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A study on implementation of CO2 abatement solutions for existing ships

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Malmö, Sweden

A study on implementation of CO_2 abatement solutions for existing ships

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DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title of Dissertation: **A study on implementation of CO_2 abatement solutions for existing ships**

Degree: **Master of Science**

Recent high fuel prices and global economic recessions have driven shipowners to turn their attention to saving operational costs of their ships. For this reason, a variety of energy saving solutions has been developed and proposed in order to improve energy efficiency of ships. In addition, IMO have also proposed the best practices for energy saving solutions for existing ships through the SEEMP Guidelines. However, these proposed energy saving solutions (i.e. CO_2 abatement solutions) do not give sufficient reliability due to the uncertainties of various parameters surrounding ships.

These uncertainties may have a significant impact on effectiveness of individual energy saving solutions to a great extent, which include future fuel prices, mutually exclusive solutions, enforcement of SOx emission regulations, financial returns on investment of solutions. At present, these uncertainties prevent shipowners from employing the energy saving solutions. In particular, small companies suffer from lack of human resources and technical expertise in employing energy saving solutions to their ships.

In this context, this dissertation analyzes reliability and availability of individual energy saving solutions for existing ships through analyzing specific challenges and effectiveness when implementing each of solutions. Finally, this dissertation proposes feasible measures to facilitate implementation of energy saving solutions.

KEY WORDS: Fuel consumption, Energy efficiency, CO_2 abatement solutions, CO_2 abatement potential, Cost effectiveness, Implementation, energy saving.

LIST OF ABBREVIATIONS

EEDI	Energy Efficiency Design Index
BIMCO	Baltic and International Maritime Council
EMS	Environmental Management System
ETS	Emissions Trading System
GHG	Greenhouse Gas
HFO	Heavy Fuel Oil
IMO	International Maritime Organization
INTERTANKO	International Association of Independent Tanker Owners
ISO	International Organization for Standardization
MARPOL 73/78	International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto
MBM	Market Based Measure
MDO	Marine Distillate Oil
MEPC	Marine Environment Protection Committee
NOx	Nitrogen Oxides
SEEMP	Ship Energy Efficiency Management Plan
SOx	Sulphur Oxides
TBT	Tributyltin
VLCC	Very Large Crude Carrier
WHR	Waste Heat Recovery

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Chapter I

Introduction

1.1 Background

In 2011, IMO adopted the first-ever mandatory regulation for greenhouse gas (GHG) emissions from ships ahead of other international organizations. This new regulation is categorized into two main sectors related to technical solutions and operational solutions for CO_2 emissions reductions. The Energy Efficiency Design Index (EEDI) is to evaluate the technical solutions on a mandatory basis, and the Ship Energy Efficiency Management Plan (SEEMP) is a management tool for implementation of the operational measures on a voluntary basis. At present, shipowners have a duty to implement the technical solutions and the operational solutions to their ships according to the IMO GHG standards (IMO, 2011e).

In addition to this, shipowners are facing a heavy economic burden due to dramatically increased fuel prices which account for a great part of operating costs of ships. Apart from the mandated GHG regulations, shipowners currently must take appropriate actions to improve their cost structure by improving the energy efficiency of their ships. However, in practice, there is a significant difference in implementing energy saving solutions between global shipping companies and small shipping companies. At present, the global shipping companies, who have adequate human resources and technical expertise for energy saving solutions (i.e. CO_2 abatement solutions), are in a dominant position in competition with small shipping companies.

To encourage further implementation of energy saving solutions, IMO have developed the guidelines for developing the SEEMP for shipowners to improve energy efficiency of ships. The energy saving solutions (i.e. CO_2 abatement solutions) for existing ships are described in this guideline, but this is general explanation of solutions without any consideration of different ship types and various operating conditions. In practice, not all solutions can be applicable to all ships in different operating conditions; some solutions are mutually exclusive with other solutions (IMO, 2012). For example, a hull coating solution and a waste heat recovery solution are not effective during the slow speed operation because of increased hull resistance and insufficient waste heat.

Meanwhile, a variety of energy saving solutions has been proposed by relevant parties to improve energy efficiency of ships due to the increased fuel prices and the mandated IMO GHG standards. However, the best practices could be different to a great extent depending on ship type, ship size, ship age, and operating conditions. In this context, shipowners should understand the effectiveness of individual energy saving solutions, and specific challenges in implementing the solutions should be identified. In addition, shipowners should evaluate the reliability and the availability of energy saving solutions through analyzing challenges and advantages when implementing the solutions. Accordingly, the result of evaluation will allow shipowners to make a decision of employing cost effective solutions to their ships.

1.2 Objectives of the Dissertation

The main objective of this study is to propose appropriate measures to facilitate the implementation of energy saving solutions (i.e. CO_2 abatement solutions) to existing ships. The feasible measures proposed in this study can be applicable to shipowners who have insufficient human resources and technical expertise for energy efficiency of their ships, by analyzing actual challenges to implementation of individual energy saving solutions.

At present, the CO_2 abatement solutions proposed by the IMO (e.g. SEEMP Guidelines) do not give sufficient reliability to shipowners due to uncertainties of various parameters surrounding ships depending on ship type, size and age. These uncertainties prevent the shipowners from employing the CO_2 abatement solutions to their ships. The details of the objective in this study are to:

- Analyze the cost effectiveness of individual CO_2 abatement solutions, and estimate the CO_2 reduction potentials by reviewing other published studies or reliable performance data in separate ship types.

- Identify specific challenges to implementation of CO_2 abatement solutions by analyzing separate ship types (e.g. tankers, bulkers and containers), which also include challenges in regulatory regimes causing negative impact on implementing the energy efficiency solutions.

- Propose applicable measures to facilitate the implementation of CO_2 abatement solutions proposed by the SEEMP guidelines, through analyzing specific challenges to implementation of individual CO_2 abatement solutions.

1.3 Methodologies of the dissertation

1.3.1 Challenges to implementation of CO_2 abatement solutions

The uncertainties (e.g. future fuel price) over implementing CO_2 abatement solutions should be analyzed from published sources and expert opinions. The ambient elements causing the specific challenges in implementing the CO_2 abatement solutions should be identified by analyzing the impact on the energy efficiency in each of ship types. In the end, with analysis of the uncertainties and the ambient conditions, the specific challenges in implementing CO_2 abatement solutions should be identified in separate ship types.

1.3.2 Cost Effectiveness of CO_2 abatement solutions

The cost effectiveness of CO_2 abatement solutions including CO_2 abatement potentials should be analyzed by evaluating the reliability and the acceptability of individual solutions from the published sources. The successful CO_2 abatement solutions performed by the shipping industry should be obtained by the published sources including up-to-date studies relating to energy efficiency of existing ships. In addition, the motivations of successful CO_2 abatement solutions should be analyzed by using expert opinions.

1.3.3 feasible measures to remove challenges to implementation

The feasible measures to facilitate implementation of CO_2 abatement solutions should be identified by evaluating the impact of specific challenges and the cost effectiveness in implementing individual CO_2 abatement solutions. In particular, the enhanced regulatory regimes (e.g. mandating the SEEMP implementation) to improve implementation of CO_2 abatement solutions should be proposed by using other energy management systems based on the environment standard i.e. ISO 14001.

Chapter II

Overview of CO_2 Abatement Solutions for existing ships

2.1 Situations related to CO_2 emissions from existing ships

2.1.1 Energy Efficiency in the shipping industry

The recent high fuel prices and global economic recessions have driven shipowners to turn their attention to saving the operational costs of their ships. In practice, they have been seeking for fuel saving solutions to reduce the high fuel costs in operation of ships. For this reason, the shipping industry has developed and introduced many energy saving solutions, including speed optimization, hull coatings, propeller/rudder upgrades, and other solutions to reduce fuel consumption from ships.

As a result of response to high fuel prices and global recessions, the significant energy savings can be achieved earlier than expected in shipping industry through employing energy efficient solutions to existing ships, which also bring about CO_2 emission reductions at the same time. Eventually, the energy efficient ships produce less CO_2 emissions than energy inefficient ships, thereby reducing further fuel consumptions from ships.

2.1.2 Uncertainties in implementing CO_2 abatement solutions

The specific uncertainties will influence the implementation of each solution to a great extent when employing the CO_2 abatement solutions to existing ships (Maddox, 2011)

- Uncertainty over high fuel prices :
  Fuel prices, which have risen dramatically over the past decades, will have a great impact on implementation rate of specific solutions, because the cost effectiveness of individual solutions is highly influenced by the fuel prices which account for most operating costs of ships.

- Uncertainty over mutually exclusive solutions :

It is widely accepted that the speed optimization is the best solution to reduce fuel consumption and CO_2 emissions. However, the speed optimization has significant impacts on implementation of other energy saving solutions. For example, the waste heat recovery systems and the hull coating will be ineffective at low engine loads (i.e. slow ship speed). Furthermore, the propulsion system upgrades, which are designed for normal service speeds, may not be effective at slow speed operations.

- Uncertainty over regulatory requirements :
  Recently, the shipping industry is facing enforcement issues against a SOx emission regulation that limits sulphur contents in fuel oil up to 0.5 % by 2020 (IMO, 2008). This SOx emission regulation will encourage the changeover of fuel type from the heavy fuel oil (HFO) containing high sulphur to the marine distillate oil (MDO) containing low sulphur contents. However, the use of MDO will have a significant impact on implementing individual energy saving solutions because the MDO price is nearly double the HFO price.

- Uncertainty over technical developments :
  Technical development will have an impact on implementation rate of solutions. For example, before the SOx regulation enters into force in 2020, the technology of SOx exhaust scrubber could be developed to the extent that the HFO continue to be used as main marine fuel with economic benefits. However, it could be possible that the implementation rates of other energy saving solutions would be decreased due to lower fuel costs by using the HFO.

- Uncertainty over financial return on investment of solutions :
  There are split incentive issues between shipowners and charterers in the charter market. This is because the party who invests in the energy saving solutions is not the same party who benefits from these energy saving solutions. In this respect, shipowners and charterers have to understand the potential advantages of the energy saving solutions, and they have to share the financial return on the investment of solutions.

2.1.3 Potential Impacts of implementation of CO_2 abatement solutions

2.1.3.1 Economic Impacts

The fuel savings due to adoption of CO_2 abatement solutions will decrease operating costs for shipowners. On the other hand, the profits for oil companies will be decreased due to reduced fuel sales volumes, and the decrease in demand for fuel will bring about further fuel price reductions in the market, thereby leading to further fuel savings of ships. Eventually, the reduced fuel costs of ships will lead to lower transport costs for goods provided that shipowners share the profits with shippers, and finally the profits may be passed on to local consumers with lower prices of goods.

After all, the CO_2 abatement solutions may eliminate economic barriers to trade; the competition with local producers will become easier due to lower transport costs. Conversely, local companies in the domestic market may suffer from strong competition with imported goods at lower prices due to lower transport costs. It is widely accepted that shipowners would obtain substantial economic benefits from additional fuel savings by implementing energy saving solutions to their ships. However, it is not clear that shipowners would pass on their profits to their customers.

2.1.3.2 Environment Impacts

Reduced CO_2 emissions by implementing energy efficient solutions will have positive environmental impacts on reducing global climate change (i.e. global warming). In addition, reduced SOx, NOx and PM emissions will have an influence on improvement of air quality for human health. In particular, SOx and NOx emissions directly contribute to harmful acid rain and have negative impacts on ecosystems and the environment.

2.1.3.3 Market Impacts

The shipowners employing energy saving solutions to their ships will have a cost advantage due to fuel savings more than those who do not employ energy saving solutions, and this will enhance their competitiveness in the shipping market. From the economic point of view, the prices of goods imported may be relatively cheaper due to reduced transport costs provided that energy efficient solutions are implemented to ships. After all, this low transport costs will encourage positive competition between local companies and import companies in order to provide their customers with lower prices of goods.

