A SYSTEMS APPROACH TO IMPROVING ENERGY EFFICIENCY IN THE SHIPPING SECTOR

SOUNDARARAJAN KAMAL

B.SC (HONS), NUS

A THESIS SUBMITTED

FOR THE DEGREE OF MASTER OF ENGINEERING

DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING

NATIONAL UNIVERSITY OF SINGAPORE

2016

DECLARATION

I hereby declare that this thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any university previously

Kamal Soundararajan

14 August 2016

ACKNOWLEDGEMENTS

The completion of this work would not have been possible without these people whom I am expressing my gratitude to.

First of all I would like to express my gratitude to my supervisors, Associate Professor Chai Kah Hin and Professor Ang Beng Wah. Associate Professor Chai has been extremely patient and kind towards me. Through his guidance, I have learnt to think out of the box and developed several analytical skills along the way. Professor Ang has helped to develop research methodologies along the way and helped me be more resourceful and precise in my approaches. Both my supervisors have been supportive even during times when several work and family related commitments challenged the submission of this thesis. I truly appreciate their guidance and am happy to be their student.

I would also like to thank my colleagues from the Energy Studies Institute as well as from DNV GL for being understanding and cooperative of my research commitments. I would like to thank my line managers, Dr Elspeth Thomson and Mr. Leo Akkerman for being extremely understanding and supportive of appointments with my supervisors even when it was during office hours.

Finally this thesis would not have been possible if not for the support I received from my father and wife. My father has continuously offered to give his advice, support and ever keen to know more about my research. My wife has been incredible during this journey, understanding and supporting me even during her pregnancy and eventual delivery.

To all the above mentioned people, I thank you.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

While cost effective energy efficiency measures exist for the shipping sector, they are not always implemented. There are several challenges the shipping sector faces that are unique from other sectors. Governments often have limited jurisdiction over ship operations and IMO guidelines only serve a limited role in influencing the behaviour of shipping companies. In addition to that, the shipping sector is well known for its ingrained and unchanged commercial habits that hinder both technical and operational advancements. Furthermore there is lack of quality data and understanding over how various parameters influence the performance of ships. By considering the point of view of the industry, the aim of this research is to provide a new perspective on how the energy efficiency in shipping can be improved. This requires one to gather research from different disciplines so that they can contribute with their disciplinary knowledge on the common topic. The first area relates to how decisions pertaining to energy efficiency are made on board, the second area is to take a closer look at energy efficiency barriers encountered in the shipping sector and the third area focuses on understanding how KPIs are used to improve energy performance within a shipping company.

To understand and formulate logical solutions to the complex problem of improving energy efficiency in the shipping sector, principles of systems thinking are applied across each of the three research areas outlined above. The aim of choosing a systems approach is to provide a more holistic and structured approach to understanding the perceived problem situation. For example the use of causal loop diagrams was found to be beneficial in outlining the different orders of influence various factors have in affecting energy consumption on board. Furthermore by considering different levels of stakeholder influence, the decision making process can be better illustrated for different energy efficiency measures. A systems approach was also found to be useful

in studying the interactions between various groups of energy efficiency barriers and stakeholders. As a whole, a systems approach facilitated a more systemic process of learning that is particularly useful in this study which is multidisciplinary in nature. Gathering research from different disciplines and presenting them using a more structured approach has helped this study provide meaningful contributions across a range of disciplines involving decision theory, barrier analysis as well as performance measurement.

Three research contributions were presented in this work. The first research contribution lies in providing a conceptual model of the decision-making process involved for energy efficiency improvements. The second is in providing a new taxonomy of energy efficiency barriers in the shipping sector. The third lies in providing valuable insights on how KPIs can be used at various levels of analysis to improve energy performance. Through causal loop models, key performance indicators were outlined to help achieve energy performance objectives at a company level. A more holistic picture of managing fleet performance through the use of KPIs was presented.

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

CLD: Causal Loop Diagram

CO_2: Carbon dioxide

EE: Energy efficiency

EEDI: Energy Efficiency Design Index

EEIs: Energy Efficiency Investments

GHG: Greenhouse Gas

HFO: Heavy Fuel Oil

IMO: International Maritime Organisation

ISO: International Standards Organisation

KPIs: Key Performance Indicators

MEPC: Marine Environmental Protection Committee

M&V: Measurement and Verification

SEEMP: Ship Energy Efficiency Management Plan

SSM: Soft Systems Methodology

UNFCCC: United Nations Framework Convention on Climate Change

1 INTRODUCTION

1.1 Research Background

The shipping sector is the main facilitator of international trade. Four fifths of total world merchandise was transported by ship in 2014 (UNCTAD, 2015). The growth of the shipping sector goes hand in hand with a growing world economy as demand for maritime transport services and seaborne trade volumes continue to be shaped by global economic growth. This is evident from how developing countries contribute to the growth of the shipping sector. Their contribution in terms of global goods loaded and unloaded was around 60% in 2014 (UNCTAD, 2015). Five of the top ten ship-owning countries are from Asia including China, Korea, Singapore and Japan. In South America, the largest ship-owning country continues to be Brazil, followed by Mexico, Chile and Argentina (UNCTAD, 2015).

A growing shipping sector influenced by economic growth and globalisation spells serious environmental concerns since it has led to increased energy consumption, and hence energy-related CO_2 emissions, by shipping. In 2012, international shipping emitted 796 million tonnes of CO_2 which accounts for 2.2% of global emissions for that year. According to the Third International Maritime Organisation (IMO) Greenhouse Gas (GHG) Study 2014, mid-range forecasted scenarios suggest that CO_2 emissions from international shipping could grow between 50% and 250% by 2050, depending on future economic growth and energy developments (IMO, 2015). CO_2 emissions being directly linked to the level of heavy fuel oil (HFO) consumed on board the ships, it was estimated that CO_2 efficiency in shipping could be increased from 25% to 75%, of which the majority is due to measures that increase energy efficiency (IMO, 2009). Furthermore in 2011, the IMO launched a landmark regulation that requires the use of minimum energy efficiency standards for benchmarking the energy performance of new ships (MEPC, 2014). As such it has been widely accepted that improving the overall energy efficiency on board is *the* key strategy for reducing global carbon emissions.

However the shipping sector is unique from other national-level CO_2 emission sectors and several challenges exist for improving the energy efficiency in the shipping sector. Governments often have limited jurisdiction over ship operations and IMO guidelines only serve a limited role in influencing the behaviour of ship owners and operators. The shipping sector is well known for its ingrained and unchanged commercial habits that hinder both technical and operational advancements (Smith, et al., 2014). Furthermore there is lack of quality data and understanding over how various parameters influence the performance and therefore efficiency of ships. This research therefore chooses to focus on better understanding energy efficiency of the shipping sector. An outcome of this study is the provision of a more holistic understanding on how energy efficiency can be improved within the shipping sector.

1.2 Research aims

The main aim of this research is to provide a holistic understanding of the various challenges and opportunities available for improving energy efficiency in the shipping sector. The presence of cost-effective potential for improving energy efficiency entices the mind to first ask what are the prevailing mechanisms allowing energy efficiency measures to be adopted in the shipping sector. The next logical question would be to find out what are the barriers that pose as challenges for this adoption. And finally the last question would relate to identifying what are some of the opportunities available. Based on these three broad areas, the following research questions are presented as part of this study.

Research Question 1: What are the decision making processes pertaining to energy efficiency improvements within the shipping sector?

Research Question 2: What are the energy efficiency barriers in the shipping sector and how do we classify them?

Research Question 3: What are the interactions between barriers, stakeholders and the decision making process for energy efficiency improvements?

Research Question 4: How are key performance indicators (KPIs) being used in the shipping sector to improve energy performance?

These research questions form the crux of this research. The study undertaken was multidisciplinary in nature, gathering research from different disciplines so that they can contribute with their disciplinary knowledge on a common problem or topic (Hannes, 2016). To understand and formulate logical solutions to this complex problem, principles of systems thinking are applied. As a methodology, this research applied Soft Systems Methodology (SSM), suggested by Checkland, (1981). The aim of the chosen methodology was to follow a structured approach to understanding the perceived problem situation better and to explore what are the potential solutions that can be augmented as part of the process. The research is largely characteristic of qualitative research that is interpretive by nature.

This field of practice in energy management or energy efficiency improvement in the shipping sector has just started to kick off and the field of knowledge surrounding this subject matter is just starting to find its way into academic research. This was a challenge during the research material collection stage as there was a lack of published literature specifically pertaining to energy efficiency in the shipping sector. Several concepts from industrial energy efficiency were borrowed and verified through semi-structured thematic interviews with stakeholders within the shipping sector. These interviews were exploratory in nature and thematic analysis was performed in order to derive preliminary results. By considering the point of view of the industry, the aim was to provide a new perspective on how the energy efficiency in shipping can be improved.

Methods of SSM were applied to the preliminary results to provide a more structured view of the problem situation. The conceptual frameworks derived from this research are further verified with industry experts to provide additional validation of the work. This is typical of action research where its value lies in its effect on practice (Gummesson, 2000).

1.3 Main research contributions

Three main research contributions are presented in this work, each addressing specific research questions outlined above.

The first main research contribution is in providing a more detailed representation of the various decision-making pathways for energy efficiency measures. Prior work reviewed are generally empirical in nature outlining the potential of various technical and operational measures that could be introduced without considering how the decisions are being made by relevant stakeholders for various measures. Through this work, a modification to the overall decision making framework for energy efficiency has been suggested for the shipping sector. Furthermore, the important role of top management and the energy manager in the decision making process was analysed.

The second main research contribution of this work lies in providing a new taxonomy of energy efficiency barriers in the shipping sector. Prior work assessing energy efficiency barriers in the shipping sector is limited and lacks a systems thinking perspective into considering interactions with the decision making process, stakeholders and barriers. It was also found that internal barriers were impacting the motivation, implementation and reporting of energy efficiency measures.

The third main research contribution of this work is in providing valuable insights into how KPIs can be used at various levels of analysis to improve energy performance. Current energy KPIs surveyed in the literature is predominately outlined to improve energy performance objectives at a ship level. Through causal loop models, KPIs are outlined that help to achieve energy performance objectives at a company level. A more holistic picture of managing fleet performance through the use of KPIs is presented.

1.4 Structure of thesis

This is not traditional disciplinary research, but is ultimately an attempt to sketch and understand the problem formulation at hand. In order to provide meaningful contribution, a range of disciplines involving decision theory, barrier analysis as well as performance measurement are to be covered. As a consequence the outline of this thesis is perhaps quite unorthodox. Nonetheless, SSM is applied in Chapters 2, 3 and 4 to provide insights to the relevant research questions. Each subsequent chapter builds on the results and analysis of the previous chapter. Checkland, (1981) defines SSM as a 7-stage process:

1. The problem situation: unstructured
2. The problem situation: expressed
3. Formulating root definitions of relevant systems
4. Building conceptual models
5. Comparing the models with the real world
6. Defining changes that are desirable and feasible
7. Taking action to improve the problem situation

The above chronological sequence improves the problem situation by facilitating a systemic process of learning. The stages outlined are used flexibly and iteratively based on the problem situation. For example, the form in which the conceptual models are presented varies across the three chapters. Given the time and scope restrictions of the thesis, stages 5, 6 and 7 was left outside the scope of study. Despite the limitations, the application of SSM stages 1 to 4 provided sufficient structure to the overall thesis. The overall thesis structure incorporating SSM stages 1 to 4 is presented in Figure 1-1.

Chapter 2: "Shipping and Energy Efficiency". This chapter focuses on addressing research question 1 (see Section 1.2). To express the problem statement accurately, the shipping sector is compared and contrasted with other energy consuming sectors. Through a literature review, relevant energy efficiency measures are also reviewed in the process. In formulating root definitions for the system in study, relevant stakeholders, uncertainties and potential relationships were defined by employing exploratory interviews with key experts. Based on these inputs, a more detailed representation of the various decision making pathways was presented with the use of influence diagrams.

Chapter 3: "Bridging the energy efficiency gap in shipping". This chapter addresses research questions 2 and 3. The chapter first defines the problem statement by assessing the state of the art related to energy efficiency barriers in the shipping sector. In modelling a conceptual framework that investigates the interactions between barriers and stakeholders and the decision making process, a new taxonomy of energy efficiency barriers was deemed to be important. This helped to express the core purpose of the system to be modelled. Inputs from Chapter 2 regarding the decision making framework was also incorporated within the barrier analysis.

Chapter 4: "Fundamental Use of KPI in Shipping". This chapter addresses research question 4. The system studied in this chapter focuses on the interaction of key factors that impact the level of energy performance in a ship. The outlining of key factors was fundamental in building up the conceptual model. Existing literature as well as key expert verification was done in defining the various first order and second order interactions. Causal loop diagrams were used to illustrate the gaps in existing KPI formulations.

Chapter 5: "Discussion and Conclusions". This chapter provides discussion of results and the conclusion of the thesis. The results of Chapter 2, 3 and 4 yielded two areas of discussion. The first area discusses how our research undertaken in developing a framework for energy performance KPIs contribute to the lack of "best practices" in improving energy performance across shipping companies. The second area discusses how a systems based approach to energy efficiency policy making can be beneficial to the shipping sector. Insights from the main chapters are used to support this claim.

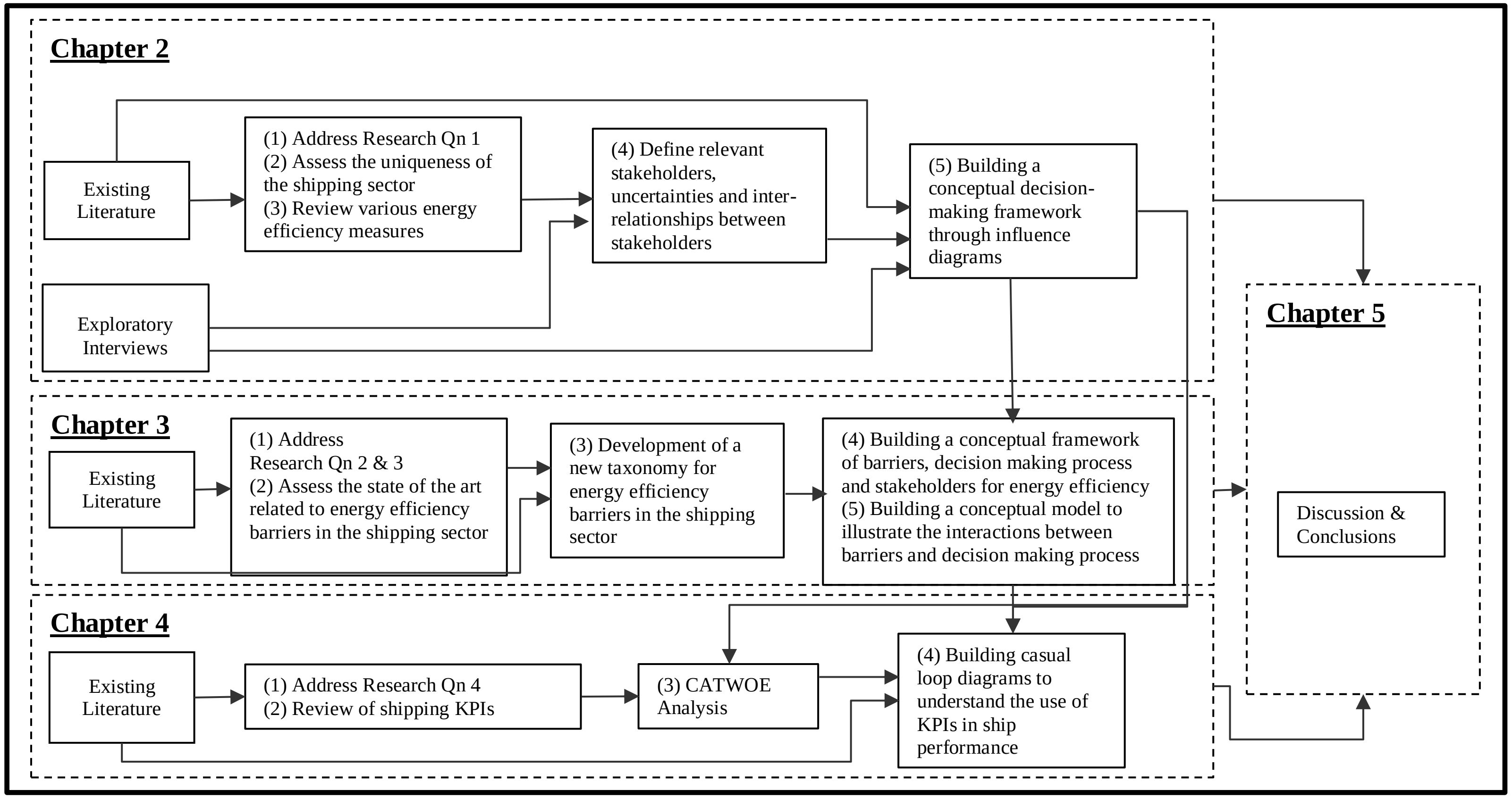


Figure 1-1 Overview of thesis structure

2 SHIPPING AND ENERGY EFFICIENCY

Energy efficiency tends to cut across three key objectives, economic competitiveness, security of supply and environmental sustainability (Heffron, et al, 2015). Environmental sustainability, specifically reducing CO_2 emissions, has taken centre stage with regards to shipping operations in the last 5 to 10 years. This has crystalized in the form of international regulations that currently oversees shipping operations. The revised MARPOL Annex VI outlines standards and regulations pertaining to improving the energy efficiency of shipping sector (MEPC, 2012).

While improving energy efficiency generally leads to fuel savings, various studies have shown that this transition to improved energy efficiency in the shipping sector has been slow and challenging (Smith, et al, 2013). In this light, understanding how energy efficiency improvements are being made in the shipping sector is a relatively new area of study.

Another important observation during the initial phases of this study was the limited amount of information publicly available with regards to ship operations; in particular the decision making processes involved. The key decision makers, details of the processes involved and the hierarchical levels that exist with respect to realizing energy efficiency improvements has not been studied in detail. This primarily stems from the fact that the entire international shipping sector, especially with regards to container transportation, is privatized and companies are usually hesitant in releasing such information, as it is traditionally thought to be vital for maintaining a competitive advantage.

Hence this chapter starts with the unstructured problem situation regarding decision making processes with the following research question (Research Questions 2, 3 & 4 is addressed in subsequent chapters):

> Research Question 1: What are the decision making processes pertaining to energy efficiency improvements within the shipping sector?

The literature on industrial energy efficiency decision-making is considerable and provides a suitable starting framework to outline the decision making processes in the shipping sector. By comparing and contrasting the energy efficiency processes with other national level sectors and the airline sector, this framework was further refined. A review of the various energy efficiency measures and stakeholders identified within the shipping sector was beneficial in choosing an appropriate approach for this chapter.

2.1 Literature Review

2.1.1 Energy efficiency decision making

Several studies have empirically studied the behaviour of people making energy efficiency investment decisions. The approach often involves empirically identifying drivers as well as barriers that negatively or positively affect the investment decision. In the area of consumer purchase decision making of energy efficiency products, Peter (1998) identifies the importance of information in the decision-making process. Similarly Sandberg & Soderstrom (2003) mentions how energy efficiency decisions are closely linked to monitoring, where poor monitoring often results in companies not realising the full potential of energy investments.

Tonn & Martin, (2000) took a further step and outlined a generic framework around the energy efficiency decision making process. It presents a generic industrial firm's energy efficiency decision making process in seven stages; from no energy savings decision making to energy efficiency program implementation to steady state energy. While this framework was very comprehensive in understanding the decision making process, it focused specifically on the adoption of measures outlined through the Industrial Assessment Centre Program in the USA. As such, certain stages such as Program Direct Effect and Routinisation were found to be not relevant to this study.

A more generic framework presented by Hasanbeigi (2010) suggests a three stage decision making process that includes (1) Awareness, (2) Motivation and (3) Action. The first stage suggests a decision maker must have sufficient awareness about energy efficiency investments. This includes understanding the various measures available as well as the potential cost savings that can be derived from this investment. The second stage focuses on understanding the company's motivation (if any) in implementing energy efficiency measures. This focuses on top management as well as the level of motivation found among the staff. The third stage of the energy efficiency decision making process involves implementable actions taken by the company to adopt energy efficiency measures. Energy management systems, benchmarking analysis, technical information dissemination are examples of implementable actions companies would need to consider in order to effectively implement energy efficiency measures.

2.1.2 A comparison of the shipping sector with national level sectors

To better develop the decision making framework specific to the shipping sector, the *uniqueness* of the shipping sector is analysed with respect to other national level sectors. National level sectors analysed here includes the building sector, transport sector, industrial sector and residential sector.

The first difference that separates the shipping sector from other sectors pertains to the policy and regulatory framework involving energy efficiency. Regulations pertaining to energy efficiency in all other sectors are regulated largely by national level laws and regulations. International organisations such as the United Nations Framework Convention on Climate Change (UNFCCC), have increasingly put pressure on developed and developing economies to provide national emission reduction targets. For national level systems, energy efficiency has been identified as a key policy tool in addressing climate change issues (Elizabeth, et al, 2009). International organisations such as the international standards organisation (ISO) provide general guidelines to improve energy efficiency processes; however these guidelines are seldom enforced at a supra-national level (ISO, 2011).

In contrast, given the cross boundary nature of the international shipping sector, a standardized approach to energy efficiency policies is not feasible. The regulatory framework, under which adoption of energy efficiency processes is governed in the shipping sector, is often recommended at a supra-national level but seldom enforced (IMO, 2009). The main supra-national body that regulates energy efficiency processes in the shipping sector is overseen by the IMO and the sub-committee Marine Environmental Protection Committee (MEPC). To date only two key measures are mandated by the IMO to obtain an International Energy Efficiency Certificate (IEEC). This involves the measurement of Ship Energy Efficiency Design Index (EEDI) and to have an on-board Ship Energy Efficiency Management Plan (SEEMP) (MEPC, 2009). A supra-national level of policy and regulatory framework for energy efficiency in the shipping sector significantly introduces challenges in terms of compliance, monitoring, reporting and verification. Furthermore, as compared with other sectors, shipping companies generally do not receive financial incentives to improve the energy efficiency of their fleet. As such, the motivation for improving energy efficiency usually originates from the shipping company itself.

