Economic Feasibility of Different Solutions for Complying with MARPOL Sulphur Emission Directive

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Summary

This thesis deals with various alternatives to achieve the new requirements for the ECA (Emission Control Area). An evaluation model for feasibility is presented, and three different solutions are implemented in the feasibility model. It also presents various fuel alternatives as well as the installation of scrubber, to meet the ECA Sulphur directive.

The main purpose with this thesis is to build an economic model that shows the return of investment for a fuel conversion, and also to obtain a comparison between different fuel alternatives. The whole thesis is based on quantitative information, because it is mainly based on numbers and statistics.

The result of the thesis is an economic model where you can in a quick way check the costs and the return of investment time for different fuel conversions. The goal of the thesis was achieved, despite the fact that the model had a more general approach to fuel conversions than what from the beginning was conceived, where the vessel Viking Cinderella was to be in focus of the model.

Language: English Key words: Fuel conversion, ECA directive, Model building

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EXAMENSARBETE

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Abstrakt

Lärdomsprovet handlar om olika alternativ för att uppnå de nya bestämmelserna för operation av fartyg i ECA (Emission Control Area) områden. I lärdomsprovet tas det upp vad som menas med en ekonomisk evalueringsmodell, samt också en beskrivning av tre olika typer av lösningar implementerade i modellen. I lärdomsprovet presenteras olika bränslealternativ och installation av scrubber, för att möta ECA områdens svaveldirektiv.

Huvudsyftet med lärdomsprovet är att med hjälp av en ekonomisk modell visa återbetalningstiden för en bränslekonvertering, och att också få fram en jämförelse mellan olika bränslen. Hela lärdomsprovet är baserat på kvantitativ information, eftersom det till stor del grundar sig på siffror och statistik.

Resultatet för lärdomsprovet är en ekonomisk modell var man snabbt kan kontrollera kostnader och återbetalningstider för olika bränsle konverteringar. Syftet med lärdomsprovet uppnåddes, trots att modellen fick en mer allmän koncentration på bränsle konverteringar än vad som från början var tänkt, där fartyget Viking Cinderella skulle ligga i fokus för modellen.

Språk: Engelska Nyckelord: Bränsle konvertering, ECA direktivet, Modell bildning

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1 INTRODUCTION

This thesis is made for by Wärtsilä Service – Business Development, Projects. Wärtsilä is a company that provides lifecycle power solutions for the marine and energy markets. Today the environmental solutions are very important. The emissions have to be reduced, and for this Wärtsilä has many different solutions. To achieve a reduction of the emissions the International Maritime Organization (IMO) came up with the Emission Control Area (ECA), meaning that within this area vessels are not allowed to operate if they don't meet the ECA requirements.

These ECA requirements mean increasing costs for ship owners. Wärtsilä's task is to provide ship owners with the most suitable and most profitable solution for their vessels to meet the requirements. In this thesis the fuel alternatives and also scrubber installation are generally presented as alternatives to meet the ECA requirements. In the next chapter the background for this thesis and also a more detailed explanation of the ECA is presented.

1.1 Background

The idea to this thesis came from a request by Viking Cinderella, concerning the profitability of a fuel conversion from Heavy Fuel Oil (HFO) to Methanol (MeOH). Viking Cinderella is a Cruise ferry that operates in the Baltic Sea between Stockholm and Turku. For the moment Viking Cinderella has a SCR (Selective Catalytic Reducer) installed on the vessel for reduction of NOx (Nitrogen) emissions. However, the new ECA requirements are concerning SOx (Sulphur) emissions.

New requirements for sulphur emissions has been made for the marine market, a proposal to reduce sulphide oxide emissions done by the IMO, which then have been approved by the EU. The new directive for the ECA came into force 1th January 2015. The sulphur limit for marine fuels in the Baltic Sea, the North Sea, English Chanel and the North Americas Sea areas were now established to 0.10%, in contrast to 2010 when the limit was 1.00%. The IMO is planning to expand the ECA in the future.

In order to meet the new requirements for sulphur emissions, ships can use low-sulphur fuels, install scrubbers or switch to alternative sulphur free fuels such as methanol and liquid natural gas. These requirements means additional costs for ship owners, therefore the fuel type for the new investment can be very important for the future profitability in a long term. The cheapest measure to meet the sulphur directive might have the most expensive operation costs. (Kommunikations-ministeriet, 2014).

Figure 1. Viking Cinderella (Viking Line, 2015)

1.2 Problem area

When it comes to engines using Methanol as fuel, Wärtsilä has not made a commercially available fuel conversion of this type yet, but an engine conversion kit has now been developed and is ready to be tested on a real vessel. In the middle of January 2015 Wärtsilä started a Methanol conversion on the Stena Germanica, to get more knowledge about Methanol. The conversion on Stena Germanica is expected to be finished in the end of 2015. The question marks are the total cost, the technical aspects, the time to complete a Methanol conversion and the profitability with Methanol. (Wärtsilä, 2014a)

Maintenance costs are difficult to estimate since there is no earlier experience of Methanol. Anyhow, an assessment for this will be done to be able to compare Methanol with other possible solutions.

Concerning the fuel terminal, the closest ones are located in Malmö and Gothenburg. As the vessel only operates on the route Stockholm – Mariehamn – Turku, bunkering in Stockholm would be necessary for a conversion to methanol to be realistic, unless there are fuel supplies established to the other ports.

1.3 Purpose

The goal is to come up with an economic model that evaluates methanol in comparison with different solutions that meet the requirements for the sulphide directive in ECA. An economic model for methanol does not exist today but similar economic models are done for other solutions like LNG, MGO and scrubber.

The main purpose is to come up with a tool that shows the return of investment for a fuel conversion from HFO to Methanol, also a comparison to other alternative solutions to see the profitability with these alternatives compared to each other.

There are several important parameters that can be determining or excluding for these fuel alternatives. These parameters can be the amount of free space on board, if the fuel type is available in the area where the vessel operates, the fuel price and also how the fuel affects the engine output. Also the cost of the installation is to be taken into account, and if it is possible to convert all engines.

1.4 Delimitation

To keep this thesis at a reasonable level delimitations have to be made. Considering the machinery system, only the most important parts, the parts that economically mean something on the engine and need to be changed, will be included in the calculations. For the fuel system, which includes everything on board such as fuel pipes, tanks, coolers and pumps, will only be roughly estimated; the ventilation and the inerting system will entirely be excluded from the calculations.