2.2 International Regulatory Framework for CO_2 emissions from ships

2.2.1 Adoption of the first-ever mandatory GHG regime

Eventually, IMO adopted technical and operational measures to improve energy efficiency and reduce CO_2 emissions from ships at MEPC 62nd session in 2011 as the new chapter 4 of MARPOL Annex VI. This is the first-ever mandatory GHG regime over the global industry sectors. The adopted CO_2 abatement measures include the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for existing ships. These regulations apply to all ships of over 400 gross tonnes, and entered into force on 1 January 2013 (IMO, 2011d).

2.2.2 Energy Efficiency Design Index (EEDI)

The EEDI regulates a minimum energy efficiency level per capacity mile (g/ton-mile) for new ships. The energy efficiency levels for new ships will be tightened gradually until the year 2050 up to 30% of CO_2 reductions compared to the average efficiency level for ships built between 1999 and 2009 (IMO, 2011d). Over time, the enhanced EEDI requirements will have a significant impact on technical development of energy saving solutions for new ships to meet enhanced CO_2 emissions levels.

According to the IMO document, the EEDI requirements will cover about 70% of CO_2 emissions from new ships including tankers, bulk carriers, general cargo, refrigerated cargo and container ships, and combination carriers (IMO, 2011e). However, the Ro-Ro ships and passenger ships are not yet covered by the current EEDI formula, but additional EEDI formulas will be developed according to a working plan at MEPC 62nd session.

2.2.3 Ship Energy Efficiency Management Plan (SEEMP)

Currently, there is no energy saving regulation for existing ships other than SEEMP. The SEEMP is to establish an energy management system for individual ships to improve energy efficiency of ships in operation. This SEEMP is required to use specific four management steps i.e. planning, implementation, self-evaluation and improvement while the energy saving solutions are applied to ships. In particular, it is important to iterate this management cycle to achieve further improvement of energy efficiency of ships (IMO, 2009).

In addition, the SEEMP guidelines recommend shipowners to use specific monitoring tool i.e. Energy Efficiency Operational Indicator (EEOI) which makes it possible to calculate energy efficiency performance of existing ships on a quantitative basis (IMO, 2009). In other words, the EEOI allows shipowners to evaluate the effectiveness of energy saving solutions applied to their ships, thereby optimizing fuel consumption and reducing CO_2 emissions.

Furthermore, the SEEMP should be developed as a ship-specific plan by the shipping company, considering operating conditions, ship type and size, and other factors. Not all energy saving solutions can be used for all ships or even the same ship under different operating conditions (IMO, 2009). Accordingly, the SEEMP should be developed and maintained by using a well-organized environment management system including top management support, qualified staff and technical expertise to improve energy efficiency of existing ships.

2.2.4 Market Based Measure (MBM)

The objective of MBM is to reduce CO_2 emissions by imposing a cost on CO_2 emissions from ships, which will be achieved by a levy on bunker fuel oil or by direct pricing on CO_2 emissions or by other financial incentives. Currently, IMO have been considering specific solutions for implementation of MBM, which include emissions trading system (ETS), bunker fuel levy, energy efficiency credits, and low port fees to energy efficient ships.

For successful CO_2 emissions reductions, the carbon prices imposed by the MBM should be high enough to stimulate shipowners to adopt energy saving solutions to their ships. The MBM will internalize costs of CO_2 emissions generated by inefficient energy usage through imposing effective price on emissions to encourage shipowners to improve fuel savings, thereby achieving CO_2 emissions reductions. After all, energy inefficient ships would subsidize more energy efficient ships by implementing the MBM.

2.3 CO_2 abatement solutions for existing ships

2.3.1 Overview

For many years, energy savings solutions have been developed to save the fuel costs. At present, the high fuel costs and the CO_2 regulations have also motivated shipowners to implement the energy efficient solutions to existing ships, which have been extensively tested and refined. Actually, many of the CO_2 abatement solutions can be applicable to existing ships as they have been fully tested to verify the effectiveness of the solutions.

In particular, shipowners cooperate with solution makers to demonstrate applicability of their solutions through shipboard testing. However, the outcome of the shipboard tests varies from different ambient conditions (e.g. sea weather). Although the shipboard tests provide a number of test reports, most shipowners have still difficulty in determining suitable energy saving solutions due to the uncertainty over the shipboard test results.

2.3.2 Scope of CO_2 abatement solutions

Meanwhile, the shipping industry has developed a variety of CO_2 abatement solutions applicable to existing ships. However, in this paper, the categories of CO_2 abatement solutions were narrow down into several promising solutions as listed in table 1, which were also classified into two main sectors i.e. operational solutions and technological solutions.

The operational solutions are not required to invest a large amount of fund but need small operational costs; however, the technological solutions need large investment in retrofitting solutions. In this paper, it should be noted that the technological solutions listed in the table 1 are limited to the solutions for retrofitting to existing ships, which is not for EEDI-based new ships.

Further details of individual CO_2 abatement solutions will be discussed over this paper later, including technical descriptions, applicability, and estimation of cost effectiveness, CO_2 abatement potentials, and challenges in implementing these solutions.

Table 1: CO_2 abatement solutions for existing ships

Solution	Type of solution
Speed optimization	Operational
Weather routing service	Operational
Autopilot system upgrade	Operational
Optimisation of trim and ballast	Operational
Propeller polishing	Operational
Hull cleaning	Operational
Hull coating	Technological
Propulsion system upgrade	Technological
Main engine adjustment	Technological
Waste Heat Recovery (WHR)	Technological
Speed control of pumps and fans	Technological

2.3.3 Lack of Awareness of CO_2 abatement solutions

The current shipping industry consists of a large number of small shipping companies which do not have technical expertise in energy saving solutions. In general, small companies suffer from the lack of human resources to evaluate effectiveness of energy saving solutions. In addition, small companies just focus on day-to-day conventional business issues, not for energy saving issues due to the lack of awareness of the benefits from energy savings of ships.

In this context, small shipping companies need more funds, technical expertise and qualified personnel in order to implement the CO_2 abatement solutions to their ships. To overcome such issues, the industry associations (e.g. INTERTANKO) are carrying out evaluating operational and technological solutions for their members to improve awareness of cost effectiveness of individual solutions.

In addition, it is also difficult for solution makers to promote their solutions to the small companies because the personnel in small companies cannot evaluate the benefits from the energy saving solutions, although proposed CO_2 abatement solutions are profitable to their ships. In this sense, it is important that the motivation for improvements of the ship energy efficiency must come from the shipowner rather than the personnel in a company because the shipping industry is so conservative in changing its management practices.

Chapter III

Evaluation of CO_2 abatement solutions for existing ships

3.1 Outline of Cost Effectiveness of CO_2 abatement solutions

3.1.1 Overview

First, the notion of cost effectiveness should be understood when implementing CO_2 abatement solutions. The cost effective solutions means that the marginal costs to employ CO_2 abatement solutions should be less than the cost savings generated by these solutions. In order words, when the marginal abatement cost (MAC) is less than zero, it is regarded as the cost effective solutions or the negative MAC solutions. The marginal abatement cost is based on the costs per unit of CO_2 emissions reduced, which include all costs for purchase, installation, and operation of CO_2 abatement solutions.

When evaluating the cost effectiveness of CO_2 abatement solutions, it is important to recognize associated uncertainties in implementing CO_2 abatement solutions, depending on ship type, size and age in the complex market conditions. Some solutions can be applicable to all ships, but other solutions may be limited to certain ship types or voyage patterns. Moreover, certain solutions can be mutually exclusive with other solutions. In this sense, the estimation of cost effectiveness for solutions may not be accurate, but they can be used as technical expertise for shipping companies which do not have sufficient information for implementation of CO_2 abatement solutions.

3.1.2 Ship Size and Age

Regarding ship size, larger ships can reduce more fuel consumption than smaller ships because fuel costs per unit of capacity are more economic as ship size is larger. On the contrary, the implementation costs of CO_2 abatement solutions are not proportional to ship size because operational costs per unit of capacity are more economic in the larger size of ships. Accordingly, CO_2 abatement solutions will be more cost effective in larger ships than smaller ships.

Regarding ship age, shipowners are reluctant to invest in CO_2 abatement solutions with high capital costs (i.e. investment costs) when ships are close to retirement. When calculating the cost effectiveness of solutions, the remaining lifetime of ships should be taken into account. Accordingly, younger ships are economically more attractive than older ships in terms of financial returns on investment of the solutions.

3.1.3 Marginal Abatement Cost (MAC) of CO_2 abatement solutions

The marginal abatement cost represents the level of cost effectiveness for CO_2 abatement solutions, and this is related to the relationship between costs and effects. For instance, the solutions with negative marginal abatement costs represent that they can reduce fuel consumption and CO_2 emissions cost-effectively compared to associated costs including capital costs, operation and maintenance costs.

Some solutions (e.g. waste heat recovery systems) often require substantial capital costs for installation onboard ships, and they also require operational costs or maintenance costs. In addition, some solutions may incur the opportunity costs when ships are taken out of service in order to install the equipment of solutions. Therefore, when calculating the marginal abatement cost, the associated costs (i.e. capital, operation, maintenance, and opportunity costs) should be taken into account.

3.1.4 Ship Speed vs. Cost Effectiveness

There is no doubt that speed optimization is the most effective solution for improving energy efficiency and reducing CO_2 emissions from existing ships. Therefore, the ship speed selection is an important factor to determine the level of cost effectiveness of ships, which is associated with relationship between ship speed and fuel consumption. The ship speed is not a linear relationship with fuel consumption; fuel consumption increases exponentially as ship speed increases. Accordingly, when selecting the optimal service speed to improve cost effectiveness, shipowners should consider speed-powering curve, fuel costs, and charter rates related to extra cargo delivery due to slow speed operation.

3.2 Evaluation of Cost Effectiveness for individual CO_2 abatement solutions

3.2.1 Scope of CO_2 abatement solutions

Recently, a variety of CO_2 abatement solutions have been suggested through numerous studies or literatures. In this paper, these proposed solutions were narrow down into several promising solutions as listed in table 2, which were also classified into two main categories i.e. operational solutions and technological solutions. In particular, it should be noted that technological solutions listed in the table 2 are limited to the solutions for retrofitting to existing ships, which is not for EEDI-based new ships. This chapter will discusses about technical descriptions, abatement potentials and marginal abatement costs for the CO_2 abatement solutions listed in table 2.

Table 2: CO_2 abatement solutions for existing ships

Solution	Type of solution
Speed optimization	Operational
Weather routing service	Operational
Autopilot system upgrade	Operational
Optimisation of trim and ballast	Operational
Propeller polishing	Operational
Hull cleaning	Operational
Hull coating	Technological
Propulsion system upgrade	Technological
Main engine adjustment	Technological
Waste Heat Recovery (WHR)	Technological
Speed control of pumps and fans	Technological

3.2.2 Speed Optimization

3.2.2.1 Overview

Speed optimization is to reduce ship speed to the extent that fuel consumption per ton mile is at a minimum level during ship operations (IMO, 2009). Speed optimization has a significant impact on reducing fuel consumption because the relationship between fuel consumption and ship speed is not linear; engine power requirement is proportional to the cube of ship speed (i.e. $P \propto V^3$). Therefore, provided that a ship is operated below the design service speed, this could reduce fuel consumption to a greater extent than if ship speed was reduced.

However, the speed optimization may extend voyage time due to the reduced ship speed. In this regard, voyage optimization can be used to compensate the extended voyage time, which can facilitate implementation of speed optimization as well. Currently, the major shipping companies have performed the advanced voyage planning to their fleets, accumulating technical expertise on the cost savings. On the contrary, the small shipping companies are limited to carry out the voyage optimisation due to the lack of human resources and technical expertise.

