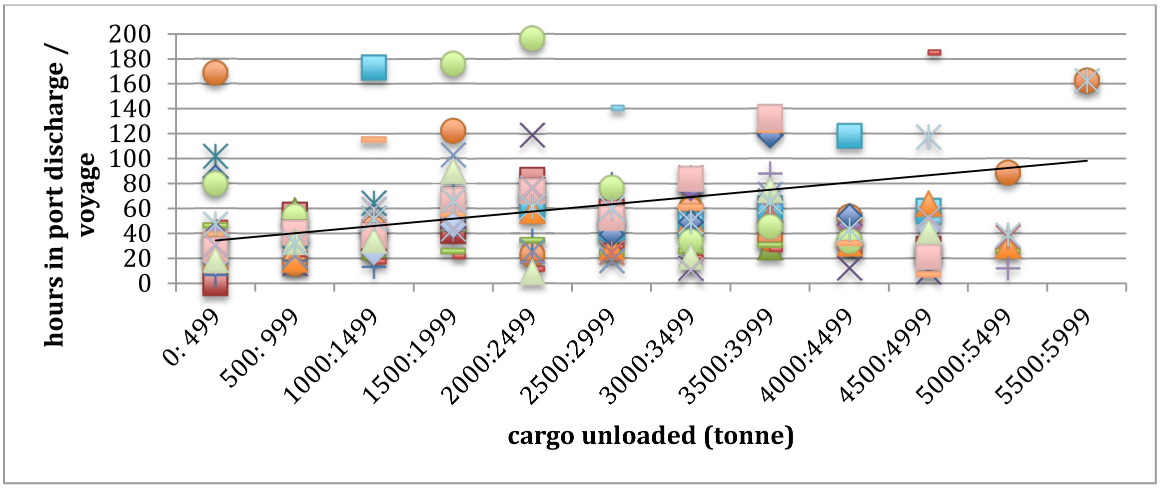

Figure 6.11; 7 700 dwt, hours in port with unloading operation.

The loading/unloading rate, tonne/h, indicates the efficiency of the ship cargo handling. Figure 6.12 indicate a faster handling in unloading operations than in loading operations. However, as previously showed in analysis, the spread of the result is too randomly distributed to draw any conclusions about loading/unloading rate.

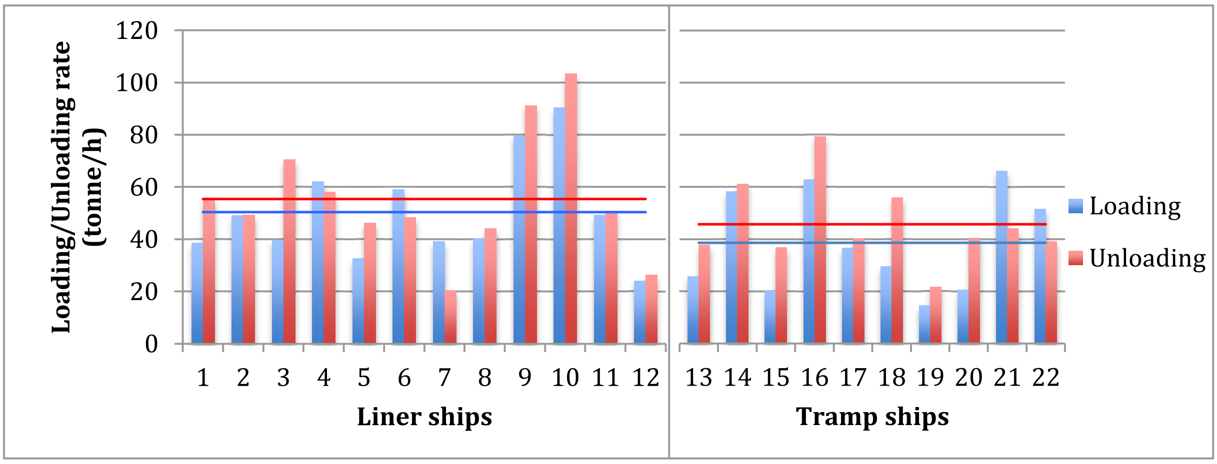

Figure 6.12; 7 700 dwt, loading/unloading rate. (Tonne per hour).

Several factors affect the ship time in port:

- Time of arrival (within/outside working hours)
- Use of port cranes/own cranes
- Technical performance
- Space availability
- Manning
- Individual port capacity/efficiency

(Christiansen , Fagerholt, Nygreen, & Ronen, 2007)

Time in port is to compile from AIS data. However, a complete analysis of what determines the time used in port is not possible with data available in study. Every port has its own characteristics and every type of cargo requires different handling. The general cargo ships in study are equipped with own gear, i.e. cranes, and AIS data do not include any information about the usage of on-board equipment. The time in port could also include bunkering operations, with or without cargo operation, which could mislead interpretation of draught data and loading/unloading calculations.

To summarise, it is important to recognise that is not possible to examine and give the whole picture the ship port performance without precise data from ship and from port.

6.3 Anchoring

With a minimum anchoring strategy, a slower speed could be chosen with the equal amount transportation work, which reduce cost and increase profitability of the voyage. Ships in systematic liner traffic normally have very little anchoring time due to a precise schedule and good port relations. Anchoring is only carried out due to circumstances beyond the control of the operator, e.g. bad weather, strike, etc., or if the ship is taken out of service. Ships in tramp traffic normally spend more time at anchor than the liners. Tramp ships could anchor while waiting for new orders and cargo. They are also more often at anchor outside the loading/unloading port waiting for berth/cargo to be ready. The contractual agreements with the charterer sometimes favour inefficient operation, where the ship operator runs the ship faster than necessary due to the possibilities of demurrage compensation.