The second area where the shipping sector varies from national level sectors pertains to the measurement and verification (M&V) processes. The M&V processes for energy efficiency improvements in national level sectors are more robust as compared to the shipping sector. M&V processes for improving energy efficiency in industrial processes, buildings and in residential services are generally well documented and follow several international guidelines.

In the industrial sector, ISO 50001- Energy Management System Standard is widely adopted by the industry as an international standard. ISO 50001 measures energy performance by an Energy Performance Indicator (EnPI). The EnPI could be energy consumption divided by production or another business metric, such as occupancy, normalized energy consumption compared to a correspondingly normalized baseline, or other metrics developed to track and communicate energy performance improvements. Energy savings, monetary savings, and percent improvement in performance are also common metrics used to determine progress in energy efficiency (Goldberg, et al, 2013). An ISO 50001 certification also outlines requirements that help with effective implementation of the standard such as setting company specific energy objectives and conducting internal audits (Gopalakrishnan, et al, 2014).

Similarly in the building sector, several guidelines and protocols have been written around M&V of energy efficiency. For example, the International Performance Measurement and Verification Protocol (IPMVP) outline specific guidelines on determining energy savings in new construction and indoor environments (Nix & Drees, 2011).

The approach to M&V in the transport sector as a whole is quite different from the industrial and building sectors. The transport sector is intrinsically not bound to one location and consists of a multitude of “sub-systems” that are interacting differently with the environment. The system boundaries are also not always clear increasing the risk of double counting. Furthermore, established and standardised evaluation procedures are very limited (Kulevska & Thenius, 2016). More often M&V of energy performance in national level transport systems is promulgated by the government through policy and regulatory compliance.

The M&V process for energy performance in the shipping sector is similar to national level transport systems without government led policy and regulatory compliance. This makes M&V processes much more challenging for the sector. Furthermore, given the dynamic nature of shipping operations, it is often challenging to attribute energy savings to energy efficiency measures implemented. For example, while slow steaming is a well-known operational measure to improve fuel efficiency, external factors such as weather conditions and dynamic port conditions adds additional uncertainties to the fuel consumption on a per voyage basis (Mander, 2016). Some sources even suggest that monitoring of bunker fuel levels before and after a particular voyage can prove challenging to standardise. For example, it is common to have disputes over the quantity of fuel between bunkerers and ship operators when using bunker delivery notes, a common approach to monitoring bunker fuel quantity and quality (Faber, et al, 2013). The use of flow meters is proven to be a more accurate approach. However this too faces consistency challenges if insufficient flow meters are installed or if flow meters are not continuously working (Faber, et al, 2013).

2.1.3 A comparison with the international aviation sector

A separate section is dedicated to comparing the aviation sector with the shipping sector given the similarities that both sectors have in terms of area of operations, the regulatory environment and their values on safe operations. Broadly speaking, given these similarities, the aviation sector has experienced much *higher levels* of efficiency in terms of energy use, operational excellence and service as compared to the shipping sector.

Increased levels of competition generally lead to higher levels of efficiency. The aviation sector is an extremely competitive sector mainly due to much higher transparencies on revenues and costs. This is due to a large majority of their business involving direct interfacing between client and the airline companies. Passenger transportation is a significant portion of aviation operations. In the shipping sector however, there are several middle man between the shipping company and the final energy service experienced by the client. In some cases, the client is often engaged with the shipping companies through long term contracts of 10 – 20 years. This tends to dis-incentivise competition within the sector (Jacobs, et al, 2012).

Forming strategic alliances in the airline industry is also quite common. A main feature of this involves the concept of ‘metal neutrality’. This means that the financial structure of each joint venture is such that the airline that sells the passenger its ticket is indifferent whether the passenger flies on its aircraft or on of its partners’ aircraft, as it will benefit financially both parties in the same way (Freshfields Bruckhaus Deringer, 2015). The shipping sector, on the other hand, is reluctant to move beyond traditional vessel-sharing agreements. We are starting to see trends of higher levels of efficiency in the containership sector, with more strategic alliances being formed.

The airline sector faces immense public scrutiny, since passenger transport is a large proportion of its operations. A strong safety culture has led to high levels of structure, standardisation, focused roles and responsibilities. This helps to set up the right frameworks for improving fuel efficiency. Fuel cost contributes to anywhere between 10% and 30% of operating costs in the aviation sector (ATD, 2005), as compared to 20% to 60% of operating costs in the shipping sector (Corbett & Winebrake, 2008). Paradoxically; ship owners and operators are more reluctant to change. The importance of improving fuel costs is generally not enforced throughout the entire chain of command.

2.1.4 Stakeholders involved in the ship energy efficiency process

The comparative analysis in section 2.1.2 and 2.1.3 highlighted the importance shipping companies have in the energy efficiency decision making process for the shipping sector. Without robust regulatory requirements from national level governments and a lack of public scrutiny throughout the shipping sector, the decisions shipping companies make have a significant impact in the adoption of energy efficiency measures.

Identifying who are the relevant stakeholders and how they are involved in the decision making process would be the next logical step. Most of the literature found revolved around describing the roles and responsibilities of personnel involved in ship operations including the ship captain, superintendent and crew. In most of these studies, the focus has primarily been on ensuring safe and reliable operations. Jafarzadeh & Utne, (2014) provided a comprehensive list of various stakeholders involved in the ship energy consumption (see Figure 2-1 below).

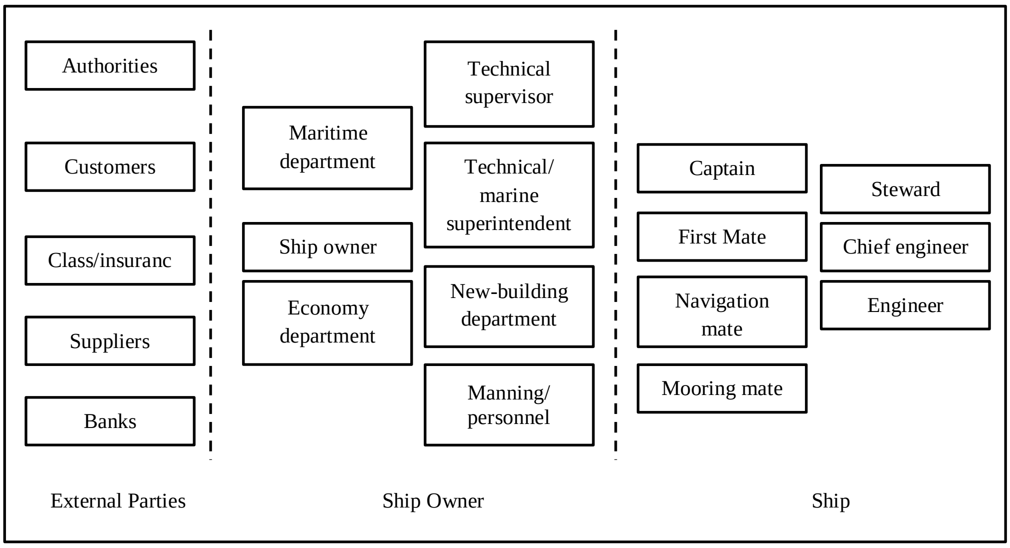


Figure 2-1: Stakeholders involved in ship energy consumption

It illustrates that stakeholders within a shipping company are not the only ones affecting the adoption / rejection of energy saving measures. And those external institutional factors such as regulations, international trade pressures and competitiveness, and shippers' requests can influence the operations of shipping companies (Lai, et al, 2011). While this is beneficial in understanding the barriers to energy efficiency improvements (see Chapter 3), it lacks sufficient granularity on the processes, such as what exactly are their roles, responsibilities and KPIs pertaining to making energy efficiency improvements.

2.1.5 Energy efficiency measures for the shipping sector

The motivation for analysing the various energy efficiency measures is to evaluate how decision making processes could vary across different measures. Extensive literature on various energy efficiency measures available for shipping can be found. Key studies include DNV GL (2014), Johnson, Johansson, & Andersson (2014), ABS (2011), Rehmatulla (2015) and Bazari & Longva (2011). A preliminary assessment showed there could be as many as 22 different types of measures that can be taken (DNV GL, 2014). Various measures can be classified broadly under three categories, technical, operational and managerial measures. These three groups of energy efficiency measures are assessed under the decision making framework for the shipping sector.

Technical energy efficiency measures can be further divided into measures undertaken for new ships and for existing ships. This distinction is important since technical energy efficiency measures undertaken for new ships are usually decided by onshore personnel. These measures include design improvements such as hull form optimisation, light weight construction and improvements made to the main engine. Improvements made to the main engine here is limited to technology improvements that are usually not feasible to retrofit. On the other hand, technical measures for existing ships are retrofitting a host of energy saving devices in various areas of the ship operation. This area includes but is not limited to, propulsion improving devices, skin friction reduction and incorporation of renewable energy. A detailed description of the energy savings potential, applicability and costing for each of these areas is available in ABS, (2011). Both onshore and offshore personnel would need to be involved in realising these energy efficiency measures coming into effect.

Operational energy efficiency measures provide significant potential for energy savings. Traditionally these refer to on-board energy management (including speed reductions) carried out by the captain and crew. Since 2011, several modes of co-operation between cargo owners, charterers, ship owners as well as the port authority have been proposed to improve energy efficiency in shipping. Enhanced technical and operational management includes weather routing, optimised trim and ballasting, hull and propeller cleaning and better maintenance of related equipment. Enhanced logistics and fleet planning include combining cargoes to achieve higher utilisation rate through optimised logistic chains, improving voyage routing and forming alliances to combine carriers' capacity. Another area that is increasingly gaining importance is port related measures that include having larger port capacity, fewer restrictions on ship draft, beam or length as well as improved cargo handling and port clearance.

The managerial energy efficiency measures include interactions with charterers in the specification of speed, when the charter contract is being designed. It also includes the assignment of ships to various routes and all related scheduling activities. Managerial energy efficiency measures could also include continuous involvement of top management throughout the energy efficiency process from planning to implementation.

2.2 Approach to outlining the energy efficiency decision making process

The literature review conducted in Section 2.1 helped to specify the approach in more detail. Firstly, given that the onus for improving energy efficiency usually lies with the shipping company, the boundary of the system in study is initially restricted to assessing the various processes that take place within the shipping company. The importance of measurement and verification processes for the shipping sector was also evident from the literature. This provided sufficient motivation to increase the granularity of the "Action" stage as part of the decision making framework. The "Action" stage was sub-divided into two stages; Implementation and Reporting. Furthermore, the literature provides sufficient motivation that technical, operational and managerial energy efficiency measures are quite distinct from each other. As such, the decision making process within each group can be assessed separately. The comparative analysis with the aviation sector shows that stakeholders within the shipping company have a significant impact on the decision making process in the absence of national level regulatory requirements and a lack of public scrutiny. The literature identifies an existing gap of how stakeholders interact with the overall decision making process. Thus the problem situation was more clearly expressed as the following:

How do relevant stakeholders influence the adoption of technical, operational and managerial energy efficiency measures?

The main objective is to understand the interactions between stakeholders and the energy efficiency decision making process, restricting the stakeholder influences to focus on understanding "first-order" interactions. It is acknowledged that external factors do impact the stakeholders' decision making process; however this is left to be explored further in Chapter 3 and 4.

2.2.1 Interview Process

As a first step, the relevant stakeholders would first need to be defined. Interviews were undertaken to help define who are *relevant* stakeholders involved in the decision making process as well as understanding their inter-relationships between the various energy efficiency measures across different stages of the decision making process. In addition, interviews were conducted to provide a higher degree of granularity of the decision making process within the four stages of the decision making framework (see Table 2-1).

Given the objectives above, the interviews were required to be semi-structured and exploratory in nature. The interviews also focused on representatives from shipping companies as well as representatives whom have worked closely with shipping companies.

Four exploratory interviews were conducted in this study. It is acknowledged that the small number of interviews conducted is a limitation in this study as it poses a risk of generalising the decision-making processes based on a small sample size. Nonetheless, understanding how the decision making processes occur within the shipping sector for different groups of stakeholders has not been explored before and this study indeed provides a first step into providing more structure to this process.

The first interviewee was an ex-consortium member and a captain of a major shipping company. The second interviewee involved is currently a senior management staff who is responsible for the energy management procedures in the container shipping sector. The third and fourth interviewees involved are experienced shipping consultants who are involved in energy management advisory and developing

SEEMP for a variety of shipping companies. A short biography of each interviewee is provided in Annex 1.

The type of exploratory interview questions developed as part of this study is presented in Table 2-1. The actual interviews did tend to deviate away from the general approach outlined. Nonetheless, useful information that met with the objectives was augmented from the interviews.

Table 2-1 Exploratory interview questions with decision making framework

Stage of Decision Making	**Exploratory Questions**
(1) Awareness	1) Are shipping companies usually aware of various energy efficiency measures? 2) Who are the relevant stakeholders involved in generating awareness? 3) Is top management aware of various energy efficiency measures available? 4) Is the crew aware of various energy efficiency measures available?
(2) Motivation	1) Are different stakeholders in the shipping company sufficiently motivated to carry out various energy efficiency measures? 2) Who are these stakeholders involved in providing motivation for EE adoption? 3) What are the key factors that influence the planning process? 4) To what level are staff responsible for planning and carrying out energy efficiency measures?
(3) Implementation	1) Are there any uncertainties that could affect the implementation? 2) Who are the people who implement the selected EE measure? 3) Is their implementation affected by other decisions from upper management/operations etc.?
(4) Reporting	1) How is fuel consumption monitored on board? 2) What are some of the issues that prevent some companies from being able to check EE savings realized? 3) What kind of mechanisms are in place to measure the level of savings from the EE measure that is implemented?

2.2.2 Representing uncertainties and inter-relationships

The functions and relationships of all the stakeholder groups in connection to the various processes will be represented in a conceptual model using influence diagrams. The use of influence diagrams also helps to understand more clearly how the decision-making process occurs throughout the entire process.

An influence diagram is a useful tool in representing the process of decision making. In decision analysis, the use of influence diagrams help to clarify not only the various uncertainties in the decision making process but also help to clarify the inter-relationships between the various processes (Karima, et al, 2013; Beilza, et al, 2010; Bielza, et al, 2011). Below is an example of the use of influence diagrams to represent the decision making processes in increasing the market value of a company (Lumina , 2016)

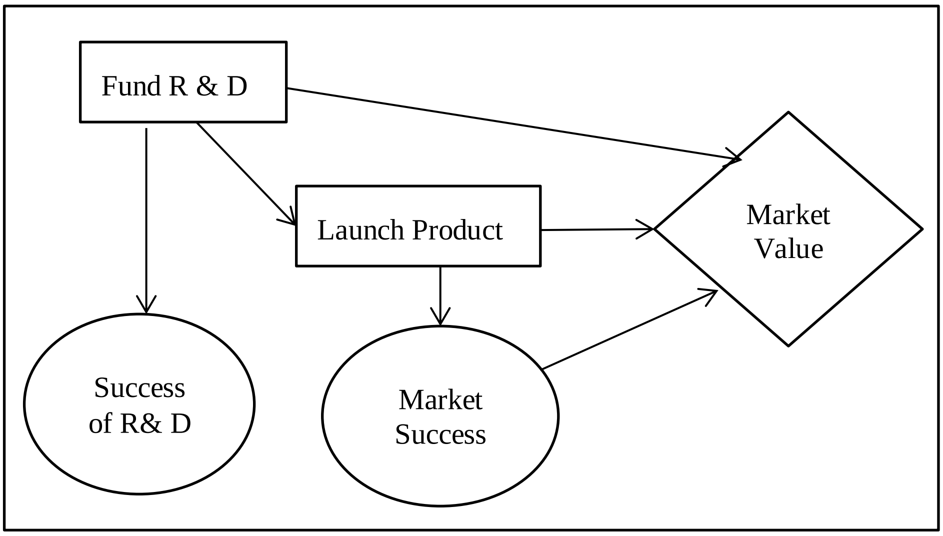


Figure 2-2: Influence diagram representing a decision making process

Starting with the objective, to increase the company's market value, is a measure of your satisfaction with possible outcomes. It might be net present value, lives saved, EBITDA or more generally, "utility". Usually, the decision maker is trying to find decisions to maximize (or minimize) the objective. In the context of our research, the utility would need to represent the over-arching objective that would encompass the multiple sub-objectives or attributes that may be in conflict among the various stakeholders identified in the research. The decision or decision variable (represented in rectangles in Figure 2-2) is a variable that the decision maker has the power to modify directly. In the context of this research, this would represent the decisions various stakeholders identified in the research that impacts the overall objective. Uncertainties are represented as chance variables (represented in ovals in Figure 2-2).

The use of influence diagrams is advantageous in this research as it provides flexibility at the same time retaining a high level of clarity in representing interactions in the overall system. For example, in the above depiction, market success is a chance variable that intrinsically has a certain probability attached to it. However, it also shows that the decision to launch a product affects the intrinsic chance of success based on the outcome of the decision. It also provides information that the chance of market success also has an impact on the market value. It should be noted here that the direction of influence is not restricted and it offers much more complex representations between chance nodes and decision nodes.

In the context of this research, the use of influence diagrams provides a framework under which various decision pathways for energy efficiency processes and uncertainties can be discussed in relation with the stakeholders identified in a more rigorous fashion.

2.3 Decision making processes for energy efficiency measures

2.3.1 Company stakeholders involved in the decision making process

Based on the interviews conducted, a summary of stakeholder influence on various energy efficiency measures was formulated in Table 2-2. It describes the extent various stakeholders are involved in the decision making processes for the three groups of energy efficiency measures. Each stakeholder is categorised according to various "levels of influence" within the company structure that is guided by their level of authority. Insights gained through the interviews and analysis conducted is detailed below for each group of stakeholders.

Table 2-2: Stakeholder influence on various energy efficiency measures

Stakeholders	Level of influence	Technical	Operational	Managerial
Consortium	Level 1			XX
Top Management	Level 2	XXX	X	XXX
Energy Manager	Level 3	XXX	XXX	XXX
Technical Superintendent	Level 3	XXX		
Ship Manager	Level 3		XXX	XXX
Ship Captain	Level 4	X	XXX	X
Crew	Level 5		XX	

2.3.1.1 Level 1: Consortium

A consortium is a strategic alliance between competing shipping lines to deal with operational concerns such as the volatility in energy prices and overcapacity of existing fleets. This is most common in the container shipping industry where it helps to ensure sufficient control over the market shares in various operating routes.

Consortium arrangement was clearly identified to have an impact on managerial energy efficiency measures. This led to a more in depth research on the roles and responsibilities of the consortium.

"Short term and long term idling of ships is a complex process that usually involves a consortium of shipping companies" (Interviewee I, 2014)

The figure below provides a snapshot of some of the existing and planned consortium arrangements.

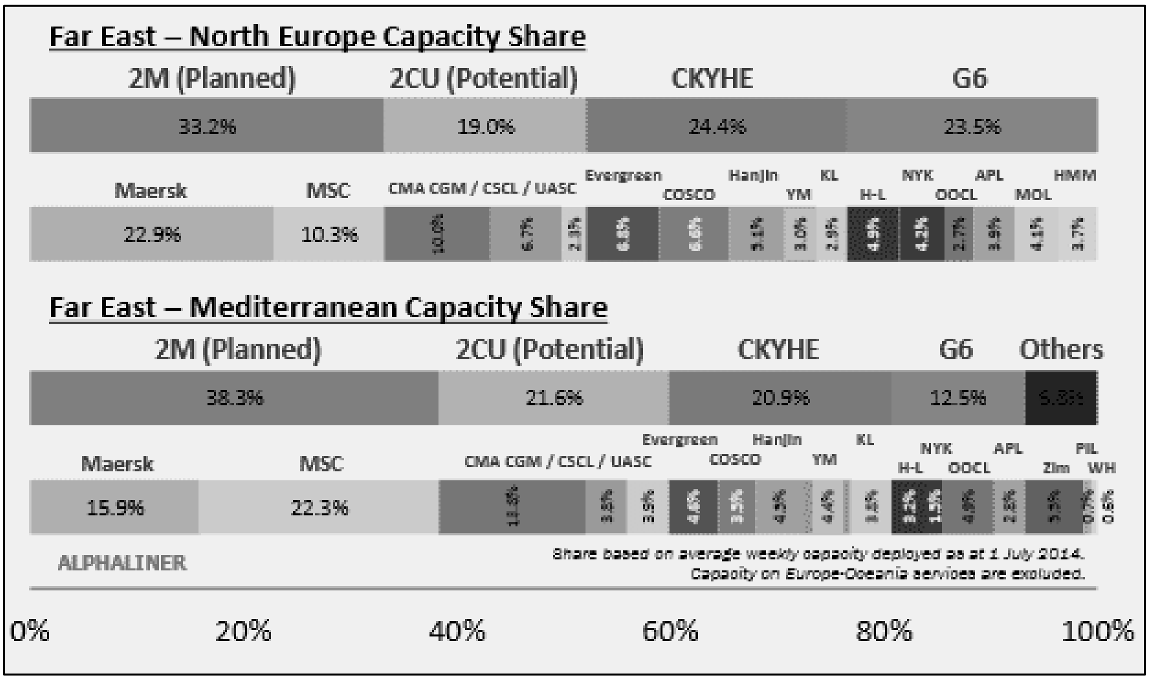


Figure 2-3: Share of Asia to Europe by Consortia

(Source: Alpha liner)

Although consortium activities pertaining to energy consumption reduction are not scheduled, it allows for significant savings through managerial energy efficiency measures at a fleet level. These include voyage and scheduling optimisations. It also allows for long-term strategic decisions pertaining to technical energy efficiency measures of new ships. For example, the Maersk Triple E class container ship of more than 18,000 TEU was built on the basis that it has several consortia tie ups with other shipping lines such as the P3 and 2M. It is also common for such consortiums to include an overall fuel reduction target (Nastu, 2010).