Traditionally, shipowners and charterers agree on a specific service speed in the charter party. However, in case of port congestion, this contracted speed is no longer beneficial to both shipowners and charterers in terms of fuel savings and CO_2 emissions reductions, even though shipowners may collect demurrage payment. To address this issue, the virtual arrival approach has been introduced for improving the ineffective practice in the chartering market. These days, to avoid unnecessary fuel consumption by the contracted speed, shipowners and charterers often agree on the slow speed operation at sea when the estimated time of arrival is officially delayed due to port congestion.

3.2.2.2 Limitation in Speed Optimization

Regarding voyage patterns, ships operating in icy weather conditions may not implement the speed optimization because safety issues are prior to fuel savings and CO_2 emissions reductions. In addition, ships engaged in short domestic voyages may not employ the speed optimization because time constraints are more significant than ships engaged in international voyages.

Regarding technical maturity, speed optimization is technically mature and applicable to existing ships, which is already being employed by major shipping companies. However, there are concerns about the negative impact of speed optimization on the main engines operating in low load conditions for extended periods.

When applying the virtual arrival approach, the additional costs may occur because estimated time of arrival must be recalculated in cooperation with shipowners and charterers (Portworld, 2009). In addition, the port infrastructure has a significant impact on costs for implementing speed optimization because the time in port should be reduced to compensate the extended voyage time due to slow speed operation.

3.2.2.3 Estimation of Speed Optimization

It is estimated that the CO_2 abatement potential of speed optimization will account for between 17% and 34% in the shipping sector by 2020 (Maddox, 2012). The penetration rates of the speed optimization have been increased due to high fuel prices and global economic recessions which constantly encourage shipowners to employ the speed optimization. In addition, engine tuning technology has influenced the penetration rates because this technology allows main engines to operate at low load conditions. Accordingly, the speed optimization has the greatest potential to reduce CO_2 emissions among technological and operational solutions.

It is estimated that the speed optimization is becoming an economically more attractive solution with the negative CO_2 marginal abatement cost of minus $368 per ton in 2020, which is 10 % higher than the estimates in 2007 (Maddox, 2012). In particular, bulk carriers and container ships do not need additional investment due to reduced speed operation. This is because that the remains of delivery capacity can be compensated with additional ships by handling a surplus of ship capacity after global economic crisis. Currently, cruise lines are also taking into account employing the speed optimization to their fleets due to increased fuel costs.

3.2.3 Weather Routing Service

3.2.3.1 Overview

A weather routing service is to optimize the ship route during the voyage at sea by using weather forecasts based on shore-based services. Initial weather routing services were developed to minimize potential hazards in ship routes by avoiding heavy sea conditions.

Over time, it was recognized that weather routing services make it possible to reduce fuel consumption and CO_2 emissions by optimizing ship routes, which leads to ensuring safe navigation and energy efficiency of ships.

Recently, weather routing services are being evolved by using advanced software to optimize ship routes in terms of safety and energy efficiency. Recent navigation charts are updated by shore-based weather routing services on a regular basis to optimize ship routes during voyages. In addition, the computer modeling makes it possible to calculate the best ship routes by using specific data provided by weather routing services (KOICA, 2013).

3.2.3.2 Limitation in Weather Routing Service

Regarding voyage patterns, ships operating in icy weather conditions may not implement the weather routing service due to restriction of their route selection. In addition, ships engaged in short domestic voyages may not employ the weather routing service because costal sea conditions are relatively safer than ships engaged in international voyages. Accordingly, the weather routing services are more applicable to ocean-going ships, but cruise ships may less applicable due to their tight voyage schedules.

3.2.3.3 Estimation of Weather Routing Service

It is estimated that the CO_2 abatement potential of weather routing services will account for between 0.9% and 3.7% in the shipping sector by 2020 (Maddox, 2012). At present, the penetration rate of this solution is high because most ships engaged in international voyages have already employed the weather routing services for the safer navigation. Therefore, it is expected that actual CO_2 abatement potential will not be much higher than the present level.

In particular, the weather routing services require the operational costs for subscription of shore-based weather routing services, which are estimated at between $800 to 1,600 per year. However, the weather routing services were already cost effective in 2007, and it is expected to become a more attractive solution with the negative CO_2 marginal abatement costs of minus $370 per ton in 2020, which is almost double the estimate in 2007. In addition, ship size and age do not influence the cost effectiveness of the weather routing service (Maddox, 2012).

3.2.4 Autopilot System Upgrade

3.2.4.1 Overview

The autopilot system is to keep voyage courses automatically based on the setting of the ship crew. The initial autopilot system was developed to keep the accurate heading to the designated direction. Over time, it was recognized that the autopilot system can reduce fuel consumption and CO_2 emissions by minimizing course adjustments which is related to hull resistance. Currently, the autopilot system is being upgraded to minimize the movement of rudders by applying advanced control system.

3.2.4.2 Limitation in Autopilot System Upgrade

Regarding voyage patterns, ships operating in icy weather conditions may not implement the autopilot system upgrade due to safety issues prior to energy efficiency. In addition, ships engaged in short domestic voyages may not employ the autopilot system upgrade due to limited route selection.

3.2.4.3 Estimation of Autopilot System Upgrade

It is estimated that the CO_2 abatement potential of the autopilot system upgrades will account for between 1.0% and 1.5% in the shipping sector by 2020 (Maddox, 2012). At present, the penetration rate of this solution is high because most ships engaged in international voyages have already employed the autopilot system upgrades for the safer navigation. Therefore, it is expected that actual CO_2 abatement potential will not be much higher than the present level.

In particular, the autopilot system upgrade requires the capital costs, which vary by ship type and size from $1,600 to $140,000 per ship. However, the autopilot system upgrades were already cost effective in 2007, and it is expected to become a more attractive solution with the negative CO_2 marginal abatement costs of minus $347 per ton in 2020, which is almost double the estimate in 2007 (Maddox, 2012).

3.2.5 Optimization of Trim and Ballast

3.2.5.1 Overview

Trim is the difference between forward and afterward draught of a ship. In general, trim levels are adjusted by arranging ballast water, ship cargos, and bunker fuels to maintain stability of ships. Over time, it was recognized that optimized trim condition can reduce hull resistance and thereby improve efficiency of propulsion units (e.g. propellers and rudders), which lead to reducing fuel consumption and CO_2 emissions (KOICA, 2013).

However, optimum trim positions can be changed by sea weather conditions or loading conditions, therefore it is required to monitor trim and ballast conditions on a regular basis by using a ship performance monitoring system. At present, the shipping industry has developed monitoring sensors with software solutions to identify the optimum trim and ballast conditions.

3.2.5.2 Limitation in Optimization of Trim and Ballast

Regarding the technical maturity, the shipping industry is currently carrying out the shipboard test for the monitoring systems such as thrust meters and software algorithms to optimize trim and ballast conditions in various ambient conditions. However, it is still needed to develop more stabilized solutions applicable to existing ships.

3.2.5.3 Estimation of Optimization of Trim and Ballast

It is estimated that the CO_2 abatement potential of the optimization of trim and ballast will account for between 1% and 3.4% in the shipping sector by 2020. However, these estimates have significant variation by ship type. Ships operating at faster speed such as container ships have higher potentials to reduce CO_2 emissions because optimized trim can improve hull resistance that is more sensitive to the faster ships. In addition, ships with full cargo holds (e.g. general cargo and other tanker ships) have less potentials to reduce CO_2 emissions because such ships may not be able to change trim condition by adjusting cargo arrangements (Maddox, 2012).

This solution requires substantial capital costs for installing the monitoring systems, which are estimated at between $75,000 and $100,000 per ship. In this regard, this solution was not economically attractive in 2007, but it is becoming an more attractive solution with the negative marginal abatement cost of minus $260 per ton in 2020, which is a significant increase compared to the estimate of minus $1.3 per ton in 2007 (Maddox, 2012).

However, there are substantial deviations in cost effectiveness between ship sizes i.e. larger ships can be more cost effective than smaller ships. This is because capital costs for installing the ship performance monitoring system are fixed regardless of ship sizes, but larger ship can reduce larger amounts of fuel use than smaller ships.

3.2.6 Propeller Polishing

3.2.6.1 Overview

The purpose of propeller polishing is to remove the roughness and organic fouling on the propeller surface. In particular, the enhanced surface smoothness by propeller polishing can improve the propeller performance and thereby reduce fuel consumption and CO_2 emissions. For instance, ships being laid-up for some period may suffer from serious organic fouling in the propeller surfaces, which also bring about reducing the propeller performance to a great extent (KOICA, 2013).

In this respect, it is important to monitor the propeller performance on a regular basis, by analyzing ship speed, engine power and fuel consumption. In order to enhance propeller performance, the propeller polishing should be done during a ship's operation in ports when necessary, not only during a ship's dry-docking on a regular basis.

3.2.6.2 Limitation in Propeller Polishing

Currently, the propeller polishing is widely applicable to existing ships, but some port authorities may prohibit propeller polishing in their ports due to concerns about the environmental impact of cleaning residues in their ports. This ban of propeller polishing in ports may incur additional costs and time for carrying out propeller polishing outside the port.

3.2.6.3 Estimation of Propeller Polishing

It is estimated that the CO_2 abatement potential of the propeller polishing will account for between 1% and 3% in the shipping sector by 2020 (Maddox, 2012). At present, the penetration rate of this solution is relatively high because most ships have already carried out the propeller polishing on a regular basis. Therefore, it is expected that actual CO_2 abatement potentials will not be much higher than the present level.

In particular, the propeller polishing requires the operational costs, which are estimated at between $6,000 and $10,000 per year, but there are no capital costs. However, the propeller polishing was already economically attractive in 2007, and it is expected to become a more attractive solution with the negative marginal abatement cost of minus $359 per ton in 2020, which is almost three times of the estimate in 2007. In addition, ship size and age have less influence on the cost effectiveness of the propeller polishing (Maddox, 2012).

3.2.7 Hull Cleaning

3.2.7.1 Overview

The purpose of hull cleaning is to remove accumulation of fouling organisms from the hull surfaces. In general, hull conditions are dependent on the quality of hull coatings or operating patterns of ships; for instance, the organic fouling on the hull is greater when operating in warm water areas or when spending longer time in port. In this regard, the hull cleaning is to keep smoothness of submerged hull parts and thereby reduce frictional resistance, which lead to saving fuel costs and reducing CO_2 emissions.

The hull cleaning can be carried out during dry-dockings on a regular basis or during ship operations in ports when it is necessary. In general, the hull cleaning can be done by scrubbing the hull surfaces with mechanical devices during dry-dockings, or it can be done by underwater hull cleaning in ports provided that port authorities approve the work.

3.2.7.2 Limitation of Hull Cleaning

Currently, hull cleaning is widely applicable to existing ships, but some port authorities may prohibit hull cleaning in their ports due to concerns over environmental impacts of hull residues. This ban of hull cleaning in ports may incur additional costs and time for carrying out the hull cleaning outside the ports.

3.2.7.3 Estimation of Hull Cleaning

It is estimated that the CO_2 abatement potential of the hull cleaning will account for between 1.0% and 5.0% in the shipping sector by 2020 (Maddox, 2012). At present, the penetration rate of hull cleaning is relatively high because most ships have already carried out hull cleaning on a regular basis according to the hull inspection regulations. Therefore, it is expected that actual CO_2 abatement potentials will not be much higher than the present level.

In particular, the hull cleaning requires the operational costs, which are estimated at the range from \$1,500 to \$140,000 per year (Maddox, 2012). However, the hull cleaning was marginally cost effective in 2007, but it is expected to become economically much more attractive with the marginal abatement cost of minus \$291 per ton in 2020, which is almost four times of the estimate in 2007.