The Figure 6.13 and Figure 6.14 show the difference of anchoring time before loading compared with before unloading of cargo.

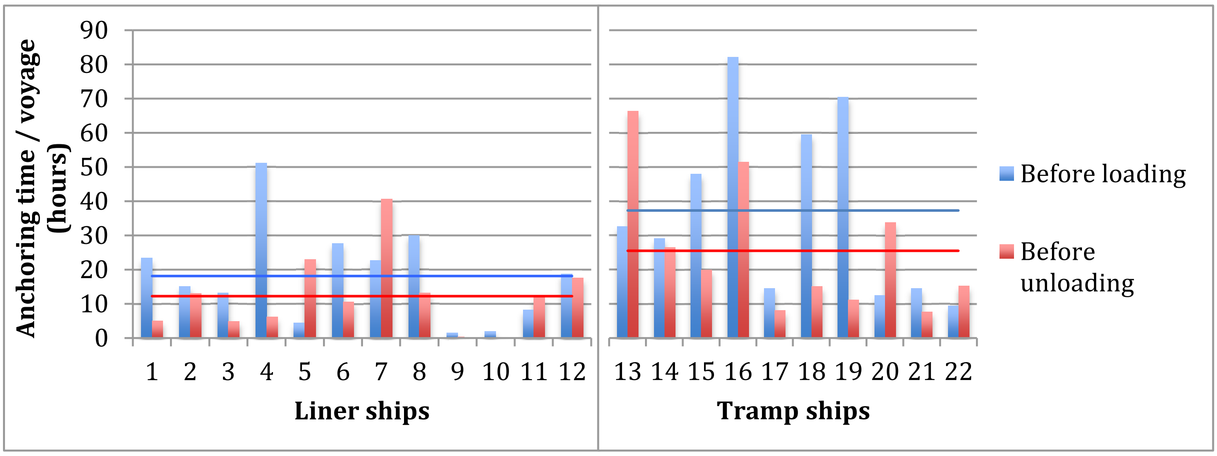

Figure 6.13; 7 700 dwt, anchoring time before loading/unloading of cargo per voyage.

The 7 700 dwt ships have an average of 47% longer anchoring time before loading than before unloading of cargo. And the group of 12 700 dwt ships have an average of 42% longer anchoring time before loading than before unloading of cargo. Both groups of ships show less difference among the liner ships between anchoring time before loading and before unloading than the ships in tramp traffic.

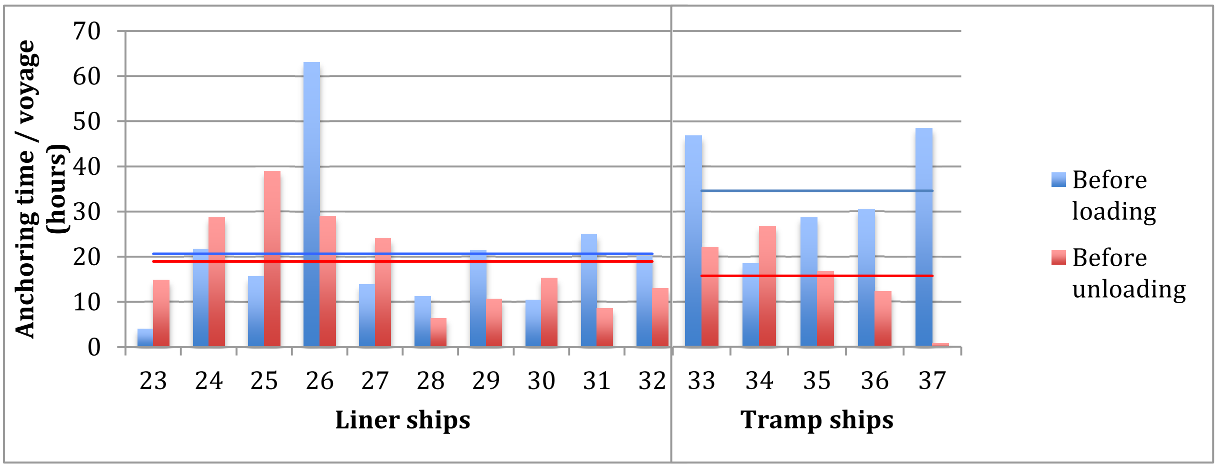

Figure 6.14; 12 700 dwt, anchoring time before loading/unloading of cargo per voyage.

The analysis of the tramp shows that the anchoring time waiting for cargo is significantly longer than the anchoring time with cargo on-board. This result could be different in a different period of study. The analysis is carried out with data from 2010-2011 when the global economic situation was in harsh and started to slowly recover after the finical crisis in 2009. An analysis of the anchoring time during the economic peak period (200-2007) before the global recession would most likely show on less time at anchor.

6.4 FUEL EFFICIENCY

Fuel efficiency could be improved by reducing the energy intensity. Energy intensity is measured as the amount of energy required per unit output. Lower energy intensity means less energy needed to produce the same output, i.e. improved energy efficiency. In study, energy is measured in fuel consumption (tonne), and the output in terms of transportation work (tonne-km).