2.3.1.2 Level 2: Top Management

The top management is usually made up of the chief executive officer, chief financial officer and chief operating officer. The top management is directly involved in the approval of technical and managerial energy efficiency measures that are either going to be applied across the entire fleet or specific to certain routes. Technical energy efficiency measures here usually involves suggestions brought forward for retrofits or decisions pertaining to the procuring or designing of more energy efficient ships. Although they are not directly involved in the design specifications on more energy efficient ships, they are usually guided by certain key indicators. Currently the EEDI serves as a suitable indicator that top management can utilise to assess the suitability of various new builds. However the lack of suitable KPIs for scheduling and fleet management was also mentioned.

> *"It remains unclear what are the key performance indicators that is considered in the scheduling and fleet optimisation. Probably, given the highly variable and dynamic nature of the business, it might be difficult to pen down what are the key performance indicators in general"* (Interviewee I, 2014)

While it may be the case that there is indeed a lack of suitable KPIs for scheduling and fleet managemet, the interviewee may also not be aware of the presence of such KPIs. This is due to the highly competitive nature of the shipping sector resulting a relatively closed environment. Thus the notion that there is a lack of suitable KPIs for scheduling and fleet management is contentious.

2.3.1.3 Level 3: Energy manager, technical superintendent and ship manager

The middle layer (Level 3) as presented in the table above involves a great deal of overlap and conflicting KPIs among the stakeholders in that layer.

The term "energy manager" is used here to encompass energy management responsibilities including identifying and proposing specific energy efficiency measures that are subsequently approved by the top management. This includes suggesting retrofits for existing fleets, optimising voyage planning, scheduling of periodic maintenance and trim optimisation. The trim, defined as the difference between the draught at aft position and forward position, is optimised by doing proper ballasting or choosing of proper loading plan. This is one of the easiest and cost effective methods that optimises ship energy performance. They also have oversight of the entire fleet and have specific KPIs targeted at attaining certain levels of energy efficiency. The objectives outlined in the company's SEEMP are usually aligned with their KPIs.

"Operational measures such as optimising the route, hull cleaning schedules, trim optimisation plan etc. is suggested by the energy manager" (Interviewee IV, 2015)

"few companies such as MAERSK has a dedicated energy management team that spearheads this initiatives" (Interviewee II, 2015)

Often energy managers would need to consult with the technical superintendent and the ship manager in outlining specific energy efficiency measures. Very few companies such as MAERSK have dedicated energy managers. In other companies such as APL, the energy management responsibilities are performed through an energy leaders program (Interviewee III, 2015). Given that such energy management activities are still in a nascent stage, often their various responsibilities are absorbed by either the technical superintendent or the ship manager.

The technical superintendent is usually in charge of ensuring whether the necessary repair works on a ship are being executed properly, especially during the dry dock of the ship. They are also referred to as a supervisor, overseer. He is the person in charge of necessary repairs and conditioning required for a ship. He also ensures that the repairing and reconstruction of the ship is being carried out properly in the allocated shipyard or dry dock.

> *"In the absence of an energy manager, a technical superintendent would provide proposals for operational energy efficiency measures"* (Interviewee IV, 2015)

The technical superintendent has technical oversight over the ship operations. However, his KPI is not aligned to optimise the technical energy efficiency of a ship. Even in the absence of an energy manager, his KPI is only focused on ensuring the technical ability for a ship engine to move from point A to B without breaking down.

The ship manger is another key stakeholder in the energy efficiency process. The ship manager's key responsibility usually is to ensure that there is a timely delivery of goods from point A to B. His KPI is usually to meet the charter's requirements and is very much client focused. The ship manager can also sometimes be referred to as the fleet controller or planner. A variety of operational and managerial measures including route diversions, trim optimisation, weather routing and scheduling of maintenance is often planned by the energy manager in consultation with the ship manager. It was mentioned during the interviews that often the KPIs of the energy manager and the ship manager are in conflict with each other.

"Ship manager also in charge of a fleet of ships, often have conflicting KPIs with the energy manager" (Interviewee IV, 2015)

The challenge that many companies face is in balancing these KPIs of each of these two groups. Generally in many companies, decisions pertaining to energy efficiency are often rejected by the ship manager. In some cases, top management may decide to provide the energy managers with higher level of authority that usually results in more energy efficiency measures becoming operationalised.

2.3.1.4 Level 4 and 5: Ship captain and crew

The ship captain and his crew are usually referred to as the offshore crew as compared to the previous stakeholders which make up the onshore team responsible for energy management. Although the ship captain is not involved in devising the various energy efficiency measures, he is solely responsible for ensuring operational energy efficiency measures related to optimal speed allocations, weather routing, voyage planning, trim and draft optimisation plans being carried out in an effective and efficient manner.

However in some cases, some of these operational energy efficiency measures can either be over-written or improvised by the ship captain. This often occurs in situations where carrying out these operational energy efficiency measures are in conflict with safety objectives. In some cases, the ship captain may even propose alternative routes or speed reductions that are not according to the plans to bring about more fuel savings. However, it is not the ship captain's prerogative to do so as his KPIs are almost always aligned with ensuring safe navigation of the ship and its contents.

"although the captain and chief officer is in charge of the vessel performance, they are not directly responsible for the fuel savings" (Interviewee III, 2015)

The crew including the various on-board staff such as the first mate, technical operators etc. play a rather straight forward role in ensuring that the instructions pertaining to operational energy efficiency measures that have been passed down in accordance to the plans outlined or instructed by the ship captain.

2.3.2 Influence diagram of the adoption of energy efficiency measures

A key output of this chapter presents the influence diagram outlining the adoption of technical, operational and managerial energy efficiency measures (see Figure 2-4). The decision pathways for each of the three measures are connected by decision variables depicted as boxes. Uncertainties impacting decision variables are outlined by circles and ovals. Exploratory interviews were the main source of input in developing the influence diagram.

It is assumed that each decision variable outlined is carried out at a particular level of influence. For example, the approval of the technical energy efficiency plan is carried out by top management (Level 2) and the implementation of the operational energy efficiency plan is carried out by the captain and his crew (Level 4&5). Similarly it is assumed that for each uncertainty variable outlined, the uncertainty originates from a particular level of influence. For example, the presence of conflicting objectives tends to originate either from the energy manager or the ship manager (Level 3). It should be noted that only uncertainties that originate within the shipping company is included in the representation. External uncertainties that impact the energy efficiency decision making process are explored in more detail through barrier analysis in Chapter 4. By positioning the decision variables and uncertainties horizontally across different levels of influence as well as vertically along the four stages of the decision making framework, this representation provides a 'big picture' representation of the overall process. Key observations of the various decision pathways along with the uncertainties involved are described in four stages.

2.3.2.1 Awareness

The representation in Figure 2-4 suggests that the decision making pathway begins with top management deciding to be sufficiently aware of the various EE measures available. Given that fuel efficiency is often mentioned as one of the top priorities for shipping companies and the increased importance energy efficiency has on reducing emissions from ships, top management is often fully aware of the importance of energy efficiency. Furthermore, internally no uncertainties were cited that impacts top management's decision of being sufficiently aware of energy efficiency measures.

The awareness of staff has been cited in the literature to be important to the overall decision making process. However through the development of the decision pathways, it was found that staff members such as the technical superintendent, ship manager and on-board crew play a more significant role at later stages of the decision making process than at the awareness stage.

2.3.2.2 Motivation

Several decision nodes as well as uncertainties are involved in ensuring that the company has sufficient motivation for the adoption of energy efficiency measures. Once fully aware of potential improvements that can be made, top management either decides to invest in an energy management team or instructs the technical department to come up with proposals for energy efficiency improvements, which are often operational in nature (Interviewee IV, 2015). Larger companies with sufficient resources tend to have a higher chance of investing in an energy management team.

Several uncertainties that affect the approval of an energy efficiency proposal are outlined. The approval of technical and managerial energy efficiency plans are often done by top management, while operational energy efficiency plans are usually approved in consultation with the ship captain. Existing responsibility allocations that exist in shipping companies today may not require the captain to be directly responsible for energy efficiency improvements (Interviewee III, 2015). Furthermore, in the absence of such an energy management team, a technical superintendent that proposes energy efficiency improvements may not have any specific KPIs that optimise energy efficiency for a fleet of ships (Interviewee III, 2015). The approval of technical energy efficiency plans are also often dependent on whether the ship is owned by the company. Existing charter party agreements introduce the issue of split incentives that significantly reduces the motivation to adopt technical energy efficiency measures that involve high initial upfront payments. In addition to that, being a consortium member tends to facilitate the approval of certain managerial energy efficiency measures. For example in the container shipping sector, a decision to carry out short term and long term idling of containerships to optimise fuel efficiency at a fleet level would require ensuring other consortium members are able to support in sharing the load of transportable goods (Interviewee III, 2015).

The influence diagram outlines the role an energy manager plays in increasing the level of motivation for the approval of energy efficiency measures. Through an energy manager, proper incentives can be put in place to push forward the adoption of energy efficiency measures that are not only operational but also technical and managerial in nature. Without an energy management team, technical and managerial measures are often under the purview of top management that may not have the time and resources to develop suitable proposals.

However, the energy manager faces risk of having conflicting objectives with other stakeholders. Seniority coupled with robust analytics of proving obtainable savings is crucial in convincing top management as well as other relevant stakeholders to approving energy efficiency plans (Interviewee IV, 2015). While the IMO has mandated the need for energy management plans on-board, it does not require shipping companies to have an energy management team in place. It is recommended through this analysis that international regulatory bodies such as the IMO look into facilitating the inclusion of energy managers as part of the overall energy management plan. Singapore serves as a useful regulatory example where large energy intensive companies are mandated to have a certified energy manager within the company.

2.3.2.3 Implementation

After the approval of an energy efficiency plan, depending on whether it is a technical, managerial or operational plan, it is implemented by different groups of stakeholders. The implementation of managerial energy efficiency plans often involves consultation with top management. For example, the outlining of charter party contracts with reduced speed allocations and the re-routing of ships would require the respective departments to consult with the chief financial and chief operating officer. As for the implementation of technical energy efficiency plans, it is often implemented in consultation with the technical superintendent in charge of the fleet. Operational energy efficiency plans are implemented by the captain and his crew.

Depending on the type of measure, different uncertainties impact the implementation process. Although it might be a challenge to verify due to the lack of publicly available information, fleet management systems may not always take into account energy objectives. Without taking into account energy objectives, decisions pertaining to voyage or route optimisation become purely based on commercial reasons. Crew competence is another key uncertainty that affects the implementation of technical and operational energy efficiency measures. Crew competence is closely linked to the crew's awareness of energy efficiency measures that in turn leads to sub-optimal behaviour when it comes to implementation. An example of such sub-optimal behaviour is when an engine operator decides to leave several auxiliary engines switched on at the same time instead of just one to reduce time spent monitoring (Interviewee II, 2015). In other cases, the crew may be unwilling to leave the comfort zone to make the changes outlined by the onshore energy management teams (Interviewee II, 2015).

While crew awareness of energy efficiency may not be important during the planning of energy efficiency measures, the results suggest that providing energy efficiency related training would help to reduce the uncertainties encountered during the implementation stage.

2.3.2.4 Reporting

A crucial decision node, as part of reporting, is the accounting of cost savings due to energy efficiency measures. The accounting of cost savings is usually carried out by onshore personnel. The close monitoring and onshore-offshore collaboration help in saving on bunker fuel and reducing CO2 emissions. For example, Maersk Line's Global Voyage Centre monitors ships 24 hours with real time data and positioning information. In 2014, Maersk Line vessels completed 37,000 voyages and Global Voyage Centre was integral to reducing overall emissions by 530,000 tonnes (Louise, et al, 2015).

In the presence of the energy manager, the energy manager is required to provide top management with cost savings obtained from implemented energy efficiency measures. Through the interviews, it was also noted that proper accounting of managerial energy efficiency measures are not currently practiced within the sector.

It is noted that there may be smaller sub-steps or decision pathways that lead up to accounting of cost savings. However a more detailed representation of the decisions involved in carrying out the accounting process was not clarified in the interviews. Nonetheless, various levels of stakeholder interactions were found to impact this decision pathway. Fuel reporting is an important component in accounting cost savings. Currently there is a lack of regulatory framework when it comes to ensuring that fuel is reported in a credible manner. For example, fuel reporting sometimes can be misrepresented by filling up or emptying the pipes (Interviewee III, 2015). If the ship in service is under a charter party agreement, certain level of consumption at various speeds would be usually outlined in the agreement. Taking into account the commercial interests, the crew often tries to match this consumption level (Interviewee II, 2015). While this behaviour is brought about by the crew, it often stems from top management's policies and guidelines surrounding this matter.

Another key uncertainty is the inability to sufficiently show the impact of various energy efficiency measures on the level of fuel saved. This is a key issue that energy managers encounter when convincing top management in making new changes. This issue mainly arises from the fact that fuel savings are measured on an aggregate basis at the end of the month where multiple operational energy efficiency measures could be implemented over that period of time. Logging fuel consumption on a voyage basis is recommended but is often not practiced.

Accurate accounting of cost savings due to energy efficiency measures could also feedback to improve the overall awareness of energy efficiency measures, allowing for continual improvements to be made within the shipping company.

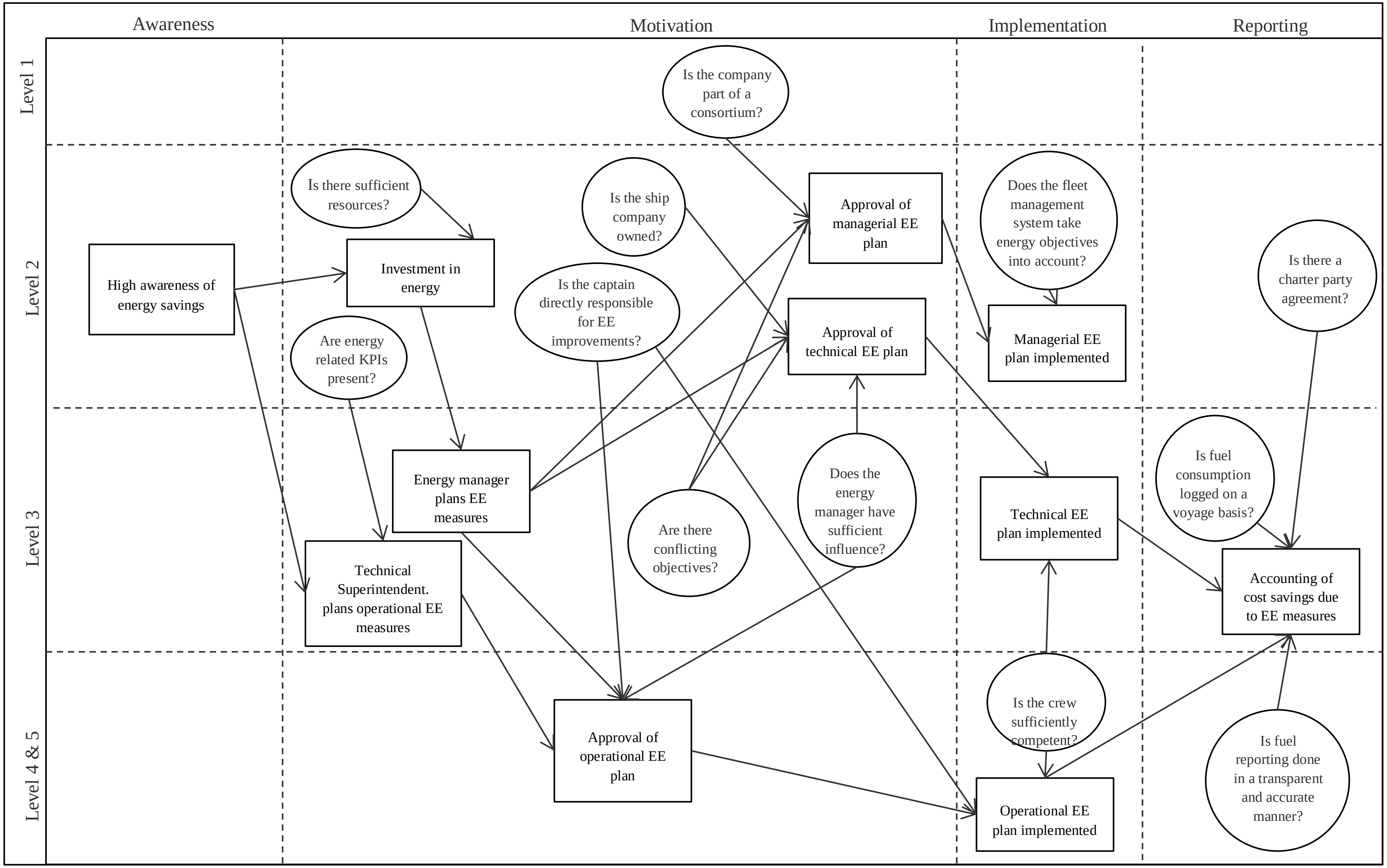


Figure 2-4 Influence diagram of the adoption of energy efficiency measures

2.4 Concluding remarks

In summary, this chapter provides a more detailed representation of the various decision making pathways for energy efficiency measures. A modification to the overall decision making framework has been suggested to include reporting as an additional stage. Furthermore, the roles and responsibilities of relevant stakeholders within the decision making process is clarified. Interactions between stakeholders, the key decision nodes as well as the uncertainties arising within the shipping company have been clarified through the representation of an influence diagram.

The following are key results of this chapter:

1. Having sufficient motivation was found to be critical to the overall decision making process.
2. Different stakeholders have a different role to play in ensuring sufficient motivation is attained.
3. Top management has an important role to play in evenly allocating responsibilities with respect to energy efficiency to relevant stakeholders.
4. The energy manager is involved in several critical pathways and requires sufficient influence to motivate top management in approving energy efficiency proposals.

3 OVERCOMING ENERGY EFFICIENCY BARRIERS IN SHIPPING

Cost effective measures, both technical and operational, are not always implemented. The inconsistency between the optimal and actual implementation is called the 'energy efficiency gap' which is often explained through the presence of energy efficiency barriers (Chai & Yeo, 2012; Trianni, et al, 2013).

A barrier can be referred to as "a postulated mechanism that inhibits investment in technologies that are both energy-efficient and economically efficient" (Sorrell, et al., 2000). However, barriers are rooted in different disciplines that are economic, organisational and behavioural in nature. This is the case for the shipping sector, where investments in technologies are not the only way to improve energy efficiency. Since operational measures also help to save fuel, the definition of barriers must be expanded to include mechanisms that inhibit the adoption of operational measures that are deemed energy saving and cost effective.

This chapter starts with the unstructured problem situation guided by the following research questions (Research Question 1 is addressed in Chapter 2):

> Research Question 2: How do we identify and classify energy efficiency barriers in the shipping sector
>
> Research Question 3: What are the interactions between barriers, stakeholders and the decision making process for energy efficiency improvements?

To better understand the problem situation a literature review of energy efficiency barriers for the shipping sector was carried out. Limited number of studies provided an assessment of energy efficiency barriers in the shipping sector (see Section 3.1).

3.1 Motivations for a new taxonomy

A crucial contribution to the classification of barriers to energy efficiency in the shipping sector comes from Jafarzadeh & Utne, (2014). This study provides a framework to bridge the energy efficiency gap in shipping by developing a framework for overcoming barriers to energy efficiency.

The study by Jafarzadeh & Utne, (2014) makes an effort to be comprehensive in listing the various barriers. It does not provide inputs on the stakeholders involved. As described in Chapter 2, the various stakeholders within the organisation have a varying influence on the barriers to adoption. Stakeholders range from an operator, who directly interacts with the engine, to a manager, who indirectly interacts with the energy system (Bogdanski, et al., 2012). Besides the stakeholders within the shipping company, we also see that there are external institutional factors that influence the operations of shipping companies.

Another issue is the lack of uniqueness of several barriers listed. Given that there is an extensive literature on energy efficiency barriers, additional barriers outlined should clearly describe how it is unique to the shipping sector or show specific examples related to the shipping sector. This was not the case, where several barriers such as imperfect budgeting, lack of trust in the organisation and a lack of confidence in energy efficiency technologies that seem to be more generic that could also apply in other sectors.

While the study by Jafarzadeh & Utne, (2014) outlines more than 40 different barriers, several overlaps can be found. Inaccuracy in information and a lack of credibility of information tends to be closely related as they often occur together or one after the other. Incompatibility between technologies and ship types versus incompatibility between technologies and operations, split incentives versus ownership of vessels are other examples where overlap can be observed.

A lack of sufficient understanding of energy efficiency barriers clarifies the problem situation. A new taxonomy for energy efficiency barriers borrowing concepts from industrial energy efficiency and exploratory interviews conducted in Chapter 2 would help provide sufficient root definition of the system in study and help understand how stakeholders influence the creation of energy efficiency barriers within and outside the organisation. It is also beneficial to understand how barriers affect the decision making process.

3.2 A new taxonomy of energy efficiency barriers in the shipping sector

Using the data gathered from interviews conducted from Chapter 2, accumulated knowledge and experience from other industrial sectors and specific examples from the shipping sector, energy efficiency barriers encountered in shipping is presented. The barriers discussed are classified according to key literature on industrial energy efficiency (Cagno, et al., 2013; Sorrell, et al., 2000). While implicit interactions between various barriers are acknowledged, it is not within the scope of this study to investigate barrier-barrier interactions or provide an exhaustive list of barriers that could be present in the shipping sector. Instead, it focuses on understanding how stakeholders within the firm and external to the firm are involved in the creation of barriers and how they can be affected by the barriers outlined. Internal stakeholders are outlined based on Chapter 2, while external stakeholders follow Cagno, et al. (2013).