However, there are substantial deviations in cost effectiveness of hull cleaning between ship types i.e. ships operating at faster speed (e.g. container ships, and cruise ships) are more cost effective than ships operating at slower speed (e.g. tanker ships and bulk carriers). This is because hull resistance is closely associated with ship speed i.e. the hull resistance increase as the ship speed increases. In addition, ship size and age have less influence on the cost effectiveness of the hull cleaning.

3.2.8 Hull Coating

3.2.8.1 Overview

The main purpose of hull coatings is to prevent the hull corrosion and accumulation of organic materials on the hull surface. Over time, it was recognized that enhanced surface smoothness by hull coating can improve the frictional resistance and thereby reduce fuel consumption and CO_2 emissions.

In the past, the hull coating technology was dependent on toxin material such as tributyl tin (TBT) in order to prevent bio-fouling on the hull surface. However, IMO currently have prohibited the use of TBT material in hull coatings since the year 2008 recognizing the fatal impact on the environment. Eventually, the new technology (i.e. biocidal coatings and fouling-release coatings) has been developed to avoid the use of toxin material in hull coatings (Bjoern, 2011).

3.2.8.2 Limitation of Hull Coating

Regarding technical maturity, there are considerable concerns over the effectiveness of new hull coating technology. Previously, the TBT-based hull coatings were an extremely effective solution to prevent hull collusion and bio-fouling albeit negative impacts on the environment due to its harmful material. However, it is not verified that new hull coating (i.e. biocidal coatings and fouling-release coatings) will continue to be effective against hull collusion and bio-fouling instead of TBT-based hull coatings.

3.2.8.3 Estimation of Hull Coating

It is estimated that the CO_2 abatement potential of hull coating will account for between 2% and 5% in the shipping sector by 2020 (Maddox, 2012). However, these estimates have uncertainty because it is not clear the effectiveness of new hull coating technology i.e. there are different opinion over the effectiveness of biocidal coatings and fouling-release coatings.

In particular, the solution requires the maintenance costs for repainting the hulls every five years, which are estimated at between \$2,000 and \$150,000 depending on ship size. However, the hull coatings were already cost effective in 2007, and it is expected to become a more attractive solution with the negative marginal abatement cost of minus \$360 per ton in 2020, which is almost double the estimate in 2007. In addition, ship size and age do not influence the cost effectiveness of the hull coatings (Maddox, 2012).

3.2.9 Propulsion System Upgrade

3.2.9.1 Overview

The purpose of the solutions is to improve the propulsive efficiency of ships by adopting advanced propulsion systems to existing ships, which lead to reducing fuel consumption and CO_2 emissions. In general, the propulsion systems (e.g. propellers and rudders) are determined at the design stage of new ship buildings because there is close relationship with ship specifications (e.g. hull form or engine power). For instance, when improving propulsive efficiency of ships, a single propeller update may not influence the propulsive performance because there is no consideration over ship specifications and water inflow to the propeller (IMO, 2009).

Currently, new design technologies make it possible to retrofit the advanced propulsion systems to existing ships. The propulsion system upgrades can be classified into two main groups. The first group was developed by using the traditional propeller, which includes the integrated propeller design with a rudder bulb, propeller nozzles and tip winglets, propeller boss caps with pins, and optimized propeller blade sections. The second group was developed by adopting more innovative approach, which includes contra-rotating propellers, wing thrusters, and pulling thrusters (IMO, 2011a).

3.2.9.2 Limitation in Propulsion System Upgrade

Regarding technical maturity, the technology of propulsion system upgrades is mature, and this is widely applicable to existing ships. However, there is technical difficulty in measuring effectiveness of propulsion system upgrades i.e. there is technical concerns in analyzing the hydrodynamic performance of the propulsion system upgrades. In addition, these solutions have uncertainty over the effectiveness during the slow speed operation.

3.2.9.3 Estimation of Propulsion System Upgrade

It is estimated that the CO_2 abatement potential of the propulsion system upgrade will account for between 3.1% and 4.0% in the shipping sector by 2020 (Maddox, 2012). However, this estimate has some variation by different options and ship type. This is because shipowners can choose the best suitable propulsion system for their ships among other propulsion systems, depending on ship type

This solution requires capital costs for installing the solution, which vary from $70,000 to $6,600,000 depending on ship type and size. In particular, the propulsion system upgrades were not cost effective in 2007, but it is expected to become cost effective solutions with negative marginal abatement cost of minus $191 per ton in 2020, which is a significant increase compared to the estimate of $58 per ton in 2007. In addition, ship size and age do not influence the cost effectiveness of the propulsion system upgrade (Maddox, 2012).

3.2.10 Main Engine Adjustment

3.2.10.1 Overview

The purpose of the main engine adjustment is to improve the efficiency of main engines by applying new fuel injection technology, and thereby reducing fuel consumption and CO_2 emissions. The technology of main engine adjustment can be classified into two main solutions i.e. “engine tuning” and “common rail”.

The engine tuning is to optimize the efficiency of engine performance at the specific operating load that is usually the most common load in ship operations. The engine tuning process entails changing the cam position or adjusting the injection timing with new fuel injectors to meet a specific engine mapping condition. The engine tuning can reduce fuel consumption effectively within a specific operating load (i.e. slow speed operation), but there might be excessive fuel consumption outside the specific operating load (IMO, 2011a).

The common rail solution is to optimize the efficiency of engine combustion over a wide range of loads. This common rail solution can control the injection timing by using electronic injector units, and it can also improve the atomization of fuel injection by using the high-pressure fuel rail. Compared to the traditional injection system, the common rail solution can reduce fuel consumption more effectively over a wide range of loads.

3.2.10.2 Limitation in Main Engine Adjustment

Regarding ship type, the common rail solution can be applicable to all ship types, but the engine tuning solution is less applicable to ferries and cruise ships. This is because the engine tuning solution was developed to optimize main engines to operate at slow speed operation for extended time, but in general ferries and cruise ships do not operate at slow speed because of their tight voyage schedule with passengers.

3.2.10.3 Estimation of Main Engine Adjustment

It is estimated that the CO_2 abatement potential of main engine adjustment will account for between 1% and 3% in the shipping sector by 2020. The main engine adjustment solutions were already cost effective in 2007 with negative marginal abatement costs of minus \$103 per ton, and it is expected to become economically more attractive solutions with negative marginal abatement costs of minus \$325 per ton by 2020 (Maddox, 2012).

From the long term perspective, the applicability of main engine adjustment solutions will be increased because fuel cost has being increased and thereby arising needs of this technology in the shipping industry. In addition, the ship size and age do not influence cost effectiveness for this solution.

3.2.11 Waste Heat Recovery (WHR) system

3.2.11.1 Overview

The purpose of waste heat recovery (WHR) system is to generate additional electricity by using waste heat from engine exhaust gas. This solution allows auxiliary engines to reduce work-loads, and thereby reduce fuel consumption and CO_2 emissions. However, the WHR system may not be effective when reducing ship speed or when engine efficiency is improved because insufficient waste heat will generate less electricity.

The WHR system can be more effective when using the lower sulphur fuels which will be regulated up to 0.5 % sulphur content by 2020, because the waste heat from engine exhaust gas is highly affected by the acid formation based on sulphur contents and dew points in the fuel (Maddox, 2012).

3.2.11.2 Limitation in the WHR system

The WHR system can be applicable to ships that can produce substantial waste heat from engine exhaust gas and consume large amounts of electricity. Therefore, it is needed that main engine power should be higher than 20,000 kW and auxiliary engine power should be higher than 1,000 kW (IMO, 2011a).

At present, the WHR system is being regarded as an experimental solution which leads to difficult retrofitting to existing ships because of spatial and operational limitations onboard ships. Therefore, this solution is more applicable to new ships because spatial issues can be addressed at the design stage of ship buildings. Furthermore, the WHR system is mutually exclusive with the slow speed operation because the waste heat is not sufficient to generate electricity at the reduced engine load (Maddox, 2012).

3.2.11.3 Estimation of the WHR system

It is estimated that the CO_2 abatement potential of the WHR system will account for between 1.7% and 5.7% in the shipping sector by 2020. However, it is not clear that this estimate can be achieved because shipowners may be reluctant to invest in the WHR system due to global economic downturn which leads to the slow steaming, and this will prevent implementation of the WHR system (Maddox, 2012).

This solution requires substantial capital costs for installation of the WHR system, which are estimated at between $2,500,000 and $12,000,000. In addition, operational costs are estimated at between $40,000 and $50,000 per year. In particular, the WHR system was not cost effective in 2007 for all ship types, and this solution still would not be cost effective in 2020 for most ship types (Maddox, 2012).

However, it is expected that this solution will become more cost effective in 2030 for most ship types, but this is still economically less attractive than other solutions because it is not clear that technical development can overcome the spatial and operational limitations when retrofitting to existing ships. In addition, ship type, size and age have a significant impact on the cost effectiveness of the WHR system due to the capital costs (Maddox, 2012).

3.2.12 Speed Control of Pumps and Fans

3.2.12.1 Overview

The purpose of speed control is to reduce energy consumption of cooling pumps and fans onboard ships, and thereby reduce fuel consumption and CO_2 emissions. This solution includes controllable speed motors and power optimization for these motors to reduce unnecessary energy consumption of pumps and fans onboard ships.

In conventional cooling systems, pumps and fans constantly circulate fixed amounts of water or air in full load conditions, which result in unnecessary energy consumption. However, the variable speed pumps and fans can supply an appropriate amount of water or air to the cooling systems, and thereby improve energy efficiency of ships.

3.2.12.2 Limitation in speed control of pumps and fans

The cooling pumps and fans account for only a small portion of the total power requirement onboard ships. Accordingly, the energy savings by this solution is relatively smaller than other solutions, and it is estimated that the cost effectiveness of this solution would vary from negative to positive until 2030. The speed control of pumps solution may be applicable to new cruise ships with EEDI, achieving additional fuel savings by reducing hotel loads.

3.2.12.3 Estimation of speed control of pumps and fans

It is estimated that the CO_2 abatement potential of the speed control will account for between 0.2% and 1.0% in the shipping sector by 2020. In particular, this solution requires the substantial capital costs, which are estimated at between \$10,000 and \$1,000,000 depending on ship type and size, but operational costs do not occur. In this respect, it is expected that this solution may not be economically attractive in the likely case, but it may become cost effective in the high case in the year 2020 with negative CO_2 marginal abatement costs of minus \$250 per ton. In addition, ship size and age do not influence on cost effectiveness of this solution (Maddox, 2012).

Chapter IV

Challenges in implementing CO_2 abatement solutions

4.1 Identification of Challenges in implementing CO_2 abatement solutions

4.1.1 Technical Challenges

Technical challenges occur from technical concerns associated with applicability of CO_2 abatement solutions. These concerns come from poor performance of CO_2 abatement solutions and unattractive financial returns and lack of confidence in the technology due to insufficient operational data (IMO, 2010). For example, there is concern about performance of main engines when it operates for extended time at lower engine speeds, which may prevent implementation of speed optimization. In addition, the lifetime of new hull coatings is one of the technical concerns. The new weather routing system is another technical concern because it should integrate weather prediction and hydro-dynamic performance in various sea conditions.

4.1.2 Operational Challenges

Operational challenges may occur when solutions cannot be used on a specific ship type because of operational or spatial limitations. For example, smaller ships may not have sufficient space to install the waste heat recovery (WHR) system in the exhaust funnel. In addition, container ships do not have appropriate space to install large solar cells due to limited deck space. In the same way, bulk carriers have hatch covers which make a limitation to use large solar cells during cargo operations. Finally, sail devices may not be applicable to ships with limited deck space such as container ships and bulk carriers (Maddox, 2012).

