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The Impacts of Voyage Optimization and Slow Steaming on the Liner Shipping Strategy through Dynamic Simulation

By

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PhD of SCIENCE

In

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2012

DECLARATION

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ABSTRACT

Title: The Impacts of Voyage Optimization and Slow Steaming on the Liner Shipping Strategy through Dynamic Simulation

Degree: Doctor of Philosophy (PhD)

In recent times, an obvious strategy in the liner shipping industry that has come to the fore is slow steaming. Shipping lines have decelerated the voyage speed to 15-18 knots on major routes, and some leading shipping lines have a plan to reduce it to below 15 knots. This is because slow steaming is helpful in reducing the operating cost and the amount of GHG emissions in the condition of high fuel prices and low freight rates. However, it also creates negative effects such as the opportunity cost, additional fixed costs and an in-transit inventory cost on a loop. Hence, net operating cost on a loop is changing dynamically due to the changes of voyage speed based on various slow steaming effects.

This study started with the basic question; is it true that as voyage speed reduces, the operating costs and GHG emissions can be reduced at the same time? If this is true, shipping lines will definitely decelerate their voyage speed themselves as much as possible. However, if not, they will concentrate just on increasing their profits by not considering environmental factors. Moreover, when considering the high uncertainties in the markets, what is the optimum operational strategy for shipping line and how can they build the optimum operational strategy that can achieve their strategic goals?

This has led the authors to set out twin aims. The first aim is to analyze the slow steaming effects and find the optimal voyage speed that can minimize the operating costs and GHG emissions in various conditions. The second is to build the optimum operational strategy that can achieve various strategic goals of shipping lines. To achieve the aims, a Dynamic Slow Steaming Evaluation Model (DSSEM) was established using System Dynamics. Moreover, the significant results were derived by simulation and the alternatives as the optimum operational strategy were presented for shipping lines.

According to the result of the simulation, slow steaming is not helpful always to reduce the operating costs. It can be reduced just within the economic range of voyage speed (24.9-11 knots), and minimized at 17.2 knots. Hence, when shipping lines control their voyage speed between 25 and 11 knots, they can enjoy the slow steaming effects. Moreover, when voyage speed is reduced by 17.2 knots, i.e. when the service loop is organized by 10 vessels of 8,000 TEU class, shipping line can minimize their operating costs using slow steaming on a loop. On the other hand, there is a negative correlation between the slow steaming effects and the increase of ship size. Hence, as ship size increases, the operating costs on a loop including an average slot cost are increased. Therefore, from the viewpoint of shipping line, it is necessary to choice one strategy of both to reduce their operating costs on a loop.

In the case of the amount of GHG emissions, it is not reduced in direct proportion to the changes in voyage speed. When shipping lines control voyage speed within the range between 25 and 14 knots, they can reduce the amount of GHG emissions efficiently from the viewpoint of elasticity. Moreover, there is a positive relationship between the slow steaming effects and the increase of ship size. So, as employed ship size increases, shipping line can improve their level of environmental performance on a loop. Moreover, this thesis provides 66 optimum alternatives as the operational strategy for shipping line with considering three main current strategic goals such as the minimization of operating costs, the improvement of environmental performance and the increase of level of service quality for shipping lines. Hence, shipping lines can select their optimal operational strategy among them with considering their own strategic goals.

Keywords: Slow steaming; Liner shipping; The operating costs; Greenhouse gas emissions; Route optimization; Fleet optimization; Speed optimization; System Dynamics; Simulation model; Optimum operational strategy.