1.5 Definitions and abbreviations

IMO	International Maritime Organization
ECA	Emission Control Area
MeOH	Methanol
LNG	Liquefied Natural Gas
HFO	Heavy Fuel Oil
MGO	Marine Gas Oil
Scrubber	Device for air pollution control, for reduction of sulphur emissions
SCR	Selective Catalytic Reduction, for reduction of Nitrogen Oxides
CAPEX	Capital Expenditures
OPEX	Operating Expenditures

2 THE COMPANY

In this chapter, a brief description of Wärtsilä is given. It will tell about what kind of business Wärtsilä is concentrated to and also the strategy of the company. The different business segments are also presented and described. Finally there is a description of Business Development Projects, the department for which this thesis is done.

2.1 Wärtsilä in brief

Wärtsilä Corporation was founded 180 years ago in Karelia, a small village in Finland (The history of Wärtsilä, 2015). Today Wärtsilä is a global company, providing lifecycle power solutions for the marine and energy markets. Today Wärtsilä have more than 17,700 employees and operates in more than 200 locations in almost 70 countries. In 2013 the company's turnover totalled 4.7 billion euro and are listed on the NASDAQ OMX Helsinki, Finland. (Wärtsilä, 2015a).

Wärtsilä's strategy is to be the leader in complete lifecycle power solutions for the global marine markets and selected energy markets worldwide. Wärtsilä also see the opportunity in gas solutions as a part of the Smart Power Generation concept as well as in environmental solutions. The strengths of Wärtsilä are the technological leadership, the integrated product and service offering, long-standing customer relationships and the unparalleled global presence. (Wärtsilä, 2015b).

Figure 2. Mission, Vision and Values (Wärtsilä, 2015)

2.2 Business segments

There are three different business segments in Wärtsilä: Ship Power, Power Plants and Service. Wärtsilä Ship Power promotes the marine industry with their integrated systems, solutions and efficient products. They offer machinery, propulsion and manoeuvring solution to all kinds of vessels and offshore applications. Wärtsilä Power Plants is a global supplier of flexible base loaded power plants, operating on various gaseous and liquid fuels. Wärtsilä service supports customers throughout the lifecycle of their installation by optimising the efficiency and performance. Service is the largest business segment within Wärtsilä. (Wärtsilä, 2015a).

2.3 Business Development Projects

Business Development Projects is a team responsible for proposal management in project sales of multi-portfolio for both marine and power plants projects, and belongs to Wärtsilä Service.

Multi – portfolio projects:

For example Wärtsilä has engines, propulsion systems, electrical & automation and ship design to offer. By definition a project is a multi – portfolio project when it contains two or more of these different sections. Simply put; it is a more complex package that offers more than just delivering an engine. (Wärtsilä, 2015c)

Example of multi – portfolio projects:

- Fuel conversions
- Re-engineering projects
- Extension projects
- Vessel efficiency projects
- Re-location projects

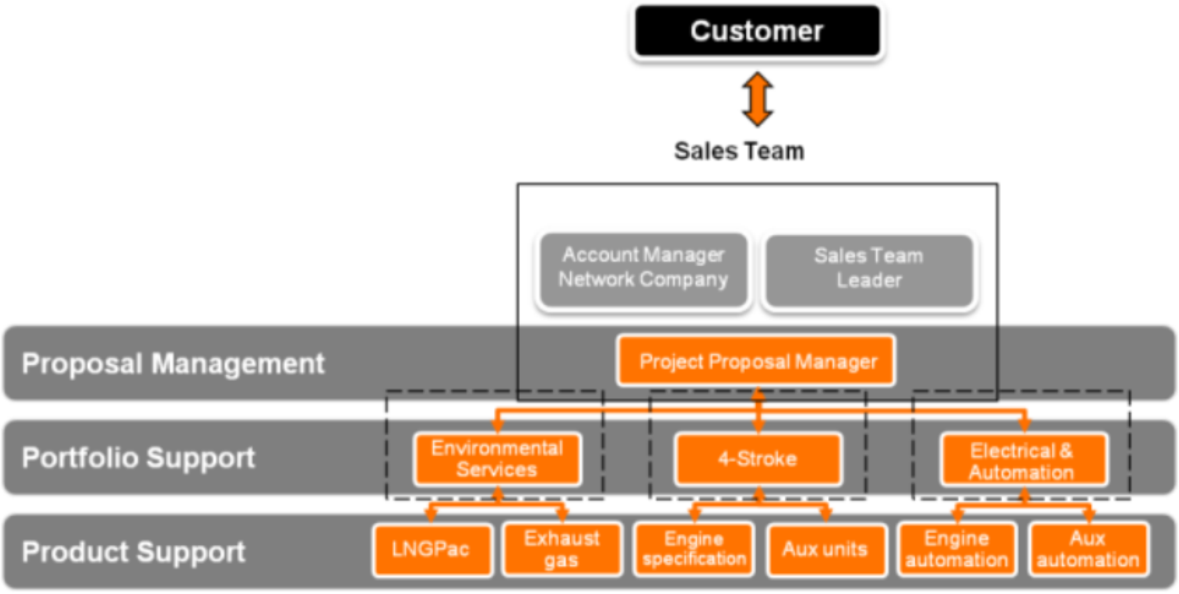

Figure 3. Organization of Business Development Projects (Wärtsilä, 2015c)

The next chapter presents the essentials and the knowledge that has been required to be able to start modelling the economic model. Also the possible solutions available to meet the new ECA requirements are presented.

3 THEORY

In this chapter the meaning of a model and also the purpose with different models are explained. Different types of models are presented in a general way; the typical structure and the content for each type of model. Presented are also the demands that are put on models, depending on what the models are to be used for, what requirements there are on the input data and the input of data.

Different fuel alternatives that meet the requirements for the ECA are presented in a general way as well as a description of Scrubbers that can be installed on board to clean the emissions in case of the ship owner wants to continue driving on HFO as fuel. Presented in the chapter are also the advantages and the disadvantages for all these different solutions as well as what a fuel conversion requires, for example if only some parts on engine needs to be changed or if a whole new engine is required.

3.1 What is a model or a system?

A model can be very varying in its shapes and styles, and is often made or built for a need on the market. A model isn’t necessary the real world, rather a tool or construction with a purpose to easier or better explain the real system or situation, which is both its strength and weakness. You can say that a model is a common language between the customer’s demands and the industry’s solution. (Husin-Hung Wu, 2003, page 1)

Generally, a model contains of information input, an information processor and also a part that shows the output and the results. Examples of models can be an economist’s graph of the stock prices, an architect’s house drawing or an engineer’s prototype of a wind turbine. (Starting point, n.d.)

3.1.1 Technical models

A technical model is often a construction or a prototype of something that is planned to be built or made. The models can be everything between drawings on a paper to prototypes of airplanes. The prototype has to be of a perfect scale compared to the real construction.