4.1.3 Regulatory Challenges

4.1.3.1 Antitrust Regulations vs. Speed Optimization

The main purpose of antitrust regulations is to prevent shipping companies from setting freight rates and service levels jointly. However, antitrust regulations also have negative impact on implementing the speed optimization; collusive activities to reduce ship speed may be restricted by the market competition laws. In the container sector, the collusive actions to reduce the ship speed are restricted by competition authorities such as the Elimination of Conference Anti-Trust Authority in the EU and the Federal Maritime Commission in the US (Maddox, 2012). Similarly, tankers or bulkers may agree on the reduced speed operations in the pooling associations jointly, but competition authorities may regulate the collusive slow speed operations as well.

4.1.3.2 Local Environment Regulations

The spread of invasive species by ships becomes a main threat to the marine environment especially to the conservation of biodiversity. Recently, IMO adopted the guidelines for the control of bio-fouling to minimize the transfer of invasive species into other ecosystems (IMO, 2011c). In this regard, some local regulations prohibit the release of cleaning residues during the hull cleaning or the propeller polishing in order to protect the local environment. Therefore, the enhanced local environment regulations make it difficult to implement energy saving solutions such as hull cleaning or propeller polishing.

4.1.4 Economic Challenges : High Fuel Costs

The foreseeable return on investment has a decisive impact on implementing the CO_2 abatement solutions i.e. energy saving solutions. In particular, uncertainty of future fuel prices may have a significant impact on implementing the energy saving solutions. In general, economic challenges occur when the energy saving solutions are marginally economical in light of high fuel costs.

Currently, the fuel costs have been breaking the historical highs over the past decades. Thus, shipping companies are focusing on implementing CO_2 abatement solutions to reduce increased high fuel costs, which was not a major concern in the time of low fuel prices. In particular, the speed reduction is becoming the best economic choice in the container shipping sector to reduce high fuel costs and surplus capacity of ships due to economic downturn. The high fuel costs have a major impact on implementing the CO_2

abatement solutions.

The differential price between heavy fuel oil (HFO) and marine distillate fuel oil (MDO) is newly emerging issues in the shipping industry. The revised MARPOL Annex 6 will regulate sulphur contents in fuel oil up to 0.5% by 2020 (IMO, 2008). In this regard, there would be two possible options in 2020 in order to meet the requirement of SOx limits.

First, it is expected that mandated regulations of sulphur limits would not be applicable to the HFO containing higher sulphur. Therefore, shipping companies may have to use the MDO which requires much higher fuel costs in comparison to consuming the HFO (ISC, 2010). Switchover from HFO to MDO will have a major impact on implementing CO_2 abatement solutions because the sudden use of high priced MDO would be a shock to the shipping industry in the year 2020.

Second, the exhaust gas scrubber technology may be developed by reducing the sulphur emissions from the HFO. This technology may prevent the fuel changeover from HFO to MDO, and thereby shipowners could reduce the high fuel costs by using relatively low priced HFO. However, it should be noted that the scrubber technology may not reduce the CO_2 emissions while it reduces SOx, NOx and PM emissions.

4.1.5 Market Challenges

4.1.5.1 Split Incentive for fuel savings in the market

The split incentive between shipowners and charterers is the biggest market challenges in implementing the CO_2 abatement solutions. This split incentive occurs from a specific situation in the charter market in which the party who benefits from fuel savings is not the same party who reduces the fuel costs (Jaff et al, 1994). In general, shipowners may invest in energy saving solutions for their ships, but the profits from the fuel savings will pass on to charterers because the party who pays for fuel costs is the charterers. There is no profit sharing between shipowners and charterers.

In principle, ships that improve energy efficiency should get higher charter rates, but in the charter market there are no benefits from improvement of ship's energy efficiency. It is difficult to improve the commercial practices due to complexity of the charter market and lack of verification process to guarantee the energy savings from ships. In a time charter, the standard service speed and the fuel consumption are specified in the charter agreements. However, there are no benefits to shipowners when they reduce the fuel consumption more than pre-agreed fuel consumption, and financial return on investment of energy saving solutions will not pass on to shipowners.

4.1.5.2 Commercial Practice issues : "Virtual Arrival" approach

In a spot charter market, the shipowner will be penalized unless the ship arrives within the designated time. Adversely, when the ship arrives within the designated time but the ship has to wait due to port congestion, the shipowner may request demurrage according to the charter party. Consequently, the opportunity to reduce fuel consumption will be disappeared in this commercial practice because the speed optimization may not be needed according to the charter agreement even when the port is not ready for cargo operation.

To improve this commercial practice, shipowner associations such as INTERTANKO and OCIMF have developed new approach (i.e. "virtual arrival") to allow the slow speed operations under charter arrangements. The "virtual arrival" approach needs specific clauses in the charter party, which includes specific terms for the slow speed operations, demurrage compensation, and profit sharing due to fuel savings between shipowners and charterers (Ranheim & Hallet, 2010). However, it is possible that the "virtual arrival" approach may be prohibited by the antitrust regulations because it can be regarded as collusive actions of slow steaming.

4.1.5.3 Boom and Bust in the shipping market

The shipping industry repeats the times of boom and recession. When freight rates are high, shipowners may have funds to invest in energy saving solutions. Nevertheless, shipowners are reluctant to take a ship out of service because the service time will make more profits. On the other hand, when freight rates are low, shipowners are reluctant to invest in energy saving solutions because the funds are not sufficient to the investment for energy saving solutions (IMO, 2011a).

For instance, during the time of boom, when the hull cleaning is carried out, shipowners can have two different options related to ship speed reduction. In most cases, shipowners may increase ship speed with the same fuel consumption, or shipowners may reduce ship speed by reducing fuel consumption, which is dependent on the relationship between freight rates and fuel prices (IMO, 2011a).

4.1.6 Lack of fuel consumption data in the shipping market

Fuel consumption data of ships is used to indicate the level of the ship energy efficiency, which may have a decisive impact on ship transaction and ship chartering. However, it is difficult to utilize the fuel consumption data for individual ships in the shipping market. At present, the international standard database (i.e. IHS Fairplay database) has the fuel consumption data for only 27 % of international ships (Maddox, 2012).

In particular, the lack of fuel consumption data prevents shipowners from investing in energy efficient solutions due to uncertainty over financial return on their investment. Furthermore, in the charter market, split incentive issues may occur between shipowners and charterers. This is because shipowners cannot demonstrate energy efficiency of ships, and charterers cannot give incentives due to improvement of energy efficiency of ships because there is no acceptable data on fuel consumption of ships.

4.1.7 Management Challenges

Currently, the shipping industry has a large number of small shipping companies, but they are suffering from the lack of human resources and technical expertise to evaluate, make a decision, and supervise the implementation of CO_2 abatement solutions. In this regard, management challenges may occur when the small companies do not recognize the importance of cost effectiveness of energy saving solutions, which may prevent implementing the energy saving solutions. Moreover, it is important that motivation for improvements of energy efficiency must come from the shipowner rather than the staff in a company because the shipping industry is conservative in changing its management practices.

4.2 Analysis of Challenges in implementing each of CO_2 abatement solutions

4.2.1 Overview

The speed optimization is the most complicated solution when implementing to existing ships because it needs closer coordination between relevant parties such as shipowners, charterers and competition authorities. In this section, further details of challenges in implementing the speed optimization are describe and discussed on a basis of the general challenges identified in section 4.1.

Other CO_2 abatement solutions are relatively less complicated than speed optimization when implementing to existing ships because they are a kind of tangible solutions, and cost effective at present or in the future in relation to the increased fuel price. In this section, further details of challenges in implementing the individual CO_2 abatement solutions are discussed on a basis of the general challenges identified in section 4.1.

4.2.2 Challenges to Speed Optimization

4.2.2.1 Overview

Speed optimization is the easiest solution to implement the energy savings, and the most cost effective solution to reduce CO_2 emissions. In addition, the speed optimization has the highest potential to reduce CO_2 emissions among other energy saving solutions. For instance, the speed optimization already reduced CO_2 emissions by almost 20 % in 2010 in comparison to the business as usual case. Moreover, it is estimated that the speed optimization can reduce CO_2 emissions by over 30 % in 2020 and then by over 38 % in 2030 (Maddox, 2012).

In order to identify the specific challenges in implementing the speed optimization, it is important to clarify how the service speed is determined in the current market. At present, in a time charter, charterers determine the service speed both in laden voyages and in ballast voyages. In a spot charter, shipowners can determine the operating speed during ballast voyages, but charterers control the service speed in laden voyages. In this section, the specific challenges in implementing the speed optimization will be discussed on the basis of ship speed setting in laden voyages and in ballast voyages.

4.2.2.2 Challenges to Speed Optimization in Ballast voyages

In a spot charter, the ship speed can be managed by shipowners during ballast voyages. Currently, high fuel costs and low charter rates have encouraged shipowners to focus on ballast voyages to reduce fuel consumption by implementing the speed optimization. For this reason, most lager tankers (e.g. VLCC) are operating at slower speeds of 11-12 knots during their ballast voyages. This operating speed can be considered as the optimal speed to minimize fuel consumption. Therefore, there are low challenges to adoption of the speed optimization to larger tankers during their ballast voyages (Maddox, 2012).

However, smaller tankers have relatively higher challenges in implementing the speed reduction during their ballast voyages. This is because shipowners who operate smaller tankers do not have adequate human resources and technical expertise to evaluate cost effectiveness of speed optimization. In addition, there are concerns over the performance of main engines operating in low power condition for extended periods. Also bulk carriers have the same challenges with the smaller tankers when implementing the speed optimization, as mentioned previously. In particular, container ships and cruise ships do not have the ballast voyages, but the speed optimization can be implemented during their all voyages.

4.2.2.3 Challenges to Speed Optimization in Laden voyage

In a spot charter, the ship speed is managed by charterers during laden voyages, and this service speed is specified in the clause of charter party. However, in the tanker industry, there are typical challenges in implementing the speed optimization as follows:

Oil companies should minimize the holding stock at their refineries to avoid the capital loss. However, slow speed operations may incur additional capital loss due to increased holding stock. Therefore, when evaluating economic benefits from speed optimization, the capital costs of holding stock should be taken into account.

In general, petroleum is traded in the spot market and futures market. In such case, future oil prices should be higher than current oil prices considering holding and storage costs. However, in the current oil market, the future oil prices are abnormally lower than the current oil prices. Due to the abnormal market situation, oil companies constantly require shipowners to operate their ships at full service speed in order to reduce transit time.

Regarding commercial practices, when a tanker arrives at the discharge port on time but has to wait due to port congestion, the shipowner can request demurrage payment to the charterer according to the charter party. In contrast, if the charterer and the shipowner in advance know about the port congestion, the ship could reduce the speed. However, in such case, the shipowner will not reduce ship speed because they can collect demurrage from the charterer according to the charter party.

4.2.2.4 Regulatory Challenges to Speed Optimization

In the tanker and bulker sectors, shipowners may operate their ships in the pooling associations in which the revenues are shared with other members. In this case, the speed reduction can be employed through collusive actions with other shipowners. However, competition authorities may not agree to the pooling associations because the collusive actions of speed reduction may bring about the supply reduction and the freight rate rise. Therefore, this regulatory intervention would prevent shipowners from implementing the speed optimization.

In the container sector, the speed reduction is more complex due to the regular service strings. The fixed service schedule may complicate the slow steaming operation because the service strings should be compensated by additional ships and voyage optimization. In general, shipowners may operate their ships jointly with other companies through the associations (e.g. conference or alliance or consortium). In this case, the slow steaming can be employed through collusive activities with other companies.

In particular, the container sector has been controlled by the commercial regulation based on “common carriage”. Historically, the container sector was granted antitrust exemption on setting freight rates and service levels jointly in the associations according to commercial regulations. Currently, the collusive activities of slow steaming also lead to freight rate rise and poor service level. In this regard, shippers constantly have requested elimination of the antitrust exemption on freight rate setting and service level setting.

