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Permanent Slow Steaming

A solution to manage the increased costs imposed by the 2015 SECA regulation?

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Abstract

In 1999 a decision was made that would prove to have dramatic consequences over a decade later. The decision was made by the Council of the European Union, and addresses the issue concerning sulphur content in marine fuels. In 2015, the maximum sulphur content allowed in marine fuels within the European sulphur emission controlled area (SECA) will be lowered from the current limit of 1.0% to 0.1%. To comply, shipping companies are burdened with dramatic cost increases, derived from either switching to cleaner fuel or new technology investments. By combining a theoretical framework with a case study, this thesis will investigate the possibility to compensate the increased costs, associated with using cleaner fuel, by utilizing the concept of slow steaming. Although very difficult to attain exact data to calculate the economic effect of slow steaming, good estimations can be achieved and the theoretical result indicates that a 10-15% reduction in cruise speed could compensate for 50-80% the increased costs. There are however several factors which complicate an implementation of slow steaming, these factors will be discussed in the thesis.

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Abbreviations

HFO	Heavy fuel oil, a.k.a. bunker oil
ISL	Institute for Shipping Economics and Logistics (German)
LNG	Liquefied natural gas
MGO	Marine gas oil
MDO	Marine diesel oil
IMO	International maritime organization
NM	Nautical miles
PM	Particular matter
SECA	Sulphur emission controlled area
TEU	Twenty foot equivalent unit

1. Introduction

In 1999 a decision was made that would prove to have dramatic consequences more than a decade later. The decision was made by the Council of the European Union in collaboration with the European Parliament and the European Commission, and was named *Directive 1999/32/EC* (EU, 1999). The Directive, which has been amended in 2005 and 2012 and today named *Directive 2012/33/EC* (EU, 2012), addresses the issue concerning sulphur, or more precisely the sulphur content in marine fuels.

The most common type of marine fuel used in shipping has up to this point been bunker oil, or Heavy Fuel Oil (HFO). HFO is a residual oil that comes from distillation and/or the cracking system of natural gas processing (Intertek, 2011). HFO naturally contains a small amount of sulphur that during combustion in ship engine is emitted into the air as Sulphur Oxide(s) (SOx). One of these sulphur oxides is sulphur dioxide (SO_2), which for long has been recognised as a major cause of acidification, or so called *acid rain* (Europa, 2007). Acidification is known to lead to a decline in aquatic ecology e.g. fish populations, and forest and terrestrial ecosystem damage (Encyclopedia of Environment and Society, 2007). Other effects associated with sulphur emissions are for example heart disease, lung cancer, and chronic bronchitis for adults, or acute respiratory infections for children (Castanas *et al.*, 2008).

In an attempt to reduce the negative consequences associated with sulphur emissions, a Sulphur Emission Control Area (SECA) have been implemented in Northern Europe. The European SECA includes the Baltic Sea, the North Sea and the English Chanel. Directive 2012/33/EC regulates the amount of sulphur permitted in marine fuels within the SECA and as of January 1st 2015, the maximum limit is set to 0.1 %, compared to the current (2013) limit of 1.0% (EU, 2012).

In order to comply with the maximum limit of 0.1% sulphur content, ship operators are more or less forced to switch to other types of fuel, as it is not economically viable to de-sulphur HFO to a 0.1% sulphur content (SWECO, 2012). There are different fuel alternatives available, e.g. LNG and Methanol, but the perhaps most obvious alternative is changing from HFO to Marine Gas Oil (MGO) as very little engine modifications are required. MGO is however substantially more expensive then HFO due to higher manufacturing costs (Ministry of Transport and Communications Finland, 2009) and, as fuel often represents the largest single cost (Delhaye *et al.*, 2010), and changing from HFO to MGO will in most cases result in a significant negative economic impact for a ship operators.

The increased fuel cost due to the 2015 SECA regulation must be managed somehow in order to not lose customers. The purpose of this thesis is therefore to investigate whether a reduction of operating speed, also referred to as Slow Steaming (SS), could be an appropriate method to compensate for the increased fuels costs imposed when switching from HFO to MGO

1.1 Background

Before commencing to define today's challenge for shipping companies imposed by the 2015 SECA regulation, this section will describe relevant background information to assist the reader in understanding the context for this thesis and in getting a better understanding of the impact of shipping in the world. Only by recognizing the importance of shipping, is it possible to understand the broader impact of the SECA regulation.

1.1.1 The shipping industry

Shipping, although perhaps not entirely understood by the main public, plays a crucial role in the global infrastructure (Bardi *et al.*, 2006). Even when looking back 5 000 years, shipping has been in the forefront of economic development and have remained a key aspect ever since (Stopford, 2009). The oldest evidence of shipping activities goes back 5 000 years to the time of Babylon, where a sea trade network between Mesopotamia, Bahrain and the Indus River was developed (Stopford, 2009). The first shipping routes used rivers and coastal sea ways to utilize trade with other communities within the region.

Going forward 2 000 years, to 1 000 B.C., sea traders had started going over open sea, e.g. across the Mediterranean Sea, as well as travelling over longer distances, further enabling trade with more distant regions (*ibid*). Continuing to the 15th century Portugal became the pioneering state that started the phenomenon of global trade with Columbus discovery of the Americas in 1492 and by Vasco De Gama's discovery of the sea route to India sailing around the Cape of Good Hope in 1497 (*ibid*). The main purpose for these expeditions was economic, or more precisely to gain direct access to the lucrative spice and silk trade from the Far East (*ibid*). As an example of the benefits associated with having direct access to the Far East, Vasco De Gama returned from India with the information that the pepper, usually purchased in Venice for 80 ducats, could be purchased in Calicut for 3 ducats.

Portugal continued its exploration and, followed by other European nations such as the Netherlands and England, had established trade networks to all parts of the globe within two decades after Columbus reached the Americas (*ibid*).

Although development in shipping technology evolved over time and became more and more sophisticated it was not until the middle of the 20th century that shipping really had its strongest impact on the global economy, with the introduction of the modern container.

1.1.2 Containerization

"The handling of cargo on the waterfront between the land and the ship is about the most horrible example of material handling that the world have ever seen and the use of containers appear to be about the best prospect for improving this problem" – Francis G. Ebel[1] 1960 (Van Ham & Rijsnebrij, 2012, p.40).

During history goods were more or less always loaded and unloaded in individual units, e.g. in barrels, sacks and wooden crates, a process that was both slow and labour intensive. In fact often two thirds of a ship's productive time was spent in port, with the result of port congestion and low levels of ship utilization (Bernhofen *et al.*, 2013). But in 1955 a trucking entrepreneur from the USA named Malcolm P. McLean acquired a steamship company with the idea of transporting entire truck trailers on board a ship (World Shipping Council, 2013a). A year later, in 1956, the first container ship, named the Ideal X, made its maiden voyage loaded with 58 metal containers between Port Newark and the Port of Houston. This marked the start of what would become a revolution in the shipping industry, enabling ships to be loaded and unloaded much quicker and thus much more cost efficient (Bernhofen *et al.*, 2013). It should be mentioned that other tests using what could be called containers had occurred prior to McLean's premier voyage, however none did prove to be a commercial success (cf. Levinson, 2006; Yukon Museum, 2012). As a consequence of the introduction of the container other important technical developments shortly followed, further increasing productivity. An example is purpose built container cranes capable of handling 400 tonnes of goods per hour increased the average productivity 40 times compared to when using manual labour (Levinson, 2006).

Five years after the first container voyage had taken place the International Organisation for Standardisation, ISO, set standards for container sizes in 1961 (World Shipping Council, 2013b). The two most common types of containers was the 20 foot container and the 40 foot container, both remaining the most commonly used types of containers even to this day (*ibid*). Standardising the sizes of a container enabled other modes of transport, i.e. rail and road, to adapt its wagons and trailers to accommodate the standard containers and thus enabling the concept of intermodal transport, resulting in a much more efficient supply chain (cf. Levinson, 2006). In essence, the introduction of the container did not just revolutionise shipping but rather it changed the way transport in general was organized as well as utilizing economies of scale and greatly reduced the costs of international trade and increased the speed of the supply chain (Levinson, 2006). It should perhaps be mentioned that some economists argue that the rapid global economic development seen during the second half of the 20th century would have occurred regardless of the introduction of the container (Krugman, 2001).

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[1] Francis G. Ebel was one of the co-authors who received the Society for Naval Architects and Marine Engineers VADM Cochrane Award in 1962 for the best peer-reviewed paper (SNAME, 2011).

Containerization is commonly regarded to have had the largest impact on consumer goods and commodities, with the transportation cost of container shipping regarded to be approximately 1 % of a commodities retail price (Roland, 2007). In 2009 approximately 90 % of all non-bulk goods were transported in containers stacked on transport vessels (Ebeling, 2009).

To put that in numbers, and to get a better understanding of the impact that the introduction of containers had on global trade, in 1960, 307 tonnes of non-bulk cargo was transported on ships. In 2004 that number was 2 855 tonnes (Hummels, 2007), an increase of over 900 %. During 2011 approximately 3 706 million tonnes of goods where transported to and from the EU27 ports (Eurostat, 2013). When including inland waterways, 520 million tonnes of transported goods have to be added (Eurostat, 2013), resulting in over 4 200 million tonnes of goods being transported by ships to, within and from the EU27 states during 2011.

The first container vessel loaded, as previously mentioned, 58 containers. The largest container ships currently have a capacity of over 16 000 TEU's and during 2013 Maersk will own the largest ship in the world, a container ship with a capacity of 18 000 TEU's (Maersk, 2013a).

As with all other things there is of course a back side to all things good and for shipping one of the major problems is air pollution.

1.1.3 Sulphur emissions

Sulphur is a natural element that exists in abundance on our planet, and is an essential component of all living cells (TSI, 2013). It is, in its native form, a non-metal solid yellow crystalline and is both tasteless and odourless (Lenntech, 2013). Sulphur can also exist in the form of different derivatives such as sulphide and sulphate minerals, and different sulphur oxides, commonly referred to as SOx. The most common sulphur oxide is sulphur dioxide, or SO2 (Lenntech, 2013). In regards to shipping, sulphur naturally exists in fossil oil, the basis for HFO and MGO, in the form of hydrogen sulphide (TSI, 2013). When the fuel is combusted in the ship's engine sulphur is released into the atmosphere in the form of sulphur oxides, i.e. in gas form, and sulphate, i.e. in solid form (Diesch et al, 2012).

When released into the atmosphere some of the sulphur oxides reacts with water vapour and oxygen in the air and transform sulphuric acid. The emitted sulphate, i.e. particulate matter, travels with the wind to e.g. habituated areas where it risks being inhaled by humans (Encyclopaedia of Environment and Society, 2007).

Sulphuric acid is a highly reactive and corrosive substance (NPI, 2013), that in nature cause a phenomenon called *acid rain* (Länsstyrelsen, 2013). Acid rain is known to cause e.g. corrosion of buildings in urban areas, forest damage as well as acidification of lakes, rivers, groundwater and land soil (Encyclopaedia of Environment and Society, 2007). Acidification occurs when soil or water bodies start to lose its capacity to neutralize or resist acidifying atmospheric depositions, e.g. sulphuric acid, (Ministry of Transport and Communication Finland, 2012). If the acid deposition rates exceed the tolerance level of a specific water or soil body, the local ecosystem may lose its entire neutralizing capacity (*ibid*).

A consequence of ecosystems losing its capacity to neutralize atmospheric depositions can be declining fish stocks in the affected water bodies and depletion of nutrients in the soil (Encyclopedia of Environment and Society, 2007). One of the most harmful consequences of acidification, from a human perspective, is that in acidic conditions aluminium and heavy metal ions, all very toxic (Ministry of Transport and Communication Finland, 2012), are more easily rinsed out of the soil and instead becomes absorbed by living organisms (*ibid*), e.g. animals, plants and trees and from there to humans when consuming these as food (cf. Encyclopedia of Environment and Society, 2007).

Sulphuric substances, both SOx and sulphates, have, to mention a few, been documented to have the following effects on human health:

- Neurological effects and behavioural changes
- Disturbance of blood circulation
- Heart damage
- Effects on eyes and eyesight
- Reproductive failure
- Damage to immune systems
- Damage to liver and kidney functions
- Disturbance of the hormonal metabolism
- Suffocation and lung embolism
  (Lenntech, 2013; Encyclopaedia of Environment and Society, 2007)

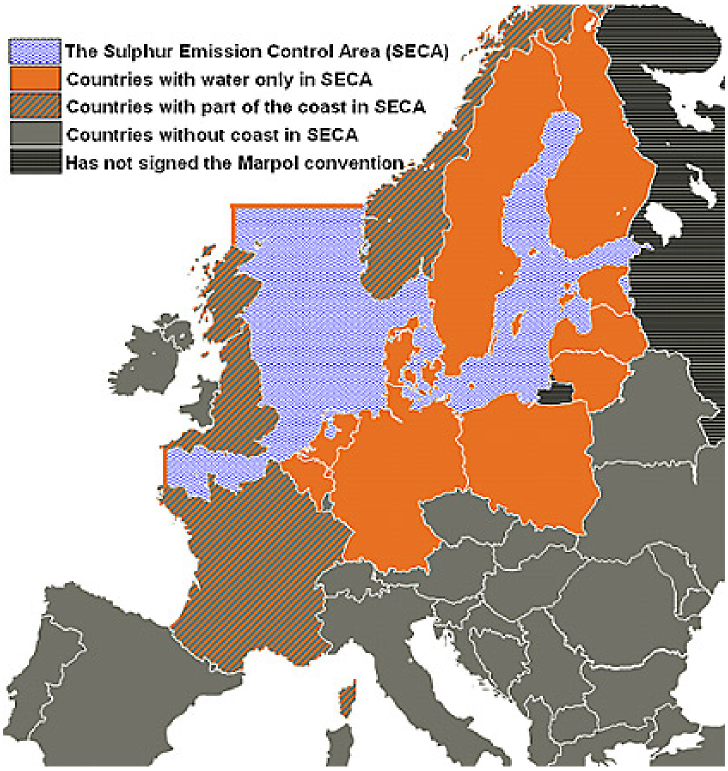
It is further estimated that the air pollution caused by ships running on high sulphur fuels is causing 50 000 premature deaths in Europe every year (Euractive, 2012). Most of these consequences have been known for several decades, and have been addressed by policy makers in different ways and different stages. The SECA regulation is how the EU has chosen to address the problem of pollutants associated with emissions from ships.

1.1.3 EU directives

In order to get a better understanding of Directive *2012/33/EU*, and the context in which it was conducted, it is necessary to go back all the way to 1975 and to *Directive 1975/716/EEC.* This directive addresses the approximation of the laws of the member states relating to the sulphur content in certain fuels (EU, 1975). In essence, it states that the content of sulphur in common fuel types has to be reduced in a progressively and significantly way, due to the negative effects sulphur emissions has on human health and on the environment (*ibid*). In 1993, and to *Directive 1993/12/EEC*, the Council of the European Communities published *Directive 1993/12/EEC* with the purpose of regulating the sulphur content in certain liquid fuels used within the European Union (EU, 1993). In essence the directive set forth to regulate the maximum permitted sulphur content in gas oil to 0.2% as from 1 October 1994 and to 0.05% as from 1 October 1996. This includes fuel used for maritime applications in general, although it does not include HFO.

Bunker oil, HFO, is addressed in the *Directive 2012/33/EC*, but instead of stating specific EU regulations, the directive refers to the MARPOL convention 73/78, imposed by the International Maritime Organization (IMO), and to the corresponding revised Annex VI regulation. IMO a United Nations branch dedicated to the safety and security of shipping and the prevention of marine pollutions by ships (IMO, 2013). The area affected by *Directive 2012/33/EC*, is as the Baltic Sea, North Sea, and the English Channel. As seen in Figure 1 below, there are countries with coastline only within the controlled area, which does not have any possibility to redirect their shipping flows to avoid this area, without going through another country.

Figure 1: Map over the European SECA



Source: Jernkontoret,2013.

Since the competitiveness of the shipping industry risk getting negatively affected by increased fuel prices, Directive 2012/33/EU, stipulates that state aid will be allowed to reduce the risk of a modal shift. The ceiling size of the state aid in any maritime investment is set to a maximum of 30 % of the total investment, given that the investment helps promoting short sea shipping (EU, 2004). The type of aid can according to the guidelines be both tax reductions and/or direct payments (e.g. reimbursement of seafarers' income tax). Both options are possible due to a lack of harmonization of fiscal systems among since Member States. This opens up for an opportunity for ship owners to seek funding from local governments when investing in new and green technology, which was the case when Viking Line recently built M/S Grace, a passenger ferry operated on LNG (liquefied natural gas). The ministry of Transport and Communication in Finland granted Viking Line €28 M to help finance the build (Viking Line, 2013). But due to the considerable size of the grant, the European Commission did also need to examine and approve the grant, which they did in 2012 (LVM, 2012). This type of aid might be necessary for the shipping industry, to financially coop with the investments that many of the alternatives to comply with the regulations require. The following chapter will present some alternatives that are more or less available today, and where state aid definitely could affect the outcome of the decision.

1.2 Alternatives to comply with the SECA regulation

In order to evaluate the pros and cons of slow steaming, other alternatives need to be discussed. This presentation is intended to give an overview of the most discussed ways to comply with the stricter sulphur regulations, with the pros and cons of each alternative. This discussion will later be used as background to understand why it is interesting to investigate slow steaming.