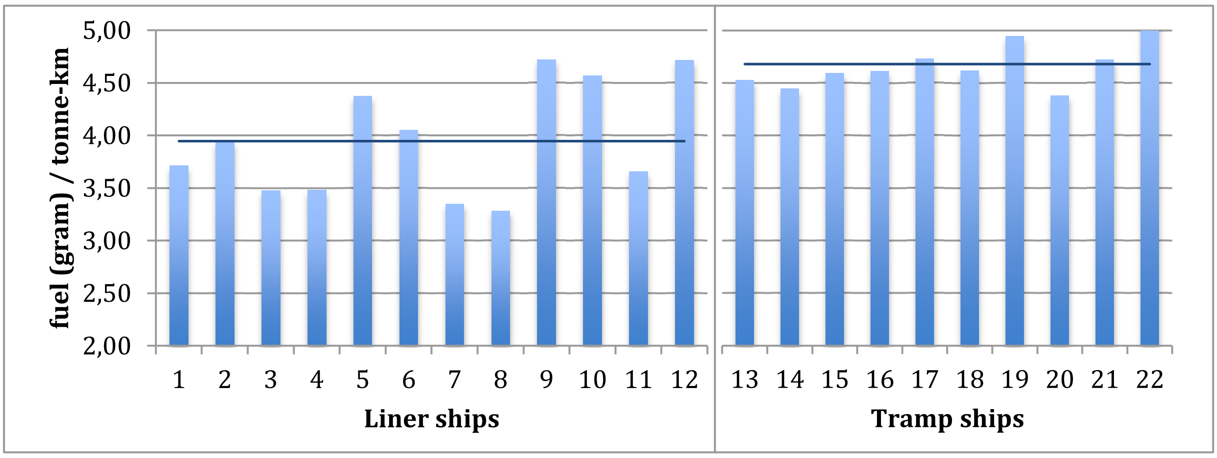

Table 6.2; 7 700 dwt ships energy intensity.

The ship with lowest energy use per tonne-km was ship 8 (Vliediep), which used 37% less fuel per tonne-km than the ship with the highest energy intensity, i.e. ship 22 (Transandromeda). The ships in tramp traffic used approximately an average of 19% more energy per tonne-km than the liner ships, this difference is a result of the tramp ships higher speed with cargo on-board (Figure 6.3) and less transportation work carried out (Figure 5.3).

6.4.1 Capacity utilization

The potential of energy efficiency improvement by reduction of energy intensity could be found by analysing the capacity utilization, which is the ratio between the actual output and the maximum potential output for the ship, expressed in percentage of the potential output. The calculations are based on the AIS draught data and same operational pattern is assumed, i.e. same speed and distance as the ship carried out in 2010-2011. The maximal capacity was set to the deadweight of the ship, i.e. 7 700 dwt.

$$\textit{Capacity utilization} = \frac{\text{transportation work (tonne−km)}}{\text{maximum transportation work (dwtkm)}}$$

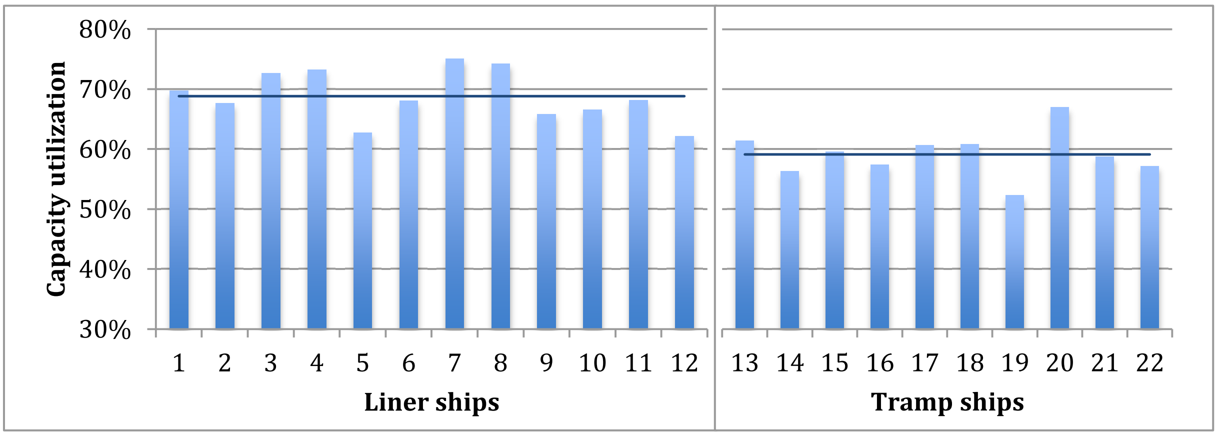

Figure 6.15; 7 700 dwt, capacity utilization.

The results of capacity utilization were distributed in the range between 52% and 75%, with an average of 64%. The results could be an effect of individual market conditions and strategy. However, a higher capacity utilization was found among the liner ships, 69%, compared with 59% for the tramp ships. This difference could be derived from more time in ballast conditions, which might be a result from the lack of return cargo and operational imbalance of tramps.

Study of short sea shipping (RoRo) made by Styhre (2009) show on a desirable capacity utilization between 75% and 88%. A maximum utilization might be profitable in the short run. However, a higher capacity utilization could lead to a more vulnerable liner system. An excess capacity is important in order to be able to serve customers even when there is a peak in demand of transportation. Not being able to respond to market fluctuations could lead to loss of customers in the long term. Liner ships in the study has yet some extra capacity in spare before reaching the optimum capacity utilization span, possible as a consequence of the financial turmoil following 2008.

In order to increase the capacitation utilization, either the demand of, or the supply of the transportation service has to be adjusted. The demand of an existing ship could be enhanced by promotional activity or by a strategic change, e.g. repositioning, price adjustment, or by adding value to the customers. By reducing supply of transportation, i.e. reducing the capacity, a higher utilization could be achieved if the company has multiple ships serving the same segment. One way of reducing capacity is to scrap ships or simply by slow steaming.

6.5 THEORETICAL SAVINGS

The anchoring operation is most often seen prior berthing at port. Congestion is one common reason why not the ship could berth directly upon arrival at port. A just in time/ perfect arrival strategy could help the ship operator to choose the right speed in order to minimize time at anchor and significant fuel savings could be achieved.