A preliminary effort was conducted to outline the stakeholders involved in the barrier-effect to distinguish between barriers external and internal to the firm. This new taxonomy is presented in Table 3-1. Information provided from interviews helped to develop the overall structure and motivations for looking at barriers in relation to external and internal stakeholders. It also helped to formalise the list of barriers. Several uncertainties described in Chapter 2 served as a starting point to understand how barriers and stakeholders are related. Literature review underpinned the various interactions between barriers and stakeholders. An example of the process is described below.

Several decision nodes and uncertainties are involved in ensuring that top management has sufficient motivation for the adoption of energy efficiency measures (see Figure 2-4). Barriers that tend to reduce the motivation for top management to invest in energy efficiency technologies includes high technical risk of new technologies, inadequacy of technologies and lack of confidence in the energy efficiency measures proposed. While these barriers affect top management (internal to the firm), they are created outside of the firm. Each sub-section below provides an overview of the barriers investigated in the literature and a discussion of how different stakeholders are involved in the process; both in terms of creation of the barrier and being affected by the barrier. The involvement of various stakeholders with different groups of barriers is represented by ticks in Table 3-1.

Table 3-1: A new taxonomy for energy efficiency barriers in the shipping sector

Barriers	Stakeholders	Regulatory Authorities	Technology Suppliers	Capital Suppliers	Market/ Charterer	Consortium	Top Management	Energy Manager	Technical Superintendent	Ship Manager	Ship Captain	Crew
Technology related	Technical risk of new technologies		✓				✓					
	Inadequacy of technologies		✓		✓		✓					
Information	Lack of information	✓	✓	✓		✓	✓					
	Lack of confidence in information	✓	✓		✓		✓					
Regulatory	IMO- related	✓					✓					✓
Behavioural	Lack of interest						✓	✓				
	Inertia					✓	✓	✓				
	Imperfect evaluation criteria						✓	✓				
Organisational	Split incentives	✓			✓		✓					
	Lack of authority						✓			✓		
	Bounded rationality						✓	✓			✓	✓
	Company culture						✓	✓	✓	✓	✓	✓
	Communication issues						✓	✓	✓	✓		
Competency related	Maintaining accuracy in information	✓										✓
	Crew's lack of competence		✓				✓					✓
	Manager's lack of technical expertise							✓	✓	✓	✓	✓
	Organisational change							✓	✓			✓
Economic	Access to finance			✓	✓		✓					
	Market risks				✓		✓					
	Misalignment of benefits with normal operations		✓		✓		✓					

3.2.1 External barriers (with respect to the firm)

3.2.1.1 Technology-related barriers

Technical risk of new technologies: Risk of failure tends to be a key barrier that affects new technologies, often involving technology suppliers and the ship owner i.e. top management. For example, the use of advanced rudders is considered as high risk of introducing new failures (Faber, et al. 2011). Furthermore, if ship owner views that new energy-efficient technologies would interfere with normal operations; there is a hesitation to invest (Marine Propulsion, 2015). For example, front-runners are usually companies who have the finances to provide sufficient competence training for calibrating and checking new technologies on board (Tobias Fleitera, et al, 2012).

Inadequacy of technologies*:* Certain energy efficient technologies are perceived to be not adequate or supporting infrastructure for adopting such technologies are not sufficiently developed. For example, a lack of infrastructure for dual fuel engines to operate is seen as a barrier (Holden, et al. 2014). In addition to that, incompatibility between technologies and ship types is also cited as a barrier. For example, the application of air lubrication is a technical energy efficiency measure which is aimed at reducing the drag resistance by reducing the viscosity of fluid near the hull surface. This was found to be unsuitable for certain types of ships. Similarly, the implementation of waste heat recovery was found to be not applicable or suitable with all ship types. The vast majority of shipping operations, with the exception of cruise liners, do not produce enough power or heat to power waste heat recovery technologies (Faber, et al, 2011). Thus, the market tends to be responsible for the creation of this barrier while technology suppliers and subsequently, the management are affected by this.

3.2.1.2 Information barriers

An exhaustive list of information barriers are identified in the literature (Jafarzadeh & Utne, 2014). However several of these barriers tend to be more related to competence such as not using information, not maintaining information and a lack of interest that would fall under internal barriers. This category of barriers represents all the external barriers related to the flow of information on energy efficient technology.

Lack of information: A high level of competition within the shipping sector has an impact on the level of information sharing among various companies (Antapassis, et al, 2009). This results in some ship owners not having sufficient information of the cost and benefits of various energy efficient technologies. Furthermore, there is asymmetric information when it comes to determining the quality of a vessel where sellers of second hand vessel have more information on the vessel quality than buyers. This is due to the fact that classification societies do not differentiate between high quality and low quality vessels (Strandenes, 2000). It can also be argued that international bodies are partially responsible for the lack of information since it can be challenging to implement higher levels of transparency among shipping companies.

Lack of confidence in information: Energy efficient technologies in the shipping sector are not regulated; in terms of having an international body that provides classification of various types of energy efficient technology. While the IMO serves as an international body, the provision of international guidelines and standards are frequently limited to safety of operations. For example in the building sector energy performance classes are outlined by the European Norm EN 15232 that technology suppliers adhere to when providing details of energy savings obtainable. Another reason for a lack of confidence in information provided stems from the fact that it is often challenging to allocate fuel savings to different measures and verify the energy saved. External conditions are often not fixed while operating a vessel or there may be varying weather conditions making it difficult to identify energy savings realised. For example, significant cost savings is expected from low friction hull coatings but cost savings is often hard to prove. Key performance indicators can help to improve the confidence in these cost saving measures. This is elaborated more in Chapter 4.

3.2.1.3 Economic barriers

Access to finance: Access to finance tends to impact smaller ship companies, as big ship owners usually are able to have access internal funding or relatively easier access to loans (Wang, et al, 2010). In many cases, this is also an effect of capital suppliers unable to see the value in evaluating the investment for which capital is being provided (Thollander & Palm, 2013). Furthermore, the market also tends to impact the level of finances available. Usually during a bust period, access to finance tends to lower impeding investments on energy efficiency.

Market risks*:* In the last few years, crude oil prices have ranged from nearly $150 to as low as $30 per barrel. Fuel cost fluctuations insert a significant uncertainty into an energy efficiency investment. For example, waste heat recovery systems in 1970s and early 1980s where not considered to have a positive net present value mainly due to cheap fuel (Wang, et al, 2010). Such trends continue to exist today, given the steep decline in prices. Market risks also exist in the area of shipping market cycles. Especially for the containership sector, they go through significant boom and bust cycles. For example during the Christmas boom periods, ship owners are reluctant to take a vessel out of service (i.e. miss out on high freight rates). Scheduled maintenance works or investments in energy efficiency usually do not take place during this time. During a bust period, lack of access to capital again tends to impede such investments (Wang, et al, 2010)

Misalignment of benefits with normal operations*:* The dynamic nature of shipping operations often causes misalignment of expected benefits. Given the need for flexible vessels, trading along different trade routes leads to design and construction of ships that are not necessarily optimized for specific voyages (Wang, et al, 2010). For example, the level of fouling varies greatly with the waters in which ships ply (Woods Hole, 1952). Despite the proven benefits of alternative coatings such as advanced silicone or fluoropolymer paints systems, they are still considered too expensive since the operating profiles of ships are market driven and may not always be able to justify the costs. In other cases, energy efficiency improvements are not put in place due to risk of misalignment with charterer requirements. For example, a charterer may outline certain limitations on level of engine power. Waste heat recovery processes could require a higher engine power than that is stipulated by the charterer (Jafarzadeh & Utne, 2014). In addition to that, energy efficiency tends to be route dependent. This can be observed from the development of energy efficiency indicators for several operating profiles (MEPC, 2012).

3.2.1.4 Regulatory barriers

The complex inter-relationship between classification societies, flag states and the IMO tends to have implications on the level of energy efficiency in shipping operations. While the IMO provides several guidelines on hull, structures, machinery and equipment that ensure safe and efficient operations, they may not have sufficient rights or competencies to enforce these regulations. Classification societies and shipping registers are entrusted to carry out these responsibilities. Few registers may not be trusted to properly administer and oversee the rules and regulations outlined due to lack of resources or competence to properly oversee internationally trading ships. While this does pose trading restrictions for these sub-standard ships, it has a small impact on companies with fixed trading routes (BIMCO, 2014).

Furthermore, several regulations imposed for environmental reasons can also indirectly increase fuel costs. For example, engine manufacturers slowing down combustion processes to comply with NOx emission regulations leads to increased fuel consumption (Jafarzadeh & Utne, 2014). Hull cleaning for certain types of hull coatings are not allowed at port, offshore operations can significantly increase fuel costs (Wang, et al, 2010). Ballast water treatment systems reduce pollution but increase fuel consumption.

3.2.2 Internal barriers (within the firm)

3.2.2.1 Behavioural barriers

Lack of interest: While reducing fuel costs is agreed to be the most important priority among others for shipping companies, a lack of interest can still result from perceived lack of incentive for investing energy efficient technologies. While ships that are more energy efficient could theoretically have higher charter rates in the market, in practice it is difficult to guarantee improved fuel consumption, since the speed is heavily impacted by varying sea conditions. Although there could be industry standards established for speed and fuel consumptions, technologies more efficient than the industry standard usually do not receive a premium price (Wang, et al, 2010, p. 23). The premium price for more efficient ships is again not justified since owners may not procure the ship for its entire lifetime.

Inertia: This refers to the resistance decision makers have to change. This can be observed at several levels within the organisation. At a consortium level, there is a presence of “closedness” that makes new insights and knowledge difficult to permeate the system. Also there is a promoting of “in-group” culture that also tends to reject contributions to problem solving from the outside. However increasingly we also see a change in mind-set of several consortiums (Roggema & Simith, 1983). Within a shipping company, the ship owner may also show signs of inertia. For example, new designs that could inherently be more efficient are not easily accepted to reduce the uncertainty in decision making (Faber, et al, 2011).

Imperfect evaluation criteria*:* Decision makers might at times lack the proper knowledge or criteria to evaluate investments, often adopting approximate criteria or routines (Decanio, 1993). This behaviour tends to be present in the shipping sector with regards to choosing payback period as evaluation criteria over more robust evaluation criteria such as net present value. A key reason for this behaviour is because ship owners do not typically expect to own a vessel for its entire life (Wang, et al, 2010).

3.2.2.2 Organisational

Split incentives*:* The principal agent problem (i.e. split incentive component of the agency theory in context of energy efficiency) has been covered quite extensively in the literature for the shipping sector (Jafarzadeh & Utne, 2014), (Rehmatulla, 2015), (IMO, 2009). Typically, the stakeholders involved are the charterer (principal) and the ship owner (agent), where the interest of the charterer focuses on the operating costs of the ship and the ship owner on capital costs. This misalignment of interests is a result of the type of shipping contracts that are used in the industry. Table 3-2 below describes how in a time charter, the principal pays the energy bill but cannot select the technology resulting in an efficiency problem. In the case of split incentives, it might not be accurate to mention that it is only due to a ship owner’s lack of incentive. A lack of regulatory framework or guidelines around the development of time charter contracts is also suggested as a cause for this barrier.

Table 3-2: Principal agent problems in shipping contracts

	Principal selects technology	**Principal cannot select technology**
Principal pays energy bill (direct energy payment)	No principal agent problem Cargo owner operated ships	Efficiency problem Time chartered ships
Principal does not pay energy bill (indirect energy payment)	Usage and efficiency problem	Usage problem Voyage chartered ships

Extracted from (Rehmatulla, 2015)

Lack of authority*:* This is usually a barrier in organisations that do not employ an energy manager or does not have strong energy management processes in place. Usually the ship manager may not have sufficient authority to put in place energy efficiency improvements. In addition to that, a ship manager's main responsibility is to ensure safety on board; energy efficiency is not his priority. This could be also viewed as a form of split incentive in the absence of an energy manager.

Bounded rationality*:* This refers to individuals and companies that tend to make satisfactory decisions instead of searching for optimal decisions. This is quite common in the shipping sector where a ship captain often uses a rule of thumb to make his decisions regarding voyage optimisation and weather routing. Similarly a ship owner may not always consider the optimal investment due to the inability to assess life cycle costs and also due to information overload (Rehmatulla & Smith, 2015). Bounded rationality could also have an impact on the crew. Crew that is often over-stretched in terms of time and resources often make sub-optimal decisions especially when it comes to measuring and verifying energy efficiency on board (Interviewee IV, 2015).

Company culture*:* As with many other sectors, company culture tends to influence the way the organisation operates. A group of individuals motivated by environmental values may benefit energy efficiency improvements as a whole. This tends to involve mainly the top management that has a trickle-down effect throughout the entire company. Maersk, for example, outlines "constant care" for the environment as part of its company values. The company culture in Maersk is an important contributing factor to the success of the Triple-E class containership being a first of its kind in setting standards on energy efficiency. A majority of shipping companies still do not inculcate an "energy culture" within their organisation.

Communication issues: Within the shipping sector, communication issues pertaining to energy efficiency improvements often arise between the ship manager and the technical superintendent. The varying expertise in commercial and technical fields between these stakeholders often results in a breakdown of communication and disagreements over the planning and implementation of energy efficiency measures. The role of an energy manager is also to improve the communication among these various groups of experts. The expertise and external influence of the energy manager often plays an important role in improving the communication.

3.2.2.3 Barriers related to competencies

Maintaining accuracy in information: While this is also an information barrier, this tends to be focused almost entirely on the crew behaviour related to the measurement and verification of fuel consumed, When fuel measurement equipment is installed on board, there is a tendency for crew complacency to not optimise the use of information. For example, fuel consumption data can be logged every hour, but it is only logged every 24 hours. Furthermore, the storage tanks needs to be usually cleaned out for accurate fuel consumption measurements. If the crew fails to clear out the sludge and water periodically, this would impact the accuracy of information. In some cases, fraudulent methods of fuel reporting can be done by filling up fuel pipes connected to the tank storage, main and auxiliary engines. Regulations can be partially contributing to this barrier since there is currently no regulations that require that pipes and engine should be empty (Interviewee III, 2015).

Crew's lack of competence: New technologies tend to challenge the level of crew competencies in utilising them properly. For example, in the use of dual fuel engines, new expertise would be required in understanding the chemical reactivity of natural gas to prevent "engine knocks". Crew would also need to familiarise with new engine designs and control systems (Crawford, 2015). Furthermore, fault diagnosis in new technologies such waste heat recovery processes on board would require additional training of crew (Interviewee IV, 2015). This tends to be an important condition when it comes to investing in new energy efficient technologies. Furthermore, crew is usually trained for safety and maintenance and not energy efficiency, as such there would still be a lack of competence in utilising energy efficiency despite training (Jafarzadeh & Utne, 2014).

Manager's lack of technical expertise: Similar to crew competence, the technical expertise of both a ship manager and energy manager can also be a barrier. For example, ship managers may not trained adequately in the technical operations during a voyage making it difficult for them to understand reasons behind a lack of energy savings that then translates to financial savings. It also at times leave the ship manager rather dependant on the inputs from the technical superintendent. Similarly a lack of staff training for energy managers presents a significant barrier in ensuring that other stakeholders such as the technical superintendent and on-board crew has more confidence in their energy management strategies (DNV GL, 2014).

Organisational change: When energy managers or crew resign, there is a relatively high level of knowledge that may be lost. This is especially the case when such personnel have worked on specific on-board energy monitoring and management systems. The process of re-hiring and re-training can result in significant costs to the organisation.

3.2.3 Economic barriers

Access to finance: Access to finance tends to impact smaller ship companies, as big ship owners usually are able to have access internal funding or relatively easier access to loans. In many cases, this is also an effect of capital suppliers unable to see the value in evaluating the investment for which capital is being provided (Thollander & Palm, 2013). Furthermore, the market also tends to impact the level of finances available. Usually during a bust period, access to finance tends to lower impeding investments on energy efficiency.

Market risks: In the last few years, crude oil prices have ranged from nearly $150 per barrel to as low as $30 per barrel. Fuel cost fluctuations insert a significant uncertainty into an energy efficiency investment. For example, waste heat recovery systems in 1970s and early 1980s where not considered to have a positive net present value mainly due to cheap fuel (Wang, et al, 2010). Such trends continue to exist today, given the steep decline in prices. Market risks also exist in the area of shipping market cycles. Especially for the containership sector, they go through significant boom and bust cycles. For example during the Christmas boom periods, ship owners are reluctant to take a vessel out of service (i.e. miss out on high freight rates). Scheduled maintenance works or investments in energy efficiency usually do not take place during this time. During a bust period, access to capital again tends to impede such investments (Wang, ete al, 2010)

Misalignment of benefits with normal operations: The dynamic nature of shipping operations often causes misalignment of expected benefits. Given the need for flexible vessels, trading along different trade routes leads to design and construction of ships that are not necessarily optimized for specific voyages (Wang, et al, 2010). For example, the level of fouling varies greatly with the waters in which ships ply (Woods Hole, 1952). Despite the proven benefits of alternative coatings such as advanced silicone or fluoropolymer paints systems, they are still are considered too expensive since the operating profiles of ships are market driven and may not always be able to justify the costs. In other cases, energy efficiency improvements are not put in place due to risk of misalignment with charterer requirements. For example, a charterer may outline certain limitations on level of engine power. Waste heat recovery processes could require a higher engine power than that is stipulated by the charterer (Jafarzadeh & Utne, 2014). In addition to that, energy efficiency tends to be route dependent. This can be observed from the development of energy efficiency indicators for several operating profiles (MEPC, 2014).

3.3 Effect of barriers on the decision-making process

Having reviewed the various categories of barriers within the shipping sector, a conceptual framework is proposed to analyse how barriers impact the decision to adopt and implement energy efficiency improvements. This study adopts the four stage decision making framework developed in Chapter 2 for our analysis of barriers. While this is a preliminary attempt, the research here takes first steps in aligning the barriers identified with the stakeholders involved at different stages of the energy efficiency process. This helps to provide useful insights to policy makers and to the industry about the stages most affected by barriers as well as the relevant stakeholders to target. Figure 3-1 summarises which barriers and stakeholders are involved in each of the four stages of the energy efficiency decision making process.

3.3.1 Barriers affecting awareness

In Stage 1, top management but also the energy manager is involved in generating awareness about the cost savings realised by energy efficiency measures. Often the energy manager interacts closely with top management and helps to improve the level of awareness pertaining to several energy efficiency measures. It could also work the other way around where top management employs the services of an energy manager to create higher levels of awareness pertaining to the level of cost savings realised. Barriers involved in this step are usually external in nature that include technology related barriers, information, and economic barriers. However top management is also susceptible to behavioural barriers for example using imperfect evaluation criteria when evaluating the benefits of certain energy efficiency measures.

3.3.2 Barriers affecting motivation

As part of Stage 2, sufficient motivation may not be generated if the shipping company fails to drill down the details pertaining to energy efficiency improvements or it is unable to accurately identify specific areas of improvement within the company. This involves asking where, when and how shall resources be allocated to bring about the improvements. In answering the "when, where and how" of energy efficiency improvements, often the technical superintendent and the ship manager needs to work closely with the energy manager to advise top management on how this can be done without significantly impacting commercial ship operations. Barriers involved in this step include information, behavioural, organisational and competence related. With the exception on information related barriers, the rest tend to be internal barriers. Information related barriers tend to restrict the quantification of cost saving measures.

3.3.3 Barriers affecting implementation

In Stage 3, on-board crew has a significant role in terms of implementation. This is especially the case for operational energy efficiency measures. The technical superintendent has a supervisory role over technical energy efficiency measures. Barriers involved in this step include regulatory, behavioural, organisational and related to competence. With the exception on regulatory barriers, the rest tend to be internal barriers. Regulatory barriers are included here mainly with regard to level of implementation. Given the international nature of the shipping sector there tends to be a lack of regulatory oversight on energy efficiency practices. Safety and increasingly low emission practices are starting to be more common.

3.3.4 Barriers affecting reporting

The fuel reporting carried out by the crew and accounting of cost savings usually carried out by the energy manager are the two primary activities as part of Stage 4. Barriers involved in the process are almost always internal barriers. Behavioural barriers such as a lack of interest as a result of misaligned incentives and competence related barriers such as not maintaining accuracy of information and a lack of competence are commonly present with the crew. Organisational barriers could also affect reporting. For example, in the absence of an energy manager the accounting of cost savings may not be as rigorous i.e. accounting may be done monthly instead of on a per voyage basis.