1.2.1 Low sulphur fuel

To comply with the 2015 SECA regulations without having to do any significant adjustments to either the ship or the engine, operators can switch from the heavy fuel oil (HFO) with 1% sulphur that is used today, to a lighter bunker fuel with 0.1% sulphur, e.g. marine diesel oil (MDO) or marine gas oil (MGO). These fuels share similar characteristic and price, but henceforth, MGO will be the focus. The obvious advantage of this alternative is that no large investments are needed; since most ship engines can switch from HFO to marine diesel with only small modifications (Pahlm, 2013). The cost for lubricant oil will however increase, since lighter fuels do not have the same lubricating properties as HFO (Pahlm, 2013). But the main drawback is that the price per tonne is higher for MGO than for HFO. A general rule is that the cleaner the fuel, i.e. lower sulphur content, the higher the price is (SWECO, 2012). The price for marine fuel with 0.1% sulphur content is estimated to be around 40-60 % higher than the price for HFO (Purvin & Gertz, 2009; Rexius, 2013). Predicted price development will be covered more in detail in chapter 3.1.1 “Fuel prices”. Whether ship operators choose to switch to a lighter fuel depends, consequently, on if they can bare the higher cost. If the price difference is too large, other solutions must be considered.

For the later investigation on the possibilities of slow steaming, it will be done for ships running on MGO. The other alternatives in this section are here considered as alternatives to slow steaming on MGO, even though slow steaming very well can be applied on any alternative. But the intention of the thesis is to find an alternative that does not need the large investments associated with following alternatives.

1.2.2 Exhaust cleaning systems and heavy bunker fuel

Heavy bunker fuel (HFO) can still be used after the new regulations if an exhaust cleaning system is used, given that the cleaning system complies with the sulphur limits set in the MARPOL convention Annex IV (IMO, 2005). These systems are often referred to as scrubbers, and the idea behind the technology is to decrease the sulphur amount in the exhaust gas. This can be done by running the exhaust through water (wet scrubbing), or running it through calcium materials (dry scrubbing) (EGCSA, 2013).

Wet scrubbing systems can use either salt water or fresh water with sodium hydroxide added (EGCSA, 2013; Finnish Ministry of Transport and Communication, 2009). The salt water system is an open system where water is pumped in from the sea, circled through the system to clean (scrub) the exhaust and then pumped back into the sea (*ibid*). Before being pumped back into the sea, it needs proper treatment to remove pollutants, to comply with the IMO (2009) wastewater regulations.

The freshwater system is a closed system which stores the residues on-board and require transport to land facilities for disposal (Delhaye *et al.* 2010). Dry scrubbing systems use calcium to absorb the sulphur in the exhausts, and the residues are, like a closed wet scrubber, stored on-board (SWECO, 2012). Both technologies are well used by land-based industries that do not have the same space requirements (AEA, 2009), but it has been problematic to transfer the technology to the shipping industry (SWECO, 2012).

The cost of installing a scrubbing system depends mainly on two factors, if the system is installed on a new ship or retrofitted on an existing ship, and if it is an open or a closed system. The technical consultancy company AEA have in their report to the European Commission (2009) summarized the costs for installing and using scrubbers (Table 1). A retrofitted open system wet scrubber will cost about €2.30M to install, and a retrofitted closed wet scrubber about €4.59M, the corresponding annual costs are €301 000 and €708 000. Green Ship (2012) has together with Alfa Laval Aalborg estimated the cost for a retrofitted closed system to about $5.8M, which is close to AEA's estimation. The main difference between running a closed and an open scrubbing system is the operation and maintenance costs (O&M), where waste disposal from the closed systems, inter alia, are included.

Table 1: Scrubber costs

Tech spec		Investment [K€/vessel]	Lifetime [years]	O&M [K€/vessel]	Fuel cost [K€/vessel]	Annual cost [K€]
New	open	1 148	15	28	41	167
New	closed	2 296	15	198	41	441
Retrofit	open	2 296	12.5	28	41	301
Retrofit	closed	4 592	12.5	198	41	708

Source: AEA (2009)

The biggest issues according to studies of this technology have been space requirements, waste disposal, and reliability (Finnish Ministry of Transport and Communication, 2009; SWECO, 2012; AGS, 2007). The on-board facility requires a significant amount of space, which decreases the goods capacity (SWECO, 2012), and could consequently affect revenues. The problem with waste disposal differs depending on what system being used. Open wet scrubbers need to have a purification plant, which requires more space and separate handling of the residue in the ports (AGS, 2007). The filtered wash water could however still affect the sea, especially semi-confined areas such as ports, and further studies need to be done on the effects of released water (*ibid*). The wash water is regulated by the IMO (2009) in Resolution MEPC 184(59), where limits are set for pH-level, hydrocarbons (PHAs), nitrates, and particulate matter (PM). Dry scrubbers and closed wet scrubbers require both on-board handling and port handling of the waste, but the logistics of the port handling is still under development (Finnish Ministry of Transport and Communication, 2009).

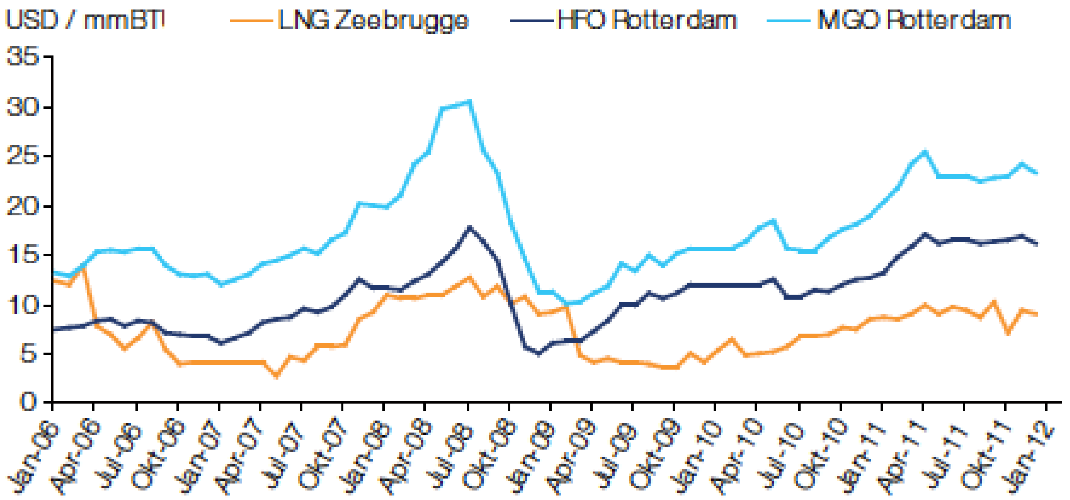
The academic opinions about scrubbers as an alternative to comply with the 2015 SECA regulations are fairly consistent. SWECO (2012) establishes in a report that the technology is still too unreliable with too high failure frequency, and that manufacturers only guarantee the cleaning level but not that the system will operate error-free. While still predicting a rapid increase in installations of scrubbers if ship operators cannot handle the price difference between high and low sulphur fuel in 2015, but believe in a decrease if operators can manage the cost of low sulphur fuel. The German maritime research institute ISL (2010) excluded scrubbers as a viable option in its report of the impacts of the new regulations, due to the technology still being in a testing phase. It is considered too unreliable to make any conclusions regarding the sustainability of scrubbers with the small number of ships using the technology at the time of writing the report. ISL also states that the residues from the scrubbers are often dumped into the sea, instead of delivered to toxic waste disposal companies in ports. The Finnish Ministry of Transport and Communication (2009) point to that the size of the equipment is the greatest challenge, since efficiency and size is said to be proportionately related, and that installation of scrubbers on old ships will be a difficult task due to the ship design. Nikopoulou (2008), a Chalmers researcher, do however call sea water scrubbing a promising technology, disregard of the environmental problems of wash water, and a relatively long investment payoff time.

1.2.3 LNG

Liquefied natural gas (LNG) is an alternative fuel that does not emit any sulphur at all, and which also have lower CO2 emissions compared to HFO and MGO (Danish Maritime Authority, 2012). This makes it a promising long term alternative for ship operators, but there are some short term issues. LNG has been a hot topic the last couple of years, primary as a green solution. Vessels operated purely on LNG are not widespread today, but there are boats running on LNG, and more are being built (*ibid*). In 2012, there were 23 LNG ships in the sulphur controlled area, and 22 of these ships sailed in Norway (SWECO, 2012). A ship build that has been well noted within the shipping industry since 2011 has been the build of Viking Lines’ first LNG passenger ferry, which made its maiden voyage between Stockholm and Åbo in January 2013 (Viking Line, 2013b). Viking Grace, as it was named, is the first large scale ferry operated on LNG and is said to be one of the most environmental friendly ships built (LNG World News, 2013).

The price for LNG fuel is today the other main advantage of this alternative, compared to MGO or HFO. It is fixed relative to the pipeline gas, which usually follows the trends of HFO and other oil products (Danish Maritime Authority, 2012). The energy content of LNG differs from the energy content of HFO and MGO (see Table 13, Appendix, for values), price comparison between LNG and oil products are therefore usually not made in USD per ton, but instead USD per Propulsion power (mmBT) (GasNor, 2012). As shown in Figure 2 below, LNG had a lower correlation to HFO and MGO the second half of the 2000s, but has followed the trend of HFO and MDO more closely since early 2009. The price development is however uncertain, and payoff time on an LNG investment will vary with the price spread.

Figure 2: LNG, HFO and MGO prices (2006 – 2012)



Source: MAN, 2012a

The cost and environmental advantages of LNG are superior to both HFO and MGO, but it comes at a price. New build LNG ships are more expensive than regular ships; the Swedish gas company SGC estimates a cost increase of between 5 – 50%, where figures in the higher end are more likely (SGC, 2011). It is also said in the same report that retrofitting existing ships into LNG ships is unlikely, since the costs are too high. Green Ship (2012) has together with MAN Diesel and Turbo made an estimation that a retrofitting of an old HFO engine to a LNG engine would cost around $7.5M. The German Institute for Shipping Economics and Logistics (ISL) (2010) concludes in a report that there would be too little time to amortise new LNG engines if installed on old ships. ISL also states that the size of the LNG tanks makes retrofitting difficult, since it requires being up to four times larger than HFO tanks (ISL, 2010). SWECO assumes that 2% of the ships within the controlled area will be LNG ships in 2015, which is in accordance with a normal phasing out time of old ships. SGS (2011) states that almost 20% of the ships within the controlled area today are 30 to 40 years old, and thus needed to be replaced before 2020, making room for a potentially larger increase in new build LNG ships.

Another concern with LNG operated ships today is the infrastructure for the fuel. The bunker oil used today is provided to ships through an effective infrastructure, with tanks in ports, bunker ships and out on barges (Danish Maritime Authority, 2012). The same infrastructure does not exist for LNG and ships that burn LNG have to have temporary solutions for bunkering the LNG (SWECO, 2012). The reason for this are the specific characteristics of LNG, to keep it liquefied it needs to be kept at -163°C, and in gas form the volume is 600 times larger than when in liquid form (Business Region Goteborg, 2012). The Danish Maritime

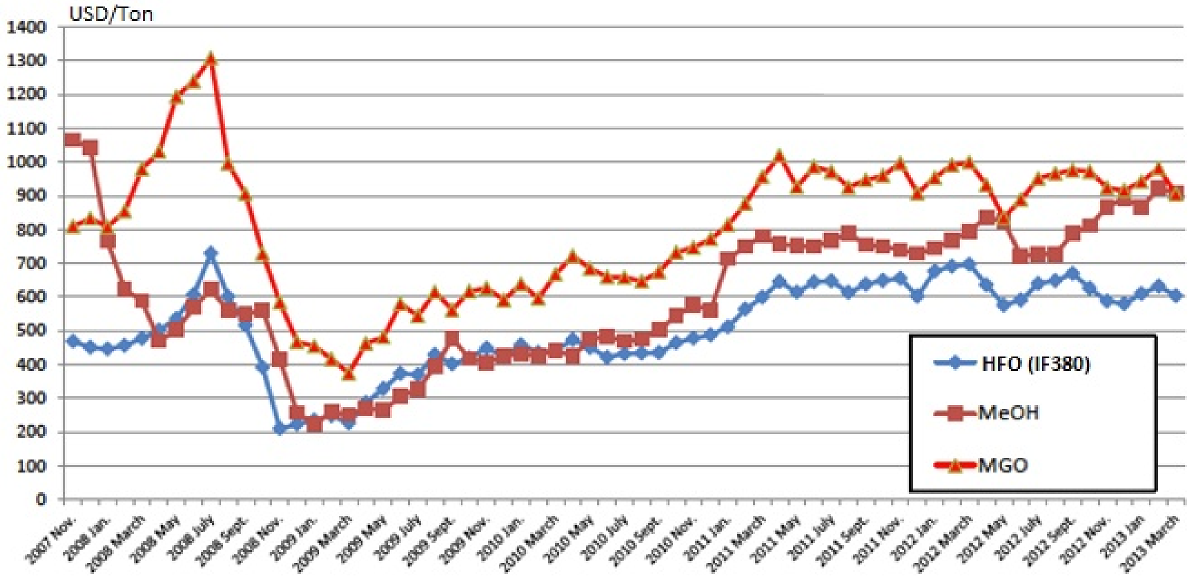
Authority (2012) have in a large EU funded project, together with other Nordic authorities and several actors from the gas and shipping industry, extensively investigated the feasibility of a LNG filling station infrastructure. The recommendation is that larger port with enough space, and with heavy traffic or where short turnaround time is important, should invest in LNG terminals with pipelines to the ships. Smaller ports with less traffic can use ship-to-ship or truck-to-ship solutions. The situation is called a chicken-and-egg problem in the report, since LNG providers are not willing to make the investments without sufficient demand, and ship operators are not willing to invest in LNG ships if the infrastructure is not in place. The safety risk factor of LNG is also something that has been debated (cf. Danish Maritime Authority, 2012; Vanem *et. al,* 2007), but the safety risk factor of the different alternatives is excluded in the evaluations in this thesis.

1.2.4 Methanol

Methanol is another alternative, which is not as frequently mentioned alternative as LNG and scrubbers, but still interesting to mention since one of Sweden's largest shipping companies, Stena Line, has decided to switch to methanol for their vessels (NyTeknik, 2013; Sjofartstidningen, 2012; Ullstrand, 2013). The decision to go with methanol was the result of a two-year research collaboration between several companies from the shipping industry (e.g. Wärtsilä, SSPA and Lloyd's Register), with the intention to find concrete solutions to reduce the energy consumption within the shipping industry (Business Region Goteborg, 2012; Sjöfartstidningen, 2013). Methanol was seen as a more realistic alternative for direct implementation, than for example LNG, since the existing infrastructure with tankers and fuel stations can be used (NyTeknik, 2013). Stena Line seems to be the only shipping company currently looking at this solution (*ibid*). Stena Lines first tests with methanol on auxiliary engines are scheduled in 2013, and if the results are positive, the intention is to have the first passenger ferry running solely on methanol in 2014, followed by conversions on 24 of the 35 ships in Stena Lines fleet the next few years (*ibid*).

The main difference between LNG and methanol is that LNG needs to be kept at -163°C to be liquefied, and methanol is liquefied at room temperature (*ibid*). This gives methanol the clear advantage of using the existing infrastructure, which LNG cannot use. Methanol does however have lower energy content than LNG, (thus also HFO and MGO, see Table 13, Appendix), which means that larger volumes are needed, i.e. larger fuel tanks. The price of methanol have followed the price of HFO, but have the last two years been traded slightly higher, but still lower than MGO, see Figure 3 below.

Figure 3: Price development of methanol (MeOH), HFO (IF380), and MGO (2008 – 2013)



Source: Wärtsilä, 2013.

1.3 Problem description and analysis

With the background and the different alternatives in mind, this chapter presents an analysis of why these factors have led the authors to the research question. It includes an analysis of the SECA regulation and the challenges it presents, a brief presentation of slow steaming, and a discussion about why it is interesting to analyse slow steaming as a substitute to the other alternatives.

1.3.1 The SECA regulation; a challenge

First and foremost, it is important to establish that the SECA regulation is not a problem in itself, but a solution to the problems associated with sulphur emissions from ships. However, the implementation of the regulation imposes a huge challenge for shipping companies operating in the emission controlled area. An important factor to understand why operators consider it challenging is that, according to managers from the industry (Boliden, 2013; Rexius, 2013; Ullman, 2013), the problem is not only the increased costs due to more expensive fuel, but also that they were not prepared for an implementation date this close to the decision date. The 2015 SECA limit of 0.1% was definitely decided by the EU in the summer of 2012, giving ship operators two and a half years to adjust to the new conditions. But as can be seen from the process leading up to Directive 2012/33/EU, it can be argued that it should not have come unexpected. It was however still believed that operators would be given more time to adapt to such a significant decrease in fuel sulphur level (*ibid*).

The relatively short time from decision to execution is regardless forcing ship operators to quickly develop and implement viable solutions. As have been discussed in the previous chapter, much of the research in alternatives that complies with the 2015 SECA regulation are still in the introduction phase, and/or demand large scale investments. Both these problems would decrease if the time to implementation was longer, since it would reduce the risk of unexpected economic outcomes due to uncertain technologies and forced premature large scale investments. Time horizon for technology investments is a well-studied academic field, and a key factor according to many studies is timing (cf. Husimen, 2001). If the timing is not right for a large scale investment, chances are that the company cannot afford the investment, and state aid is neither guaranteed nor certain to be large enough. To phase out the whole fleet until 2015 is obviously not an economically viable option for a large shipping company. Based on the life expectancy of a ship, which differs from around 25 years for tankers and dry bulk ships, to around 30 years for passenger ships (Stopford, 2009), it would take at least 25 years to completely phase out an entire fleet.

1.3.2 SECA and fair competition

Another concern with the SECA regulation regards to unfair competition, partly within the European shipping industry, but mainly for shipping as a transport mode in comparison to other modes (i.e. road and rail). Since the controlled areas do not include the whole European coast line, shipping companies operating in controlled areas will face a tougher economic situation than companies operating south of the controlled areas. This will create an uneven advantage for shipping companies operating in Southern Europe, compared to the operators active in Northern Europe. Shipping as a mode of transport, and short sea shipping in particular, could also face decreased competitiveness in relation to other modes. At the same time, the EU's Marco Polo Programme is promoting a modal shift from land transport to short sea shipping in order to reduce road congestion and emissions (EU, 2003). The SECA regulation is from this perspective somewhat contradictive to the Marco Polo Programme. To solve this problem with state aid for investments in new technology, as suggested by the EU, is not a long term solution to the problem, nor is it a reliable solution for ship operators.