The theoretical savings calculation assumes same distance and the same number of voyages during the same period of time as previous. You could expect the ship to increase the number of voyages if the time anchoring is reduced; however, this has not been taken into consideration in these calculations.

Figure 6.16 and Figure 6.17 show the results from the theoretical savings calculation.

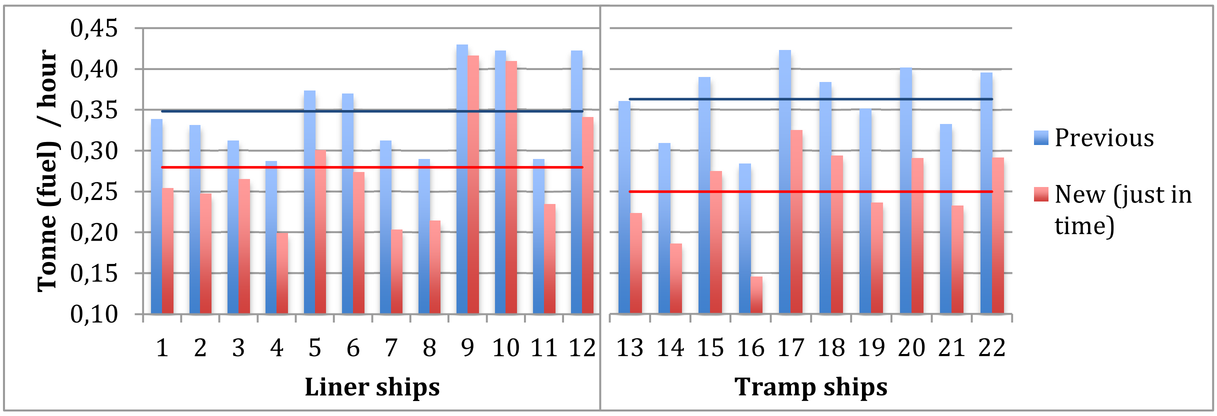

Figure 6.16; 7 700 dwt, theoretical fuel consumption savings. (Tonne/hour).

The theoretical and potential average fuel saving is 26% for the 7 700 dwt ships, where the tramp ships show on a higher potential saving (32%) compared with the liner ships (21%). Two ships, ship 9 (Nordland) and ship 10 (Wisaforest), with very little time at anchor, could only save 3% of fuel with no anchoring. The most saving, 49%, could ship 16 (Pensilvania) achieve, however, this ship had a few voyages with very long anchoring time in relation to voyage time, which could affect the reliability of the result due to other circumstances, for example; no cargo available, maintenance, etc.

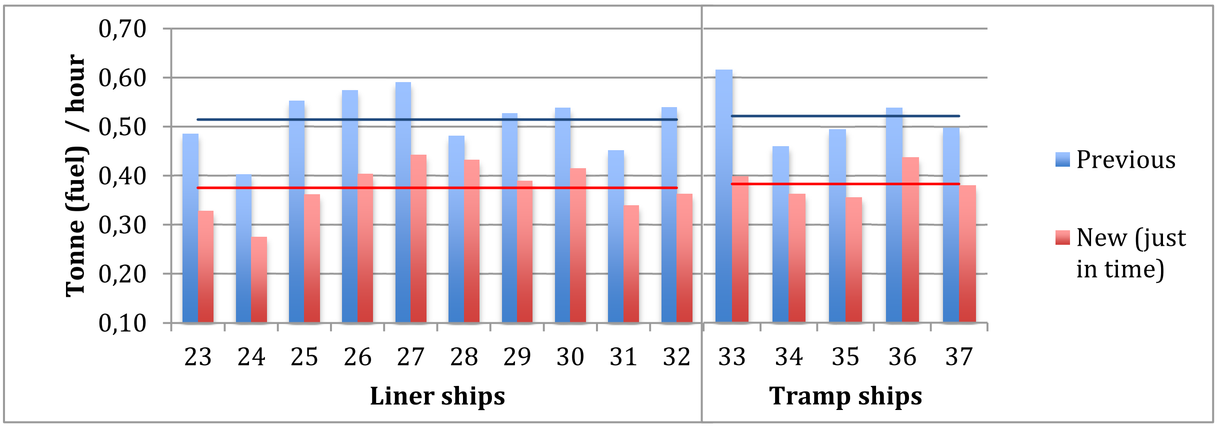

Figure 6.17; 12 700 dwt, theoretical fuel consumption savings. (Tonne/hour)

The 12 700 dwt group of ship could achieve an average saving of approximately 26%.

The theoretical saving calculations are based on average speed per voyage, which are an average of 14% lower, for both the 7 700 dwt ships and the 12 700 dwt ships, than the actual fuel consumption calculated per AIS recording, i.e. observed average speed per hour. This difference origin from the ship distribution of speed (see 6.1 Speed), and confirms the importance of an even operational speed in order to minimize fuel consumption.

The theoretical potential of a no anchoring strategy show significant opportunities in reduction of fuel consumption. 26% is not possible to achieve as an average among the ships, even though it shows on a great potential and only a few percentage in less anchoring time of an individual ship could result in significant savings in fuel consumption. The importance of collaboration between all parties in shipping is vital to carry out a no anchoring strategy. The economic benefit must be shared between the stakeholders in order to fulfil a sustainable no anchoring strategy.

7 CONCLUSION

The study highlights two main research questions:

- *Is it possible to benchmark ship fuel efficiency from AIS data?*
- *What benchmarks are useful in comparison with other ships?*

These questions have been analysed in study and the findings are summarized below.

A performance analysis of a ship operation in terms of fuel efficiency is possible from AIS data. The analysis can be used to compare and benchmark ship performance against other ships in order to track performance and identify measures of improvement.