From a god prototype it's possible to run tests that can give a similar output as the planned real construction. An example of a prototype can be an airplane or a vessel.

With the prototype it is for example possible to see how a vessel behaves in a rough sea and how it takes waves, how much water the vessel will require and it can show the waterline that occurs when the vessel is moving. From a prototype of this type it is possible to make a model and then the tools required for the construction. After that the production can start, and the real construction can be built in accordance with the look and dimensions of the prototype's features. (Godfrey design, 2010)

A technical model doesn't necessary have to be a prototype or some other physical object. A model that evaluates the lifetime for engine parts is one example. The model could show the calculated time before a maintenance would be necessary on the engine, so practically the engine shouldn't brake before this time period but it is still something that you can't be sure of. This type of technical model can be similar to an economic model which you can read about in chapter 3.1.2 below.

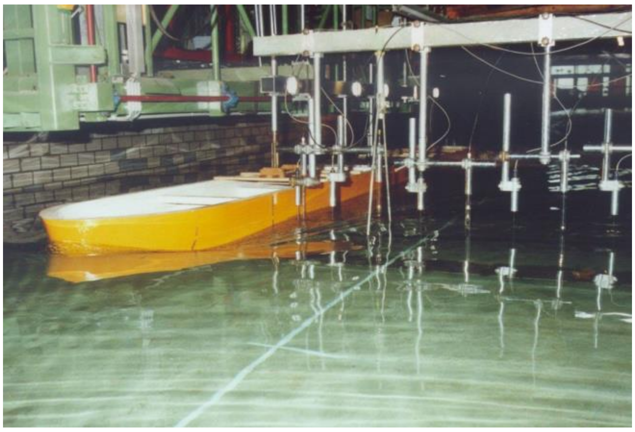

Figure 4. Wave measurement

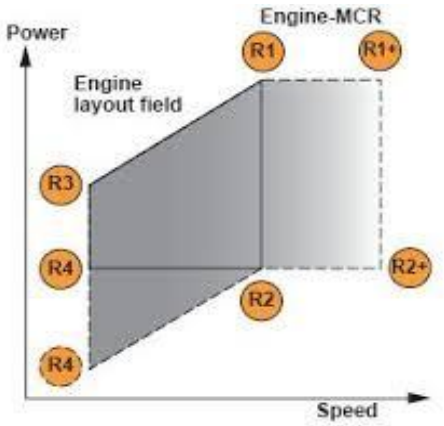

Figure 5. Power/Speed rating points

3.1.2 Economic models

The purpose with an economic model is to give a simplified understanding of reality, designed to yield hypotheses of the economical behaviour that can be tested. Important to know with economic models is that the input data often are subjective, as there are no objective input for an economic future, which means that an economic model has to be estimated to a certain extent. An economic model is a set of mathematical relations expressing an economic theory. For a trustable economic model, the model has to be testable through a case where the model has been proven to work. According to Paul Samuelson's (1973) definition of economic models, they are required to be "operationally meaningful". (Boland, 1989, p. 9-10)

There are two broad types of economic models, theoretical and empirical models. Even further both the theoretical and the empirical models can come up in many different types. Theoretical models are models that have no observation from the reality. Empiric means based on experience and stands in contrast to theoretic. An empirical model is a model that is based on a real situation. (Boland, 1989, p. 119)

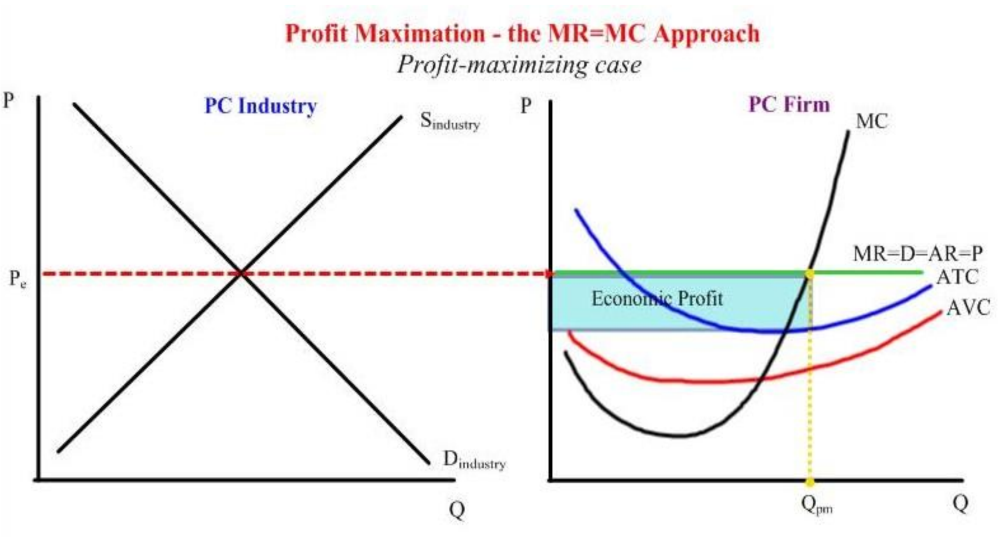

Figure 6. Example of an economic model

3.1.3 Combined models

A combined model is very effective in situations where there are many different solutions for a final common result. The purpose with this model is to combine all these possible alternatives and then through the model estimate the most profitable solution. Important for this model to work correctly is that the variables used in the calculations also are correct.

A combined model can be very useful for a transport company if we assume that they drive many times from a to b and there are a several different routes to choose between. The input data can show for example different routes and their length, cost per rout, time, the traffic, the geography or if there are many ups and downs. When all the data is collected it is implemented into the combined model and the outcome should show a list for the most profitable routes. (Namgung & Boyce, 1998)

3.2 The requirements for a model

A model's requirements often depend on a company's directives and also on the purpose of the model. If it is made for customers or only for the personnel it may also have different requirements. The requirements are for this reason often made for the specific model. In general it is important that the model is easy to understand and use. A model should not be constructed in such a way that only the writer understands it.
(West & Fowler, 1996, p. 10-11)

Below are listed some important requirements for a good model:

- Easy to understand
- Need to be reusable and usable for others than the author
- Easy to change data in the model, and still keep all the functions working
- It need to be flexible in certain extent
- Similar format to other models, on the same subject