The result of increased prices could be a shift from shipping to other modes of transport. If a shift would occur, it is likely to assume that it would differ between different shipping segments, and on different routes. A mode shift due to increased shipping prices would be more likely in industries where transportation constitutes a large share of the total cost (i.e. low value per kilo), compared to industries where shipping only constitutes a small share of the total cost (i.e. high value per kilo). It might also be more likely on routes where there are several other modes to choose from (e.g. Gothenburg – Malmö), compared to routes where there are fewer viable options (e.g. Stockholm – Helsinki). If prices increase and the shipper cannot find another alternative, there is also a risk that the operations have to move to other locations. The Swedish melting company Boliden, which are very dependent on dry bulk shipping in the Baltic Sea, discusses this as a potential outcome of SECA. According to Boliden's Head of Logistics Karl-Owe Svensson (2013), very concerned about the possible competitive disadvantage, in relation to melting companies in other parts of world, which Boliden would experience with increased transportation costs. More on the risks for modal shift is discussed in chapter 3.1.2.

1.3.3 Ship operators must take action

Regardless whether the 2015 SECA regulation is unfair from a competitive perspective, or the time to adapt is too short, the ship operators must take action. To summarize the alternatives discussed earlier, operators can;

- switch to marine gas oil (MGO),
- continue using HFO but installing exhaust gas cleaning systems (scrubbers),
- switching to natural gas engines (LNG),
- or switching to methanol.

The investment costs for switching MGO is limited compared to switching to scrubbers, LNG or methanol, but the fuel price is on the other hand higher (Danish Maritime Authority, 2012).

An option to compensate for increased fuel prices is to adopt operational improvements to reduce the fuel consumption. Reducing the speed, i.e. slow steaming, is one example of this. Slow steaming is a well-known concept within the shipping industry, and is simply based on sailing the ships with reduced cruise speed. The reason why slow steaming reduces fuel consumption is that the relationship between speed and fuel consumption is not linear and small decrease in speed results in a relatively larger decrease in fuel consumption. This means that the total amount of fuel consumed on any give trip will be less if the speed is reduced, even including the extra voyage time required. The method is today primarily used during economically tough times, to cut costs when demand is low and capacity is high (Ullman, 2013; Sjöberger, 2013; Askola, 2013). It is therefore interesting to investigate if the economic situation with the new sulphur limits could be considered as “a permanent tough time”, and consequently examine if slow stem could be used as a solution to cut costs, even with high demand. The concept of slow steaming will be more developed in the theoretical framework.

What makes this sub-alternative interesting to investigate is that it does not demand any machinery investments, and it does not have the same uncertainty as new technology or relying on state aid. It is also relatively easy and fast to implement for the operators, and it is possible to estimate the economic effects with rather good precision. To reduce fuel consumption also makes this alternative sustainable from an environmental aspect, even though other alternatives such as LNG will be environmentally superior when/if the infrastructure problem is resolved.

1.4 Purpose

With the background and problem analysis in mind, the purpose of this thesis is to investigate to what extent the increased fuel costs from using low sulphur fuel (MGO), imposed by the 2015 SECA regulation, can be compensated for by using the concept of slow steaming. The intention is to determine whether slow steaming by itself compensates enough for increased fuel costs by reducing fuel consumption, or if other solutions are needed to prevent, in the end, a cost increase for shippers. Slow steaming is as mentioned a well-known concept within the shipping industry, but does it have more potential than today's usage? After applying the concept on two cases, by analysing the potential fuel consumption, fuel cost, and time tables, it will be possible to answer the research questions below. It will also be possible to determine, from the operators perspective, if it possible to compensate for the increased fuel price by reducing the speed.

The result is intended to give the industry an indication to whether slow steaming could be a long term solution. But the thesis is also intended to be a starting point for continued research on slow steaming, since this thesis will not be able to cover all segments, ship sizes or trip distances. The calculation model used to analyse slow steaming in our cases will be applicable to any segment, ship size or trip distance due to its generality and possibility to change the input data. Hence, the thesis could hopefully be used as a framework for continued analysis of the possibilities of slow steaming.

1.5 Research question

The main research question is complemented by two sub questions below, all three questions will be answered quantitatively in the case study, with a qualitative reasoning about the result in the analysis.

Main research question

- To what extent can slow steaming be used to compensate for the higher fuel cost from using low sulphur fuel (MGO), imposed by the 2015 SECA regulation?

Sub questions

- What speed is the break-even point between today's speed with HFO, and slow steaming with HFO, and is possible to reduce to this speed?
- How will the increased lead time affect time schedules?

1.6 Limitations

It has previously been touched upon what the purpose of this thesis will be. Some areas that will not be covered have been mentioned, and this chapter will further explain the scope of the thesis.

As the main research question implies, the intention is to investigate to what extent slow steaming can be used to compensate for increased fuel costs imposed by stricter sulphur regulations, given that light fuel oil, i.e. MGO, is used. A presentation of other alternatives to comply with the 2015 SECA regulation have been included in order to provide a framework in the discussion about why slow steaming is an interesting alternative, however these alternatives are not further discussed in this thesis.

Geographical limitations

There are sulphur emission controlled areas both in Northern Europe and in North America, the focus here will be on the European SECA, as defined in the revised MARPOL Annex VI convention, Regulation 14:3 (IMO, 2008), see Figure 1 in Chapter 1. In total there are about 14 000 ships that daily sail through or within the European SECA, 2200 of these ships are daily located within the area (SWECO, 2012). To evaluate a full implementation of slow steaming, it is of most interest to look at the 2200 ships that daily operate in the area, and preferably ships that only operate there. By choosing ships that only traffic the controlled area, it will be possible to disregard how much of the traffic that is actually affected by the regulation, since low affection will decrease the interest to make any large adjustments.

Type of ship and size limitations

The result of implementing slow steaming is likely to be different between ships of different size and type of operation, so one cannot draw any general conclusions about slow steaming based on conclusions from just one ship. This thesis will however not be able to apply slow steaming on a wide variety of ship sizes, nor a wide variety of ship types. The focus will instead be on implementing slow steaming on a selection of cases from the container segment. This decision is the result from consultations with professionals from the industry (Per Sjöberger, Swedish Shipowners' Association; Gavin Roser, The European Freight and Logistics Leader Forum), who have given indications that the concept will be more easily implemented on this segment due to its characteristics. It is also of interest due to the importance of the segment to both the emission control area, and as discussed in the introduction, the global economy.

Container vessels with routs within the North Sea and Baltic Sea are usually smaller vessels. These vessels can for example be working as feeder vessels in a larger transcontinental transport system, being a link in short sea shipping systems, or being used where the draught is restricted (Stopford, 2009). Vessels with a capacity of up to 499 TEUs are referred to as *feeder* vessels, 500-999 TEU vessels are called *feeder-max*, and vessels with a capacity of 1000-3000 TEUs are referred to as *handy* vessels, which are still small enough to be used intraregional (*ibid*). The sizes of container ships that will be discussed in this thesis will be between 500 and 2000 TEUs, i.e. feeder-max and handy vessels.

Included actor

This thesis will focus on the ship operators, but other actors affected by the implementation of slow steaming might be mentioned in some discussions. This can be used to highlight where more research is needed, or to present a wider picture of how slow steaming can affect the shipping industry as such.

Factors needed for a full evaluation

To fully evaluate slow steaming as an option from the ship operator's perspective, it is necessary to evaluate the following:

1. All factors affecting the total voyage costs (e.g. fuel costs, manning, insurance, maintenance, repair, administrative costs, etc.)

2. The changes in the operator's supply (is more capacity needed?)

3. The change in the shippers demand (will shippers not accept longer lead times?)

4. The combined effect of 1), 2) and 3) on annual revenue.

This thesis is limited to calculating the fuel cost in 1), and not any other costs in 1) since much of the data needed to calculate the other factors are internal company data. It has also fallen outside of the scope of this thesis to make any predictions about changes customer demand, or the operators supplied capacity.

2. Methodology

This chapter is intended to clarify the methods used to answer the research question and come to the conclusions presented at the end of the thesis. This is an important step to give the reader an opportunity to validate the research, and draw own conclusions about the work and the conclusions. It also gives the authors an opportunity to criticize the methods, as well as the sources, used in the thesis.

2.1 Research design

The purpose of this thesis is to further contribute to the research regarding alternative methods for shipping companies to comply with the 2015 SECA regulation in a profitable way. By initiating research on the possibility of using the concept of slow steaming in combination with using MGO as a fuel, the aim is to try to establish whether it can be a solution worth pursuing.

It was early decided that the foundation of the research would be to establish a theoretical framework that would visualise how the total voyage cost would change for a given trip, sailed by a given ship at variable speeds while running on low sulphur fuel, i.e. MGO. This would then be compared to the current operating mode, i.e. current fuel and cruise speed, to establish at what cruise speed the break even cost would occur. Finally the theoretical framework would be tested on an actual scenario using actual ship data and actual routes. This would be done by conducting a case study.

The theoretical framework in this thesis is based on a qualitative approach (Collis, 2009) and includes an extensive literature review as well as open interviews with experienced shipping industry representatives as foundation. A literature review can be regarded as a systematic process that serves the purpose of finding existing knowledge on a specific topic (Collis, 2009). Literature usually refers to all secondary data that could be beneficial for the research (Collis, 2009). However for this thesis the official EU documents, i.e. primary data (Collis, 2009) used for reference are included in the literature review.

The fuel consumption formula was attained after an open interview with Henrik Pahlm (2013), Associate Professor in Marine Machinery Systems at Chalmers Technical University, as well as by a review of relevant previous academic studies (Kontovas *et al.*, 2011; Corbrett *et al.*, 2009; Eide *et al.*, 2009). The cost structure is based on several academic sources (Stopford, 2009; Delhaye *et al.,* 2010; Copenhagen Economics; 2012) and is used to illustrate that fuel represents a large part of a container vessels daily cost, i.e. 47%, which is one of the factors making at suitable segment to research for this thesis. The theoretical framework was then used to calculate the fuel consumption for a selected ship at different cruise speed and compare the result with the fuel consumption when running at the ship's design speed. The results were then used together with fuel price data to calculate the fuel cost for running at design speed using HFO and at variable speeds using MGO. This was used to establish a breakeven point, i.e. at what cruise speed the fuel cost when running on MGO would equal the fuel cost when running on HFO at design speed. The result was then used for the case study.

2.2 Research approach

The theoretical framework will start by describing how the 2015 SECA regulation is viewed upon by different industry representatives and how it is regarded to affect the shipping industry within the emission control area. The first part of the theoretical framework is also used to present the predicted price development for marine fuels. This will be followed by a thorough explanation of the concept of slow steaming; how widespread it is, and how it affects the ship operators. In the section about how it affects ship operators, a deeper investigation will be made about how other costs besides fuel costs will be affected by slow steaming. All these topics are regarded as crucial in order to create a theoretical framework that corresponds well with existing research and industry knowledge. The model used to calculate the theoretical fuel cost will be presented in Chapter 3.3.

The intention is, as previously mentioned, that the model should be applicable on a wide variety of ships and type of operations, but the drawback of making a generic model is that it will not be possible to tell for which cases it works, and for which cases it does not work, without implementing in on several cases from different segments. But as discussed in Chapter 1.6, *Limitations*, this thesis will not be able to test the model on other segments than small container ships within the emission control area. Further studies on other segments are necessary in order to confirm the model on a broader level.

2.3 Research method – a case study

As actual data from the shipping industry will be used, and due to the limitations in scope for this thesis, it is considered by the authors that a case study will be an appropriate method to properly answer the research question. A case study can be defined as an empirical inquiry that “investigates a contemporary phenomenon within its real-life context and addresses a situation in which the boundaries between phenomenon and context are not clearly evident” (Yin, 1993). The advantage of using a case study approach is that it is a flexible method, allowing tailoring the design and data collection procedures to the research question (Meyer, 2001). On the other hand, there is a risk that the research will lack important aspects as the method is highly dependent on the researcher’s skills, knowledge and frame of reference (Meyer, 2001). The author’s knowledge regarding the chosen topic has to be defined as limited, while the analytical skills should be regarded as to expect on a graduate level. The aim is the broaden the knowledge and test the analytical skills of the authors by gathering and analysing a wide range of data and information made possible by the freedom given when applying a case study method.

In order to have a guideline to follow the main steps for a case study provided and described by Collis and Hussey (2009) will be followed for this thesis. The steps are as follows:

- **Selecting the case** – In research the usual approach is to attempt to make statistical generalizations that shows that it is possible to generalize from the sample to a larger population. This is however not necessarily the situation when conducting case studies although it might be attempted to make a generalization that the result from the selected case can generally be applied in another case.
- **Preliminary investigations** – This is mainly done in order for the researcher to get familiar with the context of the chosen case. The main critique for this approach is that it can affect the researchers thoughts and believes regarding the subject being studied and might lead to bias.
- **Data collection** – When collecting the data needed for the case study the researcher need to decide in advance how, where and when the data will be collected. The data can be in various forms, i.e. both quantitative and qualitative.
- **Data analysis** – The decision here is to decide wetter to perform in-case analysis or a cross-case analysis. As the data for this thesis will be from a single sources in case analysis will be performed.

2.3.1 Selecting the cases

The selection of shipping operators for this thesis is based on the limitations given by the research question; operators should only be active within the SECA, the vessels used should be containerships with a load capacity of between 500 and 2000 TEUs.

It has been implied from the discussions with industry professionals (Gavin Roser, Per Sjöberger) that the container segment would be the most suitable segment to look into and would be of more interest to the industry compared to e.g. RoRo and RoPax. It was mentioned during the interviews that RoRo and RoPax operations will have greater difficulty in implementing slow steaming, as it mostly associated with liner shipping and normally having very little room for increased lead time. This is also supported by the ISL study (2010) previously discussed in Chapter 1.2.

A further limitation when selecting the cases was made in order to make the data collection phase more manageable; the studied companies need to have an office in Sweden. It should be noted that the last limitation reduces the number of possible cases drastically, but was seen as the most effective way to acquire the data needed. The described limitations of the scope of this thesis helped narrow down the selection of suitable cases to a handful of companies.

2.3.2. Preliminary investigations

A preliminary investigation was made in two different areas; a broader investigation of the shipping industry and a more specific investigation of shipping companies suitable for a case study. The industry investigation is covered by Chapter 3*, Previous Research.* For the investigating of shipping operators, the first step was to get familiarized with the companies using information found on each company's homepage. From the homepage ship data and route schedules were investigated before contacts were made with the companies best suited for a case study. Background information about the selected companies together with a description of given opinions regarding the 2015 SECA regulation and its implications will be presented as an introduction to each case in Chapter 4.

2.3.3. Data Collection

In order to calculate to what extent slow steaming can be used to compensate for the increased cost due the 2015 SECA regulations, a variety of data is needed. In order to calculate the cost savings normally associated with slow steaming it is necessary to collect data regarding a ship's fuel consumption, as well as the cost of fuel. The specific ship data, i.e. fuel consumption, was collected through official sources, i.e. homepages, given by the ship owners and by the engine manufacturers.

Due to the fact that the fuel consumption is only published for the ship's design speed, theoretical calculations are required to estimate the fuel consumption at different vessel speeds. This will obviously lead to an increased uncertainty in regards of using the calculated data in the model. Current vessel speed, vessel speed logs and route history can be found online (MarineTraffic) for most ships, using GPS tracking. The current price for different marine fuels is also available on online databases (e.g. BunkerWorld and BunkerIndex), with up-to-date information from a wide variety of ports around the world. These sources can be considered primary sources, and is to our understanding used by many shipping companies and for most scientific reports as well. To make a viable estimation regarding future price level for marine fuel secondary sources must be used, since the databases previously mentioned only show current prices free of charge. To gain access to more sophisticated data a one year subscription has to be signed for a cost of over $2 000 (Bunkerworld, 2013). Predictions of future fuel prices have thus been collected from industry reports, official market analysis as well as directly from the industry.

Gathering data regarding a shipping companies' cost structure for a certain vessel proved difficult to attain, most likely due to commercial reasons. For this reason a general cost structure specific to container ships have been used (Delhaye, 2010). The specific cost structure was chosen after an extensive literature review, which revealed that several reports and studies had come to very similar conclusions (cf. Delhaye, 2010; Compass, 2010; Copenhagen Economics, 2012). The different items, i.e. costs, in the chosen structure was then analysed individually to identify whether it would change with the implementation of slow steaming.

To give each case a broader perspective, representatives from the selected companies was during an interview asked about the opinion of the 2015 SECA regulation, what the perceived consequences are and what measures are, and will be, taken to comply with the new regulation. These interviews also served the purpose of giving the authors a better understanding of how different actors in the shipping industry operate and the reasoning behind the chosen business decisions.

2.3.4. Data analysis

The following approach has been used to analyse the data collected for this thesis. The 10 steps are selected by the authors as an attempt to successfully answer the research question of to what extent slow steaming can be used to compensate for the increased fuel costs associated with the 2015 SECA regulation. The 8 steps are as follow:

1. Calculate the theoretical fuel consumption for today's operation speed at sea, for each of the two selected cases.
2. Calculate the fuel cost in 2015 year prices, when using HFO, i.e. create a base line scenario.
3. Calculate the theoretical fuel consumptions for each of the two cases at reduced speed.
4. Calculate the fuel cost at reduced speed in 2015 year MGO prices.
5. Calculate the change in fuel cost between the base line case, and the theoretical scenarios with decreased speed and MGO.