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LIST OF ABBREVIATIONS

GHG	Greenhouse gas Emissions
RBV	Resource based view
IMO	International Maritime Organization
DSSEM	Dynamic Slow Steaming Evaluation Model
NOC	Net operating cost
DEOC	Designed operating cost
EFRVS	The efficient range of voyage speed
PRVS	The political range of voyage speed
ECRVS	The economic range of voyage speed
SRVS	The strategic range of voyage speed
AHP	Analytical Hierarchy Process
EOD	Experiment of Design
TOPSIS	Technique for Order Performance by Similarity to Ideal Solution
CEEI	Cost-Energy Efficiency Index

1. INTRODUCTION

1.1. Introduction

Shipping lines have always pursued the optimal solution to achieve the twin goals of the expansion of transport capability and the reduction of operating costs not only to secure competitiveness but also to survive in competitive markets of unanticipated change. This is because the liner shipping industry is sensitive to changes in economic and market conditions. Therefore, an excessive investment strategy can lead to financial difficulties, while a conservative investment strategy can impede efficient and/or timely investment.

Moreover, the liner shipping industry is capital intensive and requires high fixed costs (Stopford, 2009; Notteboom, 2006), so a trade-off between both goals is a serious issue for shipping lines. For this reason, during the last three decades shipping lines have been using various strategies to achieve their goals of minimizing the input of assets and maximizing operational efficiency. For example, they have been focusing on the increase of employed vessel size to enjoy economies of scale. Moreover, they have been improving their transport networks through introducing the Hub and Spoke, market segmentation and service diversification, and strengthening cooperation with competitors through strategic alliance, slot chart and joint service to improve their operational efficiency and to reduce their operating costs.

In particular, during the 10 years before 2009, the liner shipping industry has experienced a serious shortage of transport capacity as a result of a faster growth in transport demand than expected. Therefore, shipping lines focused on the expansion of their transport capability through new construction orders and/or Merger and Acquisition (M&A). Moreover, liner shipping companies improved their operational efficiency by the acceleration of voyage speed. For instance, in the case of the westbound service on the Far East-North Europe route, shipping lines have reduced the number of vessels and the number of calling ports on each loop, while they increased the average vessel size as shown in Table 1. In this sense, the main operational strategy of shipping lines in this period can be defined as a maximization of transport capability by the acceleration of voyage speed using large container ships on major routes.

Table 1 - Trends in the Europe-Asia Route (2004-2010)

	2004	2005	2006	2007	2008	2009	2010
Number of Services/Routes	32	34	34	34	34	30	30
Average number of vessels/Loops	8.9	8.7	8.8	8.6	8.6	9.3	9.7
Average vessel size (TEU)	5,489	5,505	6,020	6,700	6,934	8,065	8,390
Total transport capacity (000TEU)	6,406	7,355	8,441	9,545	10,819	9,256	9,780
Average number of calling Ports	14.9	10.5	10.5	10.5	10.5	15.8	15.9
Traffic volume (000 TEU)	6,238	6,852	7,805	9,101	9,074	7,817	9.100
Utilization rate (%)	97.4	93.2	92.5	95.3	83.9	84.5	93.0

Source: Drewry. (2002-2010). *Container Market: annual Review and Forecast.* Drewry Shipping Consultants Ltd.

On the other hand, environmental issues are a major challenge in the liner shipping industry also. This is because, although liner shipping is recognized as the most eco-friendly transport mode, it is a major contributor of greenhouse-gas (GHG) emissions in the shipping industry. According to the International Chamber of Shipping (ICS), liner shipping produces around 25% of GHG emissions in the shipping industry (ICS, 2009) and it is expected that this proportion will increase continuously if there is no active countermeasure to control the amount of emissions (IMO, 2009).

For this reason, the International Maritime Organization (IMO) established a goal to reduce the amount of CO_2 emissions from existing vessels by 20-50% by 2050. Moreover, IMO developed the Energy Efficiency Operational Indicator (EEOI) as a measure for existing vessels with the Energy Efficiency Design Index (EEDI) for new vessels (IMO, 2009; MEPC.1/Circ.684, 2009; MEPC 60/4/35, 2009). In addition, IMO suggested three basic approaches; namely, the enlargement of vessel size, the reduction of voyage speed and the application of new technologies. Furthermore, IMO has been working on introducing various policies such as a carbon tax and emissions trading scheme (ETS) at the same time, and, the World Wildlife Forum (WWF) has proposed a carbon tax of $25 per ton for bunker fuel on ocean carriers (Campbell, 2011).