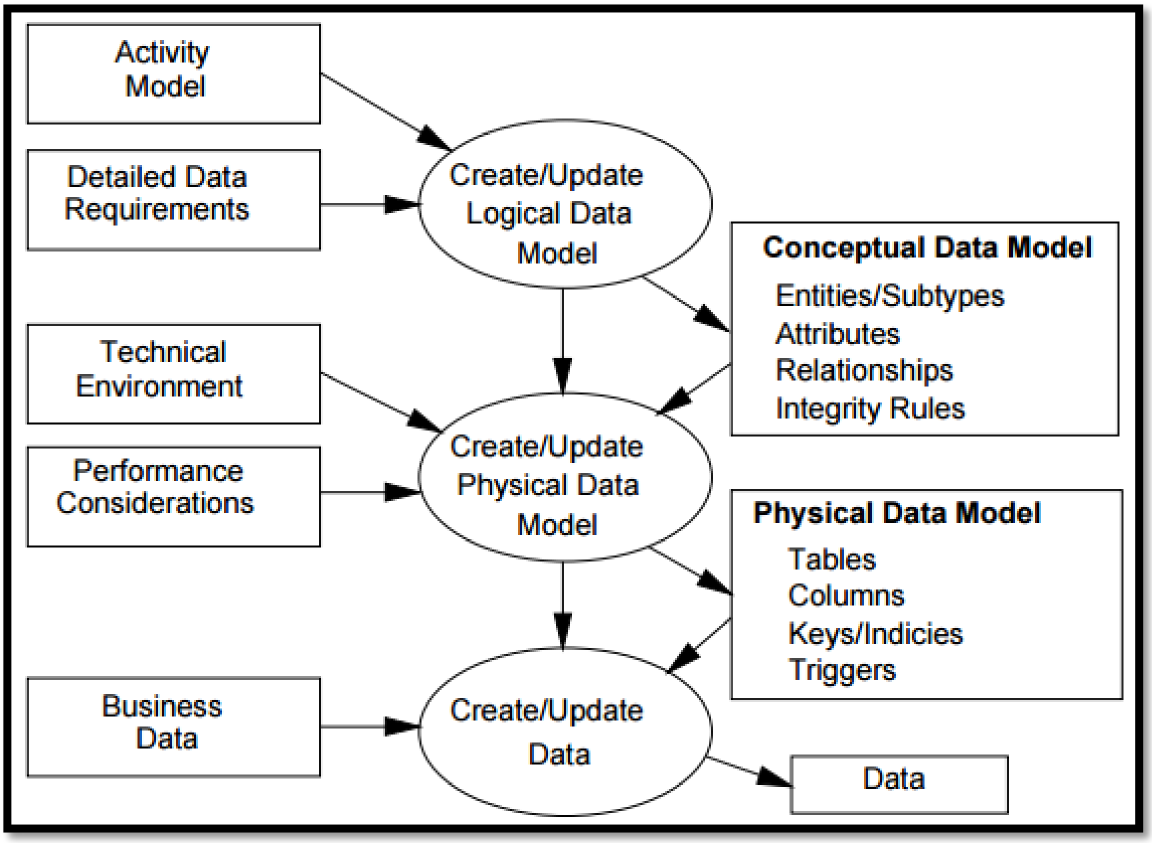

Figure 7. Modeling today. (West & Fowler, 1996)

3.2.1 Input

The data model will normally consist of entity types, attributes, relationships, integrity rules and the definitions of those objects. Below in the list by Mathew West (1996, page 5), important properties for input data for a trustworthy model is presented.

Definition related properties:

relevance:	the usefulness of the data in the context of your business.
clarity:	the availability of a clear and shared definition for the data.
consistency:	the compatibility of the same type of data from different sources.

Content related properties:

timeliness:	the availability of data at the time required and how up to date that data is.
accuracy:	how close to the truth the data is.

Finally related to both are:

completeness:	how much of the required data is available.

accessibility: where, how, and to whom the data is available or not available (e.g. security).

cost: the cost incurred in obtaining the data, and making it available for use.

Data Models address the properties related to the definition of data.

3.2.2 Data input and practice

A model is often made to explain or show a situation for the moment. Therefore models have to be updated in accordance with time changing.

For a model to be practical it has to be easy to update and modify and improvements should also be easy to make. A good construction of a model is one that has all input data that is to be changed in the further in one place, so everything is easy to fill in. When the input data is changed, the model itself should change the output based on the new input. If it is hard to modify the model it can take a month and the model will be pointless and forgotten. (West & Fowler, 1996, p. 11-12)

3.2.3 The purpose with the model for this thesis

From the model in this thesis it should be possible to see the costs for a fuel conversion during a time period of five years. It should also show how a cost increase or decrease of e.g. 10%, would affect the price of the conversion. The model should also show the difference between different fuel types. For the moment the model does not have to be synchronized with another program, it will only be used as a tool where it shall be easy to check the conversion costs by Wärtsiläs employees.

To keep this model updated it will be important to be able to rapidly change the fuel price and other parameters that constantly will be changed. The calculations for the fuel consumptions are made on an estimated value for bigger vessels operating 360 days a year, but to get the model to be as efficient as possible it is made so it will be possible to fill in the correct value for the fuel consumption for the specific vessel, if these values are available from the ship owner or -operator.

3.2.4 Challenges with model building today

A problem with data models today are that they tend to be too expensive. A reason to this is related to how data modelling is done today and also the lack of knowledge for how to build models efficiently. Sometimes models are built in such a way that if a small enhancement is to be done it will cause a major rework on the model. For these reasons models can become too expensive. So a challenge for data modelling today is to get them more flexible and stable for modifications. A big challenge today is also to get models built by same viewpoint and similar rules and constraints. (West & Fowler, 1996, p. 11-13)