In order to get a better understanding whether it is practically possible to implement slow steaming, the following step 6-8will look at the lead time consequence of slow steaming,

6. Calculate the time for the route sailed by the ships in the studied cases at today's operation speed.
7. Calculate the time for the same route, but at the decreased speed.
8. Calculate the change in lead time

2.4 Assumptions

Obviously supply and demand are two important factors to consider when doing economical calculations of this kind and an introduction of slow steaming is perhaps likely to interfere and upset the supply and demand balance existing today. However it has not been possible during the writing of this thesis to establish with great confident to what extent slow steaming will affect the demand for container shipping services. For that reason, as well as for the purpose of reducing the uncertainty in the calculated end results, it will be assumed for this thesis that the demand for container shipping services will be constant independent of whether slow steaming is implemented or not.

The cost structures for smaller container vessels, i.e. <3000 TEU's, found during the literature review assume that the ship operator and the ship owner is the same. In contrast to this, the quest for suitable operators for the case studies revealed that the majority of Swedish operators, e.g. Unifeeder, charter its vessels, almost exclusively from German owners, e.g. Jüngerhans (Unifeeder, 2013; Jüngerhans, 2013).

When estimating the fuel consumption for different fuels, it is important to consider the energy content of the fuel. It has previously been mentioned (in Chapter 1.2) that LNG differs substantially in energy content compared to HFO. But more important for this thesis is the energy content of MGO, which is very similar to HFO (Table 13, Appendix). To simplify the presentation of data, it has been assumed that the energy content of HFO and MGO are equal. Since the energy content of MGO is slightly higher than HFO, the effect of this assumption is that the proposed speed reduction is *slightly* lower than necessary.

Initially it was assumed that the costs for the owner will correspond with the charter rates paid by the charterer and thus still be able to serve as a reference for the calculations in this thesis. However, a review regarding charter rates for container vessels reveals that charter rates in the post-2008 financial crisis era is at a 20 year low, with 2009 and 2012 as its worst years (Alphaliner, 2013). This means that many non-operating ship owners are currently struggling to remain profitable, and even just to survive, as charter rates many times barely cover the operating expenses (*ibid*).

There are too many different and independent factors influencing a ship's fuel consumption that it is virtually impossible to theoretically calculate the exact consumption. However most of these factors are present and relevant regardless of the ships cruising speed and therefor are assumed to be constant and not relevant for the calculations used in this thesis.

2.6 Research quality

2.6.1 Reliability

Research reliability refers to the findings of the research. If the research is repeated, either by the same researcher or by others, and the same results are obtained the research can be said to be reliable (Collis, 2009). For this thesis data and information was gathered through literature reviews, online resources and interviews with representatives and researchers from the shipping community.

Literature review

The foundation for the literature review has been reports conducted by consulting companies and/or scientific researchers. In order to work in systematic way when retrieving the sources, specific key words (e.g. slow steam, SECA, fuel consumption) was used when searching in different databases (e.g. Business Source, Science Direct). All relevant data found was saved and categorized under each respective key word, to avoid the risk of excluding important information when writing each section of this thesis. Concerning the reliability of the findings from the literature review it would be quite uncomplicated to reproduce the results by using the reference list given in this thesis. All of the literature review are public and should be attainable for anyone interested in repeating this research, although for some literature a purchase might be required depending on the access rights to different databases granted to the researchers.

Perhaps there is a risk that the data and information found from the literature review can be interpreted differently by other researchers. However the authors have actively tried to reduce the risk of different interpretations by refereeing to original sources whenever possible. When interpretations have been done efforts have been made by the authors to explain and motivate each interpretation. Due to the authors limited knowledge in the subject it might be possible that previous research in the topic, using other synonyms, have been ignored.

Online resources

Online resources have been used to gather more specific information and data, e.g. ship data and fuel prices, as well as general information from organizations connected to the shipping industry and relevant news articles. These sources can become subjected to change on the discretion of each respective publisher, and there is no guarantee that the information will be available at a later time. This would have a negative effect on the reliability of this thesis as data used here might become unavailable fir other researchers. It should however be mentioned that the information used from these kind of sources have mainly served as background information and should not be regarded as critical for the results of this thesis.

As for the data on current and historical marine fuel prices, this data is updated frequently and will for obvious reason be subject to change as fuel prices fluctuates. This will result in a likely discrepancy between the “current” fuel prices presented in this thesis with the current fuel prices at the time when this research is repeated. This would also imply a reduced reliability; however fuel price statistics can be used if a future researcher would like to repeat the research carried out in this thesis using exactly the same data. The same goes for the recordings of actual operation speed (MarineTraffic, 2013), to attain an estimated mean operation speed. Since the standard deviation has been around 0.7 knots for the two cases, it is possible that new recordings would give a slightly different mean operation speed.

Interviews

The interviews were done in a semi-structured way (cf. Collis, 2009) were some questions were prepared but also questions raised during the interview was elaborated on to get as good an understanding of the topic as possible. The interviews were not recorded; however thorough notes were taken. Both authors were present during the live interviews.

On a couple of occasion’s semi structured telephone interviews were conducted for practical reasons. Telephone interviews were mainly used during the early phase when data and information was gathered to understand the shipping industry and the 2015 SECA regulation. No recordings were made during the telephone interviews, but thorough notes were written down during the interview. The telephone interviews were conducted by either one of the authors without the company of the other.

As neither the live interviews nor the telephone interviews were recorded it is impossible to exactly reproduce the outcome. This has a negative effect on the reliability of the parts of the thesis where data and information from these interviews was used. Also the opinions of the interviewees might change as time evolves and may result in different answers if the same persons were to be interviewed in the future.

2.6.2 Validity

Validity refers to the extent to which the research findings accurately represents a true picture of the situation being studied (Collis, 2009).

Literature review

Efforts have been made during the literature review phase to find reliable and valid sources for information. Original sources have been traced back whenever possible to avoid inference due to interpretations by other researchers as well as to avoid researcher bias. Scholar databases, available via the university (GU) library, have mainly been used and peer review comments have actively been looked for.

Reports conducted by the shipping industry, or organizations with an interest in the shipping industry, have been used as well, to get insight in how the SECA regulation is regarded from the shipping industry perspective. Most of the reports have been commissioned by the EU, by organisations within the shipping industry, or by organisation with an interest in the shipping industry, e.g. universities and research institutes. It can always be argued that these reports are biased to serve a specific purpose, i.e. lobbying or promotion, hence it is necessary to evaluate the each report, and the information given, separately. The authors' general opinion regarding the reports used as references is that they are to be considered as viable for the purpose in which they serve. No relevant criticism has been found, no reports or studies presenting a different conclusion have been found and all the reports have reached similar conclusions or results.

Some of the industry reports used as sources for this thesis lack a reference list and the raw data used for the drawn conclusion is not presented or accessible i.e. MAN (2012). As a single source the report MAN (2012) does not fulfil the requirements of what can be expected to be used in scientific research. However as a complement to other sources it is regarded by the authors as source that serves its purpose, i.e. to give the reader an understanding of how widespread the use of slow steaming is today.

When discussing the SECA regulations, the official EU Directives have always been used as the source to ensure reliability and avoid the risk of interpretations. For the SECA regulations discussed in the thesis there are both EU Directives and IMO regulations. Both sources have been used and cross referenced to reduce the risk of presenting inaccurate or biased information that can otherwise come from interpretations and descriptions made by secondary sources.

Online resources

As previously mentioned many of the ship owners and operators disclaim any responsibility from errors presented in the ship specifications found on the internet. This can be regarded as a cause for uncertainty. However the data used, mainly engine specifications and ship load capacity, have been crosschecked using other, often independent, sources.

Both current (2013), and historical data and information, have been used when witting this thesis, but as time progress new data and information will be made available. A large part of this thesis is to attempt to predict the future fuel cost situation for the shipping industry within the European SECA, and these predictions can be subject to change over time. Changes on for example fuel price, or in regulation, can lead to that assumptions made in this thesis will run the risk of becoming invalid.

Interviews

The interviewees was selected either by referral from people involved in the shipping industry or for being representatives for the chosen company used for the case study presented in this thesis. A small background control was carried out to get an idea of the knowledge and experience of each interviewee. The authors found no reason for any of the interviewees to become a subject of dismissal due to lack of knowledge or experience.

The information gathered during the interviews was cross referenced with the sources retrieved during the literature review whenever possible, to reduce the risk of misunderstandings. Follow up questions and clarifications were done via e-mail.

3. Theoretical framework

The theoretical framework is divided into three sections, which will be used as framework in the case study and in the analysis of slow steaming. The first section (3.1 SECA) will give a deeper understanding about the effects of the SECA regulation, and discuss how it is challenging to the shipping industry. It includes a review of previous research in how ship operators will be affected by the regulation, as well as a presentation of current price levels, and future price estimates, for marine fuels. The second section (3.2 Slow steaming) presents the concept of slow steaming, together with a review of when it is used today and how decreased speed could affect the ship operator. The last section (3.3 Calculations) introduces the model used in the case study to calculate the theoretical fuel consumption and fuel cost at different speeds.

3.1 SECA –effects on the shipping industry

The main effect of the 2015 SECA regulation for ship operators is the requirement to only use low sulphur fuel within the area, i.e. fuel with a maximum sulphur content of 0.1 %. This essentially means that the use of HFO will no longer be possible, without the installations of expensive scrubber equipment. Without a scrubbing system, the operator has to switch to an alternative fuel. As discussed earlier, the most common alternatives today are MGO, methanol or LNG.

The result for the ship operators when forced to switch to an alternative fuel, is either increased fuel costs, and/or the need for large machinery investments. Either way it would result in increased operating costs, which could affect the competitiveness of shipping compared to other modes. This can by extension lead to a modal shift, which will be further discussed in this chapter.

3.1.1 Fuel prices

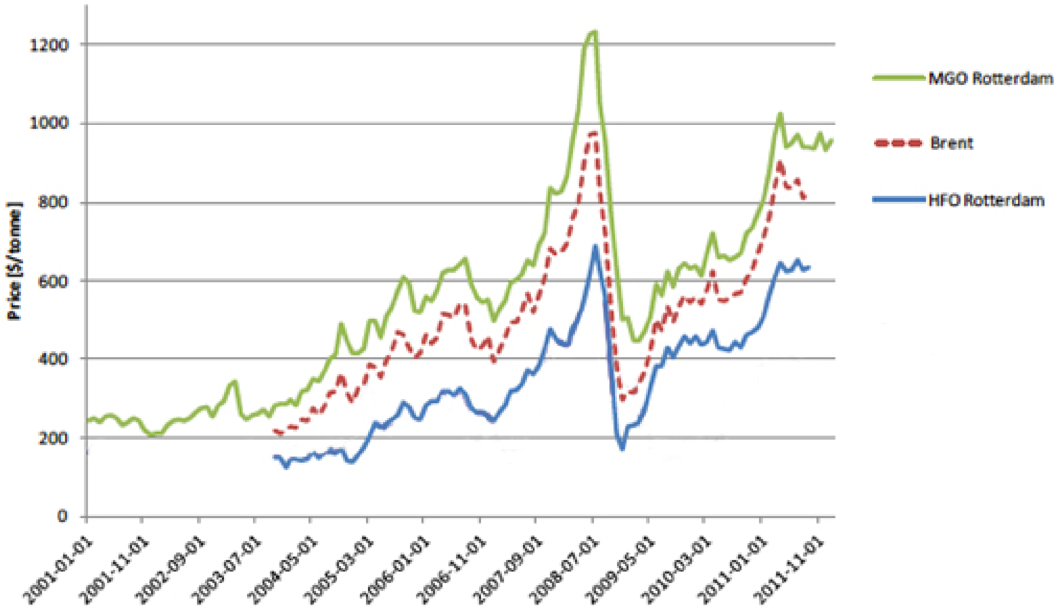
In order to calculate the economic affects the 2015 SECA regulation, fuel price estimations and predictions have to be made. This chapter will describe the historical price development for MGO and HFO as well as present an overview of what the shipping and fuel industry are predicting for the future.

To what exact level fuel price will be at in 2015 and beyond is very difficult, if not impossible, to predict and is associated with a lot of uncertainty. The large fluctuations seen in the past also contribute to the difficulties as e.g. unforeseen socio-political factors can have a huge influence on the fuel market price. Despite these uncertainties it can still serve a purpose to use these predictions as it helps explain and illustrate the economic effects for the ship operator, even though exact figures cannot be presented due to the above mentioned uncertainties. Future predictions change constantly, and more recent predictions are considered more accurate, making the source date crucial.

The following section presents a closer look on what the price scenario is estimated to be when the regulation enters into force, as well as a couple of years forward. To give a short historical picture of the price spread, the development of high and low sulphur fuels is also presented. Even though predictions should be read with caution, it is likely to assume that the spread between high and low sulphur fuel will increase in the future, due to a likely increased demand for MGO and decreased demand for HFO (SWECO, 2012).

The prices for both high and low sulphur fuels have fluctuated heavily during the last decade, as shown in Figure 4 below. The developments for both fuels have however followed the Brent oil trend, with a spread between HFO and MGO fluctuating between \$200 and \$400. Today's prices (April 2013) have decreased some from the graph below, 1% HFO cost about \$585/ton and 0.1% MGO about \$830/ton (see **Table 15**, Appendix).

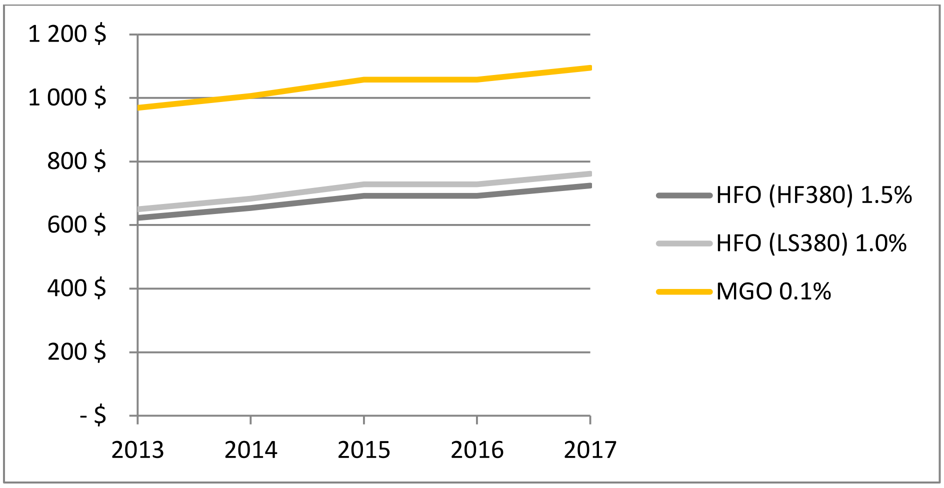
Figure 4: Historical prices in \$/ton of HFO (LS380), MGO, LNG and Brent Oil (2001 - 2011)



Source: Danish Maritime Authority, 2012 (LNG line removed from original graph)

Based on the past development, it is likely that future prices will continue to fluctuate, making exact predictions difficult. The predicted prices found in reports used for other purposes in this thesis (e.g. Delhaye *et al*. 2010; ISL, 2010) were rejected based on their dates. Figure 5 below shows a predicted trend based on the Swedish shipping company Stena Line's own predictions from November 2012. Both the price for HFO and MGO are predicted to increase, MGO slightly more than HFO, thus increasing the absolute spread. In 2015, the prices are predicted to be \$728/ton for 1% HFO and \$1058/ton for MGO, a spread of \$330/ton, or 45%.

Figure 5: Predicted price development for high and low sulphur fuel 2010 to 2025



Source: Table 16 in Appendix, Stena Line, November 2012

A spread in this size has also been predicted by other sources, dated more recently than previously mentioned reports. The Swedish technology consultancy company SWECO (2012) predicts that the difference between high and low sulphur fuel in 2015 will be about $350/ton, and the Swedish melting company Boliden's Head of Logistics points to spread of around $300 per ton (Svensson, 2013).

It should also be noted that, in a report prepared for the EU's Environment Directorate-General, the consultancy company Purvin & Gretz (2009) have reserved their predictions to up to a 60-70% spread. The report is a couple of years old, but the argument is still valid. Their high reservation depends on how the MGO will be produced by the refineries, which in turn is dependent on supply and demand of MGO. If demand for is high, refineries will have an incentive to invest in their distillation equipment, making MGO cheaper to produce, but if the demand does not reach a level where it is profitable to invest, prices for MGO will increase (Purvin & Gertz, 2009)

3.1.2 Modal shift

There has been several analysis and reports made with the goal to understand the effects of the 2015 SECA regulation on the shipping in Europe. The UK Parliament writes in a publication that addresses the effects on the SECA regulation that short sea shipping rates would increase with 20–30 %, and that there is a great risk that shippers will shift to land based transportation modes to avoid this increase.

The risk of modal shift, i.e. from sea transport to land based transport, is also addressed in the previously discussed German report by ISL (2010). In an attempt to estimate and quantify the consequences for the container shipping segment associated with the 2015 SECA regulation, ISL looked at both container and RoRo traffic, from the North Sea into the Baltic Sea. To calculate the costs, an estimation of future fuel prices was made, and an interval was used to present a best respectively worst case scenario, represented by the lowest and highest predicted fuel price. The sea transport cost was calculated for a round trip for each of the five reference routes and further broken down to cost per unit, i.e. truck, trailer or TEU. All other costs except fuel costs were kept as constants (ISL, 2010). The selected reference sea routes were chosen due to the close presence of relevant hinterland regions so that costs for the complete transport chain, i.e. from door to door, could be calculated (ILS, 2010). For comparative reasons the costs for an alternative all land based transportation was also calculated.