4.2.3 Challenges to Weather Routing Service

The initial weather routing service was to ensure the safety navigation by avoiding heavy weather condition. Over time, it was recognized that the weather routing service can improve energy efficiency of ships. Meanwhile, the weather routing services have been widely used to existing ships, and its technology is still evolving to achieve additional energy savings.

The weather routing service has been employed for over two decades. Therefore, there are no major challenges to implementation. However, split incentive issues may occur between shipowners and charterers when implementing the weather routing services. For instance, shipowners are required to invest in subscription of the weather routing service, but the party who benefits from energy savings is not the shipowners but the charterers.

In addition, some shipowners do not consider the weather routing service as the energy saving solution due to a lack of awareness of its effectiveness. In this regard, shipowners are also reluctant to train their crews to utilize the information from the weather routing services relating to the energy savings of ships.

4.2.4 Challenges to Autopilot System Upgrades

The main purpose of autopilot system is to keep navigation courses to designated points. In addition, the autopilot systems have software to minimize the rudder movements by optimizing the course adjustments, which lead to improving energy efficiency of ships. As fuel prices are expected to increase, it is expected that the autopilot system upgrade would be more cost effective solution.

Ships engaged in ocean-going voyages have already employed the autopilot systems. Therefore, there are no major challenges to implementation. However, the split incentive issues may occur between shipowners and charterers when implementing the autopilot system upgrade. For instance, shipowners are required to invest in the autopilot system upgrades, but the party who benefits from the energy savings is not the shipowners but the charterers.

4.2.5 Challenges to Optimization of Trim and Ballast

The optimized trim and ballast conditions can reduce the hull resistance and thereby improve energy efficiency of propulsion units (e.g. propellers or rudders), which lead to reducing fuel consumption and CO_2 emissions. The technology of optimizing trim and ballast conditions is evolving with a ship performance monitoring system which includes thrust measurements and software solutions to identify the optimal fuel consumption condition and thereby improve energy efficiency of ships.

However, it is still difficult to identify the optimal trim and ballast points in various sea weather and loading conditions. In this regard, there are still technical challenges in identifying the optimal fuel consumption condition with the current technology. In addition, there is different technical point of view between safer ballast conditions and energy efficient ballast conditions. In the same way, there may be conflicts between the operator who focuses on energy efficiency of ships and the crew who focuses on safety of ships when optimizing trim and ballast condition.

In addition, the split incentive issues may occur between shipowners and charterers when implementing the optimization of trim and ballast. For instance, shipowners are required to make substantial investments in the ship performance monitoring systems to identify the optimum trim and ballast conditions, but the party who benefits from the energy savings is not the shipowners but the charterers.

4.2.6 Challenges to Propeller Polishing

Propeller polishing can improve the propeller performance and thereby reduce fuel consumption and CO_2 emissions. The propeller polishing is a technically mature and cost effective solution as fuel costs increased over the past decades. However, most ships have already carried out the propeller polishing on a regular basis. Accordingly, the penetration rate of this solution will not increase so much in comparison to present level, even though fuel prices are expected to increase substantially.

Currently, the IMO adopted the guidelines for bio-fouling to minimize the transfer of invasive species to other ecosystems (IMO, 2011c). In this context, some port authorities enhanced their local environment regulations that prohibit propeller polishing in their ports because of concerns over environmental impacts of cleaning residues. This local environment regulation can be regulatory challenges in implementing the energy saving solutions (e.g. propeller polishing).

In addition, the split incentive issues may occur between shipowners and charterers when implementing the propeller polishing. In particular, shipowners are required to carry out propeller polishing to improve propeller performance and thereby improve energy savings, but the party who benefits from the energy savings is not the shipowners but the charterers.

4.2.7 Challenges to Hull Cleaning

Hull cleaning can improve the hull resistance and thereby reduce fuel consumption and CO_2 emissions. The hull cleaning is a technically mature and cost effective solution as fuel costs increased over the past decades. However, most ships have already carried out hull cleaning on a regular basis. Accordingly, the penetration rate of hull coating will not increase so much in comparison to present level, even though fuel prices are expected to increase substantially.

Regarding regulatory challenges, some port authorities prohibit hull cleaning in their ports due to concerns over environmental impacts of the hull residues. The ban on hull cleaning in ports may incur additional costs and time for carrying out the hull cleaning outside the ports. This local environment regulation can be regulatory challenges in implementing the energy saving solutions (e.g. hull coating).

In addition, the split incentive issues may occur between shipowners and charterers when implementing the hull cleaning. In particular, shipowners are required to carry out hull cleaning to improve the hull residence and thereby improve the energy savings, but the party who benefits from the energy savings is not the shipowners but the charterers.

4.2.8 Challenges to Hull Coating

The purpose of hull coatings was to prevent hull corrosion and bio-fouling. However, hull coating technology has experienced a remarkable changeover as a result of the ban on TBT materials. Over time, new coating technology (i.e. biocidal coatings and fouling-release coatings) have been developed to reduce hull resistance and thereby reduce fuel consumption and CO_2 emissions in accordance with the ban on TBT materials.

Regarding technical challenges, there are substantial concerns over the effectiveness of new hull coatings. Previously, the TBT-based hull coatings were extremely effective and inexpensive to prevent hull collusion and bio-fouling albeit negative impacts on the environment. From a long-term perspective, it is not clear that new hull coatings (i.e. biocidal coatings and fouling-release coatings) will continue to be effective in terms of financial returns and long-term performance. In particular, there is technical uncertainty over the performance of fouling-release coatings during slow speed operations.

Another challenge is that there is no reliable standard for measuring the effectiveness of hull coatings. As a result of the ban on TBT materials, at present shipowners have to employ new hull coatings, but they do not have adequate technical expertise to evaluate efficacy of new hull coatings. In particular, hull coating makers insist that their solutions can improve hull performance and thereby reduce fuel consumption, but this cannot be demonstrated by shipowners due to the lack of measurement standards. Accordingly, the absence of measurement standards makes it difficult for shipowners to employ new hull coatings (IMO, 2011f).

In addition, the split incentive issues may occur between shipowners and charterers when implementing the hull coating. In particular, shipowners are required to invest in hull coatings to improve the hull residence and thereby improve the energy savings, but the party who benefits from the energy savings is not the shipowners but the charterers.

4.2.9 Challenges to Propulsion System Upgrade

Propulsion system upgrades can improve the propulsive efficiency of ships by adopting advanced propulsion arrangements to ships, which lead to reducing fuel consumption and CO_2 emissions. However, the propulsion system upgrade needs substantial capital costs due to investment of retrofitting its equipment to existing ships. In this regard, the financial return is a challenge in implementing this solution because there would not be economic benefits from employing this solution until 2020 (Maddox, 2012).

The technology of the propulsion system upgrades is already mature, and widely applicable to existing ship. However, there is technical difficulty in measuring the effectiveness of the propulsion system upgrades i.e. there is technical concerns in analyzing the hydrodynamic performance of the propulsion system upgrades. In addition, this solution has technical uncertainty over the effectiveness during slow speed operation.

In addition, the split incentive issues may occur between shipowners and charterers when implementing the solution. In particular, shipowners are required to invest in retrofitting the propulsion system to their ships for improving propulsive efficiency and thereby reduce fuel consumption, but the party who benefits from the fuel savings is not the shipowners but the charterers.

4.2.10 Challenges to Main Engine Adjustment

The purpose of the main engine adjustment is to improve the efficiency of main engines by applying new fuel injection technology, which leads to reducing fuel consumption and CO_2 emissions. The technology of main engine adjustment can be divided into two main solutions i.e. "engine tuning" and "common rail".

There is a technical challenge in improving the efficiency of main engines due to the inverse relationship between NOx emissions and CO_2 emissions; while NO_2 emissions are reduced, CO_2 emissions will be increased during engine combustion. In particular, NOx emissions limits have been mandated in 2008 by adopting the revised MARPOL Annex 6 (IMO, 2008). To meet NOx emissions limits, engine manufactures apply the engine tuning technology aiming at reducing NOx emissions, but they cannot technically reduce CO_2 emissions at the same time. Therefore, this NOx emission regulation makes it difficult to improve energy efficiency of main engines.

In addition, the split incentive issues may occur between shipowners and charterers when implementing the engine adjustment technology. In particular, shipowners are required to invest in retrofitting these solutions to their ships for improving engine efficiency and thereby reduce fuel consumption, but the party who benefits from the fuel savings is not the shipowners but the charterers.

4.2.11 Challenges to Waste Heat Recovery (WHR) system

WHR system can generate additional electricity by using waste heat from engine exhaust gas. This solution allows auxiliary engines to reduce their work-loads and thereby reduce fuel consumption and CO_2 emissions. However, the WHR system has uncertainty over financial returns on investment in the solution and cost effectiveness in light of high fuel prices. This is because the WHR system requires substantial capital costs for installation, but it is not clear that technical development can guarantee economic benefits when retrofitting to existing ships.

Regarding operational challenges, WHR system is still in the entry-level of its product life cycle because operational and spatial problems are not resolved. For instance, ships may not have sufficient space to install the waste heat exchanger in the exhaust funnel. Furthermore, the WHR system is mutually exclusive with slow speed operation because waste heat may not be sufficient to generate electricity at the reduced engine load.

4.2.12 Challenges to Speed Control of Pumps and Fans

The purpose of this solution is to optimize the energy use of auxiliary machines (i.e. pumps and fans) onboard ship. In conventional cooling systems, the volume of water for “engine cooling” remains constant irrespective of the engine loads needed. However, by controlling speed of cooling pumps, the volume of cooling water could correspond to actual requirement.

Regarding a challenge to implementation, energy saving from this solution is relatively minor compared to other solutions. This is because cooling pumps and fans account for only a small portion of total power requirements onboard ships. Rather, the speed control of pumps and fans may be more applicable to cruise ships with high hotel loads. On the other hand, as the EEDI entered into force, it is expected that all ships will employ this solution to achieve additional fuel savings by reducing unnecessary energy consumption.

Chapter V

Feasible Measures to facilitate implementation of CO_2 abatement solutions

5.1 Overview

This chapter will propose Feasible measures to remove challenges in implementing CO_2 abatement solutions to existing ships, and will analyze advantages of proposed measures, and will discuss about possibility of implementation of proposed measures as follows.

- Fuel consumption certification
- New charter clauses for slow speed operation
- Enhanced SEEMP implementation
- Energy efficiency measurement standards
- Environmental incentive for speed optimization

5.2 Fuel Consumption Certification

5.2.1 Overview

Fuel consumption data of ships is used to indicate the level of ship's energy efficiency, which may have a decisive influence on ship transaction and ship chartering. However, there is no reliable and acceptable data on fuel consumption of ships. The lack of fuel consumption data may prevents shipowners from investing in energy saving solutions due to uncertainty over financial returns. Furthermore, split incentive issues may occur between shipowners and charterers in the charter market because shipowners cannot demonstrate energy efficiency of ships to charterers due to lack of fuel consumption data.

In this context, "fuel consumption certification" is to verify fuel consumption of ships and provide reliable data on energy efficiency of ships for shipowners or charterers. This measure will provide standard procedures for measuring fuel consumption of ships under standard ambient conditions. In addition, fuel consumption certificates should be issued by authorized organizations such as flag States or classification societies. This measure is different from the EEDI based requirements for existing ships, but it is similar to energy efficiency measurement of automobiles (e.g., liters per kilometer).

The fuel consumption certification may need “sea trials” and “model tests” to analyze accurate fuel consumption of ships. Sea trial data must be corrected to standard ambient conditions (e.g. sea weather and loading conditions) by using a reliable method. Sea trial data includes fuel used per day, engine power produced, speeds at specific ranges, and loading condition (IMO, 2011b). In addition, the “model test” should be carried out to analyze the results of sea trial data. This process is similar that EEDI requirements need actual sea trial data for verifying energy efficiency of ships (IMO, 2011d).