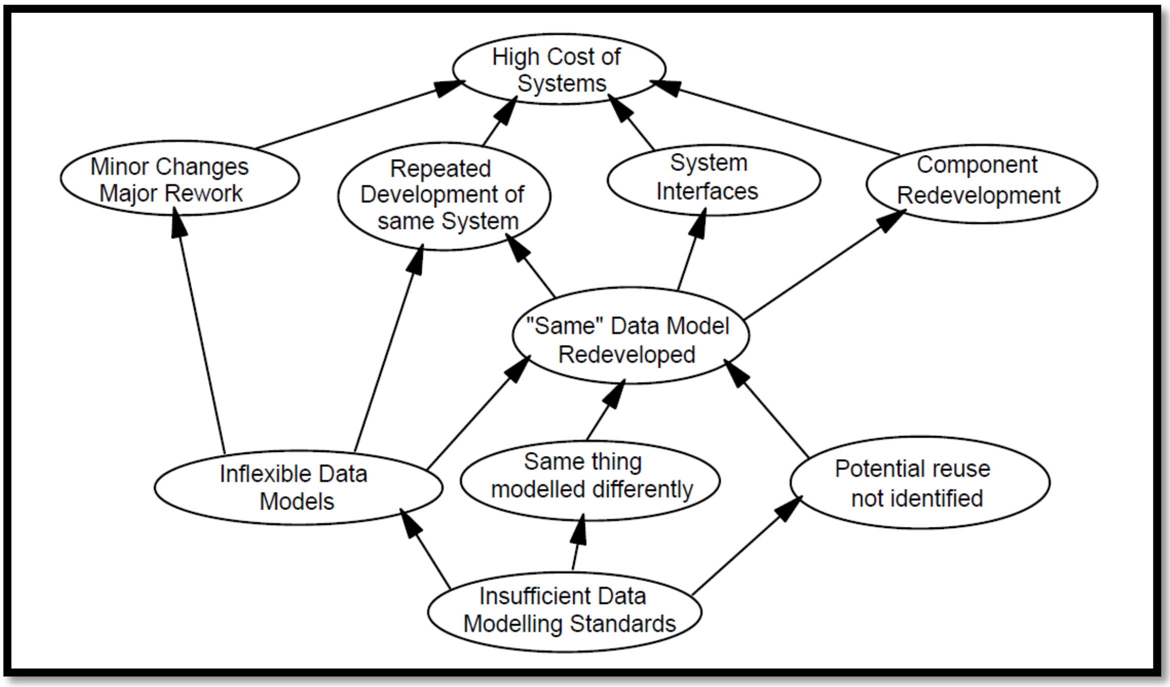

Figure 8. Some issues for Data models. (West & Fowler, 1996)

3.3 Fuel types and alternatives

Today there are a several different fuel types that are possible to choose between when driving an engine. For some fuel types there are more experience behind the fuel conversion than for others. Methanol is one of these fuel types where there is almost no experience of a conversion, but on the other hand there has been a lot of research done about the fuel. For LNG, MGO and scrubbers Wärtsilä already has a lot of experience. Below, these fuel types are shortly described with a general description. (Barner-Rasmussen, 2014, p. 16-19)

3.3.1 Methanol

MeOH stands for Methanol, also known as wood alcohol. Methanol is used as an alternative fuel and became more common in the early 1990s. Methanol is already used as a fuel in many vehicles. Methanol is an alternative to green shipping and its emissions are similar to LNG, if the combustion is done similarly. As with all emissions from combustion engines, the emissions are a result of the combustion method and the fuel composition. If for instance a Wärtsilä marine engine, using the Diesel combustion principle, is converted to operate on methanol, it would require new cylinder heads, fuel injectors, fuel pumps and high pressure double wall fuel oil pipes. Also the ventilation system, the inerting system and the fuel tanks are to be changed or upgraded.

The benefits with methanol are that it can be produced from various feedstocks like natural gas and it is easy to store since it can be stored as a liquid. Therefore no pressure or cryogenic storage is required. Regarding to the emissions methanol contains no sulphur and particulate emissions are very low. Converting a diesel fuelled Wärtsilä 4-stroke engine to operate on Methanol will not cause any power reduction compared to HFO, but it needs to be taken into account that methanol has less energy content than HFO.

Anyhow, the Methanol fuel tanks will take up nearly twice of the volume compared to the Diesel tanks for the same energy amount. Methanol has a low flashpoint which means it is regarded as a low flashpoint fuel by Classification Societies rules for ships. Methanol is also toxic which requires some precautions. (Methanol institute, 2011)

3.3.2 Liquefied natural gas

Liquefied Natural Gas or LNG, consists of about 90 % methane and 10 % ethane. When natural gas is cooled down to -162˚C it turns from gas to liquid and the volume will reduce roughly up to 600 times. This also makes the energy content per m^3 very high. The main reason why ship owners choose to use LNG as a fuel is the significant reduce of emissions and the consequently reduce of fees, as well as for the reduction of fuel costs. The price of LNG at the major import terminals today are very cost competitive compared to other alternative fuels. (AGA, 2015) (Karlsson & al, 2012, page 55)

LNG is the cleanest fossil fuel today and can reduce sulphide emissions with 99 % in a conversion from HFO to LNG, it also reduces emissions of NO_x and other particles. However, a key factor for a gas conversion is to find space for the LNG tanks on the vessel since they require more space than, for example, HFO tanks. To be able to operate on LNG the engine has to be converted or replaced with a new DF engine. If a conversion of the existing engine is possible, that is the most recommended way to go since it is economically more feasible and the engine will be nearly equivalent to a new engine. (Swedegas, n.d.; AGA, 2015; Karlsson & al, 2012, p. 56)

The negative aspects with LNG are the high investment costs and the transportation which requires some special equipment because of the condition of natural gas, also the future availability is question mark. You might lose some of the engine power output with LNG as a fuel, in case the conversion is resulting in a change of combustion principle. (Karlsson & al, 2012, p. 56)

3.3.3 Marine gas oil

Marine gas oil or MGO, is a distillate fuel used in diesel-fuelled engines for marine applications. MGO has a low content of sulphur, only 10mg/kg or in percent max 0.1% sulphur. MGO meets all the sulphur limit requirements for all European ports. The fuel has a very good viscosity and therefore it can be necessary to update fuel injection equipment for the engine, or cool down the fuel to a lower temperature than normally, in order to get the fuel more viscous, if you convert from HFO to MGO. In some cases also the exhaust valves need to be changed due to different temperature- and consequently material requirements for HFO and MGO operation. (Catlex, 2011)

The negative part with MGO is that it is expensive compared to other fuels and it can become uneconomical in the long run. The price is also expected to increase while HFO will stay the same or even decrease. The future availability is also a bit of a question mark. (Barner-Rasmussen, 2014, p. 19)

3.3.4 Scrubber

Installing an exhaust gas cleaning system called scrubber, is an option with the lowest lifecycle cost for today's alternatives to meet the requirements of ECA. Scrubbers are also compact and easy to install and retrofit on a vessel design for it, but for vessels were the scrubber does not exist in the original design, it can be hard to find the place for it. There are three different types of scrubbers; open loop scrubber, closed loop scrubber and hybrid scrubber. (Barner-Rasmussen, 2014, p. 19)

Open loop scrubber is the simplest variant of scrubbers. The emissions come into the scrubber where it will be sprayed with seawater. When the sulphide oxide reacts with the water, an acid solution occurs that immediately can be released into to seawater again. No chemicals are needed since the seawater's natural alkalinity neutralizes the acid. This can however vary because in some areas the water alkalinity can be so low that the water from the scrubber wouldn't be allowed to release into the sweater. (Barner-Rasmussen, 2014, page 19)