As the ISL report looked in detail at the goods flows that are at risk of a modal shift, some interesting findings could emerge. The calculations made by ISL (2010) suggest that in 2015, the risk of a modal shift will have to be applied to 2.7 million trailers just for the RoRo corridors connected to Germany, e.g. via Russia, Baltic and Nordic states. Of these trailers, approximately 600 000 trailers are expected to shift to either land routes, or to routes with shorter sea transport legs. In the container shipping segment, it was calculated that up to 823 000 TEU's are expected to shift from sea to land routes, due to increased fuel costs. Looking at the costs, ISL (2010) estimates a cost increase of €40 to €380 per trailer, and €30 to €63 per TEU, just based on the extra fuel cost related to the 2015 SECA regulation.

Another study, also discussed earlier, was assigned by the Finnish Ministry of Transport and Communication, hereby referred to as FMTC. The study looks at how the freight charges, i.e. the cost for using a shipping service, will be affected by the new sulphur limit of 0.1%. The reason for looking at how the freight charges will be affected is described to be based on information from Finnish shipping companies, and the Confederation of Finnish Industries, suggesting that the increased fuel prices will, in time, be incorporated in the sea freight costs.

Similar to the German ISL study, the FMTC study estimates the future fuel price as an interval and presents two different scenarios. Further, the calculations are based on two fuel consumption estimations, a maximum and a minimum, for ships bound for Finland, the maximum being 2.6 million tonnes of fuel, and the minimum being 1.8 million tonnes of fuel (Finnish Ministry of Transport and Communication, 2009). The fuel costs for the two scenarios are set to €111/ton and €480/ton respectively, and the result is a cost increase for sea based Finnish foreign trade of between €190 million and €1.18 billion. It should be noted that these calculations do not take into account the possible fuel savings through the use of sulphur scrubbers (*ibid*). The result on sea freight charges is according to this study quite severe, indicating a 44–51% freight charge increase for container shipping compared to 2009 cost levels (*ibid*), see Table 2 below.

Table 2: Effect of the estimated fuel price increase on freight charges

	Sulphur content		
Freight Type	**1.0 %**	**0.5 %**	**0.1 %**
Container	4-13 %	8-18 %	44-51 %
Paper reel	3-10 %	6-14 %	35-40 %
Lorry	3-10 %	6-14 %	35-41 %
Private car	3-10 %	6-14 %	35-41 %
Oil	3-8 %	5-11 %	28-32 %
Freight on bulk	4-11 %	7-15 %	39-44 %
Timber	3-10 %	6-14 %	35-40 %
Steel products	3-10 %	6-14 %	35-40 %

Source: Finnish Ministry of Transport and Communication, 2009

A report requested by the Swedish government and created by the Swedish Maritime Administration (2009) also sets out to assess the consequences of the 2015 SECA regulation, with a focus on the risk of modal shift. The report starts out by concluding that the availability of low-sulphur fuel will be sufficient after 2015, a perhaps not irrelevant factor to consider for continued exploration. The conclusion regarding future low-sulphur fuel availability is shared by the FMTC study, the Swedish Petroleum industry as well as by US- and Canadian analysis made for the North American SECA (*Ibid*). The report looks at the consequences for both the Swedish shipping industry as well, as for the shipping industry as a whole, and uses three scenarios to estimate future fuel costs. Each Scenario is based on a predicted crude oil price level, which is seen as representative for marine fuel cost levels, and compared to a base scenario represented by the actual cost level of $60/barrel in November 2008.

Scenario one is based on a crude oil price of 100$ per barrel, which was a forecast by the International Energy Agency, that was at the time seen as a realistic estimation of the cost level for crude oil in 2015. The second scenario in this study is based on a 75 % increase, i.e. $175 per barrel, and the third scenario is based on a 150 % increase, i.e. $250 per barrel. The main conclusion stated in the report is that a modal shift most likely will occur for all three scenarios (ibid). In scenario one, the expected modal shift measured in tonne-km was 2 %. In scenario two, the expected modal shift measured in tonne-km was 7%. Finally, in scenario three, the expected modal shift is a 10% decline for shipping (ibid). When looking at estimations of fuel costs in 2015, the report indicates a cost increase of up to 70% for ships operating strictly within the European SECA (*ibid*), which is in the top of the previously discussed estimations. In absolute terms, the report estimates the total cost increase to be in the region of 13 billion SEK in 2015, based on all ships calling Swedish ports during 2008. As a comparison on a micro level, the socioeconomic benefits, e.g. reduced need for medical care and soil sanitation, of using low sulphur fuel would correspond to SEK 4 billion (*ibid*). When looking at the cost for the shippers, the estimation is a cost increase for shipping transports in the region of 20-28%. This result is described to be based on a cost structure where fuel costs comprise between 40-50% of the total expenses associated with operating a ship (*ibid*).

When combining the results and conclusions of the above described reports a couple of things stand out. Perhaps the most obvious is that all the reports concludes that the operating costs will be increased due to the 2015 SECA regulation, thus having a negative effect on transport by sea. When examining the figures it seems realistic to expect a cost increase for the ship operators of at least 40-50%.

3.2 Slow steaming

This chapter will present the current situation for slow steaming, with data of to what extent it is being utilized today. This is followed by a presentation of how ship operators could be affected by decreasing their operation speed.

3.2.1 How widespread is slow steaming today?

This section aims at giving the reader an understanding of how the concept of slow steaming is applied in the shipping industry today and the reasons for implementing it in the daily operation.

The shipping industry in general

Slow steaming started to become much more common during the 2008 financial crisis due to a reduced demand for shipping services (Rodrigue et al, 2012) and has continued to be a common practise as the market slowly recovers from the effects of the recent economic downturn (Rexius, 2013; Ullman, 2013).

In 2011 MAN Diesel & Turbo (2012) conducted a web survey where over 200 representatives of the global bulk and container shipping industry were asked to what extent slow steaming was used in the their operation. The aim was to investigate how each operator approached the concept of slow steaming; including the approach to measures used to maximize the return on slow steaming, and to evaluate the results of the taken measures. Of the over 200 representatives being asked, 149 replied that slow steaming had been implemented in their operations although only 6 % reported that they never steam at full engine load, i.e. always using slow steaming to some degree (Table 3). The majority, 78.5 %, reported using slow steaming in combination with full load steaming some, or all, of the time (MAN, 2012b).

Table 3: Combination of slow steaming, and full load steaming

Full load steaming	Percentages
All the time (only full load)	21.5
Some of the time	60.4
Hardly at all	12.1
Never (only slow steaming)	6.0

Source: MAN Diesel & Turbo (2012)

Further, the report shows that, of the 149 respondents that reported having implemented slow steaming in their operations, the vast majority in both the bulk and container shipping industry reports running on engine loads between 30 to 50 per cent (Table 4). That might indicate further potential when it comes to implementing slow steaming.

Table 4: Typical engine load for slow steaming vessels (percentages)

Segment	10-30 %	20-40 %	30-50 %
Container	17.8	25.8	56.4
Bulk/Tank/Others	5.9	11.9	82.2

Source: MAN Diesel & Turbo (2012)

A.P. Møller - Mærsk A/S, one of the largest shipping companies in the world, with over 1000 vessels in operation (Maersk, 2013a), writes in their 2012 Sustainability Report that slow steaming is the norm and that continuous work in technological research is conducted to further improve the benefits of slow steaming (Maersk, 2012).

Another study, conducted by the independent research and consultancy organization CE Delft (2012), also concludes that slow steaming is widely practised today due to changes in the market as a result of the 2008 financial crisis. This study was commissioned by the two non-governmental organizations Transport and Environment and Seas at Risk, involved in promoting sustainable transportation solutions, and the protection of marine environments. The report also states however, that it is likely that shipping companies will increase the operating speed when market circumstances changes, i.e. higher demand for shipping services. It should be noted that the above mentioned statement was based on a limited survey and may not be statistically significant in regards of expressing the opinion of the shipping industry (CE Delft, 2012).

The notion that shipping companies primarily use slow steaming as a tool to manage market fluctuations is further supported by discussions and interviews with representatives from the shipping industry (Ullman, 2013; Sjöberger P., 2013; Askola, 2013; Rexius, 2013).

Despite the seemingly wide spread use of slow steaming today there seems to be uncertainties whether slow steaming is used solely during economic down turns or if it is used as an overall strategy to save costs. The above mentioned reports and studies are all conducted during a time in which the shipping industry has been suffering from economic down turns (BIMCO, 2012).

The container segment

When looking more specific at container liner shipping slow steaming has become increasingly more common during the recent years (Alphaliner, 2013; Notteboom & Cariou, 2011; Wiesmann, 2010). Some of the main causes to the increase are described to be the following points (Wiesmann, 2010):

- An overall decrease in demand for container transport services due the downturn in the global economy due to the 2008 financial crisis.

- An over capacity in ship tonnage, i.e. more newly build ships, due to the increase in global demand for transport services prior to the financial crisis of 2008.
- Increasing fuel prices.
- Increasing operating costs, e.g. manning, lube oil and maintenance.

Another reason why slow steaming has become a preferred alternative today, is that gives the operator the possible to increase the speed, and thus the capacity (shorter route time equals more routes), when market conditions improve (Wiesmann, 2010). A reason why slow steaming is not utilized at all, seems to be the complexity of dealing with different external factors that influence the shipping service provided, e.g. ad hoc customer orders, port congestions, insufficient communication systems (cf. Askola, 2013; Rexius, 2013; Sjöberger P., 2013). These factors all influence the shipping operations, i.e. causing delays, and often forcing the shipping service provider to increase the cruise speed to make up for lost time in port to be able maintain the shipping service provided, i.e. keeping to the schedule.

To summarize, it certainly seems that slow steaming is actively used today, primarily as a response to the current market situation i.e. still recovering from the 2008 financial crisis. It has not been possible to determine exactly to what extent it is used today; however it seems to be, at least from a theoretical perspective, openings for further use of slow steaming. As indicated from the above mentioned reports only a minority of the operators have implemented slow steaming to 100 % and one of the main reasons for implementing slow steaming is to save costs, which is very much current with the 2015 SECA regulation. The main challenges in practise seems to be the external factors mentioned, e.g. port congestions, but if resolved there would be severely less obstacles to implement slow steaming to an even greater extent.

3.2.2 How will ship operators be affected by slow steaming?

Besides reducing fuel consumption, slow steaming comes with some drawbacks for the operator, and in order to evaluate slow steaming, these drawbacks need to be considered. These, although important, are not included in the case study, since the data needed to make accurate calculations are in most cases sensitive for the companies, and thus hard to attain.

Effect on supplied capacity and revenues

Reduced speed will naturally increase the lead time, which could affect the number of trips per year. If fewer trips are made, the total supplied capacity per year will decrease, which could have a negative effect on revenues. It will however not affect revenues if the demanded capacity could be redistributed among the remaining trips, provided that the ships are not already operated fully loaded every trip. If redistribution is not an option, more ships are needed to meet the demand, which means large investments.

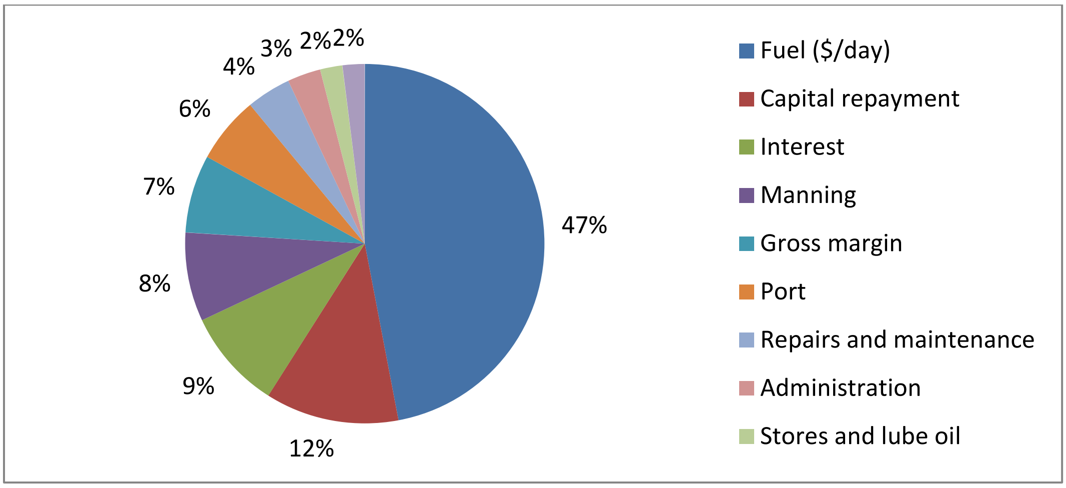
When interviewing actors from the industry (Pahlm, 2013; Rexius, 2013; Sjöberger, P., 2013; Ullman, 2013), it becomes evident that this is a major concern. But there is, and have been ever since the start of the economic turmoil in 2008, an overcapacity in the container segment (Alphaliner, 2013). According to the shipping-data provider Alphaliner (*ibid*), the operators' weak utilization levels will continue during 2013 due to a continued market growth below the overall capacity. For an individual company, it is however more interesting to look at the *individual* capacity in relation to the *individual* estimated demand when evaluating slow steaming, and not general market figures.

Effect on cost structure

Unfortunately, as stated by Martin Stopford (2009), there is not one internationally accepted classification of costs in the shipping industry, which can lead to confusion when discussion cost structure. The cost structure also differs between different types of ships (cf. Delhaye *et al.*, 2010; Copenhagen Economics, 2012), and between different companies, depending on where the ships are flagged, how they are financed, how old they are, etc. (*ibid*). Since this thesis will focus on containerships, a general cost structure for this segment was chosen from Delhaye's *et al.* (2010) report on short sea shopping to the European Commission.

Before choosing this particular cost structure, several sources were compared (e.g. Stopford, 2009; Delhaye, 2010; Copenhagen Economics, 2012; Sjöberger, P., 2013). It was found that the cost items included were almost identical, but the division of these items into different classes (e.g. voyage costs or operating costs) differed slightly between some sources. The classification is however not important, as long as the same overall cost items can be found in different sources. The relative sizes of each cost item, in relation to the total cost, were also found to be very similar between the sources (*ibid*). The similarities between the different sources lead to the possibility to choose one that best fitted this thesis, i.e. cost structure for smaller container vessels. The chosen cost structure below (Figure 6: Cost structure container ship (600-2000 TEU)) from Delhaye et al. (2010) is for a 600 TEU container vessel, but is very similar to Copenhagen Economics (2012) report on the competitiveness of Swedish shipping, prepared for the Swedish authority *Trafikanalys*. In the latter report, vessels of up to 25 000 DWT are said to fit this cost structure, roughly equivalent to up to 2 000 TEUs based on Maersk's feet (2013a).

Figure 6: Cost structure container ship (600-2000 TEU)



Source: Delhaye et al., 2010

As seen in the figure above, fuel makes up a large part of the total cost, which makes it understandable how devastating increased fuel prices would be. Slow steaming is intended to reduce the amount of fuel consumed, with the goal to leave the percentage share of total costs as untouched as possible, but it is unknown how other costs are affected by slow steaming. How will e.g. manning, financial costs and maintenance be affected? When discussing the effect on the engine with Maritime Engineer Henrik Pahlm, it was found that slow steaming could have a negative effect on the engine, which has also showed to be a concern in the industry (Sjöberger, C., 2013). If this is true, maintenance costs can increase, and possibly also the write off time, increasing capital repayment. Maersk (2012), with a large focus on slow steaming, have concluded through extensive studies that slow steaming was not harmful for the engines. The marine engine manufacturer MAN also concludes in a recent report that as long as the preventive maintenance is conducted in accordance with the recommendations, running on low sulphur fuel is does not harm the engine (MAN, 2010a)

In the cost structure above, it is assumed that the operator also owns the ship, this is however not the case in the case study. Both companies studied are chartering their boats on a time charter contract, but this is not believed to alter the cost structure, due to the charter price reflects the capital cost (Delhaye, 2010; Maersk, 2013c). According to Delhaye's study, the capital cost is approximately $3100 per day for a 600 TEU ship, and according to Maersk's report on the container market (2013c), the time charter price per day is approximately $4200. This will decrease fuel cost share of total costs from 47% to 44% (authors' calculations).

Tradition and contracts

Legislative issues concerning slow steaming have recently been debated due to a British lawsuit between a shipper and an operator from the bulk segment. The ship Pearl C was let for a time charter to the shipper Clipper Bulk Shipping, for a series of voyages during six to nine months. Clipper Bulk withheld the hire to the operator and owner Bulk Ship Union for breach of contract, on the grounds of not delivering the cargo with "utmost despatch", i.e. as fast as possible (Hendersson & Burdass, 2012). The master mariner had on orders of the owner reduced the speed under the 13 knots stipulated in the contract, which the shipper considered to be a reason to deduct the time lost due to the slow steaming (*ibid*).

The court found that the operator had committed breach of contract, and ruled in favour of the shipper. Even though this case was not in the container segment, it will still be relevant here since the speed now can be used as a benchmark for assessing whether a vessel have proceeded with utmost despatch or not (The Loadstar, 2013). It is however possible to disclaim all time-related liabilities through contracts, which most container operators in liner traffic do (*ibid*). To help operators to include slow steaming in their contracts, the shipping association BIMCO, who develop standard contracts, have developed special clauses for slow steaming (cf. BIMCO, 2013).

3.3 Calculations

This chapter will present a description of formulas used for the calculations in this thesis.

3.3.1 Fuel consumption

In order to be able to calculate how much of the increased fuel costs associated with the 2015 SECA regulation, it is necessary to determine the specific fuel consumption for a vessel at different operating modes, i.e. different vessel speeds. The most accurate method is naturally to measure the fuel consumption directly on board the vessel during different operating modes. Efforts have been made during the writing of this thesis to gather such data from ship owners and ship operators, although unfortunately proved to be unsuccessful. Instead data on fuel consumption was gathered from the engine documentation provided by the engine manufactures. Engine manufactures usually specify the fuel consumption for 100% and 85 % engine load, i.e. engine power, in accordance with ISO 3046/1-2002 (ISO, 2013).