5.2.2 Advantage of fuel consumption certification

Fuel consumption certification could directly eliminate the issue of the split incentives between shipowners and charterers in the charter market. With valid fuel consumption certificates, charterers could utilize specific information on individual ship’s energy efficiency in their chartering decision, and shipowners could get incentives due to the improvement of energy efficiency of ships. Furthermore, potential ship purchasers could utilize fuel consumption certificates in their purchase decision. In particular, the certificates make it more attractive for shipowners to invest in energy saving solutions.

5.2.3 Possibility of implementation : Fuel Consumption Certification

The fuel consumption certification would be applicable to all CO_2 abatement solutions, by encouraging implementation of individual energy saving solutions. In addition, it is expected that possibility of implementing the fuel consumption certification would be high because this measure would directly eliminate split incentive issues between shipowners and charterers by providing reliable data on energy efficiency of ships.

5.3 New Charter Clauses for slow speed operation

5.3.1 Overview

In a time charter, the charterer manages ship speed and pays for fuel costs. Time charters are mainly used in the container sector to maintain its service strings. However, shipowners have concerns over the engine damage due to low load operations during slow steaming. To address this issue, the industry associations such as BIMCO have developed new time charter clauses for slow steaming, and such clauses have been well accepted by associated parties such as shipowners, charterers and shippers (BIMCO, 2009).

In a spot charter, the shipowner pays for fuel costs and manages ship speed during ballast voyages. However, shipowners could not employ slow steaming during laden voyages because service speeds are specified in the charter party. Currently, there is an issue of the "virtual arrival" approach which allows shipowners to reduce ship speed by negotiation with charterers when the port congestion is expected. The "virtual arrival" approach can reduce fuel costs and CO_2 emissions by implementing slow steaming. However, there are no specific clauses for the reduced speed operation and the "virtual arrival" approach in a spot charter, which prevents shipowners from implementing speed optimization.

The industry association i.e. BIMCO is now developing new spot charter clauses for the slow speed operation and the "virtual arrival" approach. The spot charter clauses would be more complex than the time charter clauses because of commercial practices in the charter market; the charterers require keeping regular service speed and the shippers require reducing transit time of their cargo. To address this issue, spot charter clauses should allow shipowners to reduce ship speed provided that ships do not operate below the pre-agreed ship speed.

5.3.2 Advantage of new charter clauses for slow speed operation

In a time charter, there are split incentive issues during slow steaming; shipowners have concerns over engine damage due to low power operations, whereas charterers can benefit from fuel savings through slow steaming. In this regard, the new time charter clause will address specific terms to allow shipowner to prevent main engine damage due to slow steaming (BIMCO, 2009).

In a spot charter, there are more complex split incentive issues than a time charter during slow steaming; there are issues about sharing profits and obligations between shipowners and charterers. In this regard, the new spot charter clause will address specific terms to share the profits from fuel savings. Shipowner can collect demurrage compensation by saving fuel costs, and charterers can also reduce fuel costs with slow speed operation.

Consequently, the new charter party clauses to allow the reduced speed reduction would remove split incentive issues between shipowners and charterers, and thereby improve implementation of speed optimization and reduce fuel consumption and CO_2 emissions.

5.3.3 Possibility of Implementation : new Charter Clauses

The industry associations have developed the standard charter party clauses, and relevant parties such as shipowners and charterers could use the new clauses in their charter party. Possibility of implementing new charter clauses for slow speed operation would be high because the industry associations (e.g. BIMCO) are focusing on developing more practicable charter clauses to encourage their members to implement the slow speed operation. However, the new charter clauses are only applicable to speed optimization.

In particular, the new charter clauses for slow speed operation would be effective on a voluntary basis, not a mandatory basis. There would be strong opposition to mandatory slow speed operation because the benefits from speed optimization are highly related to fuel prices and freight rates. Therefore, possibility of implementing new charter clauses for slow speed operations on a mandatory basis would be low.

5.4 Enhanced SEEMP implementation

5.4.1 Overview

SEEMP is a ship-specific energy management plan to minimize fuel consumption and CO_2 emissions in the ship operation. However, current regulatory requirements are not sufficient to improve the effectiveness of the SEEMP. Shipowners do not necessarily set the goals, implement the plans, evaluate the progress, or verify the improvement of energy efficiency of ships because the SEEMP implementation is not mandatory. For this reason, the SEEMP has a limitation in encouraging shipowners to improve the environment performance of ships.

In principle, the SEEMP is one of the best practices to remove management challenges in implementing energy saving solutions. However, it is difficult for small shipping companies to improve energy efficiency of their ships by using the SEEMP because they do not have sufficient human resources and technical expertise. To overcome this issue, shipowners must develop specific procedures to manage energy efficiency and monitor fuel consumption by using other environmental management system (IMO, 2009).

To improve environment performance of ships, the environmental management system (EMS) based on ISO 14001 should be used and mandated to enhance effectiveness of SEEMP implementation. The EMS requires a policy statement for energy savings, identification of energy saving activities, setting measurable goals (e.g. specific target of the EEOI), establishing audit program, and top management participating. The EMS structure has substantial benefits for improving the SEEMP implementation.

5.4.2 Advantage of enhanced SEEMP implementation

The mandatory use of the EMS based on ISO 14001 structure will have a significant influence on increasing awareness of importance of energy saving activities, and thereby removing management challenges in implementing energy saving solutions. In particular, the EMS based on ISO 14001 would ensure that top management recognizes importance of energy efficiency and secures human resources and technical expertise to analyze, evaluate and oversee the energy efficiency solutions. Accordingly, this measure would improve the SEEMP implementation, and thereby improving energy efficiency of ships and reducing CO_2 emissions.

5.4.3 Possibility of enhanced SEEMP implementation

The environment standard i.e. ISO 14001 is not a technical standard; it does not change any technical requirements in other management regulations. Therefore, the EMS based on ISO 14001 is widely being used in many industries especially in the shipping sector as a form of the SEEMP. This EMS structure establishes a management framework to improve the SEEMP implementation which can assist for shipowners to identify and reduce the negative energy saving activities.

In this context, the mandatory use of the EMS to improve the SEEMP implementation would have a substantial influence on improving energy management performance and thereby reduce CO_2 emissions. However, this measure will not ensure that environment management performance is improved in a short period of time because it may take some time to be effective (Johnny, 2011). Therefore, it is expected that some shipowners, who have insufficient human resources and technical expertise, may be reluctant to implement this measure for the time being.

5.5 Energy Efficiency Measurement Standards

5.5.1 Overview

Many of the energy saving solutions have been developed and introduced to the shipping industry for many years, but these solutions still have not been widely implemented to existing ships. This is because the performance of the energy saving solutions cannot be verified in actual ship operating conditions, and thereby cannot encounter shipowner to employ to their ships.

Currently, there are no reliable verification procedures for measuring the energy saving solutions for existing ships; the measurement of energy saving solutions depends on manufacturers' statements, results of shipboard tests, and other studies. In this context, this measure is to request institution of reliable energy efficiency measurement standards for verifying effectiveness of energy saving solutions (i.e. CO_2 abatement solutions).

At present, this measure has been discussed in IMO to establish the energy efficiency measurement standards; a verification issue regarding the EEDI was initially discussed in MEPC 61/5/22, and the establishment of standards for measuring hull and propeller performance has been discussed in MEPC 63/4/8 and MEPC 63/23. IMO discussion is an initial phase to establish the energy efficiency measurement standards, but this active

IMO commitment will extend to overall CO_2 abatement solutions, and not just for the hull and propeller solutions.

5.5.2 Advantage of Efficiency Measurement Standards

This measure would assist in removing technical and management challenges; this measure would reduce technical uncertainty of measuring the performance of solutions, and small shipping companies that have insufficient human resources to evaluate CO_2 abatement solutions (i.e. energy saving solutions) would obtain reliable information for measurement of the various solutions.

5.5.3 Possibility of implementation : Efficiency measurement standards

The energy efficiency measurement standards could be applicable to the CO_2 abatement solutions that require specific equipment: autopilot upgrades, hull coatings, propulsion system upgrades, main engine tuning, WHR, and speed control of pumps and fans. The issue determining the effectiveness of this measure may be the certification cost, as the manufacturers currently pay for the certification of solutions. Another issue is the certification procedure i.e. what should be certified and how is the standard defined. There would not be significant opposition to this measure depending on who certifies the CO_2 abatement solutions. Therefore, the possibility of implementation will be medium level (Maddox, 2012).

5.6 Environmental Incentive for Speed Optimization

5.6.1 Overview

There are two main measures regarding regulatory incentive for encouraging slow speed operation. The first measure is to provide additional incentives for ships operating at slow speeds from port States, thereby giving expeditious port State inspections or priority in berthing ships. Another measure is to grant an exemption on antitrust regulations to ships operating at slow speeds. The strict enforcement of antitrust regulations could ensnare shipowners operating in the industry associations (i.e. pools or conferences). To address this issue, competition authorities should grant exemption on antitrust regulations to ships operating at slow speed (Maddox, 2012).

5.6.2 Advantages of Environmental Incentive for slow speed operation

This measure would directly eliminate regulatory challenges i.e. antitrust regulations for slow steaming. Current antitrust regulations have negative impact on implementing the speed optimization; collusive activities to reduce ship speed are restricted by the market competition laws. Therefore, this measure would have significant impact on improve the implementation of the speed optimization.

5.6.3 Possibility of implementation : Environmental Incentive

The port State incentive is expected that possibility of implementation is a reasonable level because various ports already have provided the incentives for the sake of good environmental performance. For example, the ship speed is limited in Los Angeles/Long Beach and the environmental incentive is regulated in Sweden. However, CO_2 emission is a global issue as opposed to the local issues, and financial incentives from individual ports are not directly related to global CO_2 emissions. Accordingly, the direct impact on local environments would be low as compared to NOx and SOx emissions which have a direct impact on local air quality (Maddox, 2012).

Regarding the antitrust actions, the lawmakers are reluctant to grant antitrust exemptions to ships operating at slow speed. From a legal perspective of view, the exemption of antitrust actions would be considered as unfair activities to the open competition market. Therefore, the antitrust regulations regulating the slow speed operations could potential challenges to implement CO_2 abatement solutions (Maddox, 2012).

Chapter VI

Conclusion and Recommendation

6.1 Conclusion

The recent high fuel prices and global economic recessions have driven shipowners to turn their attention to saving operational costs. For this reason, the shipping industry has developed and introduced many energy saving solutions including speed optimization to reduce fuel consumption from existing ships. In this regard, IMO have proposed the best practices regarding energy saving solutions through the SEEMP Guidelines. However, these proposed energy saving solutions do not give sufficient reliability because of the uncertainties of various parameters surrounding ships.

These uncertainties may have a significant impact on effectiveness of individual energy saving solutions to a great extent, which include future fuel prices, mutually exclusive solutions, enforcement of SOx emission regulations, financial returns on investment of solutions. At present, these uncertainties prevent shipowners from employing the energy saving solutions. In particular, small companies suffer from lack of human resources and technical expertise in employing energy saving solutions to their ships. In this context, shipowners should understand the effectiveness of energy saving solutions, and specific challenges in implementing solutions in order to evaluate the reliability and the availability of energy saving solutions.

When evaluating cost effectiveness of solutions, the associated uncertainties should be considered depending on ship type, size and age. Some solutions can be applicable to all ships, but others may be limited to certain ship types or voyage patterns, and certain solutions can be mutually exclusive with other solutions. In particular, energy saving solutions will be more cost effective in larger ships than smaller ships, and younger ships are economically more attractive than older ships in terms of financial returns on investment of the solutions. In addition, speed optimization is the most effective solution for improving energy efficiency and reducing CO_2 emissions. Therefore, the selection of ship speed is an important factor to determine the cost effectiveness of ships because of relationship between ship speed and fuel consumption.