Closed loop scrubbers are technically more complicated than open loop scrubbers. In closed loop scrubbers the water circulates in the exhaust-cleaning device. The emissions are sprayed with water that is mixed with caustic soda and the sulphide oxide reacts with the water solution and neutralizes. The water from the exhaust-cleaner has to be treated before it can be released into the seawater. The advantage with the closed loop scrubber is that it is not dependent on the seawaters alkalinity. (Barner-Rasmussen, 2014, page 19)

Hybrid scrubbers can be used both as open and closed loop scrubbers, this gives the ship owner more flexibility. The hybrid scrubber can also be an advantage if the ship is to be sold and the new owner wants both an open and a closed loop scrubber. (Barner-Rasmussen, 2014, page 19)

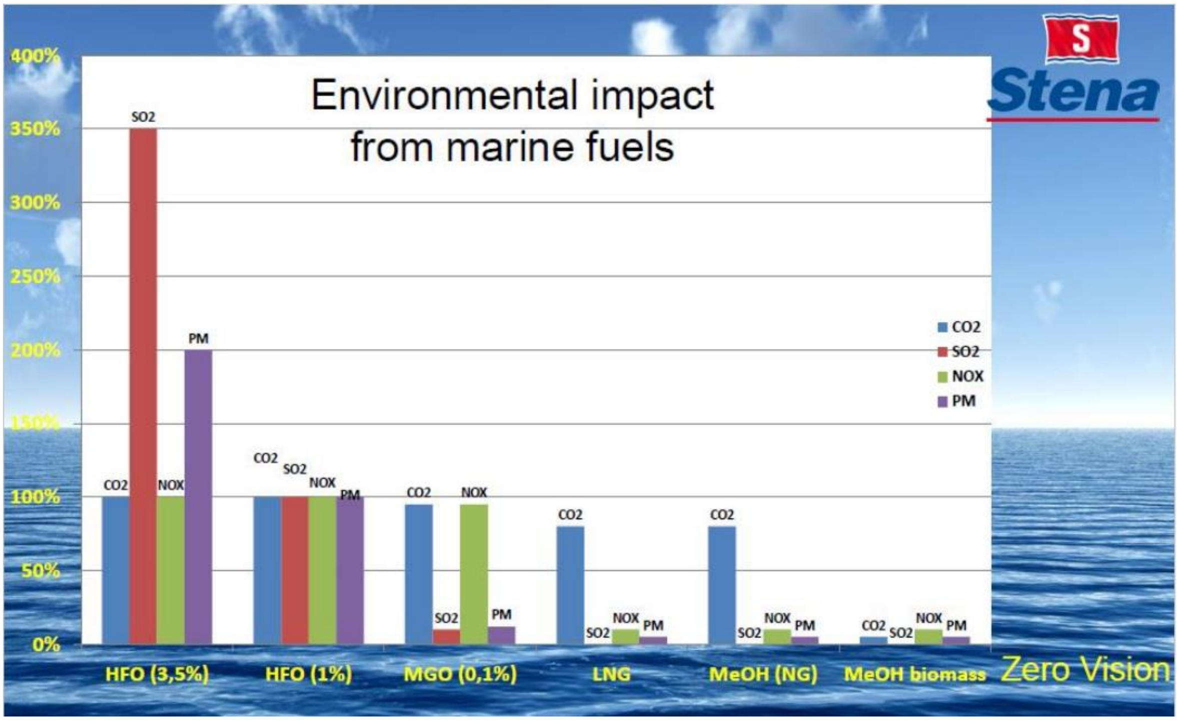

Figure 9. Table of fuel emissions from different fuels. (Wärtsilä, 2014)

3.3.5 Summary of theory

There are many different kinds of models, it is important to choose the right type of model to get out as much as possible from the model, therefore it may be advantageous to investigate different alternatives before starting modelling.

A model can be either a physical construction or it can be done on a paper or by a computer to show a system. It is recommended to use some ordinary model building, which can be find on Internet, to make it even more common and understandable. Models show and describe systems in an easy way and are to be easy understood, they should also be as simple as possible. A good model gives an understanding of something bigger only by looking at it, and it should be easier to understand a model than a text. In many situations it can be said that model building is like expressing a theory in mathematical terms.

When it comes to the choice of fuel type it often depends on the existing engine, the vessel type and also where the vessel is to operate. The construction of a vessel can limit the choice of fuel type. For example LNG and scrubbers requires a lot of space; LNG takes up tank space and the scrubber needs space for the installation itself. Depending on where the vessel operates the fuel might not be available or it may be very expensive in the area. It is also to consider both CAPEX and OPEX, a fuel that is cheap to convert to might be expensive to operate the vessel on and vice versa.

4 METHOD

The purpose with this chapter is to describe how I have reached my main target with this thesis. It tells about my course of action, the collection of information and also processing and analysis of information. For this thesis all information is taken from journals, the Internet and Wärtsilä's internal information sources. The discussions have mostly taken place during normal work tasks in the office.

In chapter 4.1, I describe different research methods; both qualitative and quantitative. In chapter 4.2, different investigation methods are compared with each other. The purpose is to find a suitable method for the main purpose with my thesis. In chapter 4.3, I describe the critical view of my method. And finally in chapter 4.4 I describe more about when, where and how I have done my investigations during my thesis work.

4.1 Different types of research methods

The choice of method should be based on the problem for the research. A natural result of choice will then be a combination of different methods. Different methods have their strengths and weaknesses and by combining these methods these sides can take out each other. Therefore there are often a lot to gain by combining quantitative and qualitative methods. Also different research methods enhance the validity of the information if they end up with the same results. Different methods can also be a feasibility study to another method, and then the first method will become an understanding phase to the second and main method. In chapter 4.1.1 and 4.1.2 the quantitative and the qualitative methods are presented.

4.1.1 Quantitative research method

The quantitative research method is based on earlier research. This means that the information is completely available for the theory and problem formulation phase. This method has been proven to work as long as the investigator is critical to both the information and the tools that are used in the research.

When using a quantitative method it is very important to remember to be critical to the information. A big problem with the quantitative method is that people finds it easy to trust information expressed in numbers. This makes it easy to misuse and misinterpret the information you have. (Holme, & al, 1996, p, 154-162)

4.1.2 Qualitative research method

The qualitative research method is a method that is based on interviews and you will therefore have a better relation to the information source. Regarding the qualitative methods the focus on how valid the used information is, isn’t as important as in the quantitative research methods. This because of the purpose of a qualitative research is primarily to obtain a better understanding of a certain factor and therefore the method will not have the statistical representativeness in focus. So, what you want with a qualitative research is to get information or in other words an aspect of something from someone that is involved in what you investigate. For example if you do a research about unemployment you want to hear out a group of unemployed persons with different situations to get their opinions on the matter in question.