7.1 AIS DATA

All ships over 300 gross tonnage engaged on international trade, and all cargo ships over 500 gross tonnage engaged in domestic trade are required to carry AIS equipment on-board. The purpose with AIS is to improve safety and efficiency on sea in operation. Stored AIS data can also be used to analyse the performance and fuel efficiency of a ship.

The reliability of AIS data in terms of ship position accuracy is high, as it transmits gps coordinates. The AIS data used in study was recorded once every hour, and analyse of data through visualization showed on only minor faulty recordings, due to system disturbance. However, this disturbance is important to correct in order to carry out an accurate ship operational analysis, as the method of AIS data analysis relies on correct data. The method of only use complete voyages with no disturbance in recordings turned out to give the best result.

7.2 FUEL EFFICIENCY BENCHMARKS AND MEASURES

Ships in study show on a significant potential in fuel consumption reduction. The speed distribution diagram confirms the importance of an even speed. Short periods in high speed increase the average fuel consumption (tonne/h).

By comparing the average speeds without and with cargo, the analysis show on a significant higher speed with cargo on-board for the tramp ships. This is a result of their nature of business where contractual agreements give the operator an incitement of high-speed operation. It can also be a consequence of the turmoil following the financial crisis in 2008.

All ships had an operating speed significant higher than the best economic speed, i.e. lowest cost per nautical mile. The theoretical potential savings in cost per day at sea, with same fuel quality came out at 20%. With the use of bunker fuel with low sulphur content (MGO 0.1%), the potential possible saving is 30%, which is showed in chapter 6.1.1 (Table 6.1). The higher fuel price, the lower economic speed and greater potential in cost reduction by slow steaming, as illustrated in chapter 3.6.2 (Figure 3.4).

The operator differences analysis showed on tendency of the operator performance against other operators. One operator, Transatlantic, had a higher fuel consumption per hour than the average at a given speed. Their potential of fuel consumption reduction tuned out to be 5-10% for both of their ships in study (Figure 6.5). Ships with a large proportion of long voyages tend to have lower fuel consumption per hour compared with ships with a larger proportion of short voyages, which show on the importance of operation at an even speed in order to reduce the average fuel consumption. The operator performance indicator can also be used in comparison between individual ships.

The performance indicator analysis of port time, i.e. time in port/voyage and loading/unloading rate showed that time in port is possible to benchmark, however, other data is necessary for a complete port performance analysis. The group of 12 700 dwt had an average of 8% longer time in port compared with the group 7 700 dwt ships. This difference was expected to be significant higher and illustrate the complexity of a ship time in port, as the cargo handling time does not only set the time.
Analysis of anchoring time per voyage with and without cargo gave the indication of the tramp ships more time at anchor compared with the liner ships. The difference between anchoring with and without cargo was also less for the liners ships. Some liner ships had very little time at anchor, which show on good port efficiency and optimized operation.

The energy intensity indicator showed that the tramp ships used an average of 19% more energy per output (tonne-km) in comparison with the liner ships. The spread between the best and worst performing ships were 37%. These results should be viewed in context with the capacity analysis in chapter 6.4.1, where ships with a low capacity utilization are the ships with high energy intensity, i.e. low performance. The analysis in also indicated spare of 10-20% before hitting the desirable span (75-88%) of capacity utilization.

An implementation of a no anchoring/ just in time strategy could theoretically reduce the fuel consumption in average with approximate 26% for the ships in study (chapter 6.5). Where the 7 700 dwt tramp ships showed higher potential in savings than the liner ships, as illustrated in Figure 6.16.

To summarize, all fuel efficiency indicators are related to each other. The most useful performance indicators, i.e. benchmarks are: distribution of speed (chapter 6.1), fuel performance i.e. fuel consumption/average speed (chapter 6.1.2), energy intensity i.e. input/output (chapter 6.4).

Fuel efficiency can be improved by increasing the output of a ship i.e. more cargo. However, the most important measures are speed reduction, i.e. slow steam, and operation at an even speed. The theoretical no anchoring strategy/just in time calculations confirm that there are great opportunities to minimise anchoring time in favour of speed reduction.

The method of AIS data analysis for a ship performance in terms of fuel efficiency is possible as study show. For a precise and accurate result it is important to compare the ship against ships engaged in the same, or similar trade, in order to minimize the characteristics and prerequisites of an individual trade.

8 FUTURE STUDY

Suggestions of future areas of study are given in this chapter.

AIS data is very useful in the analysis and comparison of a ship operational pattern. In this study, a case study with 44 ships were carried out and further analysed. An interesting subject for future study would be to narrow the objects to one ship, in order to be able to dig even further down in the operational pattern.

In study, AIS data from 2010-2011 was used. During this period of time, the economy started to recover after the financial turmoil in 2008-2009. What differences could be found by comparing the findings from this study with a study made from data before the financial crisis in 2008-2009? Possibly were the ships running at an even higher speed, were they anyway more fuel efficient in terms of output per consumed fuel?

The findings of the study showed that the time in port could be determined from AIS data. However, an analyse of what determine the time in port, and what can be done to predict congestion or delay at or outside port, in order to minimize anchoring could add extra knowledge in the subject. How can a no anchoring strategy work in reality? What information needs the ship operator?

Contractual agreements sometimes favour insufficient operation, due to laytime and demurrage compensation. What need to be done in order to overcome this issue? Can the benefit of slow steaming be shared between the stakeholders? A shared benefit probably adds administration, how can this be solved?