Challenges to implementation of CO2 abatement solutions

Regarding the technical challenge, it occurs from technical concerns associated with applicability of CO_2 abatement solutions. For example, there is concern about performance of main engines when it operates for extended time at lower engine speeds. This concern may prevent implementation of speed optimization. In addition, the lifetime of new hull coatings is one of the technical concerns. New weather routing system is another technical concern because it should integrate weather prediction and hydro-dynamic performance in various sea conditions.

Regarding the operational challenge, it may occur when solutions cannot be used on a specific ship type because of operational or spatial limitations. For example, smaller ships may not have sufficient space to install the waste heat recovery (WHR) system in the exhaust funnel. Regarding regulatory challenges, antitrust regulations have negative impact on implementing the speed optimization; collusive actions to reduce the ship speed may be restricted by competition authorities. In addition, some local regulations prohibit release of cleaning residues during hull cleaning or propeller polishing in order to protect the local environment. Therefore, the enhanced local environment regulations make it difficult to implement energy saving solutions.

Regarding the future fuel price, uncertainty of future fuel prices may have a significant impact on implementing the solutions. In general, economic challenges occur when the solutions are marginally economical, considering high fuel costs. The speed reduction is becoming the best economic choice in the container shipping sector to reduce high fuel costs and surplus capacity of ships due to economic downturn. The high fuel costs have a major impact on implementing the solutions. Regarding the impact of SOx emission regulation, there are two possible cases when SOx emission regulation is entered into force in 2020. First, main marine fuel in shipping sector could be changed from HFO to MDO, which would influence implementation of other solutions because the high priced

MDO would be a shock to the shipping industry in 2020. In other case, the exhaust gas scrubber technology may be developed by reducing the sulphur emissions from HFO, and this technology may prevent the fuel changeover from HFO to MDO, and shipowners could reduce high fuel costs by using relatively low priced HFO.

Regarding the split incentive, this is the biggest market challenges in implementing energy saving solutions. This split incentive occurs from a specific situation in the charter market in which the party who benefits from fuel savings is not the same party who reduces the fuel costs. In principle, ships that improve energy efficiency should get higher charter rates, but in the charter market there are no benefits from improvement of ship's energy efficiency. It is difficult to improve the commercial practices due to complexity of the charter market and lack of verification process to guarantee the energy savings from ships.

Regarding "virtual arrival" approach, This approach needs specific clauses in the charter party, which includes specific terms for the slow speed operations, demurrage compensation, and profit sharing due to fuel savings between shipowners and. However, it is possible that the "virtual arrival" approach may be prohibited by the antitrust regulations because it can be regarded as collusive actions of slow steaming. Regarding, "boom" and "bust" in the shipping market, when freight rates are high, shipowners may have funds to invest in energy saving solutions. Nevertheless, shipowners are reluctant to take a ship out of service because the service time will make more profits. On the other hand, when freight rates are low, shipowners are reluctant to invest in energy saving solutions because the funds are not sufficient to the investment for energy saving solutions.

Regarding lack of fuel consumption data, the fuel consumption data is used to indicate the level of the ship energy efficiency, which may have a decisive impact on ship transaction and ship chartering. However, it is difficult to utilize the fuel consumption data for individual ships in the shipping market. Therefore, the lack of fuel consumption data prevents shipowners from investing in energy efficient solutions due to uncertainty over financial return on their investment. Furthermore, in the charter market, split incentive issues may occur between shipowners and charterers. This is because shipowners cannot demonstrate energy efficiency of ships. Regarding management challenges, small shipping companies are suffering from the lack of management resources to evaluate implementation of CO_2 abatement solutions. This may occur when the small companies do not recognize the importance of cost effectiveness of energy saving solutions, which may prevent implementing the energy saving solutions. Moreover, it is important that motivation for improvements of energy efficiency must come from the shipowner rather than the staff in a company because the shipping industry is conservative in changing its management practices.

Speed optimization,

Speed optimization is the easiest solution to implement the energy savings, and the most cost effective solution to reduce CO_2 emissions. In addition, the speed optimization has the highest potential to reduce CO_2 emissions among other energy saving solutions. The penetration rates have been increased due to recent high fuel prices and global economic recessions. Smaller tankers have relatively higher challenges in implementing the speed reduction during their ballast voyages due to sufficient management resources to evaluate cost effectiveness of speed optimization. In addition, there are concerns over the performance of main engines operating in low power condition for extended periods.

In the oil market, slow speed operations may incur additional capital loss due to increased holding stock. In addition, in the current oil market, the future oil prices are abnormally lower than the current oil prices. For this reason, oil companies require shipowners to operate their ships at full service speed in order to reduce transit time. In current charter market, there is non-economic commercial practice; if the charterer and the shipowner in advance know about the port congestion, the ship could reduce the speed; however, in such case, the shipowner will not reduce ship speed because they can collect demurrage from the charterer according to the charter party. Competition authorities may regulate the collusive slow speed operation through the industry associations (i.e. the pools or conferences); the antitrust regulation may prohibit shipowners from implementing speed optimization collusively.

Weather routing service

Regarding weather routing service, this solution is more applicable to ocean-going ships, but cruise ships may less applicable due to their tight voyage schedules. Penetration rate is relatively high because most ships engaged in international voyages have already employed. Therefore, actual CO_2 abatement potential will not be much higher than the present level. Regarding autopilot system, this solution requires the capital costs varying by ship type and size.

Optimization trim and ballast

There are still technical challenges in identifying the optimal fuel consumption condition in various sea states and loading conditions. In addition, there is different technical point of view between safer ballast conditions and energy efficient ballast conditions. The faster ship has higher CO_2 abatement potential because optimized trim can improve hull resistance that is more sensitive to the faster ships. In addition, ships with full cargo holds have less abatement potentials because such ships may not be able to change trim condition. In addition, larger ships can be more cost effective than smaller ships. This is because capital costs for installing the monitoring system are fixed regardless of ship sizes, but larger ship can reduce further fuel consumption than smaller ships. This solution requires substantial capital costs for installing the monitoring systems, In this regard, this solution was not economically attractive in 2007, but it is becoming an more attractive solution in 2020.

Propeller polishing and Hull cleaning

Some port authorities may prohibit propeller polishing or hull cleaning in their ports due to concerns about the environmental impact of cleaning residues in their ports. This ban of these solutions in ports may incur additional costs and time for carrying out propeller polishing or hull cleaning outside the port. The penetration rate is relatively high because most ships have already carried out the propeller polishing or hull cleaning on a regular basis. Therefore, actual CO_2 abatement potentials will not be much higher than the present level. Propeller polishing and hull cleaning was already economically attractive in 2007, and it is expected to become a more attractive solution in 2020. In particular, ships operating at faster speed (e.g. container ships, and cruise ships) are more cost effective than ships operating at slower speed (e.g. tanker ships and bulk carriers). This is because hull resistance is closely associated with ship speed i.e. the hull resistance increase as the ship speed increases.

Hull coating

There are considerable concerns over the effectiveness of new hull coating technology. It is not clear the effectiveness of new hull coating technology i.e. there are different opinion over the effectiveness of biocidal coatings and fouling-release coatings. Another challenge is that there is no reliable standard for measuring the effectiveness of hull coatings. Hull coatings were already cost effective in 2007, and it is expected to become a more attractive solution in 2020.

Propulsion system upgrade

There is technical difficulty in measuring effectiveness of propulsion system upgrades. In addition, these solutions have uncertainty over the effectiveness during the slow speed operation. Propulsion system upgrade needs substantial capital costs due to investment of retrofitting its equipment to existing ship. In this regard, the propulsion system upgrades were not cost effective in 2007, but it is expected to become cost effective, which is a significant increase compared to the estimate in 2007.

Main engine adjustment

The common rail solution can be applicable to all ship types, but the engine tuning solution is less applicable to ferries and cruise ships. This is because the engine tuning solution was developed to optimize main engines to operate at slow speed operation for extended time, but in general ferries and cruise ships do not operate at slow speed because of their tight voyage schedule with passengers. The main engine adjustment solutions were already cost effective in 2007, and it is expected to become economically more attractive by 2020. However, there is a technical challenge in improving efficiency of main engines due to the inverse relationship between NOx emissions and CO_2

emissions. In particular, NOx emissions limits have been mandated in 2008. For this reason, engine manufactures apply the engine tuning technology aiming at reducing NOx emissions, but they cannot technically reduce CO_2 emissions at the same time. Therefore, this NOx emission regulation makes it difficult to improve energy efficiency of main engines.

Waste heat recovery (WHR) system

The WHR system can be applicable to ships that can produce substantial waste heat from engine exhaust gas and consume large amounts of electricity. The WHR system is being regarded as an experimental solution which leads to difficult retrofitting to existing ships because of spatial and operational limitations onboard ships. Therefore, this solution is more applicable to new ships. In particular, the WHR system is mutually exclusive with the slow speed operation because the waste heat is not sufficient to generate electricity at the reduced engine load.

This solution requires substantial capital costs for installation of the WHR system. In particular, the WHR system was not cost effective in 2007 for all ship types, and this solution still would not be cost effective in 2020 for most ship types. However, this solution will become more cost effective in 2030 for most ship types, but this is still economically less attractive than other solutions because it is not clear that technical development can overcome the spatial and operational. In addition, ship type, size and age have a significant impact on the cost effectiveness of the WHR system due to the capital costs

Speed control of pumps and fans

Regarding speed control of pumps and fans, this solution requires the capital costs, depending on ship type and size, but operational costs do not occur. In this respect, this solution may not be economically attractive in the likely case, but it may become cost effective in the high case in the year 2020

6.2 Recommendation

It should be noted that the measures to facilitate implementation of solutions should remove specific challenges in implementing solutions to existing ships. In this regard, this dissertation discussed about specific challenges that have significant impacts on the implementation of energy saving solutions. As mentioned in chapter VI, the feasible measures to facilitate implementation of solutions are described as follows.

- Fuel Consumption Certification

  The fuel consumption certification will directly eliminate split incentives between shipowners and charterers; with valid fuel consumption certificates, charterers could use information on individual ship's energy efficiency in their chartering decision, and shipowners could get incentives due to improvement of energy efficiency of ships. This measure would be applicable to all CO_2 abatement solutions.

- New Charter Clauses for slow speed operation

  The new spot charter clause will address specific terms to share the profits from fuel savings. Shipowners can collect demurrage compensation by saving fuel costs, and charterers can also reduce fuel costs with slow speed operation. Consequently, the new charter party clauses will remove split incentives between shipowners and charterers and improve implementation of the speed optimization and reduce fuel consumption and CO_2 emissions.

- Enhanced SEEMP implementation

  To improve environment performance of ships, the environmental management system (EMS) based on ISO 14001 should be used and mandated to enhance the SEEMP implementation. This measure would establish a management framework to improve the SEEMP implementation which can assist for shipowners to identify and reduce the negative energy saving activities.

- Energy Efficiency Measurement Standards

This measure would reduce technical uncertainty of measuring the performance of solutions. In particular, small companies which have insufficient human resources to evaluate energy saving solutions would obtain reliable information for measurement of the various solutions. This energy efficiency measurement standards will be applicable to the CO_2 abatement solutions that require specific equipment: autopilot upgrades, hull coatings, propulsion system upgrades, main engine tuning, WHR, and speed control of pumps and fans.

- Environmental incentive for Speed Optimization

  This measure would directly eliminate regulatory challenges i.e. antitrust regulations for slow speed operation. Current antitrust regulations have negative impact on implementing the speed optimization; collusive activities to reduce ship speed are restricted by the market competition laws. Therefore, this measure will have significant impact on implementation of the speed optimization.

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