A problem with the quantitative method is that the questions for the interviews or the formulas can be steered to a desired outcome and therefore show a distorted picture of the reality. Also a relationship that is to close between the researcher and the investigated group can be a problem – this because the investigated group can try to get the investigation led to what the researcher strives for. (Holme et.al., 1996, p, 100-117)

4.2 My choice of method

I have chosen to use the quantitative method throughout my thesis. I see the quantitative method as most suitable for my thesis, because of the economic model for which I have needed previously measured statistic values. Also for the theory part I see this method as the most suitable, since everything is about earlier investigation and proven theories.

Most of the values for the model are taken from Wärtsilä’s own measured values to get a result that best match Wärtsilä’s own products. For values taken from Internet that hasn’t been Wärtsilä’s own values, I have checked that the values have been the same between several different sources. This to get as valid information as possible for my model.

4.3 Critical view of used method

Since I have chosen to use only the quantitative method for my thesis it has been important to be critical to the information. I have linked the collected information with my previous knowledge to the matter in question to my best knowledge. If I have been unsure of the information, I have validated information from different sources to ensure that the information is correct.

I also had to be critical to the statistic values since there where almost never a date from when the measures were made. With new updates on the engines the values may have been changed, which means that the values used in the model have had to be updated to get the best result. All in all it is to be understood that the calculation model modified for the purpose of this thesis is only a calculation tool. The quality of the output will always be completely dependent on the quality of the input. Therefore it is important to use expert opinions in gathering the input data.

5 EMPIRICAL PART

I have done this thesis by myself, with support from my supervisors both from Wärtsilä and Novia. Most of the thesis has been done at Wärtsilä in Runsor where I have had access to all internal data input required for my economic model. It has taken about three months to complete this thesis.

The planning of my thesis began during the end of January 2015. I started to think about all what I was supposed to do and what the final results were supposed to contain. When I had that done, I started to collect information needed to reach my goals for my thesis. When the information was collected and the theory was clear I started to work on my economic model. The calculation model has been the hardest part of my thesis and also the part that has required most time. The beginning of the model took a long time since it was hard to figure out how to build up the model. When I had an idea of how to do that, I started to fill in random input data only to get the model to work with all the formulas, which also took me a while. I worked with my model about two month.

Regarding the economic model I have used an old model, done for other fuels and updated the old model with methanol. I decided together with my supervisor at Wärtsilä to keep the old model as a base to keep everything as before, so the structure should stay known by other employees of Wärtsilä.

6 RESULT

In this chapter I present the result I have achieved with this thesis. In chapter 6.1 I describe my practical work with the thesis, what the model contains and how it works. In chapter 6.2, I give more information about the input data, the calculations and in chapter 6.3 the output is described for my model. In chapter 6.4 I present the calculations and also the calculated and used values for my model.

6.1 Economic model

The practical work for this thesis is a tool for fuel conversations. The economic model for fuel conversions is made in Microsoft Excel. The purpose with this tool is to show the costs and savings with different solutions, to meet the ECA requirements. The results are partially based on estimations, since the costs will vary from vessel to vessel and future costs or incomes for a ship owner are impossible to know. For example the fuel price can’t be exactly predicted years in advance, complete maintenance costs are impossible to know on beforehand, and also the income can only be estimated.

The model shows the results for fuel conversions in form of a graph where you see the savings compared to MGO, which is considered the baseline. From the graph you can also see how an increase or decrease of 10 % of the price affects the costs of the conversion. You also have the possibility to adjust the initially chosen fuel price by using the slide bars above the graph, the graph will then change the output according to the slide bars.

6.2 Input data

The input data is partially done on estimations and partially on real values. Some of the input data for the moment are made to match the engines on Viking Cinderella. The input data in the model consists of costs as well as technical data for the fuel, the engine and also costs for maintenance. The maintenance costs for methanol are estimated to be the same as for a Wärtsilä GD (Gas-Diesel) engine, since there are no values for maintenance costs on methanol, but the GD technology is similar in both engine types. The model offers the possibility for the user to fill in the known fuel consumption for the specific vessel, and of course you are able to fill in the features for the engine you want to check.

6.3 Output

The output data is presented in form of a table as well as in a graph. The table shows exactly the same thing as the graph but in numbers. For the table, MGO is set as the base line and the other fuels are evaluated to MGO as savings. The savings are then summed to the previous year's costs, and you see that the other fuels are fast becoming more profitable than MGO despite the fact that MGO has by far the lowest installation costs.

As well as in the table MGO stands for the base also in the graph. The other alternatives, methanol, LNG, HFO + scrubber are compared to MGO that forms the x-axis in the graph. By having the values compared to each other like this you get a clear picture of how the fuels stand to each other. This is shown in Figure 9.