A challenge with this kind of data is that it is quite limited, i.e. only specified for two engine power loads, and it has to be converted to correspond with vessel speed. Even if the fuel consumption is specified for additional engine loads, e.g. 75, 50 and 25 %, it is still missing for the engine loads in between. Further, it is necessary to relate the power outlet from the engine to a vessel's speed. To accomplish this, official vessel data provided by the owners was collected for the selected ship. The data collected was the specified top speed for the selected vessel and the engine model. When combing the fuel consumption data at 100 % power load provided by the engine manufacturer with the specified vessel design speed, the fuel consumption at the given top speed can be assessed.

Further, it is necessary to assess the fuel consumption for different vessel speeds. For this purpose the data provided by the engine manufactures is unfortunately insufficient and thus has to be approached in another way. A literature review and interviews with industry representatives have revealed that the most common approach to assess fuel consumption at different vessel speeds is to use the indirect relationship between speed and fuel consumption given by the cube law (Harilaos *et al.*, 2009; Kontovas *et al.*, 2011; Eide *et al.*, 2009; Sjöberger, 2013), it should be noted that no such direct relationship exists in reality (Pahlm, 2013), the actual relationship rather being between the engine load and the fuel consumption but the result is still close to the reality (ibid). The relationship given by the cube law (Formula 1) states that the fuel consumption is proportional to the cube of the vessel speed (Eide et al, 2009). This also means that the difference in fuel consumption is proportional to the cube of the difference in vessel speed, and from this relationship the fuel consumption at different vessel speeds can be calculated.

Formula 1

$$\frac{F.C._1}{F.C._0} = \left(\frac{V_1}{V_0}\right)^3 \rightarrow F.C._1 \ = F.C._0 * \left(\frac{V_1}{V_0}\right)^3$$

$F.C._0 = Fuel\ Consumption\ @\ design\ speed$

$F.C._1 = Fuel\ Consumption\ @ < design\ speed$

$V_0 = Design\ speed\ speed$

$V_1 = < Design\ speed$

Fuel consumption is usually presented in the unit g/kWh and sometimes in tonne/h. Vessel speed is usually presented in the unit knots. 1 knot represents 1.852 km/h.

To determine the amount of fuel consumed during a specific route at a specific vessel speed, used for the economical calculations, the route distance have to be determined. This was done by using the online ship tracking service provided by MarineTraffic (2013), and the online distance calculator provided by AXSMarine (2013). When the route distance is determined, the amount of fuel consumed for that specific route could be calculated by using Formula 2 below:

Formula 2

$$F = \left(F.C._0 \times \left(\frac{v_1}{v_0}\right)^3\right) \times \frac{d}{v_1}$$

$F = Fuel\ Consumed\ per\ trip\ (d)[tonne]$

$F.C._0 = Fuel\ Consumption\ @\ design\ speed\ [ton/h]$

$v_0 = design\ speed\ [knots]$

$v_1 = < design\ speed[knots]$

$d = route\ distance\ [nautical\ miles]$

3.3.2 The effects of slow steaming on fuel cost

Using the result calculated using Formula 2, the fuel cost for the specific route, at a specific speed, can be assessed by multiplying the amount of fuel consumed with the price of the fuel used (Formula 3). This will provide the fuel cost for a certain route, i.e. distance, for different types of fuel.

Formula 3

$$C_{HFO} = F \times P_{HFO}$$

$C_{HFO} = Cost\ running\ on\ HFO\ [USD]$

$F = Fuel\ Consumed\ [tonne]$

$P_{HFO} = Price\ for\ HFO[USD/TON]$

By utilizing this, a fuel cost can be calculated for a reference case, in this case it is the fuel cost when running on HFO at today's operation speed of the vessel. This cost is then used to calculate what the corresponding fuel consumption when running on MGO would be by using the formula:

$$C_{HFO} = C_{MGO} \quad \rightarrow \quad F_{HFO} \times P_{HFO} = F_{MGO} \times P_{MGO} \quad \rightarrow \quad F_{MGO} = \frac{F_{HFO} \times P_{HFO}}{P_{MGO}}$$

When the corresponding fuel consumption required for having the same fuel cost as when running on MGO, Formula 4, below, is then used to calculate at what vessel speed ($v_{1\ b.e}$) that fuel consumption would equate to. The result is the vessel speed required to fully compensate for the increased costs associated with price difference between HFO and MGO.

Formula 4

$$v_{1_{b.e.}} = \sqrt{\frac{F_{MGO} \times {v_0}^3}{d \times F.C._0}}$$

$V_{1_{b.e.}} = Break\ even\ vessel\ speed\ [knots]$

However, the estimated relationship between a ship's speed and the corresponding fuel consumption given by the cube law is only valid to approximately 50% engine load (Seas at risk, 2010). Below 50% engine load, the fuel consumption will start to increase, thus rendering in higher fuel costs. To control whether the break-even vessel speed is practically valid the vessel speed at 50% engine load is calculated using the Formula 5, derived from the above mentioned relationship given by the cube law (Formula 1).

Formula 5

$$\%_{engine\ load} = \left(\frac{v_1}{v_0}\right)^3 \rightarrow \boldsymbol{v}_{1_{50\%\ engine\ load}} = \sqrt[3]{50\%_{\boldsymbol{engine\ load}} \times \boldsymbol{v_0}^{\boldsymbol{3}}}$$

The calculated vessel speed at 50% engine load is the estimated vessel speed leading to the lowest fuel consumption practically achievable. This value is then compared with the calculated break-even vessel speed. If the break-even speed is lower than the speed at 50% engine load, it is not theoretically achievable to fully compensate for the increased costs, and the 50% engine load speed is used instead.

The fuel cost, based on 2015 estimates, for either the break-even speed or the 50% engine load speed, is then compared to the reference fuel cost, i.e. current vessel speed using HFO. After this final calculation it is possible to determine to what extent slow steaming can be used to compensate for the increased fuel costs associated with running on MGO instead of HFO.

3.3.3 The effect of slow steaming on lead time

To analyse how slow steaming will affect the schedule, the time at sea between each port is calculated. It is possible to include the start-up and slow-down distance in the calculations, by either applying a standard scenario (e.g. 30 minutes from 0 knots to operation speed, and vice versa), or by live data recordings. After calculations with a standard scenario, the conclusion was that the time increase in per cent was unchanged. It was thus regarded by the authors that adding a standard scenario would only complicate the case without adding any value. To apply real data would not be fair, since there are too many factors that affect the situation, mainly for the slow-down distance, where timing and slot times could be a reason for either a very long or short slow down.

The time has therefore been calculated through dividing the distance [nm] with the speed [knots, or nm/h]. The weakness of this method is that it is assumed that the ship reaches the operation speed right away, and goes from the operation speed at sea to standing still in a second. This is however still believed by the authors to be the best suitable way of illustrating the difference in time between two operation speeds.

4. Case study

The case study consists of two sections. The first section visualizes how much the operators theoretically need to reduce the speed to compensate for the increased fuel cost, derived from the use of low sulphur fuel (MGO). The second section gives presents how a lower speed would affect their routes in terms on increased lead time.

4.1 Slow steaming's effect on fuel cost

To give a more diversified picture of the speed reduction necessary to compensate for more expensive fuel, the fuel consumption curve is illustrated for two different ships. The two ships are all smaller containerships (962 - 1036 TEUs), operated by different shipping companies, and with operations solely within the emission controlled area. In each of the cases, a break-even point will be presented, at which the fuel cost of MGO will be the same as it would have been without the SECA regulation, i.e. still using HFO and sailing at today's operational speed. The fuel cost is expressed per route, which in both cases is a two-week route with several port calls. The operation speed at sea for each ship today has been detected through several recordings of the actual speed on the online GPS vessel tracking site MarineTraffic (Table 18 & 19, Appendix). The speed is, as previously throughout the thesis, always expressed in knots (kn). No recordings have been registered for when the ship has been in port, slowing down for port entry, increasing speed after leaving a port, or sailing in waters with speed restrictions (e.g. the Kiel Canal). All the ship data needed to make the calculations are found in the Appendix, in Table 16 and 17.

4.1.1 Andromeda J – fuel cost

Andromeda J, with a capacity of 962 TEUs, is owned by the German shipping company Jüngerhans, and sails under the German flag (Grosstonnage, 2013a). At the time being (April, 2013), it is operated by the Danish shipping company Unifeeder on a time charter contract, sailing between Sweden, Germany and Great Brittan (Unifeeder, 2013b; Rexius, 2013). Unifeeder has a regional office in Gothenburg, Sweden, from where the company controls its Swedish and Baltic operations (Rexius, 2013). The company operates in both the feeder and short sea shipping segment, where the feeder traffic provides cargo to larger transatlantic shipping lines (e.g. Hanjin, NYK Line, etc.), and the short sea shipping services are focused at larger end customers with the need for door-door services within Europe. In total, Unifeeder operates around 40 ships, with approximately 140 port calls every week (*ibis*).

Table 5: Two-week sailing route for Andromeda J below shows the current schedule of Andromeda J, which begins in Gothenburg on Tuesday week 1, and ends in Gothenburg on Tuesday, week 2. The blank spots in the schedule indicate that the ship is at sea.

Table 5: Two-week sailing route for Andromeda J

	Port	Distance [nm]
Tuesday	Gothenburg	-
Wednesday	-	-
Thursday	Bremerhaven	353
Friday	Hamburg	93
Saturday	Hamburg	-
Sunday	Immingham	379
Monday	Felixstowe	202
Tuesday	Teesports	262
Wednesday	Grangemouth	140
Thursday	Grangemouth	-
Friday	-	-
Saturday	Bremerhaven	452
Sunday	Hamburg	93
Monday	-	-
Tuesday	Gothenburg	395
Sum		2,369

Source: Unifeeder, 2013b; AXSMarine, 2013

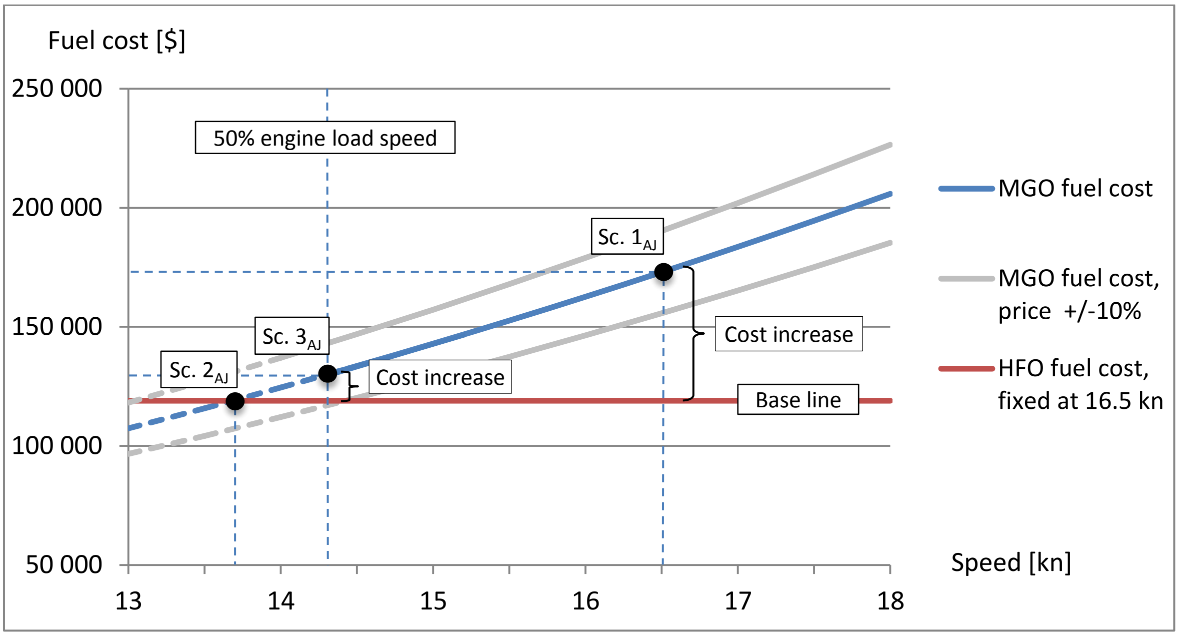
The target speed for all Unifeeder's ships is 17 knots, according to Unifeeder's Country Manager in Sweden, Lars Rexius (2013), and its design speed is 18 knots (Table 16, Appendix). This speed has been calculated to be the slowest possible speed, at which the time schedule can be maintained (*ibid*). The recordings of the live ship speed has however proven to be slightly lower (Table 18, Appendix), moving around a mean of 16.5 knots, with a standard deviation of 0.79. The standard deviation indicates some fluctuations in their operation speed at sea. The reason for these differences can be several, and will be discussed in the Analysis in chapter 5.

Figure 7: Image of Andromeda J

Source: Shipspotting, 2013a

The graph below, Figure 8, illustrate an estimation of the total fuel consumption for Andromeda, when sailing the full two-week route. The blue middle line shows the fuel cost based on the predicted 2015 prices for MGO, and the red base line is fixed at the estimated fuel cost based on predicted 2015 prices for HFO, when sailing in 16.5 knots on HFO, i.e. representing the current situation. The two grey lines illustrate how the cost curve would shift if the estimated MGO price in 2015 would increase or decrease with 10%.

Figure 8: Fuel cost curve Andromeda J (full two-week route)



Based on 2015 fuel price estimate, Figure 5 in Chapter 3.1.

To illustrate how slow steaming would impact the fuel cost for Andromeda J, three scenarios have been made. The first scenario (Sc.1_{AJ}) is that Unifeeder continue to operate Andromeda J in 16.5 knots, but using MGO instead of HFO as fuel, to comply with the regulations. The estimated cost increase, derived from the estimated MGO price in 2015 (Figure 5, Chapter 3.1), is illustrated by the gap between Sc.1_{AJ} and the base line. With a reduction of vessel speed, the fuel cost will decrease along the fuel cost line until it reaches the base line, i.e. break-even fuel cost, in scenario 2 (Sc.2_{AJ}). At that point the fuel consumption has decreased to an extent that it fully compensates for the increased fuel price that comes with running on MGO.

But as discussed in Chapter 3.3, there is a point when further speed reductions actually result in increased fuel consumption and further reductions after this point are futile. This inflection point is calculated using Formula 4, and for Andromeda J that equals to 14.3 knots, which is represented by scenario 3 (Sc.3_{AJ}) and the dotted “50% engine load speed “ Line in Figure 8 above. Below this point in the graph, the dotted lines to the left of Sc.3_{AJ} illustrates that coordinates along the lines after Sc.3_{AJ} just exist in theory. This means that the break-even speed, to fully compensate for the increased fuel cost (Sc.2_{AJ}), is not viable in practise.

Since it is not viable to reduce speed below 14.3 knots, a switch to MGO will, under these circumstances and assumptions, inevitably result in a cost increase. This cost increase is illustrated by the gap between Sc.3_{AJ} and the base line. Table 6 below shows the base case based on the current situation and using 2015 HFO price estimates, and the three different scenarios discussed above. If there is no reduction of the operational speed (Scenario 1), the fuel cost will increase by approximately 45.3%, equivalent to the estimated price difference, or $53,954 for specified route. Scenario 2 is the theoretical break even scenario, which shows that a speed reduction to 13.7 knots could fully have compensate for the increased fuel price. But as mentioned, when reducing the vessel speed below 14.3 knots, the fuel consumption starts to increase, making this scenario strictly theoretical.

With a speed reduction to 14.3 knots, just before the fuel consumption starts to increase, the theoretical fuel cost would still be higher than the base line scenario, but only by 9%, or $10,658. This is a clear improvement from not reducing speed at all, whit a cost increase of $53,954 (45.3%). It is also noticeable to see that a 2.2 knot speed reduction from 16.5 to 14.3 (13.4%), results in a 25% decrease in fuel consumption.

Table 6: Fuel cost scenarios for Andromeda J (full two-week loop)

	Base Line (B.L)	**Scenario 1 (Sc.1_{AJ})**	***ΔSc.2/B.L***	**Scenario 2 (Sc.2_{AJ})**	**Scenario 3 (Sc.3_{AJ})**	***ΔSc.3/B.L***
Fuel	HFO (1 %)	MGO (0.1 %)	-	MGO (0.1 %)	MGO (0.1 %)	-
Speed [kn]	16.5	16.5	*0%*	13.7	14.3	*-13.4%* *(-2.2 kn)*
Fuel cons [ton]	163.5	163.5	*0%*	112.5	122.6	*-25.0%* *(-40.9 ton)*
Fuel price* [$/ton]	728	1,058	*45.3%* *($330)*	1,058	1,058	*45.3%* *($330)*
Fuel cost [$]	**119,025**	**172,979**	*45.3%* *($53,954)*	**119,025**	**129,683**	*9.0%* *($10,658)*

*Based on 2015 fuel price estimates, Figure 5, Chapter 3.1.1

As mentioned in Chapter 3.1.1, price estimates should always be taken with caution, and it is thus interesting to see how a change in price 2015 would affect the result. The two grey lines in Figure 8 shows how the cost curve would shift from a 10% increase or decrease in the 2015 price estimate and Table 7 below show how it would affect the required speed reduction and the potential fuel cost increase. If the price would decrease by 10%, the theoretical break-even speed would be 14.4 knots, which almost exactly is the lowest speed possible. If the price would increase by 10% however, the speed would theoretically need to be lowered to 13.1 knots, but since that is lower than the inflection point, a reduction to 14.3 knots is still the lowest speed possible. The cost increase at this speed would theoretically be 19.8% higher than the base line scenario. But with a further increase in fuel price, it would be even more reason to make some adjustments to the operation speed.