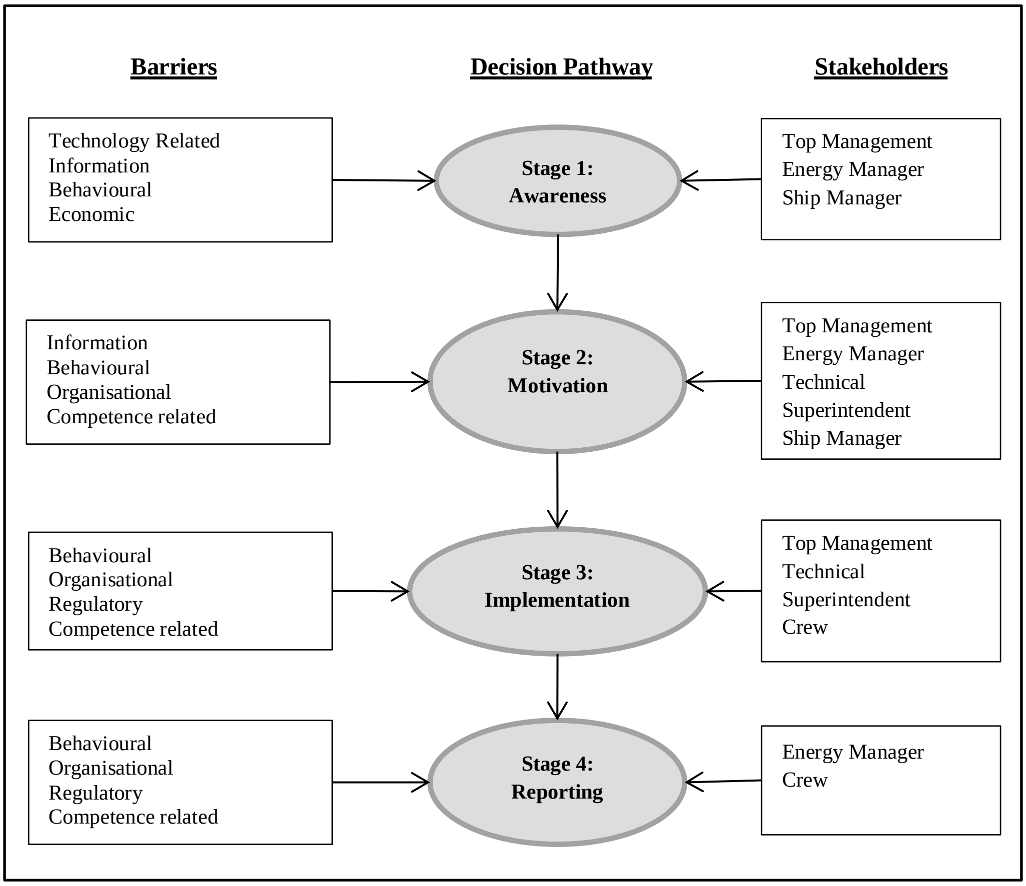


Figure 3-1: Overview of barriers and stakeholders involved in decision making

3.3.5 Interaction between barriers

Understanding barrier-barrier interactions is crucial for effective energy efficiency policy making as well as decision making (Chai & Yeo, 2012). The analyses in the previous sections highlighted the importance of internal barriers on energy efficiency decision making process. Furthermore, Table 3-1 shows the significant involvement of top management in several of the barriers outlined. A preliminary attempt was made to illustrate potential interactions that exist between barriers as well as understand qualitatively how top management influences the process. Figure 3-2 illustrates these interactions as a causal loop diagram[1]. The detailed barrier analysis

[1] A more rigorous discussion on the use of causal loop diagrams is presented in Chapter 4

as part of Section 3.2 served as inputs to outlining the causal relationship between barriers.

An important observation made was that certain internal barriers were created (or at very least reinforced) as a result of *decisions* that were made with regards to the adoption of energy efficiency. For example, management that has low awareness of the impact of energy efficiency measures has less willingness to invest in an energy management team that could lead to management's lack of technical expertise with regards to energy efficiency. Additionally, a reduced level of motivation amongst top management could lead to poor company culture, less resources committed for crew training on energy efficiency as well as a lack of interest.

From Chapter 2 discussions, it is evident that top management is predominately responsible for the transition from high level of awareness to high level of motivation on energy efficiency adoption. Top management is also highly responsible for the company culture and hiring of suitable technical expertise. This influence of top management in the overall energy efficiency decision making process as well as on barrier creation is illustrated in Figure 3-2 as thick arrows. It shows the connection between awareness and motivation is a critical pathway that has significant implications on the creation of internal barriers downstream. It also shows that reducing the level of barriers to improved awareness of energy efficiency adoption is highly external in nature.

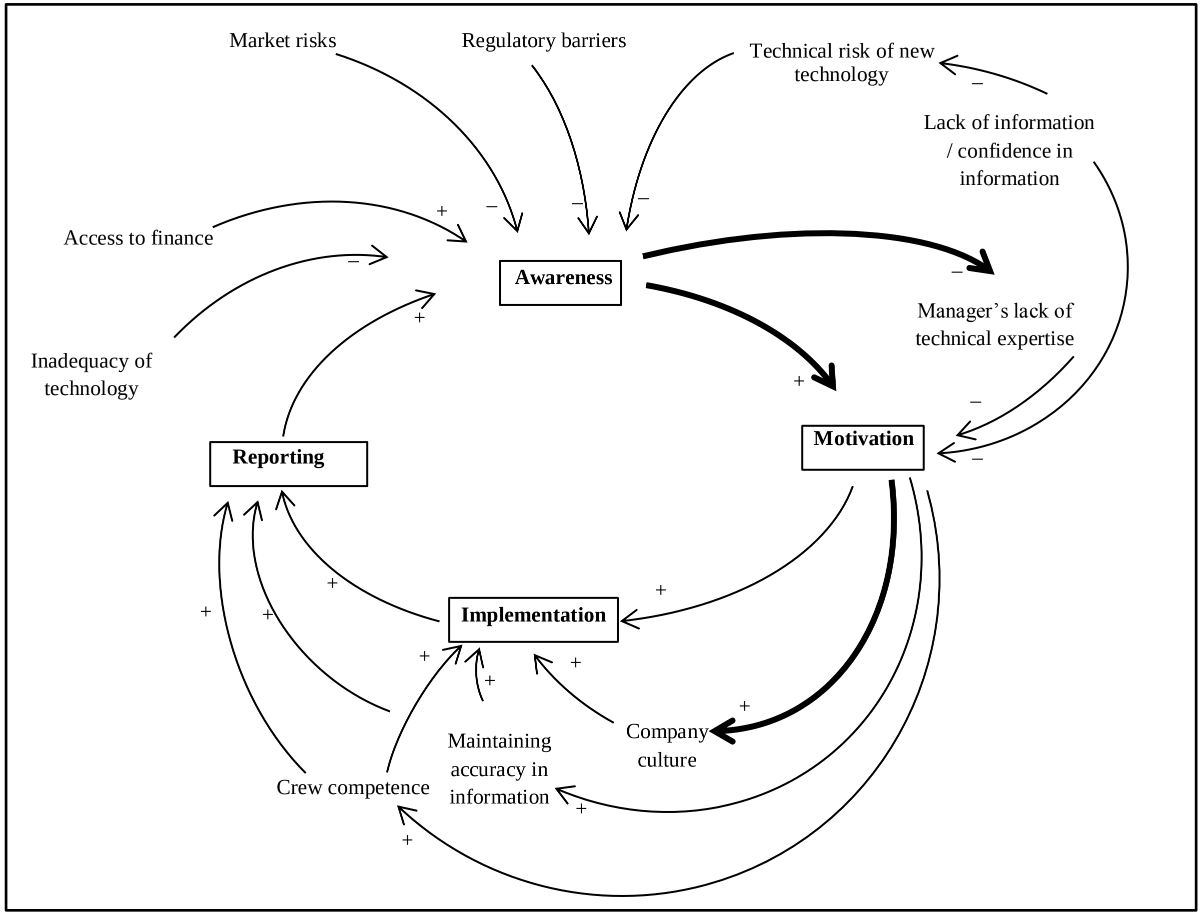


Figure 3-2: Interaction between barriers

3.4 Concluding remarks

In summary this chapter provided a new taxonomy of energy efficiency barriers encountered in the shipping sector. External barriers were distinguished from internal barriers to outline how various stakeholders were involved in the creation of barriers. The influence of barriers on the decision making process was also further investigated. The following are key results from this chapter:

1. Top management was found to significantly impacted by external barriers as well as involved in the creation of internal barriers
2. Internal barriers were found to be predominately impacting the motivation, implementation and reporting of energy efficiency adoption
3. Top management that is predominantly responsible for generating higher levels of awareness and motivation for adoption of energy efficiency measures was identified as a critical pathway that leads to the generation of several internal barriers.

This chapter also provides motivation for public policies to be more targetted at top management in reducing barriers to increased levels of awareness and motivation. Several international efforts are already underway to improve this. One of the ways pertains to the development of KPIs. In the next chapter, KPIs within the shipping sector is studied in greater depth.

4 FUNDAMENTAL USE OF KPIS IN SHIPPING

This chapter focuses on understanding the fundamental use of KPIs in the shipping sector, particularly KPIs that trace energy performance, through the formulation of the root definition of relevant systems and building conceptual models. The importance of key performance indicators (KPIs) is highlighted by (Gray, et al, 2015) that mentions organisations are dependent on "proxies" in their attempt to represent true performance. While the overall objective is to understand the challenges and opportunities of improving *energy efficiency* in the shipping sector, often safety and operational decisions made affects the overall *energy performance* of the shipping system.[2]

This chapter starts with the unstructured problem situation guided by the following research question (Research Questions 1,2 & 3 is addressed in previous chapters):

> Research Question 4: How are KPIs used in the shipping sector to improve energy performance?

The problem definition and the root definition of the system are presented in Section 4.1 and 4.2. Conceptual models through causal loop diagrams are presented to illustrate the interactions between various factors that impact energy performance in Section 4.3. These help to provide a basis upon which KPIs can be developed. The key result of this chapter identifies relevant KPIs for energy performance as well as potential conflicts with other safety and operations related KPIs.

---

[2] Energy performance can be referred to the optimal use of energy on board so as to increase the margin of profit or the growth of revenue.

4.1 Approach using causal loop diagrams

Representing a system with systems dynamics is done by using the causal loop diagram (CLD). It includes the key system elements and the relationships among them, based on cause having an influence on effects. Causal loop modelling is a tool for mapping a set of relationships forming a 'system' – such as a policy, a strategy or a regulation. The end result is a 'picture' showing causal links amongst key drivers or influential variables which affect the system's behaviour or outcomes. Thus, a CLD reveals the systemic relationships (structures) underlying a complex system.

CLDs have been used extensively to represent system dynamics in the transport sector. One established reference is the development of Metropolitan Activity Relocation Simulator (MARS) that has been benchmarked against other published models to help decision makers in the development of cities (Pfaffenbichler, et al, 2008). Similarly the use of CLDs has been recommended to better understand transport planning that takes into account the number of transport system users, transport resistance, energy cost, pricing measures and infrastructure (Ermberger, 2000).

CLDs have also been extensively used in improving performance in supply chain dynamics. A CLD framework for improving demand management, delivering orders, managing the manufacturing flow and replenishment or purchases is presented in (Ermberger, 2000).

Most approaches to developing CLDs involve (1) collecting information about scientific or technical studies that endorse this causal relation, (2) an expert's opinion on the theme or a combination of both. In this study we use a combination of both whereby a causal relation is developed based on the literature and analysis from Chapter 2 and 3. These causal relations are then verified with an expert(s) from the shipping sector. The modelling approach (7 stages) proposed below is based on (Campuzano & Mula, 2011; Ermberger, 2000; Checkland, 1981).

1. **Defining the problem and formulating root definition:** The problem definition provides the basis and core purpose of building the conceptual model. The core purpose is always described as a transformation process in which an entity is transformed into a new form of the same entity (Checkland, 1981). The analysis conducted takes into account several factors to identify the root definition in providing the necessary characteristics required for successful modelling of the system.

2. **Defining first-order influences:** Based on the problem definition, first order influences are centred on what factors directly increase or decrease energy consumed on board. This has to be also assessed together with the resulting effect of increased energy consumption on board. Through Chapter 2 findings, a preliminary first-order influence on energy consumed on board is proposed. This is further refined though industry consultation.

3. **Defining second order influences:** Second order influences must have an influence on the first order elements. The three pillars of sustainability, economic, environmental and social were used as a basis to outline three key areas of second order influence (Hansmann, et al, 2012). Sustainability being a key tenet of improving performance in the shipping sector helps to provide a more structured and organised approach of developing relevant factors that have a second order influence. Second order influences are discussed in three domains; operational performance, environmental compliance and safety performance.

4. **Defining third-order influences:** According to (Ermberger, 2000), the previous two steps must be repeated with new elements that influence them.

Factors that are external to the system that influence ship performance in the three areas of sustainability are identified.

5. **Defining relations and feedback loops:** Relations among system elements is assigned by a positive or negative sign. If the sign of the relation is not clear, it is necessary to redefine the elements. Feedback loops are subsequently derived. Positive loops will be the motors of change, while negative ones will be the causes of system stability. It is necessary to identify the relations where there are backlogged materials or information lags (Ford, 2009). Four CLDs representing first order and second order influences as well as a combined CLD representing first, second and third order influences were developed

6. **Refining and validating the model:** A refinement of the model is carried out by either removing or simplifying non-relevant influences. The validation process was carried out by checking and verifying the initial five CLDs, developed in the previous stage, with a subject matter expert from DNV GL Shipping Advisory Services.

   This validation process was performed as per (Ermberger, 2000).

   At the beginning of the engagement, the method of causal loop diagramming was explained to the subject matter expert by using simple, intuitively understandable examples. After this phase the subject matter expert was able to understand mental models depicted with causal loop diagramming technique. The subject matter expert was then shown the five CLDs developed in Stage 5. The CLDs were discussed in detail and corrected where necessary.

7. **Devising possible solutions to the problem:** A comparative analysis relating the existing energy KPIs in the literature with the developed model was

carried out. This resulted in a “gap” analysis, sheds light on important factors and relations that are currently not included in performance measurement. In addition to that, it sheds light on conflicting KPIs with different objectives. The model also allowed energy KPIs developed at a ship level to be distinguished from those developed at a company level. Based on these analyses a refined set of energy KPIs is proposed.

There are two limitations to this approach that surround challenges in representing complex processes without making the causal loop diagram too complicated. Firstly the types of transport good are not distinguished. Time sensitive and high value transport goods can impact the speed, and distance travelled that subsequently impact energy consumption. Secondly, factors assessed to have weak interactions with energy performance during the literature review and interview process are not outlined.

Stage 1 is summarised in Section 4, 2. Stage 2 is outlined in Section 4.3. CLDs as a result of Stages 3, 5 and 6 are outlined in Section 4.4. The CLD as a result of Stages 4, 5 and 6 is outlined in Section 4.5. The analysis and results as part of Stage 7 is outlined in Section 4.6.

4.2 Defining the problem and formulation of root definition

From the exploratory interviews conducted as part of Chapter 2 problem formulation, a lack of standards when it came to fuel consumption monitoring was found to be consistent.

“when fuel is being reported, there are no regulations to ensure that the pipes connected to the tank and engines must be empty. Fuel reporting sometimes can be misrepresented by filling up or emptying the pipes” (Interviewee III, 2015)

“there is no proper checks in place or incentives to ensure that the data logged such as fuel consumption is based on actual operational requirements or basically tweaked to meet a guaranteed consumption level” (Interviewee II, 2015)

This provided sufficient motivations to analyse further how existing shipping KPIs are structured or not structured around energy performance. While energy performance is an important consideration within the shipping sector, most of these KPIs tend to focus on safety performance, operational performance, environmental performance as well as human resource performance. For example, the Shipping KPIs Standard outlined by BIMCO, the world’s largest international shipping association, provides very little guidance on developing KPIs for energy performance. The list of KPIs proposed by BIMCO is presented in Annex 2. Since energy consumption is very central to various processes on board, it becomes challenging to *identify the interaction between key factors* that affect energy performance. Furthermore, having too many KPIs could also result in conflicting results.

Besides not being able to properly outline the interaction between key factors that affect energy performance, *energy performance KPIs for the shipping sector can get extremely complex if not formulated properly*. One could take the example of a motor car and simply measure the fuel consumed per trip to provide a suitable energy performance indicator. While this may be the case for one vehicle, the situation gets far more complicated for a ship, where just measuring the fuel consumption is a challenging task. Furthermore, ships are subject to a large number of internal and external conditions that all tend to impact the level of energy consumed on the ship. The situation gets even more complicated when a fleet of ships is considered across a variety of shipping routes. It becomes evident that a single expression may be an over simplification of energy performance.

The problem statement can therefore be expressed as follows:

There is a lack of understanding in developing and utilising KPIs to improve overall energy performance for an individual ship or a fleet of ships

With the problem statement defined, the next step involves formulation of the root definition for the system in study. History of SSM research has shown that a successful root definition tends to incorporate certain factors within its formulation. These factors of a well-defined root definition are embodied in the so called CATWOE (Customers, Actors, Transformation, World view, Owners, Environmental Constraints) analysis (Asikainen, 2016). [Again, Table 4-1 must be referred to]

Table 4-1: Six fundamental factors (CATWOE) for root definition

Factors of CATWOE	**Description**
(C) Customers	The victims or beneficiaries of T
(A) Actors	Those who would do T
(T) Transformation process	The conversion of input to output
(W) World view	The world view which makes this T meaningful in context
(O) Owners	Those who could stop T
(E) Environmental constraints	Elements outside the system which it takes as given

The CATWOE analysis first begins by defining the "customers" of the system, which are the beneficiaries or victims affected by system activities. Customers are identified as the shipping company whom will benefit from the activities related to energy performance. Similarly the actors in this system whom would carry out the activities would refer broadly to the shipping company and its subsidiaries. The Owners who can stop the transformation also refers to the shipping company since it is ultimately up to them if they would want to go ahead with the transformation.

The transformation process which is central to the CATWOE analysis refers to the development, investment and implementation of energy performance measures. This could include the entire gamut of operational and technical energy efficiency measures as well as managerial decisions pertaining to scheduling of fleet voyages and measurement and verification of energy consumption on board.

As for the world view which makes the transformation meaningful, it would be to reduce the level of global CO_2 emissions.

The Environmental constraints in this case would broadly refer to prevailing market conditions. This is the case because often shipping company have to take into account client's request to deliver time sensitive cargo or are faced with very low freight rates without having much room for investments. Furthermore, increasing competition among shipping companies also reduces the transformational process. In addition to that, Chapter 3 summarises a number of energy efficiency barriers that serve as constraints to this transformation.

Based on the conducted CATWOE analysis, a simple root definition of the system can be formulated as follows:

An organisation comprising of onshore and offshore staff that optimises overall energy consumption through the development, measurement and verification of a set of related KPIs

4.3 First Order Influences: Energy consumption at a ship level

Based on the problem definition and root definition of the system, the energy consumption at a ship level was chosen as a starting point to identify first order influences.

The first question that was addressed pertains to the impact of increased energy consumption on board. Borrowing examples from transport economics, higher energy consumption on board leads to two direct outcomes, increased operational costs and increased emissions. HFO continues to be the primary fuel source for energy consumed on board ships. HFO contributes to 20 to 60% of the operating costs of a ship. It is noted that increased energy consumption through deliverable transport work also yields profit, however this will be included under second order influences. A significant amount of SOx, NOx and CO_2 emissions results from increased fuel consumption on board.

The next question relates to the factors that affect the increase in energy consumption on board. Distance travelled, speed of ship, time spent during a voyage, and the size of freight transported positively impact the energy consumed on board.

Analysing technical and operational energy efficiency measures proposed in the literature, two additional first order of influence factors were identified (ABS, 2011; DNV GL, 2014). The first factor "energy efficiency investments (EEIs)" involves the retrofit of energy efficiency technologies on-board. This includes technology upgrades such as improved propulsion system, engine modification, incorporation of a bulbous bow, implementing waste heat recovery systems etc. Certain operational energy efficiency measures that require additional software, training of staff or additional man-hours is also included in the first factor.

The second factor “scheduled maintenance” relates to the planned of servicing of the ship. This is distinguished from the first factor such that there is no additional technology, software or knowledge utilised to decrease the level of energy consumed on-board. Instead the regular in-service polishing to reduce surface roughness on propellers, hull cleaning, servicing of technical equipment during dry docking are some examples included under scheduled maintenance. Since regular maintenance has shown to improve energy performance on-board *over a period of time*, a delay has been introduced in the causal loop diagram (represented with the following symbol “││”).

A key finding from Chapter 3 was that awareness and motivation of energy efficiency adoption tends to be rather central to the creation of internal barriers within the company. Crew competence was a key “barrier” that contributed to this inefficiency. Furthermore, through industry consultations five direct measures as part of SEEMP was linked to crew competence. These measures include crew awareness, crew familiarisation and training, improved fleet management, improved cargo handling and best practices in energy management. Given the reasons mentioned above crew competence with regard to energy efficiency improvements is also incorporated as an additional first order factor. Figure 4-1 provides the first order causal influences on energy consumption on board.

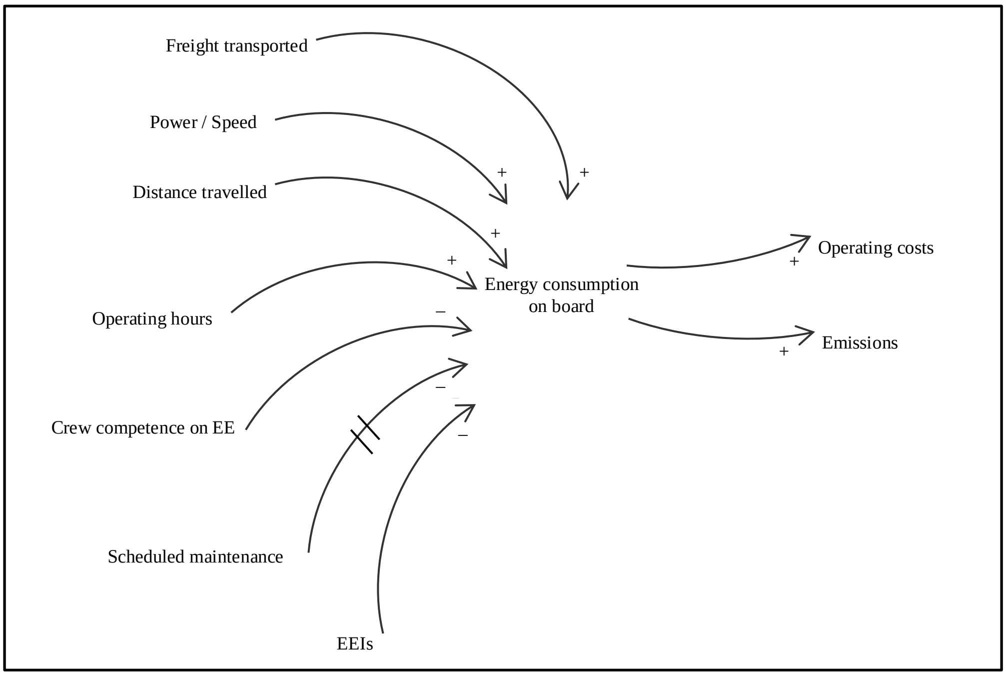


Figure 4-1: Causal relationships affecting energy consumption on board

4.4 Second Order Influences

Employing the three pillars of sustainability, second order influences are discussed in three domains; operational performance, environmental compliance and safety performance.