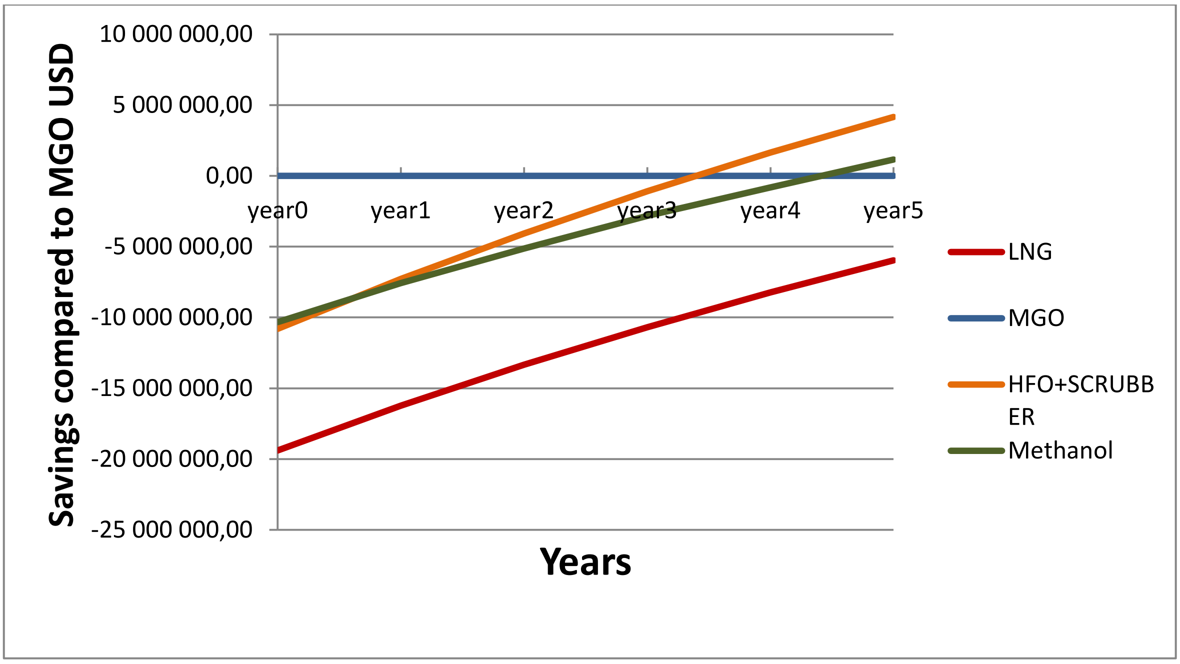

Figure 10. Graph showing the savings compared to MGO per year

In chapter 6, conclusions of my work are presented. It tells how well I have achieved my goals and my opinion about the model overall as well as how the model could be further developed.

6.4 Calculations for Viking Cinderella

Input data:

Conversion cost	P_C
Off hire cost	P_{OH}
Operating cost	P_O
Fuel price	P_f
Annual Energy based fuel price	P_{fj}
Annual Maintenance cost	P_M
Savings	ξ
Yearly running hours	h
Engine output	P_e
Annual average energy consumption	J_{tot}
Calorific fuel value	J_f
Awerage engine load	P_{ave}
Engine efficiency	η
Weighted average cost of capital	ρ
MGO cost per year	ϕ

Calculations for the graph:

MGO cost per year:

$$\phi = J_{tot} * P_{fJ} + P_M$$

Other alternatives, compared to MGO and expressed as savings:

$$\xi = (\phi - P_M - P_O) * (1 - \rho)^{x_{year}}$$

Return of investment (ROI), as earnings compared to MGO:

$$f(x) = P_C + P_{OH} + \sum_{year\ 0}^{year\ x} \xi$$

Average annual energy consumption:

$$J_{tot} = P_{ave} * \mathrm{h} * \eta \ \text{, Where } P_{ave} = P_e * 0.85$$

Fuel price per energy content:

$$P_{fj} = \frac{P_f}{J_f}$$

BASELINE	DF conversion	Scrubber	Methanol
Conversion cost	18 387 466	10 000 000	9 520 168
Offhire	1 000 000	800 000	800 000
Annual operating cost MDO	67 951	0	752 468
Annual operating cost LNG	6 440 468	0	0
Annual operating cost HFO+Scrubber	0	6 112 462	0
Annual operating cost MeOH	0	0	6 182 841
Annual operating cost total	6 508 419	6 112 462	6 935 309
Annual Difference in operating costs	-395 956	395 956	-822 847

Used fuel price:

MGO	600	$\$/ton$
HFO	330	$\$/ton$
LNG	10	$\$/MMBTU$
Methanol	200	$\$/ton$

Annual fuel consumption in ton:

	When operating on:		
	Methanol	LNG	Scrubber
Methanol	15 680	–	–
LNG	–	15 100	–
MDO	1 570	115	–
HFO	–	–	6 112 460

Estimated Service cost for four engines:

Year	Running hours	Service cost [$]
1	3 000	4 900
2	6 000	114 900
3	9 000	14 900
4	12 000	205 000
5	15 000	4 900

6.5 Choice of fuel alternatively scrubber

As you can see from the graph in chapter 5.3 HFO + scrubber is the alternative with the lowest cost today and MGO is clearly the most expensive in a long term. CAPEX for LNG is very high, but still it will be more profitable than MGO after a few years. LNG is also an appreciated fuel today, and people will recognise that you operate the vessel on LNG.

Methanol has a lower CAPEX cost than LNG but seems to have a similar OPEX as LNG. A benefit with methanol is that it is easy to produce and may be competitive in the future if the fuel will become more common. It will get an even lower price from today in accordance with technical development. Another benefit with methanol is that it can be produced from almost everything, although today mostly produced from natural gas, in the future methanol might become the “bridge” to a renewable fuels.

7 CONCLUSIONS

In this chapter I tell about my own opinion about the achievements of this thesis. In chapter 6.1, I present how well I think I reached my goals with this thesis and further in chapter 6.2, I tell about whether the model corresponds to the expectations from the first beginning of my thesis or not. Finally in chapter 6.3, suggestions for further development of the model are discussed.

7.1 How well did I reach my goals?

I am satisfied with the final result of the economic model for this thesis. The model shows the cost and the savings with different alternatives, which was the main purpose with this thesis. However, I want to make it clear that the model only shows an approximation of the reality and it is impossible to have a model of this type that would be 100 % correct. Basically the quality of the output from the model equals the quality of the input. It is important to understand that expertise is needed to correctly estimate the input variables. The final result of this thesis slightly differs from the originally intended outcome.

The focus on optimising the tool for Viking Cinderella in particular, as it was meant from the beginning, finally took form as a tool that in a general way now can be used for different vessels. This is however a more useful model so in the end I think that the final result of the model is very good. Now it can be used for all kind of conversions.

7.2 The quality of the model

The economic model is a good model so far, but there is room for further development. Also much of the input data for methanol can be updated after the conversion is finalized on Stena Germanica, and after a few years the maintenance costs for methanol can also be updated.

For my own part, this thesis has given me more knowledge about the various alternatives to meet the requirements for the ECA. I have gotten a better insight into how the fuel conversion process is done and a better knowledge about all the costs associated with fuel conversions.

7.3 Proposal for further modeling

Further model development could be to improve the model's format to a more modern and professional format, however that might not be necessary since the model only is to be used within Wärtsilä.

The model can be updated with more input data to get an even better outcome if such a thing would be necessary. The fields for which you can add your own values could also be expanded with more options, and then it could be possible to even further affect the outcome of the model. The model could also be expanded with a possibility to see how the fuel consumption depends on what load the engines are driven on. Additional modification to the model could be a function that shows the situation for “N” years, in additional to the 5 years that the model shows today.

7.4 Final conclusions

This thesis has been very rewarding to me, since my work in Wärtsilä is much about fuel conversions it has been a god experience for me to come in contact with all fuel types and also to understand how a scrubber is working. Now I also have a better understanding of costs and what solution might be the most suitable in specific situations. I also believe that I now can give customers better guidance in these matters.

Finally I want to thank my supervisors Roger Nylund at Novia UAS and Joel Knif at Wärtsilä for good support and guidance through this thesis.

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