Nowadays, one of the obvious operational strategies in liner shipping markets is slow steaming. In 2009, with the significant decrease in transport demand, shipping lines started utilizing slow steaming as one of the operational technique alternatives to downsize their operating capacity or utilize their idle capacity. However, from the middle of 2010, most shipping lines began to adopt slow steaming as their main operational strategy to reduce operating costs. In the case of the Far East-North Europe route, 93% of liner services had already adopted slow steaming in 2011, and the average voyage speed was reduced from 23-25 knots in 2008 to 15-18 knots (Ultra Slow Steaming) in 2011(McCarthy, 2012; Barry Rogliano Salles, 2011; Soren, 2012). Moreover, some leading shipping lines have a plan to reduce their voyage speed to below 15 knots on major routes.

This is because slow steaming is helpful in reducing operating costs (Notteboom and Vernimmen, 2008; Ben, 2009; Cariou and Notteboom, 2011) and the amount of GHG emissions (IMO, 2009; Ronen, 2011; Cariou and Cheaitou, 2012) by the reduction of bunker fuel consumption in the condition of higher bunker fuel prices and low freight rates as shown in Figure 1. According to Maersk-Line, when voyage speed is decelerated by 20%, the bunker fuel consumption and the amount of CO2 emissions can be reduced by more than 40% and 20% respectively.

Moreover, slow steaming is a useful strategy for shipping lines to reduce operational loss and financial hemorrhage during an economic recession through the downsizing of their transport capability and the full utilization of their fleets (Stopford, 2009). According to Germanischer Lloyd (GL), when voyage speed is reduced from 25 knots to 19 knots, operating costs and financial costs can be reduced by 11% and 19% on a single vessel. For this reason, 93% of liner service in Asia-North Europe route and 76% in Far East-US East Coast route had already adopted slow steaming in 2011, and this is expected to increase continuously (Barry Rogliano Salles, 2011).

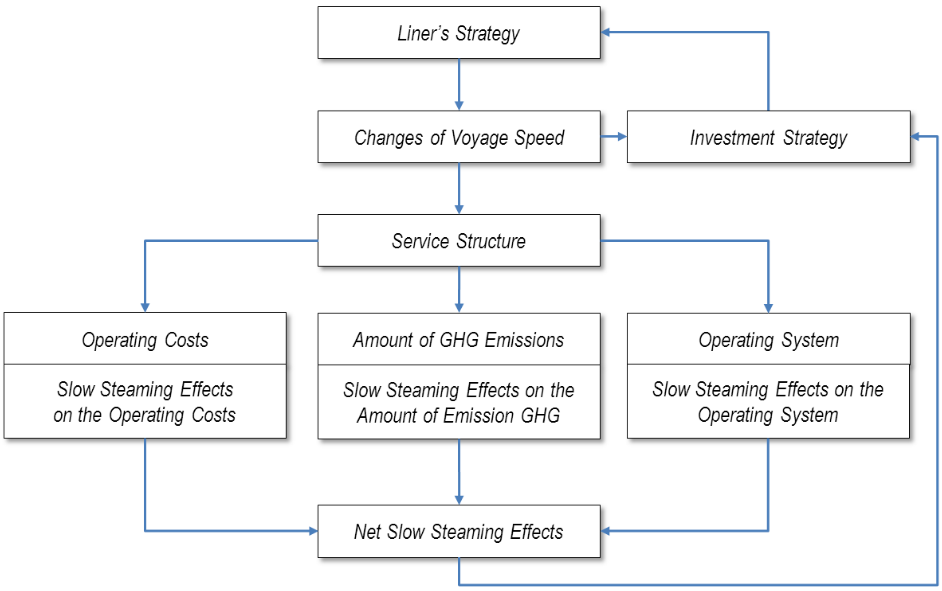


Figure 1 - The effects of slow steaming on liner shipping service and costs

1.2. Aim of Thesis

This thesis started with some basic questions in three sectors as follows. From the viewpoint of the effectiveness of slow steaming, firstly, is it true that the more voyage speed is reduced the more operating cost and the amount of GHG emissions can be reduced at the same time? A number of articles and studies published by journals and newspapers claim that slow steaming is the best solution to reduce operating costs and GHG emissions at the same time. Moreover, many studies argued that slow steaming is helpful in reducing the operating costs (Notteboom and Vernimmen, 2008; Ben, 2009) and the amount of GHG emissions (Ronen, 2011; Cariou and Cheaitou, 2012; IMO, 2009) by the reduction of bunker fuel consumption. If so, as voyage speed decreases, can shipping lines reduce their costs and GHG emissions more at the same time?