4.4.1 Energy and operational performance interactions

Operational performance is closely linked to productivity that includes profitability and operational costs. The following CLD diagram (see Figure 4-2) provides the causal loop interactions relating profitability and operational costs with increasing energy consumption. The profitability of a shipping company is directly linked to the freight rate charged to the customer as well as the freight transported (Taylor, 1976). The reinforcing loop (R) in Figure 4-2, suggests a higher freight demand leads to higher profitability that in turn increases the tonnage in service. Increased tonnage leads to increased freight, creating a feedback loop (Taylor, 1976).

As for the balancing loops (B) the increase in freight transported leads to higher energy consumption (through increased power or travelling additional distance and operating for longer periods) that in turn increases operational costs and freight rates. The causal link between freight rates and operational costs is relatively strong. Besides fuel prices, service charges, terminal fees as well as fines contribute to freight rates. Furthermore, longer distances would require more crew on board increasing the operational costs that is reflected in freight rates (MI Network, 2015).

There are two processes here that have delays. Operational costs leading to increased freight rates tends to be delayed usually since shipping companies instead of passing on the costs would initially attempt to optimise other forms of operating costs. Similarly profitability leading to increased tonnage takes time as the company requires going through several levels of decision making before procuring additional fleets. It also takes time before the new fleets are in service.

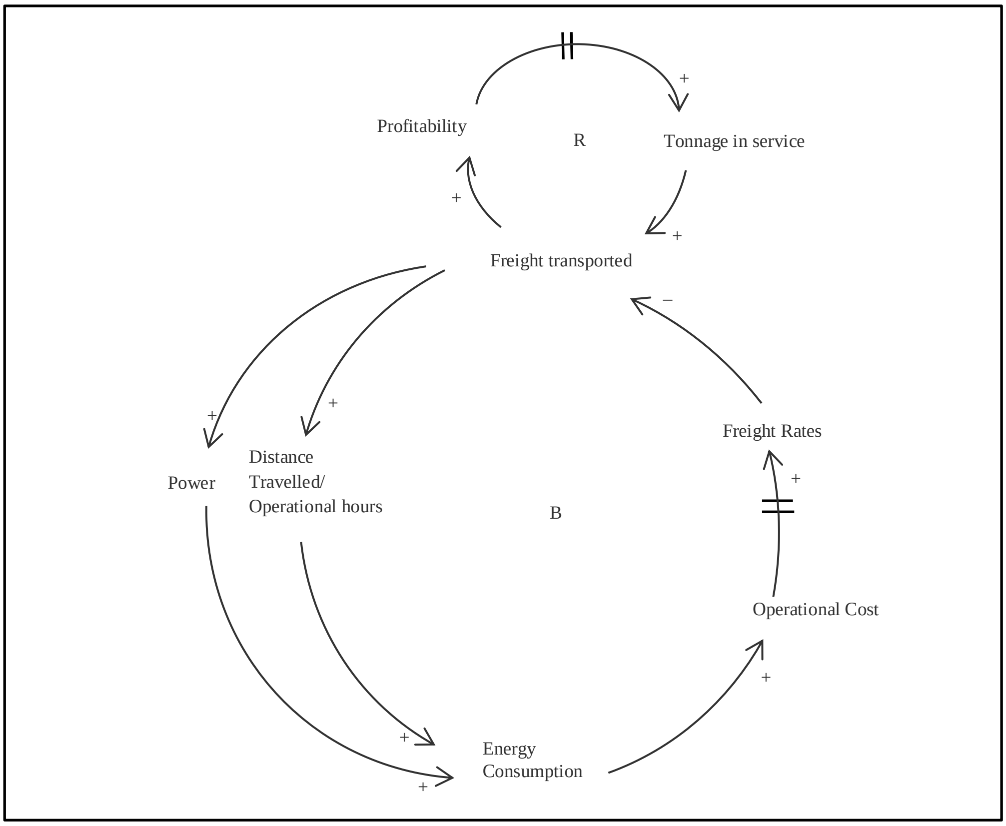


Figure 4-2: Second level interactions with operational performance

4.4.2 Energy and Environmental compliance interactions

Environmental compliance here is limited to CO_2 emission reductions. SOx and NOx emission reductions are not taken into account due to their relatively low degree of interaction with energy performance. In Figure 4-3 we represent the causal links where higher energy consumption leads to higher emissions. We assume HFO is the primary fuel type. An important factor here is port restrictions. Although it tends to be external in nature it has an internal impact on the tonnage in service (Bertho, et al, 2014). The IMO, through EEDI and other carbon reducing policies and guidelines have caused ports to become more stringent on the level of emissions produced at port (IMO, 2016). A reduction in the number of ports of call for a particular fleet would reduce the overall tonnage in the long run. This in turn helps to drive the perceived need for energy efficiency investments to capture more freight demand.

This is in contrast to government incentive schemes that help companies invest in EE technologies, more commonly seen in other national level sectors. This tends to shift the burden of reducing emissions to external intervention that reduces the perceived need for EE investment.

However, we also observe that both the balancing loops that help to reduce emissions are loops with delay. An increase in port restrictions will only reduce the polluting fleet of ships in service over several months or even years. Furthermore, the open maritime registry has created an environment where shipping companies can navigate away from expensive and heavily regulated jurisdictions and select instead registries environmental policy is less likely to be enforced (Buckley, 2008).

Similarly for EE investments, it requires time for implementation and actualisation of energy savings.

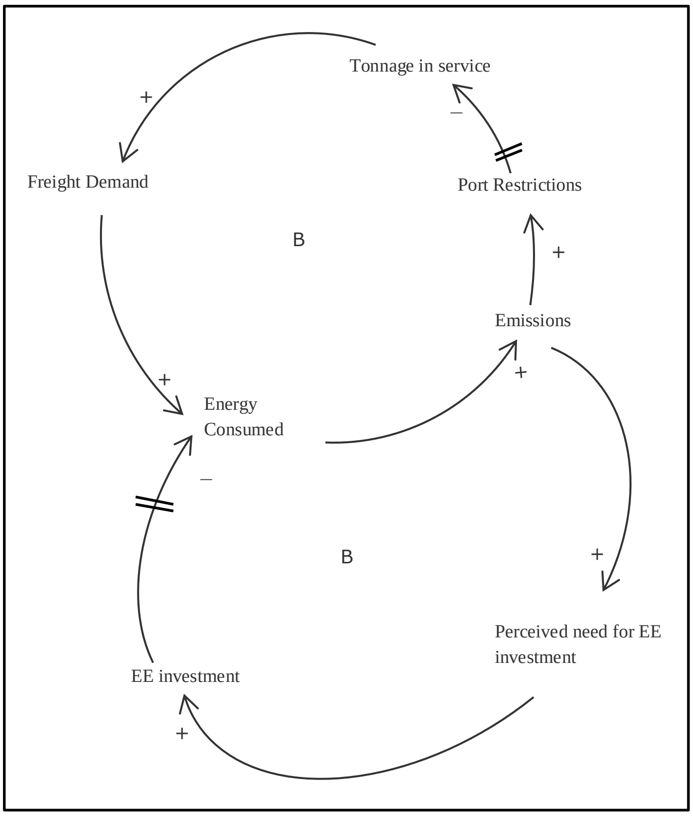


Figure 4-3: Second level interactions with environmental compliance

4.4.3 Energy and safety performance interactions

Safety performance is often paramount to the overall performance of any ship and its associated company. A combination of minimal manning, sequences of rapid turnarounds, short seas passages can lead to a higher number of operating hours per crew member without sufficient rest. This tends to result in a higher number of safety lapses (Jespen, et al, 2015). This is not only unique to the shipping sector but can be observed broadly across several other passenger and freight transport sectors.

Also in the presence of increasing safety lapses, the risk of investing in newer technologies is perceived to be higher by the company. Furthermore, the company is usually required to invest resources to train their crew to achieve higher levels of safety. In this aspect, the crew as well as the company is less likely to invest in more EEIs in the long run (Interviewee IV, 2015).

The importance of scheduled maintenance is emphasized in Figure 4-4. Scheduled maintenance includes hull and propeller cleaning, main engine performance tuning as well as other non-energy related equipment checking. It is found through discussions with shipping consultants and related literature that scheduled maintenance not only helps to improve energy consumption directly but also reduces the number of safety lapses (DNV GL, 2014).

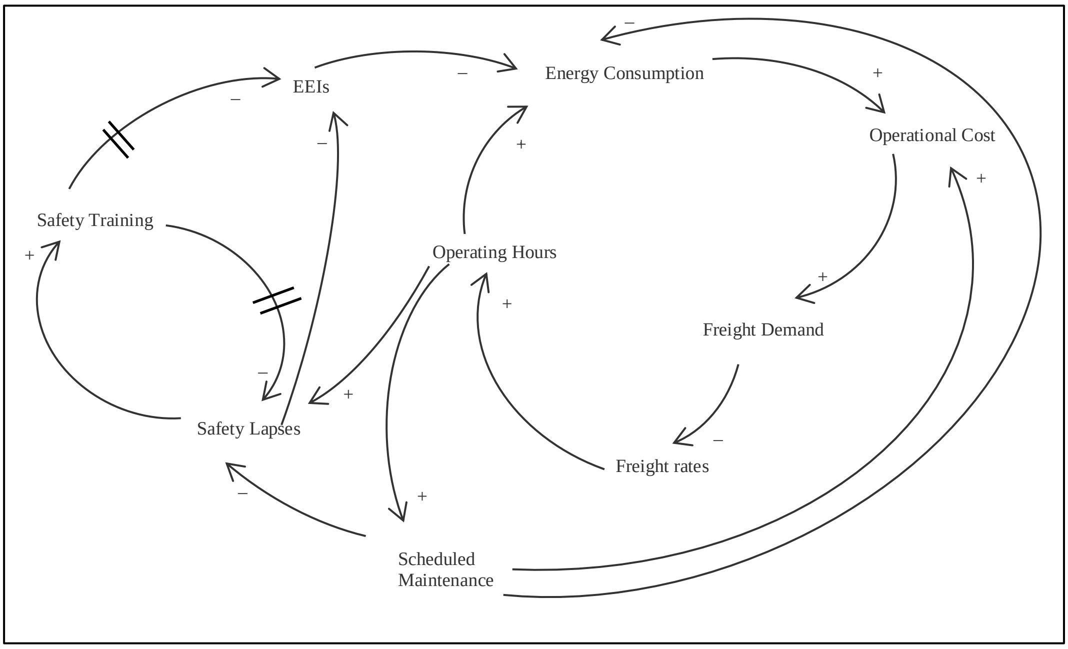


Figure 4-4: Second level interactions with safety performance

4.4.4 Modelling other second level causal loop interactions

Reducing manpower costs to improve short term operating costs is a common strategy among several sectors. The shipping sector is no different in terms of reducing crew size to reduce short term operating costs. This “quick fix” is represented by the balancing loop in Figure 4-5. However, reducing crew size would in turn mean number of operating hours per crew member is higher. This causes less time available for senior crew to train and junior crew to receive training on energy efficiency measures that in turn reduces overall competency for energy management. Training of crew was found to be an important barrier to energy efficiency improvements from previous chapter. Training here includes a wide number of measures that improve energy performance. Awareness raising, proper measurement and verification of energy consumption, training on effective implementation of measures are just some of the various training areas that are conducted or suggested to shipping companies (DNV GL, 2014). The reinforcing loop in Figure 4-5 suggests that over time, the solution of reducing crew size may not be a suitable option to reducing operating costs.

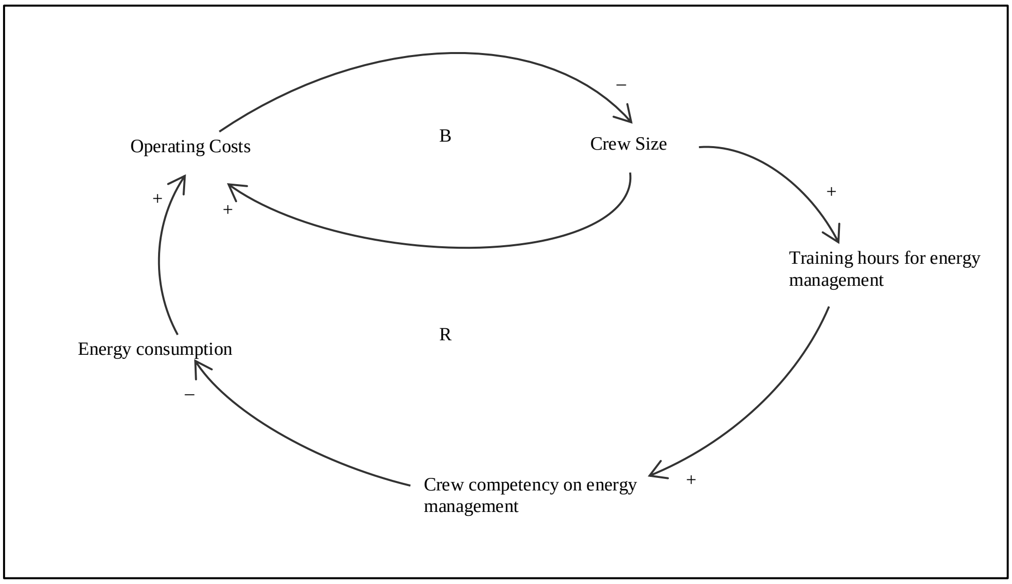


Figure 4-5: A fix that fails involving crew management

4.5 Third Order Influences: External factors affecting the system

Oil prices, external competition, global shipping incidents, port state control inspections and weather related risks are the external factors that were assessed in the existing model. The summary of the inter-relations is illustrated below in Figure 4-6.

A more detailed description of how each external factor impacts the overall system can be found in each sub section.

4.5.1 Oil Prices

Oil prices here refer to HFO prices that are pre-dominantly used as a fuel for ships. Freight rates are rather sensitive to unexpected shocks in the oil market. Freight demand on the other hand is not as elastic to changes in freight rates. In times of higher oil prices the freight demand reduction is not proportional to increase in freight rates (Poirier & Zaccour, 1990), especially the case of the oil tankers sector.

On the flip side, higher oil prices have improved the level of operational energy efficiency, for example the level of slow steaming that takes place on board. When oil spiked in 2008, it was reported that a significant focus was on reducing fuel costs through the deployment of newer, more efficient ships; reduction of travel speeds (slow steaming); and consolidation into larger vessels to amortize fuel costs (Tipping, et al, 2015).

An increase in oil price does also directly have an impact on the tonnage in service. As observed in the late 2000s, several smaller ships were decommissioned. However this is a delayed response as decommissioning of ships involves several layers of approval and reallocation of staff. The delay in response is even larger when the industry experiences low oil prices, since that would involve investing again in smaller ships or increasing the fleet size that have been previously decommissioned.

The interaction between oil prices and the perceived need for technical EEIs was also closely examined. Through the analysis it is found that there is no direct causal link between the two factors. At times of higher oil prices, shipping companies are generally not incentivised to make technical energy efficiency investments as consumers are still willing to pay higher freight rate. During lower oil prices while it seems intuitive that shipping companies have a higher profit margin that helps them to invest in energy efficient technologies, it is yet to be verified. Furthermore, oil price fluctuations are too erratic for shipping companies to use as a basis to make long term investment decisions (Husain, 2015).

4.5.2 Level of Competition

Increasing levels of competition can bring about several changes in the shipping industry. The container shipping sector provides several valuable lessons on how level of competition impacts overall shipping sector. Broadly the impacts can be analysed according to the size and maturity of the company. Larger companies such as Maersk tend to apply sustainability as a key tenet of competing better in the market. This is usually by increasing the level of EEIs in new builds, increasing the tonnage in service by building larger ships with higher carrying capacity (Barrass & Derett, 2012).

The impact of increased level of competition for smaller players in the market is different. Increased competition forces several smaller companies to focus more on short term measures. According to a 2014 study, the container shipping sector, especially smaller companies, faced lower earnings that are more volatile and were pricing at marginal costs (Glave, et al, 2014). Furthermore increased levels of competition often mean smaller shipping companies prefer their fleets to be in operation rather than be scheduled for maintenance unless it is mandated or regulated (Interviewee I, 2014). These "quick fix" measures were found to inadvertently increase energy consumption in the long term. For example, higher levels of competition leads to longer operating hours per crew this in turn leads to a lesser emphasis on training. Training of crew to be competent in energy efficiency technologies tends to be a key element not only for short term operational EE improvements as well as long term technical EE improvements.

4.5.3 Shipping incidents, weather related risks and PSC inspections

Shipping incidents at sea tend to influence the overall safety procedures on board. This is a sort of kick back response that ensures the shipping industry learns from various external incidents to better improve their safety performance. The model illustrates the conflict in safety performance and energy performance as increased focus on safety-related training could reduce the emphasis on energy management / training related to new technologies.

Furthermore, external weather related risks could encourage longer operating hours or additional distance travelled mitigating these risks also leading to additional energy consumption. It could also cause the ship to encounter higher currents that would increase energy consumption for propulsion. For simplicity the increased propulsive power due to weather related risk is outlined by a reduction in slow steaming. Port state control inspections could also lead to additional energy consumption, while ensuring a reduction in safety lapses.

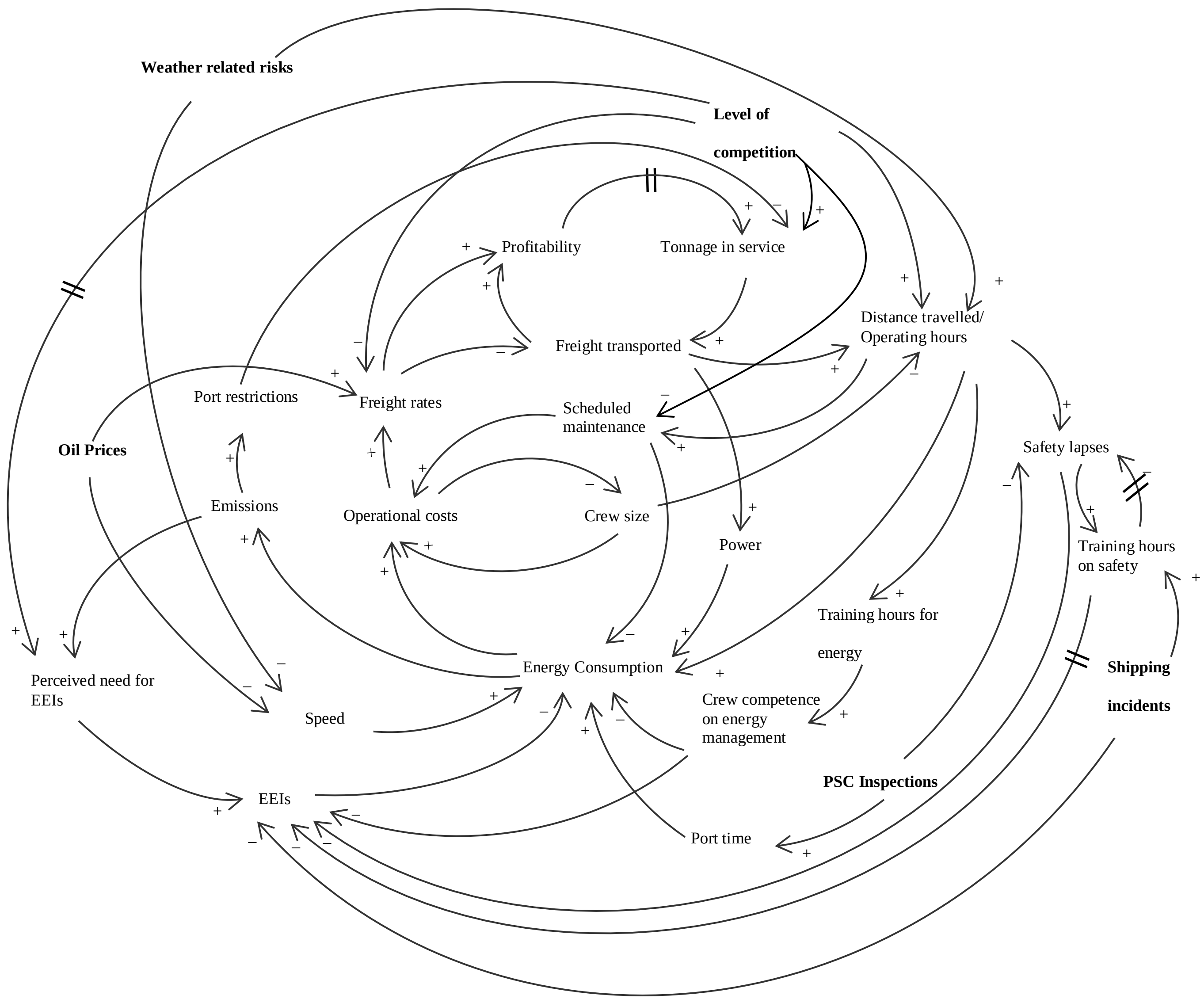


Figure 4-6: A summary CLD of energy consumed onboard

4.6 Analysis and Results

Although the use of KPIs is prevalent, there remains an underlying complex problem of correctly identifying and addressing trade-offs between a set of KPIs (Maani & Fan, 2008). As suggested by (Maani & Cavana, 2007) too many KPIs tend to lead to an over-reaction or redundant actions, wasting time and resources. The reason cited for this behaviour is because KPIs are very often viewed as 'linear' without paying attention to the interactions amongst them.

Quantifying the impact different factors have on the energy performance through weightage is intentionally left out in this analysis as it might lead to the universal conclusion that every company/fleet has the same priority of problems. Every company is unique and depending on the context, such weightages can be different for different companies. Even for the same company, the weights could change over time. What is found to be more useful is a framework outlining a series of factors that management can use to identify areas of improvement.

The CLDs developed in the previous section will be used in conjunction with existing KPIs to ascertain the dynamic interdependencies and trade-offs between individual and groups of indicators (Santos, et al, 2002). For instance, a better understanding of energy performance objectives at different level of analysis involving different stakeholders are valuable in assessing the redundancies of certain KPIs and the need to outline additional KPIs.

4.6.1 Comparative analysis with existing KPIs

Table 4-2 summarises the existing KPIs identified in the literature as well as through industry consultation on managing energy performance on board.