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APPENDIX 1 - ECONOMIC SPEED

	7700 dwt Operating cost: 4066 USD / day						12700 dwt Operating cost: 5403 USD / day					
	HFO 1%			MGO 0,1%			HFO 1%			MGO 0,1%		
Speed	fuel (USD) /day	cost/ nm	fuel of total	fuel (usd)/ day	Cost/ nm	fuel of total	fuel (usd)/ day	cost/nm	fuel of total	fuel (usd)/ day	cost/nm	fuel of total
1.0	457	188	10%	637	196	14%	1068	270	17%	1488	287	22%
1.1	461	171	10%	642	178	14%	1072	245	17%	1493	261	22%
1.2	464	157	10%	647	164	14%	1077	225	17%	1500	240	22%
1.3	469	145	10%	653	151	14%	1082	208	17%	1507	221	22%
1.4	474	135	10%	660	141	14%	1087	193	17%	1515	206	22%
1.5	479	126	11%	668	131	14%	1094	180	17%	1524	192	22%
1.6	485	119	11%	676	123	14%	1101	169	17%	1534	181	22%
1.7	492	112	11%	685	116	14%	1109	160	17%	1545	170	22%
1.8	499	106	11%	695	110	15%	1117	151	17%	1556	161	22%
1.9	507	100	11%	706	105	15%	1127	143	17%	1569	153	23%
2.0	516	95	11%	718	100	15%	1137	136	17%	1583	146	23%
2.1	525	91	11%	731	95	15%	1147	130	18%	1598	139	23%
2.2	535	87	12%	745	91	15%	1159	124	18%	1615	133	23%
2.3	545	84	12%	760	87	16%	1171	119	18%	1632	127	23%
2.4	557	80	12%	776	84	16%	1185	114	18%	1650	122	23%
2.5	569	77	12%	792	81	16%	1199	110	18%	1670	118	24%
2.6	582	74	13%	810	78	17%	1214	106	18%	1691	114	24%
2.7	595	72	13%	829	76	17%	1230	102	19%	1713	110	24%
2.8	610	70	13%	849	73	17%	1246	99	19%	1736	106	24%
2.9	625	67	13%	870	71	18%	1264	96	19%	1761	103	25%
3.0	641	65	14%	892	69	18%	1283	93	19%	1787	100	25%
3.1	657	63	14%	916	67	18%	1302	90	19%	1814	97	25%
3.2	675	62	14%	940	65	19%	1323	88	20%	1843	94	25%
3.3	693	60	15%	966	64	19%	1345	85	20%	1873	92	26%
3.4	713	59	15%	993	62	20%	1367	83	20%	1904	90	26%
3.5	733	57	15%	1021	61	20%	1391	81	20%	1937	87	26%
3.6	754	56	16%	1050	59	21%	1415	79	21%	1971	85	27%
3.7	776	55	16%	1081	58	21%	1441	77	21%	2007	83	27%
3.8	799	53	16%	1113	57	21%	1468	75	21%	2044	82	27%
3.9	822	52	17%	1146	56	22%	1495	74	22%	2083	80	28%
4.0	847	51	17%	1180	55	22%	1524	72	22%	2123	78	28%
4.1	873	50	18%	1216	54	23%	1554	71	22%	2165	77	29%
4.2	899	49	18%	1253	53	24%	1585	69	23%	2209	76	29%
4.3	927	48	19%	1291	52	24%	1618	68	23%	2253	74	29%
4.4	955	48	19%	1331	51	25%	1651	67	23%	2300	73	30%
4.5	985	47	20%	1372	50	25%	1686	66	24%	2348	72	30%
4.6	1015	46	20%	1415	50	26%	1721	65	24%	2398	71	31%
4.7	1047	45	20%	1458	49	26%	1758	63	25%	2449	70	31%
4.8	1080	45	21%	1504	48	27%	1796	62	25%	2502	69	32%
4.9	1113	44	21%	1551	48	28%	1836	62	25%	2557	68	32%
5.0	1148	43	22%	1599	47	28%	1876	61	26%	2614	67	33%
5.1	1183	43	23%	1649	47	29%	1918	60	26%	2672	66	33%