Table 7: MGO price's impact on speed, Andromeda J

	MGO fuel price -10%	Scenario 3 (Sc.3_{AJ})	MGO fuel price +10%
MGO est. price [$/ton]	952	1058	1164
Price change [$]	-106		106
Speed [kn]	14.4	14.3	14.3
Fuel consumption [ton]	125.0	122.6	122.6
Fuel cost [$/day]	119,025	129,683	142,651
Cost increase (base line case) [%, ($)]	0% (0)	9% (10,658)	19.8% (23,626)
Break-even fuel cons. [ton]	125.0	112.5	102.3
Break-even speed [kn]	14.4	13.7	13.1

4.1.3 Nordic Bremen – fuel cost

Nordic Bremen is operated by SCA Transforest, a subsidiary to the Swedish manufacturing company SCA, focused mainly on marine transportation (SCA, 2013a). SCA Transforest has a container division, Container Express (Contex), with two ships sailing the same route between the Baltic Sea and Rotterdam (SCA, 2013b; 2013c). These two ships stops in Russia and Sweden, before heading southwest to the Netherlands, on 14-days loop (*ibid*). Nordic Bremen is owned by the German shipping company Nordic Hamburg, and sails under the Cypriote flag (Grosstonnage, 2013c). Its capacity and speed is similar to Andromeda J, and both ships share the same engine model, made by Caterpillar's marine engine company MAK (Grosstonnage, 2013c; Containership Info, 2013). Nordic Bremen can carry 2036 TEU's, and have a design speed of 18.5 knots (Table 7, Appendix). The recorded operation speed has a mean of 16.0 knots, with a standard deviation of 0.74 (Table 19, Appendix).

Nordic Bremen's two-week route is a bit longer than Andromeda J's route (approximately 386 nautical miles), but has fewer stops; only four stops compared to Andromeda J with 8 stops. All ports except Rotterdam are located within the Baltic Sea, compared to Andromeda J, where all ports are located in the North Sea.

Table 8: Two-week sailing route for Nordic Bremen

	Port	Distance [nm]
Wednesday	Rotterdam	-
Thursday	-	-
Friday	-	-
Saturday	Stockholm	780
Sunday	-	-
Monday	St. Petersburg	372
Tuesday	St. Petersburg	-
Wednesday	Sundsvall	452
Thursday	Sundsvall	-
Friday	Umeå	123
Saturday	-	-
Sunday	-	-
Monday	-	-
Tuesday	Rotterdam	1028
Sum		**2,755**

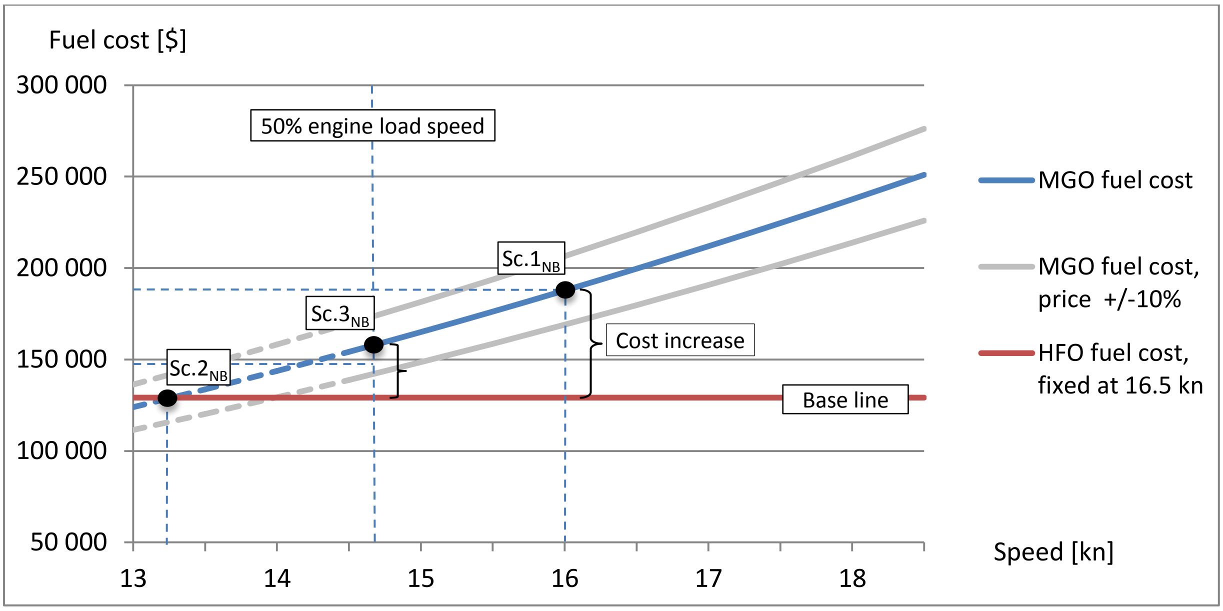
Source: SCA contex, 2013b; AXSMarine, 2013

Figure 9: Image of Nordic Bremen

Source: Shipspotting, 2013c.

The cost curve for Nordic Bremen is illustrated below (Figure 10), with the fuel cost for the full two-week route. As for the Andromeda J graph (Figure 8), the blue middle line shows the fuel cost based on the predicted 2015 prices for MGO and the red base line represent the current situation, fixed at a sea operational speed of 15.5 on HFO. The two grey lines illustrate how the cost curve would shift if the estimated MGO price in 2015 would increase or decrease with 10%.

Figure 10: Fuel cost curve Nordic Bremen (full two-week route)



The same three scenarios are used in this case. Scenario 1 suggests that SCA Contex continue to operate Nordic Bremen at the same speed as today (15.5 knots) with MGO, a cost increase illustrated by the gap between the point Sc.1_{NB} and the red base line. The break-even scenario, Sc.2_{NB}, is reached through the theoretical speed of 13.2 knots, which like in Andromeda J's case also is located below the minima, i.e. the 50% engine load speed and thus only exists in theory. In Nordic Bremen's case, the infliction point is located at 14.7 knots, which thus is the lowest possible speed. This point is Sc.3_{NB}, where the total cost increase has reduced from the distance between Sc.1_{NB} and the base line, to Sc.3_{NB} and the base line.

Table 9: **Fuel cost scenarios Nordic Bremen (full two-week route)** below shows the reference case based on the current situation and using 2015 HFO price estimates, and the three different scenarios discussed above. Without any peed reduction as in Scenario 1, the fuel cost increase will still increase by approximately 45.3%, in this case $58,577. Scenario 2 is only possible in theory, but would have left the fuel cost at the same level when decreasing the speed to 13.3 knots. When reducing the speed to the 50% engine load level, at 14.7 knots, the fuel cost increase would be 22.4%, or $28,932 under the assumptions and circumstances in this thesis and particular case. Even though it will not be possible to fully compensate for the increased fuel cost, at the 2015 estimated MGO price, the fuel cost increase will be reduced to almost half, by a speed decrease of 1.3 knots.

Table 9: Fuel cost scenarios Nordic Bremen (full two-week route)

	Base Line (B.L)	**Scenario 1 (Sc.1_{NB})**	*ΔSc.2/B.L*	**Scenario 2 (Sc.2_{NB})**	**Scenario 3 (Sc.3_{NB})**	*ΔSc.3/B.L*
Fuel	HFO (1 %)	MGO (0.1 %)	-	MGO (0.1 %)	MGO (0.1 %)	-
Speed [kn]	16	16	*0%*	13.3	14.7	*-8.2%* *(-1.3 kn)*
Fuel cons [ton]	177.4	177.4	*0%*	122.1	149.4	*-15.8%* *(-28.0 ton)*
Fuel price* [$/ton]	728	1,058	*45.3%* *($330)*	1,058	1,058	*45.3%* *($330)*
Fuel cost [$]	**129,179**	**187,736**	*45.3%* *($58,577)*	**129,179**	**158,112**	*22.4%* *($28,932)*

*Based on 2015 fuel price estimates, Fig 5, Chapter 3.1.1

Table 10 below shows the data for the grey lines in Figure 10, which illustrates how a 10% decrease or increase in the MGO price in 2015 would affect the outcome. A 10% decrease in price, from $1058 to $952 would reduce the cost increase to 10.2%. In Andromeda J's case, this scenario reached break-even, but since the break-even speed for Nordic Bremen in this scenario, 14.0 knots, is lower than the minima of 14.7 knots, it is not possible to fully compensate for the prince increase. If the price would be 10% higher, at $1164, the required operating speed would be 12.7 knots. Since this point is well below the minima, it is also not possible in reality. The end result from a MGO price increase of 10%, would be a cost increase of approximately 34.6% compared to the base line case.

Table 10: MGO price's impact on speed, Nordic Bremen

	MGO fuel price -10%	Scenario 3 MGO	MGO fuel price +10%
MGO est. price [$/ton]	952	1058	1164
Price change [$]	-106		106
Speed [kn]	14.7	14.7	14.7
Fuel consumption [ton]	135.7	149.4	149.4
Fuel cost [$/day]	129,179	158,112	173,923
Cost increase (Base Line case) [%, ($)]	10.2% (13,121)	22.4% (28,932)	34.6% (44,744)
Break-even fuel cons. [ton]	126.6	114.0	103.6
Break-even speed [kn]	14.0	13.3	12.7

4.2 Slow steaming's effect on time schedule

As explained in Chapter 3.3 about the calculations, the time at sea is calculated through the distance and the speed. These are not in any way any authentic times for the two ships, but the intention is to show the increase in lead time caused by the decrease in operation speed.

4.2.1 Andromeda J – schedule

By adding up the 9 different legs in the two-week route that Andromeda J sails today, the total time spent at sea is discovered, and when sailing at today's operation speed, the time at sea will be approximately 143.6 hours (Table 11). If the speed is reduced to 14.3 knots, i.e. the 50% engine load factor speed where the lowest fuel consumption is reached, the time would increase by approximately 22.2 hours, or 15.5%. An extra day might sound a lot, but when looking at each leg at a time, for example the leg between Hamburg and Immingham, a 3.6 hour time increase is not that much on a 23 hour trip.

Table 11: Time increase Andromeda J

	Distance [nm]	Time, 16.5 knots [h]	Time, 14.3 knots [h]	Increase [h]
Gothenburg - Bremerhaven	353	21.4	24.7	3.3
Bremerhaven - Hamburg	93	5.6	6.5	0.9
Hamburg – Immingham	379	23.0	26.5	3.6
Immingham – Felixstowe	202	12.2	14.1	1.9
Felixstowe – Teesport	262	15.9	18.3	2.5
Teesport – Grangemouth	140	8.5	9.8	1.3
Grangemouth – Bremerhaven	452	27.4	31.6	4.2
Bremerhaven - Hamburg	93	5.6	6.5	0.9
Hamburg - Gothenburg	395	23.9	27.6	3.7
Sum	**2,369**	**143.6**	**165.8**	**22.2 (15.5%)**

In Andromeda J's case, it was also studied how much time the ship spent in port at each of the stops. This time varied a lot, from just over 6 hours in Bremerhaven to 32 hours in Hamburg, with a mean of around 16 hours and a standard deviation of around 7.5 hour (Table 20, Appendix).

4.2.2 Nordic Bremen – schedule

The total time for the 5 legs of Nordic Bremen today is approximately 172.2 hours, when sailing at 16.0 knots (Table 12). Since the speed reduction is not as big for Nordic Bremen as for Andromeda J, the time increase will naturally be smaller, in this case approximately 15.4 hours, or 8.9%. To put this increase in perspective, the leg between Rotterdam to Stockholm will increase 4.4 hours on a two day trip (48.8 hours).

Table 12: Time increase Nordic Bremen

	Distance [nm]	Time, 16.0 knots [h]	Time, 14.7 knots [h]	Increase [h]
Rotterdam - Stockholm	780	48.8	53.1	4.4
Stockholm - St. Petersburg	372	23.3	25.3	2.1
St. Petersburg - Sundsvall	452	28.3	30.8	2.5
Sundsvall - Umeå	123	7.7	8.4	0.7
Umeå - Rotterdam	1028	64.3	70.0	5.8
Sum	**2,369**	**172.2**	**187.6**	**15.4 (8.9%)**

5. Analysis and discussion

To continue the case study, this chapter will further analyse the previous findings from the case study. It will be related to the theoretical discussions about the shipping industry from earlier, as well as focusing on building up an argument for the conclusion and answer to the research question. The validity of the result will also be discussed,

5.1 Implications of the 2015 SECA regulation

5.1.1 Risk of modal shift

The risk of modal shift, as a consequence of the cost increase in sea transportation associated with the 2015 SECA regulation, seems to be a realistic one. All of the reports and studies found on the subject, as well as information presented during the interviews, are all more or less congruent. In terms of numbers, the extent of trafficked goods being at risk to shift from shipping to road and/or rail can only be estimated at this point, but it should be safe to state the a noticeable modal shift will occur when the new sulphur regulation goes into place in 2015. Based on the lack of harmonisation in the European railway infrastructure it is likely to assume that of the goods affected by a modal shift, most will go onto road. It is not a part of this thesis to estimate how much goods will shift to other modes, but based on the results presented in the used reports, in combination with the fact the European trade is still recovering from the 2008 financial crisis, i.e. a temporary decrease in European trade likely to increase, One might expect an extra 500,000 - 1,000,000 trailers and TEU's on the European road network in the years shortly following 2015. This will obviously be a severe problem for many of the small, one vessel, shipping companies active within the European SECA, and it might be reasonable to think that many of these will go out of business if the demand for shipping services will decrease further.

Since an already increase in road transport is regarded as a problem within the EU, leading to increased greenhouse gas emissions as well as added congestions, it might be expected that efforts on finding effective counter measures for the risk of modal shifts would be a high priority, but no such indications have been found by the authors. It might be argued that a modal shift is regarded as an incentive needed to increase investments in the European rail transport network, another main EU objective. But when considering that short sea shipping is also being promoted by the EU, as a counter measure to reduce the problems associated with road transportation, the situation becomes rather complex and difficult to understand from a political perspective.

Of course it is easy to forget in the midst of all the discussed problems and challenges that the sulphur regulation is in fact a solution to a very real problem that is affecting the health and wellbeing of millions of humans. From that perspective it would perhaps best be described as negligence if no actions to reduce sulphur emissions were taken by policy makers.

5.1.2 Other stakeholders

It is not only the shipping industry that is affected by the new sulphur regulation, but rather all stakeholders connected to the industry. Shipping company owners, employees and suppliers will obviously all be affected by the increased operational and/or investment costs and by a possible reduction in demand for shipping services. However, in the end shippers, i.e. the buyers of sea transportation, are perhaps one of the stakeholders most affected, as the increased costs most likely will be transferred from the carriers to the customers, i.e. shippers. For high value goods, where the transportation cost only represents a small percentage of the retail or wholesale price, the affect is easily manageable. For low value goods, e.g. bulk commodities, where transportation constitutes a large part of the commodity price, the 2015 SECA will most likely have severe consequences.

Producers and manufactures of e.g. bulk commodities can be forced to move its facilities to locations not affected by the new sulphur regulation as an increase in transportation cost would seriously affect the possibilities of successfully competing on a global market. This will have an economic impact, both on a regional as well as on a national level for the affected states, of different magnitudes. This would perhaps be an indication to state and regional policy makers to address the issue for political and socioeconomic reasons. In fact, state aid activities addressed at reducing the economic consequences of the new sulphur regulation has been approved by the EU, enabling individual states to support its stakeholders using different approved schemes.

5.2 The container segment

It has become evident during the writing of this thesis that the short sea and feeder container segment is a very dynamic segment with quite a lot of ad hoc activities. In such an environment it obviously makes sense to be flexible to be able to adjust to e.g. last minute customer requests. This can be a hindrance to implementing permanent slow steaming as the possibility to adjust the speed to compensate for last minute delays is eliminated. However there is always a balance between being flexible and being inefficient or ineffective. One challenge for shipping companies to become more efficient in its operations is the fact that there is a dependency on other actors in the supply chain, e.g. port handling, port congestion, which more or less makes it a necessity to have some kind of buffer, e.g. extra time slots in the schedule or being able to adjust the operational speed. This is of course a kind of sub-optimization and would indicate that measures to further integrate the shipping supply chain, i.e. ship operators, ports and customers, should lead to increased efficiency and thus making it possible to utilize the concept of slow steaming in an even more profound way.

5.3 Slow steaming

Slow steaming is actually a very simple concept. The fact that reduced speed leads to reduced fuel consumption has been known for a long time and the practise is used by shipping companies to different extents. Especially after the 2008 financial crisis slow steaming often became common practise to save cost and reduce capacity to better fit the demand. During the case study it also became evident that the actual operational speed often was less than the design speed of the vessel.

Maersk Line, perhaps the biggest advocate for incorporating slow steaming as an integrated part of ship operation, have taken the concept on step further, more or less completely altered the ship and propulsion design of its new vessels to be optimized at lower speeds. This can perhaps be seen as an indication that there are still gains to be made in terms of saving money on fuel consumed.

5.4 Determining fuel consumption

The task of determine a vessel's fuel consumption have proved to be very challenging, to say the least. It is a very complex task to determine the fuel consumption at different vessel speeds, mainly due to a lot of different factors influencing the result. Some factors are common for every ship, e.g. sea currents and wind effects, and some factor varies from vessel to vessel, e.g. hull design, cargo load, engine type. Initially the aim of the thesis was to gather very exact data measured on-board the vessels, selected for the case study, but unfortunately no such data could be provided by the ship owners nor from the ship operators. The alternative method then was to use theoretical estimations to calculate the fuel consumption at different operating speeds.