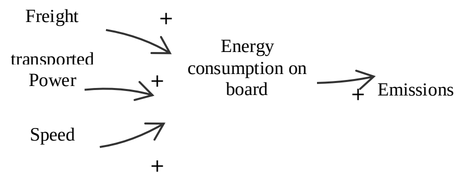
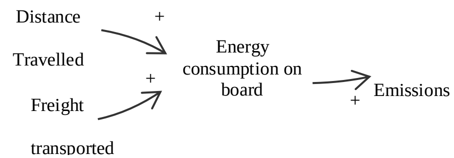
First order interactions are most commonly represented in existing KPIs. EEDI, EEOI and EVDI include a number of first order factors that affect energy consumption and subsequently carbon emissions. They collectively fall under the group of fuel consumption indexes. These indexes are generally used to assess ship performance across different operating profiles as well as to benchmark ship's overall energy performance with other ships of similar classes.

The other indicators such as service hours, engine efficiency, ballast water quantities and propeller slip measurements involve specific performance measures that impact the operational performance of a ship per voyage. They are usually measured on a per voyage basis and allow offshore crew to identify areas of improvement in each specific technical area.

Overlapping the existing set of KPIs with internal factors identified in the CLDs revealed several gaps (see Table 4-3). Although crew competence, scheduled maintenance, EEIs and operational costs have a first order interaction with energy consumed they are not part of existing energy KPI formulations.

Crew competence on its own is not easily measured, however the number of training hours allocated for energy efficiency can be a suitable proxy. Although energy consumed is a key component of operating costs, existing KPIs do not outline energy consumed as a fraction of operating costs.

Table 4-2: Comparison between existing KPIs

Performance Measure	**Description**	**Units**	**Representation in CLD**
Energy Efficiency Design Index	• Assesses a new ship's level of energy efficiency • Introduced by IMO in 2011 (regulated) • Measured at ship level • Usually used to benchmark theoretical performance across new ships	It is measured as in terms of CO2 emitted per ton.nautical mile . $\frac{\text{Engine power(kW)} \times \text{SFC}(\frac{g}{kWh}) \times C_F}{\text{Capacity (DWT)} \times \text{Speed (kt)}}$ SFC: specific fuel consumption CF : carbon conversion factor	
Energy Efficiency Operational Indicator	• Aims to help ship operators improve their energy efficiency through operational measures • Introduced by IMO in 2005 (voluntary) • Measured at a ship level • Can be used for different levels of analysis. Across voyages for single ship and across ships for a single time period	It is measured as the mass of CO2 emitted per unit of transport work $\frac{\sum_j FC_j \times C_{Fj}}{m_{cargo} \times D}$ *j* is the fuel type; FC_j is the mass of consumed fuel *j* C_{Fj} is the fuel mass to CO2 mass conversion factor for fuel *j*; m_{cargo} is cargo carried (tons) or work done (number of TEU or passengers) or gross tons for passenger ships D is the distance in nautical miles corresponding to the cargo carried or work done	

(Table 4-2 continued)

Performance Measure	**Description**	**Units**	**Representation in CLD**
Existing Vessel Design Index (EVDI)	• Measures the ship's theoretical CO2 emisssions per nautical mile travelled • Unlike EEDI, it is designed for application to existing vessels. • Measured at ship level • Usually used to benchmark across new ships • Not widely adopted (voluntary)	The formulation identical to EEOI.	Representation is identical to EEOI
Service hours	• Proposed as a new surrogate for transport work • Not widely adopted (voluntary) • Measured at ship level • Helps to benchmark running hours of main engine • Energy performance measure for single ship over a period of time or per voyage	Number of hours per voyage per ship Number of hours per annum per ship	Operating hours →(+) Energy consumption on board
Main / Auxiliary engine efficiency	• Commonly reported by crew • Main engine fuel consumption and the rotation work • Measured at ship level • Energy performance measure for single ship over a period of time or per voyage • Widely adopted	Measured in [g/kWh]	Power →(+) Energy consumption on board
Ballast Water Quantities	• Commonly reported by crew • Measured at ship level • Energy performance measure for single ship over a period of time or per voyage • Not widely adopted	Ballast water quantity transported for each voyage can be measured by the crew	Freight transported →(+) Energy consumption on board
Propeller Slip	• Not commonly reported • Using the theoretical and actual distance travelled the slip can be calculated on a per voyage basis	Measured in percentage	Distance →(+) Energy consumption on board

Table 4-3: A comparison between existing KPIs and energy performance factors

Factors involved in energy performance	Degree of interaction with energy consumed	Typical units of measure	Currently represented in existing KPIs
Energy consumed	N.A	Joules, tonnes	Yes
Freight transported	1st Order	Tonnes	Yes
Distance travelled	1st Order	Nautical miles	Yes
Operating hours	1st Order	Hours, days	Yes
Speed	1st Order	Knots	Yes
Scheduled maintenance	1st Order	Days, weeks	No
Crew competence on energy management	1st Order	Unavailable	No
EEIs	1st Order	Dollars	No
Operational costs	1st Order	Dollars	No
Emissions	1st Order	tonnes CO2	Yes
Port time	Higher order	Hours / days	No
Training hours for energy management	Higher order	Man-days	No
Perceived need for EEIs	Higher order	N.A	No
Safety lapses	Higher order	Number of occurrences	No
Training hours for safety	Higher order	Man-days/months	No
Freight rates	Higher order	Dollars	No
Tonnage in service	Higher order	Tonnes	No

4.6.2 Conflicting KPIs

One of the concerns of having too many KPIs is that conflicts may arise. Using the model outlined above, such conflicts can be identified using a more systematic approach. The Shipping KPI standard was launched for general use in 2010 by InterManager and later revised in 2012. It is now a de facto standard set of key performance indicators for ship operations and ship management. Details of the various KPIs outlined in Annex 2. These performance indicators were critically analysed and cross-referenced with the modelling results. Four KPIs were found in conflict with energy performance.

Ship availability: This is an operational performance measure. This representation suggests that a perfect score is attained when your actual unavailability is zero despite planned unavailability. This is in conflict with energy performance indicators since ensuring sufficient hours is being allocated and used for scheduled maintenance is a key element of improving energy performance.

Dry-docking planning performance: This KPI is a sum of the differences between agreed dry-docking and actual dry-docking duration and associated costs. Similar to ship availability, the target for this KPI is to ensure actual dry-docking duration and costs is minimal with respect to planned dry-docking duration and costs. This is in conflict with energy performance through scheduled maintenance. It is suggested that this KPI should not target absolute reduction in dry-docking costs and duration. Instead it should target minimal deviations between scheduled and actual dry-docking.

Flawless Port State Control Inspections: Through this KPI, PSC inspections are ideally expected to have zero deficiencies. Previous studies have estimated that this KPI has the largest contribution to health and safety as well as for security performance. This also suggests the importance of this KPI is due to its significant contribution to costs (Duru, et al, 2012). A port state detention of the ship can be very costly in terms of off hire. In a highly competitive environment, companies may spend additional resources in terms of man-hours and fuel to avoid such costs.

Budget performance: Similar with flawless PSC inspections, budget performance has the highest contribution to operational performance. Through our analysis we have observed that to reduce operational costs, the system requires reductions in scheduled maintenance, crew size or energy consumption. Both crew size reductions as well as reducing maintenance time have feedback loops that would increase energy consumption.

4.6.3 Proposed energy KPIs as part of this research

Based on the analysis done in Sections 4.6.1 and 4.6.2, it is found that most KPIs for energy performance are currently outlined for "ship level" measurement and analysis. While ship level indicators are beneficial to benchmark performance with other ships of similar class and size, it is suggested in Chapter 2 how several decisions pertaining to energy efficiency are made at a higher level involving top management, energy manager, ship manager and/or the technical superintendent (referred to as "company level") . In other words, company level KPIs would provide a more holistic picture of ship fleet performance and help provide a more informed decision pertaining to the energy performance or energy efficiency improvements. Table 4-4 provides a summary of 4 company level KPIs and 2 ship level KPIs for energy performance measurement proposed through this study.

Table 4-4: Proposed KPIs as part of this study for the shipping sector

Level	Key Performance Indicator	Areas of influence
Company	**Energy competence factor:** Training hours allocated for energy performance per operating hours	Energy management Crew awareness Familiarisation & Training
	EEI performance tracking: $ invested on EEIs Avoided energy costs (theoretical versus actual)	Technical performance benchmarking Energy management
	Route efficiency: Actual distance / theoretical distance travelled	Voyage planning
	Utilisation factor: Actual freight transported / capacity	Voyage planning Fleet Management
Ship	**Fuel Consumption Indexes** Power rating / freight transported / speed (kJ/ton.mile) Energy consumed / distance travelled * freight transported (kj / ton.mile)	Weather routing Speed optimisation Trim & Draft Optimisation
	Scheduled maintenance ratio: (Man-days allocated for scheduled maintenance + man-days for unscheduled maintenance) / total operating hours	Propeller & Hull Optimisation Engine Performance Optimisation

4.6.3.1 Company level KPIs

In outlining company level KPIs, the study utilised the gaps identified in the current KPI formulation (see Section 4.6.1) and cross referenced them with company level objectives pertaining to energy performance.

Voyage and fleet planning are company level objectives that are usually optimised based on the supply and demand of freight dynamics. While it is still unclear how exactly voyage and fleet optimisation is modelled across different companies (mainly due to commercial sensitivity) IMO does provide guidelines on how such planning of voyages is to be conducted (MEPC, 2000). The main objective of voyage and fleet planning as outlined in this document is to ensure safety of life, safety and efficiency of navigation and protection of marine environment. Several safety related considerations such as hazardous characteristics of cargo, provision of well rested crew and up to date certificates and documents concerning vessels are outlined. As such the extent of energy performance considerations within voyage and fleet planning is limited. Furthermore, it was suggested in the research that voyage and fleet planning usually falls under the purview of a ship manager who is usually not incentivised through energy-related KPIs.

Route efficiency and utilisation factor are two company level KPIs suggested for voyage and fleet planning to take energy performance into consideration. It is suggested to be used in conjunction with existing voyage and fleet optimisation to minimise the difference between actual and scheduled quantities. A discussion on the four company level KPIs proposed is presented.

Energy competence factor: Ensuring that crew deployed on the fleet is aware of energy performance and familiar with relevant energy performance measures on board are important company level objectives related to crew resource management. With higher levels of software sophistication and technical advancements, training related to energy performance is an ongoing operational requirement. Thus it is suggested to measure training hours allocated to energy performance as ratio of total operating hours. Total operating hours can be measured on an annual basis per ship and benchmarked against other ships. Similar to the airline sector where pilots require a certain number of simulation hours to keep their flying status current, ensuring the overall crew on board a vessel meets a minimum energy competence level would contribute towards certain minimum energy performance standards.

EEI performance tracking: This KPI proposed is track the performance of energy efficiency investments made on board. In Section 4.6.1 we have observed that while EEIs have a first order impact on the level of energy consumed on board, it is currently not formulated as a KPI. During one of the interviews, it was suggested that tracking the impact of individual energy efficiency improvements (operational or technical) can be challenging when done on a per voyage basis for a particular ship. Often at a ship level it is difficult to track this since fuel consumed is impacted by several factors that differ across various operating profiles and weather patterns. Tracking the absolute amount of energy investments as a performance measure can be observed in other sectors within the energy industry for example in international clean energy financing firms. Tracking energy costs at a company level on an annual basis is also relatively common in industrial energy performance tracking (Siemens, 2014). The amount of dollars invested in energy efficiency improvements and monitoring actual versus theoretical avoided energy costs is suggested as a company level KPI for EEI performance tracking. This could be tracked on an annual basis across the entire fleet of ships as well as across ships operating within a particular route. This would help provide critical inputs pertaining to the level of energy efficiency investments that could be made to improve energy performance based on different operating patterns.

Route efficiency: This KPI indicates the level of route efficiency between round trips. Drawing parallels with the airline industry, minimising excessive time spent on the ground during aircraft is an important component of aircraft scheduling. As such actual time spent between rotations is benchmarked with the time allocated according to schedule as a measure of overall performance (Jacobs, et al., 2012). Similarly in the shipping sector, voyages often involve a round trip of several days or months at a time. Besides proposing actual operating days as a function of scheduled operating days for a particular operating profile, actual distance travelled as a function of theoretical distance between round trips is proposed since service speeds can also be easily augmented from these indicators.

Utilisation factor: This KPI incorporates information about ship utilisation. While actual freight transported is frequently reported, actual freight transported as a fraction of ship capacity can provide a measure of how well the ship is utilised. This can be aggregated across different voyages for a fleet of ships that will represent transport load as a fraction of tonnage in service. Tonnage in service has a higher order interaction with energy performance and is not included in current energy KPI formulations.

4.6.3.2 Ship level KPIs

As for ship level KPIs, the literature suggests existing KPIs well represent the energy performance of ships on a voyage basis through fuel consumption indexes. Fuel consumption indexes are built utilising the four first order factors presented in this study; speed, distance travelled, freight transported and power rating in a number of ways. Two forms of fuel consumption indexes are proposed. The first form provides performance measurement of propulsion systems on-board. The amount of propulsion energy used to displace one tonne of ship over a unit distance. The second form is identical to the formulation of EEOI.

Besides fuel consumption index, the study finds that scheduled maintenance is not considered as a KPI for energy performance objectives. While it may be measured at a ship level, this is primarily for book keeping purposes. Regular maintenance has shown to improve energy performance. It has a first order interaction with energy consumption on board and has strong links to ensuring high levels of operational energy efficiency on board. Measuring the number of man-days allocated for scheduled / unscheduled maintenance as a fraction of total operating hours is one way of indicating ship energy performance.

4.7 Concluding remarks

In summary, Chapter 4 employed system dynamic tools to represent systemic relationships between various factors that impact the energy consumption within the shipping sector. A conceptual model summarising inter-relations between internal and external factors affecting energy consumption was presented. By aligning existing energy KPIs with the conceptual model, gaps and conflicts in the use of KPIs for energy performance were identified. Key results from this chapter include the following:

1. Current representation of energy KPIs usually involved first order interactions. Higher order interactions are often neglected in existing energy KPI formulations.
2. Internal factors that have first order interactions with energy efficiency such as crew competence and scheduled maintenance are not part of existing energy KPI formulations.
3. A large number of KPIs outlined in the shipping sector creates an avenue for conflicting objectives to arise. Four KPIs outlined for operational, security and budget performance was found to be in conflict with energy performance objectives.
4. Company level KPIs such as assessing the overall crew competence, tracking of energy efficiency investments, route efficiency and ship utilisation was proposed as part of this study to provide a more holistic picture of ship fleet performance

5 DISCUSSION AND CONCLUSION

Based on the multi-disciplinary research undertaken in this study, from decision analysis, barriers to understanding how performance is measured, this discussion section sheds some new light into overcoming some of the challenges and leveraging on the opportunities to improve energy efficiency in the shipping sector.

5.1 Improving energy performance through company best practices

Through this study, several gap areas pertaining to energy performance has been identified within a shipping company. Top management plays a critical role in the adoption of energy efficiency measures on board, but often their decisions are influenced by stakeholders who have lesser incentives for change. The reluctance to change age-old practices is a significant challenge within the shipping sector. Furthermore, fuel measurement and reporting vary from company to company, making it very challenging for ship owners to pin-point a particular problems pertaining to energy performance. While having an energy manager on board has shown to significantly improve the situation, again it is challenging to convince top management of particular set of measures if the fuel measurement and reporting is flawed or at very least inconsistent.

Having company best practices in performance measurement can improve transparency and data validity. While this study makes no attempt in providing any solutions, it does provide the key ingredients that would need to be present in order to enable best practices in energy performance.

The energy manager is involved in several critical pathways of decision making. As described in Chapter 2, the energy manager is responsible for providing sufficient motivation to top management for the approval of energy efficiency plans. He would also have to manage conflicting objectives with technical superintendent and ship manager. Having a set of company best practices on the development of energy efficiency measures would help to reduce some of the internal barriers encountered by the energy manager.

The importance of training and increased levels of crew competence was also shown to have a significant impact on adopting energy efficiency improvements on board. Such training requirements should be further engrained into the KPIs of energy managers and crew. On the area of KPIs, the research highlighted the importance of company level KPIs for improving energy performance. The use of improved route efficiency and better utilisation of freight transport as company level KPIs provide motivations for objective specific KPIs to be formulated

5.2 Role of policy makers in improving energy efficiency

The presence of barriers tends to create complexity for policy makers. While the presence of market failures implies that a market based measures would not be effective, command and control measures may also bring about unexpected outcomes from ship operators. For example, through minimum technical standards such as the adoption of EEDI, the perceived need for improving operational efficiency may be lower among ship operators. The key point is that policy makers need to be aware of the differentiated impact policies may have on related stakeholders when formulating policies. Also it helps to formulate a certain policy that could re-enforce positive behaviour with a number of related stakeholders.

One area that can be inferred from our analysis is how information can be used effectively in energy efficiency policy making. Information related barriers tend to affect two areas of energy efficiency decision making process; enhancing interest on energy efficiency and improving the knowledge of inefficiencies. Publications such as the IMO GHG Study 2009 and 2014 as well as guidelines relating to the adoption of on-board SEEMP are useful examples of how IMO has utilised information to generate sufficient interest among ship owners, research institutes and other stakeholders to take suitable action. However its impact on improving knowledge on how inefficiencies can be practically overcome is quite limited. For example, a comparison between SEEMP and ISO 50001 reveals that SEEMP is missing critical elements of a "best practice" guide (Hannes, 2013). By providing a more detailed set of standards such as requirements of an energy review process, goals and indications as well as processes for energy efficiency in design and procurement, would help to overcome information-related barriers in the decision making process.

Policy makers' role could also extend in the development of KPIs. Company level KPIs outlined in this study for example, route efficiency and utilisation factors can be enhanced with higher levels of data transparency. This also helps companies develop industry benchmarks upon they can base individual fleet performance.

The challenge of improving energy efficiency in the shipping sector is one that needs to extend well beyond that of the IMO. As highlighted in Chapter 3, while IMO has provided and can continue to provide guidelines on hull, structures, equipment and procedures that ensure safe and efficient operations, they may not have sufficient rights or competencies to enforce these regulations. Policy makers would need to collaborate more closely with third party organisations that could provide competencies and experience in more effective policy making.

Third parties could also play a role in providing endorsement for best practices developed related to sustainable shipping. For example, the recognition of Green Award ships by DNV GL is a first step in this direction. The scheme offers an excellent opportunity to reward companies which set best practice examples for shipping. DNV GL being one of the largest ship classification societies in the world gives early adopters confidence in processes and procedures outlined in such schemes.

5.3 Conclusion

The application of systems thinking in addressing the challenges and opportunities of adopting energy efficiency measures in the shipping sector provided a multi-lateral perspective of the problem situation and helped to provide a more structured approach in addressing the research questions outlined in this thesis.

The research undertaken in this thesis started out with trying to understand what are the decision making processes pertaining to energy efficiency improvements in the shipping sector. Through exploratory interviews conducted a more detailed represented of the processes was presented. This included identifying a number of decision nodes in attaining awareness, motivation and implementation of energy efficiency measures was presented. An additional stage on reporting was also suggested for the shipping sector given the uniqueness of the shipping sector and the challenges outlined in the exploratory interviews with regards to proper accounting of cost savings of energy efficiency measures. Top management was repeatedly identified to be involved in several stages of the decision making process, particularly with respect to having sufficient motivation for the adoption of energy efficiency measures.

In the area of barrier analysis, this study set out to understand what are the various energy efficiency barriers as well as how to classify them. Through a detailed literature review, insights obtained from the detailed energy efficiency decision pathways and the uncertainties involved, a new taxonomy of energy efficiency barriers was developed for the shipping sector. Furthermore, the study also set out to study what kind of interactions took place with respect to barriers, stakeholders and the decision making process. As part of the new taxonomy, internal barriers were found to be significantly impacting the adoption of energy efficiency measures. This was validated by mapping the taxonomy of barriers with the decision making processes outlined. Furthermore, several causal relationships through a causal loop diagram revealed again how top management is significantly impacted by external barriers and is responsible for the creation of internal barriers. A “big picture” analysis through the use of influence diagrams showed how stakeholders impacted the decision making process. The planning of energy efficiency measures by energy managers was a critical pathway for successful approval of energy efficiency measures. This suggested that in the absence of energy managers, a company would not have sufficient motivation to plan and approve energy efficiency measures given the significant number of uncertainties in the motivation stage.

Throughout the study, the use of KPIs has been suggested in the literature as well as through the interviews conducted, but a rigorous assessment of how energy KPIs are developed or could be developed was not studied in detail. Starting from first principles, several orders of interactions between factors that affect energy consumption were investigated through causal loop diagrams. This work was overlapped with existing KPIs to reveal several gaps such as the lack of certain company level objectives being met and that some first order interactions are not captured in existing KPIs. A set of company level KPIs were proposed.

So far, neither countries nor the industry has suggested anything more demanding on the IMO process than having a more structured approach to measure emissions. While this has been commendable, the hope is that this study provided more reasons to start thinking of improving energy efficiency in the shipping sector as a multi-lateral problem with multi-lateral solutions.

REFERENCES

ABS. (2011). *Ship Energy Efficiency Measures*. Retrieved 1 November, 2011, from ABS: http://ww2.eagle.org/content/dam/eagle/publications/2013/Energy%20Efficiency.pdf

Antapassis, A., Athananssiou, L., & Rosaeg, E. (2009). *Competition and Regulation in Shipping and Shipping related Industries.* Boston: Martinus Nijhoff Publishers.

Asikainen, M. (2016). *Challenges to the development of energy performance measurement: a systems thinking apporach.* JYVASKYLAN YLIOPISTO.

ATD. (2005). *Fuel and air transport.* Air Transport Department, Cranfield University.

Barrass, C., & Derett, D. (2012). Chapter 52 – Looking Forward into the Next Decade. In D. Derett, *Ship Stability for Masters and Mates* (pp. 457-463). Elsevier.