5.2	1220	42	23%	1700	46	29%	1961	59	27%	2732	65	34%
5.3	1258	42	24%	1752	46	30%	2005	58	27%	2793	64	34%
5.4	1297	41	24%	1807	45	31%	2051	58	28%	2857	64	35%
5.5	1337	41	25%	1862	45	31%	2098	57	28%	2922	63	35%
5.6	1378	41	25%	1920	45	32%	2146	56	28%	2989	62	36%
5.7	1420	40	26%	1979	44	33%	2195	56	29%	3058	62	36%
5.8	1464	40	26%	2039	44	33%	2246	55	29%	3128	61	37%
5.9	1508	39	27%	2101	44	34%	2298	54	30%	3201	61	37%
6.0	1554	39	28%	2164	43	35%	2351	54	30%	3275	60	38%
6.1	1601	39	28%	2230	43	35%	2406	53	31%	3352	60	38%
6.2	1649	38	29%	2297	43	36%	2462	53	31%	3430	59	39%
6.3	1698	38	29%	2365	43	37%	2520	52	32%	3510	59	39%
6.4	1748	38	30%	2435	42	37%	2579	52	32%	3592	59	40%
6.5	1800	38	31%	2507	42	38%	2639	52	33%	3676	58	40%
6.6	1852	37	31%	2580	42	39%	2701	51	33%	3762	58	41%
6.7	1906	37	32%	2655	42	40%	2764	51	34%	3850	58	42%
6.8	1961	37	33%	2732	42	40%	2828	50	34%	3940	57	42%
6.9	2018	37	33%	2811	42	41%	2894	50	35%	4032	57	43%
7.0	2075	37	34%	2891	41	42%	2962	50	35%	4125	57	43%
7.1	2134	36	34%	2973	41	42%	3030	49	36%	4221	56	44%
7.2	2194	36	35%	3057	41	43%	3101	49	36%	4319	56	44%
7.3	2256	36	36%	3142	41	44%	3173	49	37%	4419	56	45%
7.4	2318	36	36%	3230	41	44%	3246	49	38%	4522	56	46%
7.5	2382	36	37%	3319	41	45%	3321	48	38%	4626	56	46%
7.6	2448	36	38%	3410	41	46%	3397	48	39%	4732	56	47%
7.7	2514	36	38%	3502	41	46%	3475	48	39%	4841	55	47%
7.8	2582	36	39%	3597	**41**	47%	3554	48	40%	4951	55	48%
7.9	2651	35	39%	3693	41	48%	3635	48	40%	5064	55	48%
8.0	2722	35	40%	3791	41	48%	3718	48	41%	5179	55	49%
8.1	2794	35	41%	3891	41	49%	3802	47	41%	5296	55	49%
8.2	2867	35	41%	3993	41	50%	3888	47	42%	5415	55	50%
8.3	2941	35	42%	4097	41	50%	3975	47	42%	5537	55	51%
8.4	3017	35	43%	4203	41	51%	4064	47	43%	5660	55	51%
8.5	3094	35	43%	4310	41	51%	4154	47	43%	5786	55	52%
8.6	3173	35	44%	4420	41	52%	4246	47	44%	5914	55	52%
8.7	3253	35	44%	4531	41	53%	4340	47	45%	6045	**55**	53%
8.8	3334	35	45%	4645	41	53%	4435	47	45%	6178	55	53%
8.9	3417	**35**	46%	4760	41	54%	4532	47	46%	6312	55	54%
9.0	3501	35	46%	4877	41	55%	4630	46	46%	6450	55	54%
9.1	3587	35	47%	4997	41	55%	4730	46	47%	6589	55	55%
9.2	3674	35	47%	5118	42	56%	4832	46	47%	6731	55	55%
9.3	3763	35	48%	5241	42	56%	4936	46	48%	6875	55	56%
9.4	3852	35	49%	5366	42	57%	5041	46	48%	7022	55	57%
9.5	3944	35	49%	5494	42	57%	5148	46	49%	7171	55	57%
9.6	4037	35	50%	5623	42	58%	5256	46	49%	7322	55	58%
9.7	4131	35	50%	5754	42	59%	5367	**46**	50%	7476	55	58%
9.8	4227	35	51%	5888	42	59%	5479	46	50%	7632	55	59%
9.9	4324	35	52%	6023	42	60%	5593	46	51%	7790	56	59%
10.0	4423	35	52%	6161	43	60%	5708	46	51%	7951	56	60%
10.1	4523	35	53%	6300	43	61%	5825	46	52%	8115	56	60%
10.2	4625	36	53%	6442	43	61%	5944	46	52%	8280	56	61%
10.3	4728	36	54%	6586	43	62%	6065	46	53%	8448	56	61%

Economic speed, MGO 0,1%

Economic speed, HFO 1%

10.4	4832	36	54%	6731	43	62%	6188	46	53%	8619	56	61%
10.5	4939	36	55%	6879	43	63%	6312	46	54%	8792	56	62%
10.6	5046	36	55%	7030	44	63%	6438	47	54%	8968	56	62%
10.7	5156	36	56%	7182	44	64%	6566	47	55%	9146	57	63%
10.8	5267	36	56%	7336	44	64%	6696	47	55%	9327	57	63%
10.9	5379	36	57%	7493	44	65%	6827	47	56%	9510	57	64%
11.0	5493	36	57%	7652	44	65%	6960	47	56%	9696	57	64%
11.1	5608	36	58%	7812	45	66%	7096	47	57%	9884	57	65%
11.2	5726	36	58%	7976	45	66%	7233	47	57%	10075	58	65%
11.3	5844	37	59%	8141	45	67%	7371	47	58%	10268	58	66%
11.4	5964	37	59%	8308	45	67%	7512	47	58%	10464	58	66%
11.5	6086	37	60%	8478	45	68%	7655	47	59%	10663	58	66%
11.6	6210	37	60%	8650	46	68%	7799	47	59%	10864	58	67%
11.7	6335	37	61%	8824	46	68%	7945	48	60%	11068	59	67%
11.8	6461	37	61%	9001	46	69%	8094	48	60%	11274	59	68%
11.9	6590	37	62%	9179	46	69%	8244	48	60%	11483	59	68%
12.0	6720	37	62%	9360	47	70%	8396	48	61%	11695	59	68%
12.1	6851	38	63%	9544	47	70%	8550	48	61%	11910	60	69%
12.2	6984	38	63%	9729	47	71%	8706	48	62%	12127	60	69%
12.3	7119	38	64%	9917	47	71%	8863	48	62%	12347	60	70%
12.4	7256	38	64%	10107	48	71%	9023	48	63%	12569	60	70%
12.5	7394	38	65%	10300	48	72%	9185	49	63%	12794	61	70%
12.6	7534	38	65%	10494	48	72%	9348	49	63%	13022	61	71%
12.7	7675	39	65%	10691	48	72%	9514	49	64%	13253	61	71%
12.8	7818	39	66%	10891	49	73%	9681	49	64%	13486	61	71%
12.9	7963	39	66%	11093	49	73%	9851	49	65%	13722	62	72%
13.0	8110	39	67%	11297	49	74%	10022	49	65%	13961	62	72%
13.1	8258	39	67%	11503	50	74%	10196	50	65%	14203	62	72%
13.2	8408	39	67%	11712	50	74%	10371	50	66%	14447	63	73%
13.3	8560	40	68%	11924	50	75%	10549	50	66%	14694	63	73%
13.4	8713	40	68%	12137	50	75%	10728	50	67%	14944	63	73%
13.5	8868	40	69%	12353	51	75%	10910	50	67%	15197	64	74%
13.6	9025	40	69%	12572	51	76%	11093	51	67%	15453	64	74%
13.7	9184	40	69%	12793	51	76%	11279	51	68%	15711	64	74%
13.8	9344	40	70%	13016	52	76%	11467	51	68%	15973	65	75%
13.9	9506	41	70%	13242	52	77%	11656	51	68%	16237	65	75%
14.0	9670	41	70%	13470	52	77%	11848	51	69%	16504	65	75%
14.1							12042	52	69%	16774	66	76%
14.2							12238	52	69%	17047	66	76%
14.3							12436	52	70%	17323	66	76%
14.4							12636	52	70%	17601	67	77%
14.5							12838	52	70%	17883	67	77%
14.6							13042	53	71%	18167	67	77%
14.7							13248	53	71%	18455	68	77%
14.8							13457	53	71%	18745	68	78%
14.9							13667	53	72%	19038	68	78%
15.0							13880	54	72%	19335	69	78%