The most commonly used method, found during the literature review phase and discussed in chapter 3.3**,** is to use the indirect relationship given by the cube law that states that a vessel's fuel consumption varies with the difference in speed by a power of three. None, except one, of the reports discuss the accuracy of this estimation is and a negative side is that it is difficult to determine just how much this estimation deviates from the actual fuel consumption. One report mentions that the result given by this estimation is within 3% of the lowest consumption (Sea-at-risk, 2010). As no actual data was available to compare the estimated results with, and since no other studies found discussed the issue, no definite conclusion regarding the accuracy of the estimation model could be made

The fact that only one study found discuss the issue can indicate that either it can be argued that the other reports have shown negligence, or that the estimation is so well documented, tested and accepted that the need to mention it no longer exist. Since no criticism against using the estimation model have been found during the literature review, and the fact that all of the interviewees from the industry confirm this method of estimating a ship's fuel consumption, the later alternative seem more likely to be correct.

Another concern raised regarding the application of the just discussed estimation model is whether the reference speed, referred to as *v0* in this thesis, can be any given speed or if it should be the maximum speed of the vessel. If it can be applied to any reference speed it would mean that at any given speed there would always be a quite dramatic decrease in fuel consumption. In fact that would imply that the fuel consumption derived from a speed reduction to a given speed would vary depending on the initial speed, e.g. the fuel consumption at 14 knots would vary depending on whether the initial speed was 20 or 17 knots. This seems highly unrealistic and for that reason only the defined maximum speed of the vessel has been used as reference speed for the calculations in this thesis.

Another concern raised was if the estimation model is valid during the entire speed range, i.e. from the maximum speed down to zero. During the interviews it was made evident that at some point, i.e. speed, or rather engine load, the fuel consumption will start to increase again. This means that at a certain infliction point, slowing down will be counterproductive from a fuel cost saving perspective. Since a vessel's speed depends on several different factors it made no sense in defining the infliction point in vessel speed. Engine load made a better definition as the fuel consumption calculations in this thesis are based on the given fuel consumption at 100% engine load provided by the engine manufacturer.

This was also addressed in one of the reports (Sea-at-risk, 2010), stating that the estimation model is applicable without major discrepancies between 50-100% engine load and that somewhere between 25-50% engine load, fuel consumption starts to increase. When examining the engine documentation, provided by the engine manufacturer, similar patterns can be noted.

The exact infliction point is obviously difficult to determine without actual fuel consumption data for the specific ship. By setting the breaking point to 50% engine load, in accordance with the Sea-at-Risk report (*ibid*) for the calculations in this thesis, the intention is to not overestimate the effect of slow steaming.

Combining all these factors discussed it is the authors believe and hope that the calculations made, in respect to fuel consumption, are as good as theoretically possible given the information at hand.

5.5 The empirical results

When examining the calculated results it becomes obvious that the speed, or rather the fuel consumption, required to fully compensate the increased fuel price is below the 50% engine load infliction point in both cases. A speed below this limit cannot with confidence be said to result in the fuel consumption as the formula suggests. That would imply that it is not possible to fully compensate for the increased fuel price for neither of the vessel under these particular assumptions, at least not based on the price predictions used for MGO and HFO in 2015.

Table 213 below shows a summary of the two cases, with the base line scenario, i.e. today's situation in 2015 HFO price, and Scenario 3, i.e. 50% engine load speed in 2015 MGO price. All figures are expressed at a distance equal to the total two-week route that the vessels sail today. Scenario 1 (not in Table 213) in the case study represents a situation where the speed was unchanged, and fuel switched to MGO, this resulted in a fuel cost increase of approximately 45.3%. The theoretical evidence shows that this cost increase is reduced for both cases in Scenario 3, but it differs quite a bit between how much it is possible to reduce the increase in the two cases.

Table 213: Case summary, full two-week route

		Andromeda J	**Nordic Bremen**
	Maximum speed [kn]	18	18.5
Base line	Operation speed [kn]	16.5	16
	Fuel consumption [ton]	163.5	177.4
	Fuel cost [$]	**119,025**	**129,179**
Scenario 3	Slow steaming speed [kn]	14.3	14.7
	Fuel consumption [ton]	122.6	149.4
	Fuel cost [$]	**129,683**	**158,112**
Change	Change in fuel consumption [%]	-25.0%	-15.8%
	Change in fuel cost [%]	**+9.0%**	**+22.4%**
Lead time	Lead time base line speed [h]	143.6	172.2
	Lead time, slow steam [h]	165.8	187.6
	Change in time for full route [%]	**+15.5%**	**+8.9%**

5.5.2 Fuel cost analysis

In Andromeda J's case, it is possible to reduce the speed to 14.4 knots, and theoretically reduce the fuel consumption by 25%, which results in a total fuel cost increase of 9%. In Nordic Bremen's case, a reduction to 14.7 knots would theoretically result in a fuel consumption decrease of 15.8%, increasing the total fuel cost by 22.4% compared to using HFO. How this would affect shipping operators, if the numbers turn out to be accurate, can only be speculated about. Both a 9% and 22.4% cost increase are unhesitatingly better than a 45.3% cost increase, but with a profit margin of 7% as the cost structure in Chapter 3.2 suggests, a prince increase for customers is inevitable if no other actions are taken.

The following question will then be how a 9% or 22.4% cost increase would affect the customer demand. It depends on the price elasticity of the customers, which in turn depends on the attractiveness of other transport solutions. If other alternatives becomes more attractive for customers, a modal shift is a very real risk. For manufacturing companies within the SECA, especially manufacturers of goods with low value to weight ratio on a global market, increased transportation costs can lead to a decreased competitive advantage compared to companies within the same industry from other regions. A cost increase of the magnitude seen in the case of Nordic Bremen could have severe consequences, and as discussed in the case of Boliden, it could lead to a relocation of Boliden's production facilities.

The price for MGO in 2015 is however a crucial factor to determine the possible outcome. It was illustrated that a 10 % decrease of the MGO price does theoretically result in a break-even situation, in one of the situations, where the ships could keep the fuel cost at base level, while using MGO. The break-even speed for a MGO price at 10% less than the estimate was 14.4 for Andromeda. The MFO price that would cause this would demand a price spread between MGO and HFO of just over $220, which is well below the estimated spread of $330. The spread used was based on Stena Lines predictions, and correlates well with several other sources, as discussed in Chapter 3.1. But a future prediction cannot be argued to be true based on several sources agreeing on it today, since there are a lot of things can happen that would affect the price and create a whole new scenario.

5.5.3 Lead time analysis

How the increase in lead time will affect the decision to slow down or not is very hard to discuss without knowing the exact details about the route. In the two cases, the total time at sea increased 15.5% for Andromeda J, and 8.9% for Nordic Bremen, due to a smaller speed decrease. Whether this speed reduction is viable or not mainly depends on how much idle time there is for the ships, i.e. time when the ship is not at sea, nor being loaded or unloaded. If there are no gaps at all, it is simply not possible to reduce the speed. But the results from the recordings of the actual time in port for Andromeda J during one two-week route, between just over 6 hours and 32 hours, indicates that it might be room for a speed reduction. Once again, it is not know why the time in different port differs as much as it does. There are by natural reasons more loading and unloading in some ports than others, there might be a queue system in others, or the ships might have to wait for tidal movements to sail in or out from a port. With full knowledge of the idle time, it would however be possible to determine if some, or all, legs could have been sailed slower.

There have been some indications when talking to industry representative (Askola, 2013) that timing and communication is more important than speed. If unnecessary waiting times could be reduced and substituted for longer time at sea, a permanent speed reduction could be possible. It has however become clear that a schedule is not a fixed piece of paper, but rather a living and constantly changing document. Simultaneously as recording the live arrival and departures for Andromeda J on MarineTraffic, the Master schedule was supervised, and it was noted that it changed both expected departure time and expected arrival times several times over several days. The arrival and departure day was the same as the schedule for almost all stops; it was mainly the time of the day that differed, often quite substantially.

A fear expressed from several actors (Chapter 3.2.2) is that it will be necessary to add an extra vessel if speed is reduced. The time increase in Andromeda's case is just over 22 hours, almost one extra day, i.e. 15 days instead of 14 days for the given route. Since all arrivals and departures are fixed to a specific day every week, it is not possible to have a rolling schedule. That means that the only real solution is that the time increase needs to be distributed over the whole route. This implies that for all stops, the time in port has to be reduced with a couple of hours. Unifeeder had made several calculations if it would be economically viable to add an extra vessel, but came to the conclusion that it would be more beneficial to keep the amount ships currently in use (Rexius, 2013).

When discussing the fill grade with Unifeeder, it was discovered that the vessels had a 90-95% fill grade. Since Unifeeder charter the ships used in its operation, the capacity can in fact be controlled much better and quite easily be adapted to the current market demand, compared to owning the fleet. This would imply that the fleet in operation can be well optimized to current market condition when chartering the ships instead of owning the ships. The actors who take the largest hit from an over capacity are the ship owners, who will face a difficult time to find operators to charter its ships.

5.6 Interpreting the results

It has become evident that a result based on one specific ship cannot be used to draw general conclusions for other ships, not even for ships with similar characteristics. Factors such as, e.g. specific engine and propeller optimisation, trimming of the ship through ballast water, play a significant role on vessels fuel consumption. These factors also vary from ship to ship and even on the skill of the crew. These factors have not been possible to attain for the selected ships, and has thus not been a part in this thesis.

As can be seen from the results and analysis made, it does not seem possible to state that a certain vessel speed will lead to a certain cost compensation, as the actual speed of a vessel, as previously mentioned though out this thesis, depends on several other factors besides engine work. But it seems to be quite plausible that for ships of the type used in the case study, a majority of the cost increase induced when switching to MGO can be compensated for by reducing the operational speed from 16-17 knots to 14-15 knots, i.e. a decrease of 10-15%.

So how can the information presented in this thesis be used? The main area of this thesis have been to provide an indication of to what extent slow steaming can be used to compensate for the increased costs associated with switching to from HFO to MGO. Secondly, even if the specific results are not applicable on ships with other characteristics then the ones selected in the case study, it is not difficult to use the framework to calculate a result for a different ship. If e.g. actual consumption data is accessible, the framework used in this thesis can also easily be altered to accommodate different kind of data, hopefully making it useful for different actors with access to different types of data.

6. Conclusion

The main research question, i.e. *"To what extent can slow steaming be used to compensate for the higher fuel cost from using low sulphur fuel (MGO), imposed by the 2015 SECA regulation?"*, have been found to be difficult to answer on a general level i.e. for an entire fleet, and can really only be determined vessel by vessel.

The empirical results from the two studied cases imply that it is possible, from a theoretical perspective, to compensate for approximately 50-80% of the increased cost, by reducing the operational speed from 16.0-16.5 knots to 14.3-14.7 knots. These calculations were based on two container vessels with a load capacity of around 1,000 TEU's, a main engine power of 8,000-9,000 kW and a design speed of 17-19 knots.

The model used to calculate the estimation of the fuel consumption is very commonly used and accepted, both in academia as well as by the shipping industry. It is based on the indirect relationship between fuel consumption and speed and is given by the cube law. However there are limitations to the model, and in order to not overestimate the effect of slow steaming, a lower limit was set at which further speed reductions results in a fuel consumption increase. This point was set at a speed that corresponds with an engine load of 50%, i.e. slow steaming is only assumed to be effective between speeds corresponding to 50-100% engine load.

The required speed, at which the decreased fuel consumption theoretically would compensate for the increased fuel cost, was in both cases found to be below the 50% engine load at 13.3-13.7 knots, thus not applicable in reality. That indicates that it will not be possible to fully compensate for the increased fuel cost, derived from switching from HFO to MGO, by using slow steaming in these two cases.

The spread between the price for HFO and MGO do have a great effect on what the cost increase for switching from HFO to MGO will be. When calculating the economic affects, recent market predictions have been used as estimations of the fuel price in 2015. The difference in price between HFO and MGO in 2015 is today (April 2013) estimated to be over $300/ton. As there are no ways to validate these assumptions, a scenario based on a 10% deviation from the predicted price for MGO was conducted to illustrate it would affect the results. It showed that a 10% MGO price decrease could result in a break-even speed above the minima for one of the cases, thus theoretically valid in reality. The speed in that particular case was a reduced from 16.5 knots to 14.4 knots, which fully compensates for the extra cost induced by using MGO instead of HFO.

The time increase, as a consequence of the stated speed reduction, was calculated and was found to be approximately 15 and 22 hours respectively, depending on the current operation speed. An analysis of the time spent in port for one of the vessels in the study reveals that there might be room for lowered operating speed and shorter time in port for some of the legs during the monitored two week route.

7. Further research

There are several more aspects of slow steaming that need to be researched. A number of factors have been mentioned in the thesis, e.g. other costs that are affected by slow steaming, changes in supplied capacity, and changes in demand. These three areas, i.e. costs, supply and demand, are considered to be to most important areas for further research. But there is also a need to validate the fuel consumption theoretically calculated in this thesis.

Slow steaming do have a positive effect on fuel consumption, but it could have a negative effect on other costs. Maintenance and repairs is an example of a cost item that there are different opinions about, some argue that slow steaming will not harm the engines, whilst other argue that it could harm the engines.

The speed reduction could affect how many port calls a ship can do on a fixed schedule, and thus decrease the supplied capacity. It is important to investigate how the reduced speed can be compensated for, by for example increased communication between ships and ports, or improved port routines.

If the speed reduction results in considerably increased lead times for customers, shippers tied up capital will increase, and it could reduce their supply chain flexibility through fewer trips. These factors could affect the shippers' costs and is thus likely to affect their demand for shipping services. Increased shipping costs will also affect the demand, and further studies on customers' requirements and price sensitivity are necessary.

8. References

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9. Appendix

Table 14: Typical energy content of selected fuels

Fuel type	Energy content
Light fuel oil (e.g. MGO)	11.9 kWh/kg
Heavy fuel oil	11.3 kWh/kg
Methanol	5.5 kWh/kg
LNG	13.0 kWh/kg

Source: GasNor, 2012

Table 15: 10 day price average for marine fuel (April 2013)

Sulphur content	HFO (HF380) 1,50%	HFO (LS380) 1,00%	MGO 0,10%
Date	**$/Ton**	**$/Ton**	**$/Ton**
2013-04-26	$ 582.0	$ 595.5	$ 848.0
2013-04-25	$ 575.0	$ 590.0	$ 840.0
2013-04-24	$ 573.5	$ 586.0	$ 835.0
2013-04-23	$ 565.0	$ 577.0	$ 821.0
2013-04-22	$ 568.0	$ 582.0	$ 823.0
2013-04-21	$ 575.0	$ 587.5	$ 824.5
2013-04-20	$ 569.0	$ 581.0	$ 818.0
2013-04-19	$ 574.0	$ 585.0	$ 819.0
2013-04-18	$ 568.0	$ 580.0	$ 828.0
2013-04-17	$ 577.5	$ 586.0	$ 840.0
2013-04-16	$ 582.0	$ 595.5	$ 848.0
2013-04-15	$ 575.0	$ 590.0	$ 840.0
10 days average	**$ 572.7**	**$ 585.0**	**$ 829.65**

Source: Bunkerindex, April 2013

Table 16: Price per ton prediction for maritime fuel from 2014 to 2017

Sulphur content	HFO (HF380) 1,50%	HFO (LS380) 1,00%	MGO 0,10%	MGO vs. LS380	MGO vs. LS380
Year	**$/Ton**	**$/Ton**	**$/Ton**	**Spread ($)**	**Spread (%)**
2013	$ 622.0	$ 650.0	$ 969.0	319.0	49%
2014	$ 654.0	$ 683.0	$ 1006.0	323.0	47%
2015	$ 692.0	$ 728.0	$ 1058.0	330.0	45%
2016	$ 692.0	$ 728.0	$ 1058.0	330.0	45%
2017	$ 724.0	$ 761.0	$ 1095.0	334.0	44%

Source: Stena Line, November 2012

Table 17: Andromeda J vessel specifications

IMO number	9355422
DWT (Summer)	11,052 tonnes
Built	2006
Owner	Jügerhans
Flag	Germany
Current operator	Unifeeder
Container capacity	962
Engine	Catepillar, MAK 9M43C
Engine Power	8400 kW
SFOC 100 %	176 g/kWh
SFOC 85 %	175 g/kWh
Design speed	18 knots
Operation speed	16.5 knots

Source: Grosstonnage, 2013a; Caterpillar, 2012; Table 18 Appendix

Table 18: Nordic Bremen vessel specifications

IMO number	9483695
DWT (Summer)	13.200
Built	2011
Owner	Nordic Hamburg
Flag	Cyprus
Current operator	SCA Contex
Container capacity	1036
Engine	Caterpillar, MAK 9M43C
Engine Power	9000
SFOC 100 %	177 g/kWh
SFOC 85 %	176 g/kWh
Design speed	18.5 knots
Operation speed	15.5 knots

Source: Grosstonnage, 2013c; Caterpillar, 2012; Container Info, 2013; Table 19 Appendix.

Table 19: Operation speed at sea, recordings for Andromeda J

Time	Average speed
2013-05-08 (12.00-13.00)	16.76
2013-05-09 (15.30-16.30)	16.91
2013-05-10 (10.20-11.20)	16.84
2013-05-11 (13.50-14-50)	17.16
2013-05-11 (19.00-20.00)	14.98
Mean	**16.53**
Standard deviation	**0.79**

Source: MarineTraffic, 2013a

Table 20: Operation speed at sea, recordings for Nordic Bremen

Time	Average speed
2013-05-10 (07.00-08.00)	15.64
2013-05-11 (16.30-17.30)	14.93
2013-05-12 (03.00-04.00)	15.98
2013-05-15 (14.00-15.00)	16.81
2013-05-15 (18.50-19.50)	16.88
Mean	**16.04**
Standard deviation	**0.74**

Source: MarineTraffic, 2013b

Table 210: Andromeda J, time in port

Port	Time in port [h]
Gothenburg	19.8
Bremerhaven	6.3
Hamburg	18.7
Immingham	*
Felixstowe	11.3
Teesport	10.7
Grangemouth	16.5
Bremerhaven	8
Hamburg	32
Mean	**15.9**
Standard deviation	**7.5**

* Data missing for Immingham

Source: MarineTraffic, 2013c