Bazari, Z., & Longva, T. (2011). *Assessment of IMO Mandated Energy Efficiency Measures for International Shipping.* The Marine Environment Protection Committe MEPC 63/INF.2.

Beilza, C., Gomez, M., & Shenoy, P. (2010). Modeling challenges with influence diagrams: Constructing probability and utility models. *Decision Support Systems*, 354-364.

Bertho, F., Borchert, I., & Mattoo, A. (2014). *The Trade-Reducing Effects of Restrictions on Liner Shipping.* Washington D.C: World Bank.

Bielza, C., Gomez, M., & Shenoy, P. (2011). A review of representation issues and modeling challenges with influence diagrams. *Omega*, 227-241.

BIMCO. (3 July, 2014). *Flag State Auditting*. Retrieved from BIMCO Education: https://www.bimco.org/en/Education/Seascapes/Maritime_Matters/2014_07_02_Flag_state_auditing.aspx

Bogdanski, G., Spiering, T., Li, W., Herrmann, C., & Kara, S. (2012). *Energy Monitoring in Manufacturing Companies-Generating Energy Awareness through Feedback.* Berlin Heidelberg: Springer .

Buckley, J. (2008). *Business of shipping* . Cornell Maritime Press, Inc.

Cagno, E., Worrell, E., Trianni, A., & Pugliese, G. (2013). A novel approach for barriers to industrial energy efficiency. *Renewable and Sustainable Energy Reviews*, 290-308.

Campuzano, F., & Mula, J. (2011). Modeling a Traditional Supply Chain by Using Causal Loop Diagrams. In F. Campuzano, & J. Mula, *Supply Chain Simulation* (pp. 75-88). London: Springer-Verlag.

Chai, K., & Yeo, C. (2012). Overcoming energy efficiency barriers through systems approach—A conceptual framework. *Energy Policy*, 460-472.

Checkland, P. (1981). *Systems thinking, systems practice.* Chichester, UK: Wiley.

Corbett, J., & Winebrake, J. (2008). The Impacts of Globalisation on International Maritime Transport Activity. *Global Forum on Transport and Environment in a Globalising World.* Guadalajara, Mexico: OECD.

Crawford, M. (December, 2015). The Power of Dual-Fuel Diesel Engines. *ASME*.

Decanio, S. (1993). Barriers Within Firms to Energy-Efficient Investments. *Energy Policy*, 906-914.

DNV GL. (2014). *Energy Management Study.* DNV GL Maritime.

Duru, O., Bulut, E., Huang, S., & Yoshida, S. (2012). Shipping Performance Assessment and the Role of Key Performance Indicators (KPIs): 'Quality Function Deployment' for Transforming Shipowner's Expectation. *Conference of International Association of Maritime Economists.* Taipei.

Elizabeth, D., Cochran, J., & Vorum, M. (2009). *Energy Efficiency Policy in the United States: Overview of Trends at Different Levels of Government.* Colorado: National Renewable Energy Laboratories.

Ermberger, G. (2000). Causal Loop Model to Describe Transport System's Effects on SocioEconomic Systems. *Proceedings of the 18th International Conference of the Systems Dynamics Society* (p. 61). Norway: System Dynamics Society.

Faber, J., Behrends, B., & Nelissen, D. (2011). *Analysis of GHG Marginal Abatement Cost Curves.* CE Delft 11.7410.21.

Faber, J., Nelissen, D., & Smit, M. (2013). *Monitoring of bunker fuel consumption.* CE Delft.

Ford, A. (2009). System Dynamics Models of Environment, Energy and Climate Change. In R. Meyers, *Encyclopedia of Complexity and Systems Science* (pp. 9014-9034). New York: Springer.

Freshfields Bruckhaus Deringer. (2015). Shipping line consolidation: what did the airlines do? Retrieved January 01, 2016

Glave, T., Joerss, M., & Saxon, S. (November, 2014). *The hidden opportunity in container shipping.* Retrieved from McKinsey & Company: http://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/the-hidden-opportunity-in-container-shipping

Goldberg, M., McKane, A., & Vetromile, J. (2013). *International Approaches to Measurement and Verification of Continual Improvement in Industrial Facilities.* Lawrence Berkeley National Laboratory.

Gopalakrishnan, B., Ramamoorthy, K., Crowe, E., & Latif, H. (2014). A structured approach for facilitating the implementation of ISO 50001 standard in the manufacturing sector. *Sustainable Energy Technologies and Assessments* (7), 154-165.

Gray, D., Pavlov, A., & Micheli, P. (2015). *Measurement Madness: Avoiding Performance Management Pitfalls.* Chicester, West Sussex: Wiley.

Gummesson, E. (2000). *Qualitative methods in management research.* London: SAGE Publications.

Hannes, J. (2013). *Towards understanding energy efficiency in shipping.* Goteberg, Sweden: Chalmers University of Technology.

Hannes, J. (2016). *In search of maritime energy management.* Sweden: Chalmers University of Technology.

Hansmann, R., Mieg, H., & Frischknecht, P. (2012). Principal sustainability components: empirical analysis of synergies between the three pillars of sustainability. *International Journal of Sustainable Development & World Ecology* , 19(5) 451-459.

Hasanbeigi, A., Menke, C., & duPont, P. (2010). Barriers to energy efficiency improvements and decision making behaviour in the Thai industry. *Energy efficiency*, 3(1): 33-52.

Heffron, R., Mc Cauley, D., & Sovacool, B. (2015). Resolving society's energy trilemma through the Energy Justice Metric. *Energy Policy*, 168-176.

Holden, D., Brown, A., & Sollie, P. (2014). *Liquefied Natural Gas (LNG) Bunkering Study*. Texas: Maritime Administration, PP087423-4, Rev 3.

Husain, F. (3 September, 2015). *OIL Price & Curious Case of Shipping Industry*. Retrieved from LinkedIn.

IMO. (2009). *Second IMO GHG Study 2009*. London: International Maritime Organisation.

IMO. (2015). *Third IMO Greenhouse Gas Study 2014*. London: International Maritime Organisation.

IMO. (2016). *Energy efficiency measures*. Retrieved from International Maritime Organisation: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Technical-and-Operational-Measures.aspx

Interviewee I, H. (1 June, 2014). Exploratory Interview on Decision Making in Shipping Companies. (K. Soundararajan, & K. Chai, Interviewers)

Interviewee II, . (02 June, 2015). Exploratory interview on decision making processes on energy efficiency processes. (K. Soundararajan, Interviewer)

Interviewee III. (1 April, 2015). Exploratory Interview on the various energy efficiency processes that take place on board. (K. Soundararajan, & K. Chai, Interviewers)

Interviewee IV. (25 November, 2015). Exploratory Interview on the assessment of factors affecting energy efficiency improvement. (K. Soundararajan, Interviewer)

ISO. (2011). ISO 50001-Energy management. *Management system standard*. International Standards Organisation.

Jacobs, T., Garrow, L., Lohatepanont, M., Koppelman, F., Coldren, G., & Purnomo, H. (2012). Airline Planning and Schedule Development. In C. Barnhat, & B. Smith, *Quantitative problem solving methods in the airline industry* (pp. 35-101). New York: Springer.

Jacobs, T., Garrow, L., Lohatepanont, M., Koppelman, F., Coldren, M., & Purnomo, H. (2012). Airline Planning and Schedule Development. In L. C. Barnhart and B. C. Smith, *Quantitative Problem Solving Methods in the Airline Industry* (pp. 35-98). Springer.

Jafarzadeh, S., & Utne, I. (2014). A framework to bridge the energy efficiency gap in shipping. *Energy*, 603-612.

Jespen, J., Zhao, Z., & van Leewen, W. (2015). Seafarer fatigue: a review of risk factors, consequences for seafarers' health and safety and options for mitigation. *Int Marit Health.*, 66(2): 106-17.

Johnson, H., Johansson, M., & Andersson, K. (2014). Barriers to improving energy efficiency in short sea shipping: an action research case study. *Journal of Cleaner Production*, 317-327.

Karima, S., Philippe, P., & Frederic, V. (2013). Using the BCD model for risk analysis: An influence diagram. *Engineering Applications of Artificial Intelligence*, 2172-2183.

Kulevska, T., & Thenius, G. (2016). *Methods for the calculation of energy savings in the transport sector.* Concerted action Energy efficiency directive.

Lai, K.-H., Lun, V., Wong, C., & Cheng, T. (2011). Green shipping practices in the shipping industry: conceptualization, adoption and implications. *Resour Conserv Recycl*, 55(6):631e8.

Louise, K., Karolina, G., & Eva, H-S. (2015) Sustainability Report 2014. Retrieved 17 June, 2016, from http://www.maersk.com/sustainability/

Lumina . (2016). *Lumina Decision Systems*. Retrieved 1 September , 2015, from http://www.lumina.com/

Maani, K., & Cavana, R. (2007). *Systems Thinking, System Dynamics* . Canada: Pearson Education.

Maani, K., & Fan, A. (2008). Systems Thinking for Team and Organisational learning Case of Performance Measure Conflicts in a Multinational Supply Chain. *Proceedings of the 52nd Annual Meeting of the ISSS.* Madison, Wisconsin.

Mander, S. (2016). Slow steaming and a new dawn for wind propulsion: A multi-level analysis of two low carbon shipping transitions. *Marine Policy*, In Press, Corrected Proof.

Marine Propulsion. (15 July, 2015). Maritime industry approaches technology tipping point. *Marine Propulsion and auxillary machinery* .

MEPC. (2000). *Guidelines for voyage planning.* Marine Environmental Protection Control RESOLUTION A.893(21).

MEPC. (2009). *Guidance for the Development of a Ship Energy Efficiency.* London: The Marine Environmental Protection Committee.

MEPC. (2012). 2012 Guidelines on the method of calculation of the attained energy efficiency index (EEDI) for new ships. *RESOLUTION MEPC.212(63)*. The Marine Environment Protection Committee.

MEPC. (2012). *Report of the Marine Environment Protection Committee on its sixty-thrid session.* Marine Environment Protection Committee MEPC 63/23.

MEPC. (2014). *EU Project "Energy Efficient Safe SHip OPERAtion" (SHOPERA).* Marine Environment Protection Committee MEPC 67/INF.14.

MEPC. (2014). The review of the status of technological developments on the EEDI regulation under regulation 21.6 of MARPOL Annex VI. 67th Session Agenda item 4. The Marine Environment Protection Committee.

MI Network. (24 December, 2015). 8 Main Factors that Affect Ocean Freight Rates. *Maritime Law.* Retrieved from http://www.marineinsight.com/maritime-law/8-main-factors-that-affect-ocean-freight-rates/

Nastu, P. (22 April, 2010). *Environmental Leader.* Retrieved 9 November, 2015, from Environmental & Energy Management News: http://www.environmentalleader.com/2010/04/22/ship-consortium-sails-full-steam-ahead-toward-15-25-fuel-reduction/

Nix, O., & Drees, K. (2011). *Measurement and verification of energy savings*. Institute for building efficiency.

Peter T, du Pont. (1998). *Energy Policy and Consumer Reality: The role of energy in the purchase of household appliances in the U.S. and Thailand.* Dissertation submitted to the Faculty of the University of Delaware.

Pfaffenbichler, P., Emberger, G., & Shepherd, S. (2008). The Integrated Dynamic Land Use and Transport Model MARS. *Networks and Spatial Economics*, 8(2) 183-200.

Poirier, A., & Zaccour, G. (1990). Maritime and Pipeline Transportation of Oil and Gas: Problems and Outlook. *HEC* (p. 306). Montreal: Technip.

Rehmatulla, N. (2015). Barriers to energy efficiency in shipping: A triangulated approach to investigate the principal agent problem. *Energy Policy*, 44-57.

Rehmatulla, N., & Smith, T. (2015). Barriers to energy efficient and low carbon shipping. *Ocean Engineering*, 102-112.

Roggema, J., & Simith, M. (1983). Organizational Change in the Shipping Industry: Issues in the Transformation of Basic Assumptions. *Human Relations*, 765-790.

Sandberg, P., Soderstrom, M. (2003). Industrial energy efficiency: the need for investment decision support from a manager perspective. *Energy Policy*, 1623-1634.

Santos, P., Belton, V., & Howick, S. (2002). Adding value to performance measurement by using system dynamics and multicriteria analysis. *International Journal of Operations & Production Management*, 1246-1272.

Siemens. (2014). *Managing Energy Using Key Performance Indicators.* Siemens Retail & Commercial Systems.

Smith, T., Day, S., Bucknall, R., Mangan, J., Dinwoodie, J., Landamore, M.,Wrobel, P. (2014). *Low Carbon Shipping - A Systems Apporach, Final Report.*

Sorrell, S., Schleich, J., Scott, S., O'Mally, E., Trace, F., & Boede, U. (2000). *Reducing barriers to energy efficiency in public and private organizations.* Sussex, UK: Science and Policy Technology Research (SPRU).

Strandenes, S. (2000). The Shipbroking Function and Market Efficiency. *Maritime Economics & Logistics*, 17-26.

Taylor, A. (1976). System Dynamics in Shipping. *Operational Research Quarterly*, 27(1) 41-56.

Thollander, P., & Palm, J. (2013). *Improving energy efficiency in industrial energy systems.* London: Springer-Verlag.

Tipping, A., Schmahl, A., & Duiven, F. (19 Febuary, 2015). Impact of reduced oil prices on the transportation sector. *Strategy and Business*.

Tobias Fleitera, T., Hirzel, S., & Worrel, E. (2012). The characteristics of energy-efficiency measures – a neglected dimension. *Energy Policy*, 502-513.

Trianni, A., Cagno, E., Thollander, P., & Backlund, S. (2013). Barriers to industrial energy efficiency in foundries: a European comparison. *Journal of Cleaner Production*, 161-176.

UNCTAD. (2015). *Review of Maritime Transport.* United Nations Publications.

Wang, H., Faber, J., Nelissen, D., Russell, B., & St Amand, D. (2010). *Marginal Abatement Costs and Cost Effectiveness of Energy-Efficiency Measures.* Marine Environment Protection Committee MEPC61/INF.18.

Woods Hole. (1952). *Marine fouling and its prevention.* Maryland: United States Naval Institute.

ANNEX 1: SHORT BIOGRAPHIES OF INTERVIEWEES

Interviewee I

Interview I was an ex. managing director of a large container shipping liner. He has previously been stationed in Tokyo, Bangkok, China and other international destinations within the company overseeing strategy and deployment of shipping operations. He is active within the Singapore Shipping Association, holding a senior position in strategy development. In addition to that, Interviewee I actively supports the academia in maritime studies.

Interviewee II

Interviewee II has more than 30 years of offshore shipping experience. He has served as a captain for more than 25 years in several container shipping liners. He holds a Master Mariner Class 1 (unlimited) license and is specialised in vessel delivery and sea trials, vessel repair and dry docks. He is a qualified ship security officer in accordance to ISPS. The interviewee is also an experienced trainer and lecturer on marine operations, navigation and maritime resource management. He currently focuses on providing sustainable solutions for container ship operations.

Interviewee III

Interviewee III is the global head of shipping advisory for an international shipping classification and advisory firm. He currently coordinates 40+ Shipping Advisory practitioners in 9 locations on 4 continents in terms of service agenda, service and knowledge development, go-to-market, ways-of-working etc. Previously he worked for more than 7 years in an international management consultancy. He has several publications in the areas of information and communication technologies in shipping, ship energy efficiency and green shipping. He obtained his PhD in Environmental Economics.

Interviewee IV

Interviewee IV is a senior shipping advisory consultant for an international shipping classification and advisory firm. Her role encompasses strategic & management advisory in the maritime industry. She is involved in environmental impact projects for the shipping sector and deals with regulatory issues such as maritime emissions, ballast water management and energy efficiency. She has been extensively involved in projects related to market analysis and growth potential of LNG fuelled shipping, technical & operational feasibility, economic & environmental benefits and developing business case for LNG fuelled shipping & LNG bunkering. She is also a regular speaker at various conferences and seminars in South East Asian Maritime Arena. She obtained a Master of Business Administration in Global Logistics & Supply Chain Management.

ANNEX 2: SHIPPING KPIS

The following information is the tables below are extracted from Shipping KPI Quick Sheet, Version 2.4.

SPI	KPI	KPI Value Formula	KPI MinReq	KPI Target	PI
Health and Safety Performance	Flawless Port state control performance	$\frac{A}{B}$	0.33	1	A: Number of PSC inspections resulting in zero deficiencies
					B: Number of PSC inspections
	Lost Time Injury Frequency	$\frac{A + B + C + D}{E * 10^{-4}}$	2.5	0.5	A: Number of fatalities due to injuries
					B: Number of lost workday cases
					C: Number of permanent total disabilities (PTD)
					D: Number of permanent partial disabilities
					E: Total exposure hours
	Health and Safety Deficiencies	$\frac{A}{B}$	5	0	A: Number of health and safety related deficiencies
					B: Number of recorded external inspections
	Lost Time Sickness Frequency	$\frac{A + B}{C * 10^{-6}}$	2.5	0.5	A: Number of cases where a crew member is sick for more than 24 hours
					B: Number of fatalities due to sickness
					C: Total exposure hours
	Passenger Injury Ratio	$\frac{A}{B * 10^{-6}}$	2	0.2	A: Number of passengers injured
					B: Passenger exposure hours
HR Management Performance	Crew disciplinary frequency	$\frac{A + B + C + D + E}{F} * 24 * 365$	0.02	0	A: Number of absconded crew
					B: Number of charges of criminal offences
					C: Number of cases where drug and alcohol is abused
					D: Number of dismissed crew
					E: Number of logged warnings
					F: Total exposure hours
	Crew planning	$A + B$	15	0	A: Number of crew not relieved in time
					B: Number of violation of rest hours

SPI	KPI	KPI Value Formula	KPI MinReq	KPI Target	PI
	HR deficiencies	$\frac{A}{B}$	5	0	A: Number of HR related deficiencies B: Number of recorded external inspections
	Cadets per ship	$\frac{A}{B}$	0	3	A: Number of cadets under training with the ship manager B: Number of ships under technical management (DOC)
	Officer retention rate	$100\% - \frac{A-(B+C)}{D} * 100\%$	70	95	A: Number of officer terminations from whatever cause B: Number of unavoidable officer termination C: Number of beneficial officer termination D: Average number of officers employed
	Officers experience rate	$\frac{A}{4 * B}$	0.6	0.9	A: Number of officer experience points B: Number of officers onboard
	Training days per officer	$\frac{A}{B}$	0	0.03	A: Number of officer trainee man days B: Number of officer days onboard all ships under technical management (DOC)
Environmental Performance	Releases of substances as def by MARPOL Annex 1-6	$A + B$	1	0	A: Number of releases of substances covered by MARPOL, to the environment B: Number of severe spills of bulk liquid
	Ballast water management violations	A	1	0	A: Number of ballast water management violation
	Contained spills	A	3	0	A: Number of contained spills of bulk liquid
	Environ-mental deficiencies	$\frac{A}{B}$	5	0	A: Number of environmental related deficiencies B: Number of recorded external inspections
Navigational Safety Performance	Navigational deficiencies	$\frac{A}{B}$	5	0	A: Number of navigational related deficiencies B: Number of recorded external inspections

SPI	KPI	KPI Value Formula	KPI MinReq	KPI Target	PI
	Navigational incidents	$2A + B + 2C$	1	0	A: Number of collisions B: Number of allisions C: Number of groundings
Operational Performance	Budget performance	$\frac{\lvert A-(B-C)\rvert}{A} * 100\%$	10	2	A: Last year's running cost budget B: Last year's actual running costs and accrual C: Last year's AAE (Additional Authorized Expenses)
	Drydocking planning performance	$\left(\left\lvert\frac{B-A}{A}\right\rvert + \left\lvert\frac{D-C}{C}\right\rvert\right) * 100$	10	2	A: Agreed drydocking duration B: Actually drydocking duration C: Agreed drydocking costs D: Actual drydocking costs
	Cargo related incidents	A	2	0	A: Number of cargo related incidents
	Operational deficiencies	$\frac{A}{B}$	5	0	A: Number of operational related deficiencies B: Number of recorded external inspections
	Passenger injury ratio	$\frac{A}{B}$	2	0.2	A: Number of passenger injured B: Passenger exposure hours
	Port state control detention	$A(if\ B > 0)$	1	0	A: Number of PSC inspections resulting in a detention B: Number of PSC inspections
	Ship availability	$\frac{(24 * 365 - B) - A}{24 * 365 - B} * 100\%$	97	100	A: Actual unavailability B: Planned unavailability
	Vetting deficiencies	$\frac{A}{B}$	5	0	A: Number of vetting deficiencies B: Number of vetting inspections
Security Performance	Port State Control performance	$\frac{A}{B}$	0.33	1	A: Number of PSC inspections resulting in zero deficiencies B: Number of PSC inspections
	Security deficiencies	$\frac{A}{B}$	5	0	A: Number of security related deficiencies B: Number of recorded external inspections

SPI	KPI	KPI Value Formula	KPI MinReq	KPI Target	PI
Technical Performance	Conditions of class	A	1	0	A: Number of conditions of class
	Failure of critical equipment and systems	A	1	0	B: Number of failures of critical equipment and systems

SPI	KPI	KPI Value Formula	KPI MinReq	KPI Target	PI
These KPIs has no association to an SPI	CO2 efficiency [g/tonmile]	$\frac{A}{B * 10^{-6}}$	84	36	A:Emitted mass of CO2 [ton]
					B: Transport work
	Fire and Explosions	$A + B$	1	0	A: Number of fire incidents
					B: Number of explosion incidents
	NOx efficiency [g/Cargo Unit] mile	$\frac{A}{B * 10^{-3}}$	2.2	0.9	A:Emitted mass of NOx [kg]
					B: Transport Work
	Port state control deficiency ratio	$\frac{A}{B}$	8	0	A:PSC deficiencies
					B: Number of PSC inspections
	SOx efficiency [g/Cargo Unit] mile	$\frac{A}{B * 10^{-3}}$	1.5	0.6	A: Emitted mass of SOx [kg]
					B: Transport Work