APPENDIX 2 – SHIPS IN STUDY

7 700 dwt					
Nr	LRNO	Name	Year	Operator	Flag
1	9263540	VARNADIEP	2002	Feederlines BV	NETHERLANDS
2	9277321	VRIESENDIEP	2004	Feederlines BV	NETHERLANDS
3	9277307	VOSSDIEP	2003	Feederlines BV	NETHERLANDS
4	9229075	VEERSEDIEP	2001	Feederlines BV	LIBERIA
5	9277319	VELSERDIEP	2003	Feederlines BV	NETHERLANDS
6	9381380	VIKINGDIEP	2008	Feederlines BV	NETHERLANDS
7	9224142	VECHTDIEP	2000	Feederlines BV	LIBERIA
8	9224154	VLIEDIEP	2001	Feederlines BV	LIBERIA
9	9229087	NORDLAND	2002	Feederlines BV	NETHERLANDS
10	9255579	WISAFOREST	2002	Feederlines BV	NETHERLANDS
11	9263552	VASADIEP	2002	Feederlines BV	NETHERLANDS
12	9439216	UAL CYPRUS	2008	Universal Africa Lines NV	NETHERLANDS
13	9352339	FLINTERLAND	2007	Flinter Shipping BV	NETHERLANDS
14	9224130	PAZ COLOMBIA	2000	Harren & Partner Ship Mgmt	ANTIGUA & BARBUDA
15	9413456	HERMANN SCAN	2007	Hermann Buss GmbH & Cie KG	ANTIGUA & BARBUDA
16	9287443	PENSILVANIA	2005	Navesco SA	COLOMBIA
17	9414187	VLISTDIEP	2007	Onego Shipping & Chartering BV	NETHERLANDS
18	9362815	HARTWIG SCAN	2006	Scan-Trans Chartering KS	ANTIGUA & BARBUDA
19	9362827	HANSEN SCAN	2006	Scan-Trans Chartering KS	ANTIGUA & BARBUDA
20	9414199	LIFTER	2007	Strahlmann E Reederei eK	ANTIGUA & BARBUDA
21	9187928	TRANSCAPRICORN	2000	Transatlantic Rederi AB	NETHERLANDS
22	9187916	TRANSANDROMEDA	1999	Transatlantic Rederi AB	NETHERLANDS
12 700 dwt					
Nr	LRNO	Name	Year	Operator	Flag
23	9357224	BBC GEORGIA	2008	BBC Chartering & Logistic GmbH	ANTIGUA & BARBUDA
24	9357236	BBC VERMONT	2008	BBC Chartering & Logistic GmbH	ANTIGUA & BARBUDA
25	9433262	BBC ALASKA	2008	BBC Chartering & Logistic GmbH	ANTIGUA & BARBUDA
26	9433298	BBC MARYLAND	2010	BBC Chartering & Logistic GmbH	ANTIGUA & BARBUDA
27	9433286	BBC FLORIDA	2009	BBC Chartering & Logistic GmbH	ANTIGUA & BARBUDA
28	9357212	BBC DELAWARE	2007	BBC Chartering & Logistic GmbH	ANTIGUA & BARBUDA
29	9337236	BBC ZARATE	2007	BBC Chartering & Logistic GmbH	ANTIGUA & BARBUDA
30	9357200	BBC MAINE	2007	BBC Chartering & Logistic	ANTIGUA &

				GmbH	BARBUDA
31	9433274	BBC MONTANA	2009	BBC Chartering & Logistic GmbH	ANTIGUA & BARBUDA
32	9488035	BRATTINGSBORG	2010	OXL NV	SINGAPORE
33	9488047	CLIPPER ANGELA	2011	Clipper Projects A/S	SINGAPORE
34	9431460	SE PACIFICA	2009	SE Shipping Lines Pte Ltd	SINGAPORE
35	9453781	SE PELAGICA	2010	SE Shipping Lines Pte Ltd	SINGAPORE
36	9431434	SE PANTHEA	2009	SE Shipping Lines Pte Ltd	SINGAPORE
37	9431472	SE POTENTIA	2009	SE Shipping Lines Pte Ltd	SINGAPORE
38	9337224	ROSARIO	2007	Marlow Navigation Co Ltd	CYPRUS
39	9453793	MARSELISBORG	2010	BD-Shipsnavo GmbH & Co	LIBERIA
40	9465394	FREDENSBORG	2011	Jutha Phakakrong Shipping	SINGAPORE
41	9488059	ELSBORG	2011	Nordana Line A/S	PANAMA
42	9488061	ELLENSBORG	2011	Nordana Line A/S	PANAMA
43	9626716	JANNES H		Krey Schiffahrts GmbH	ANTIGUA & BARBUDA
44	9646455	AGGERSBORG		Taizhou Sanfu Ship Engineering	PANAMA