Secondly, what is the optimal speed to minimize operating costs and slot costs? If the answer to the first question is yes, shipping lines will definitely decelerate their voyage speed as far possible as to increase their profits and improve the level of environmental performance. However, if not, shipping line will concentrate on increasing their profits and not consider the environmental factors. Moreover, IMO cannot force shipping lines to reduce CO2 emissions without taking into consideration their economic situation. Thirdly, what does slow steaming have to do with the vessel size? If there is a strong correlation between slow steaming and vessel size, as voyage speed decreases and as the vessel size increases, shipping lines can reduce their operating costs while enjoying both benefits of slow steaming effects and the economies of vessel size at the same time. If not, liners need to choose either one of two strategies.

On the other hand, from the viewpoint of environmental issues, firstly, how much can CO_2 emissions can be reduced by slow steaming? If slow steaming is really helpful in reducing the amount of CO_2 emissions, a lot of CO_2 emissions have been reduced already by slow steaming in the markets. If so, there is a need to evaluate how much CO_2 emissions can be reduced by slow steaming in liner shipping. This is because the estimation of the amount of CO_2 emissions in the market is important to shipping lines and policy makers, *i.e.* IMO and governments, as basic information for developing operating strategies and relevant emission policies. Moreover, with the slow steaming strategy, how can shipping lines reduce the amount of CO_2 emissions to the maximum level while minimizing their operating costs? The basic strategic goal of shipping lines is the maximization of their profits. Thus, there it is necessary to find the solution to achieve both goals of minimization of operating costs and maximization of the amount of CO_2 emissions.

Moreover, from the viewpoint of operational strategies, how can shipping lines reduce operating costs and CO_2 emissions efficiently? Regarding this, IMO has suggested two approaches for voyage optimization, *i.e.* route optimization and fleet optimization, and the improvement of energy efficiency that consists of three methods such as enlargement of vessel size, slow steaming and new technologies (IMO, 2009). However, each approach has some distinguishing characteristics. In the case of voyage optimization, it can be defined as an operational strategy to maximize operational efficiency through the minimized input of resources (number of vessel, transit time). However, slow steaming is defined as an operational technique to reduce operating costs by the deliberate reduction of operational efficiency. The question is: how can shipping lines establish and/or improve their operational strategies using both approaches?

In recent times, many studies have verified the effectiveness of slow steaming in liner shipping. Notteboom and Vernimmen (2008) built a cost decision model to analyze the impact on the operating cost by the changes of bunker fuel price, and Ronen (2011) analyzed the changes of operating costs with considering the oil prices, vessel size and voyage speed. Cariou and Cheaitou (2012) analyzed the relationship between the changes of voyage speed (the number of ships) and the operating cost and the amount of CO_2 emissions, and argued the sustainability of slow steaming from the economic and environmental viewpoints.

Nevertheless, there remains an unexplained aspect to solve the basic questions that proposed by this thesis. This has led the author to re-examine the impacts of slow steaming on the amount of CO_2 emissions and operating costs from different perspectives, and to set out three aims as shown in Figure 2. The first is to analyze the impacts of slow steaming on operating costs and the amount of GHG emissions in liner shipping and to discover whether the reduction in voyage speed always contributes to reducing the operating costs of shipping lines. The other aim in this part is to analyze the changes in operating costs and GHG emissions by the increase of vessel size.

The second is to simulate the relationship between voyage speed and the amount of CO_2 emissions, and to evaluate any changes in the amount of CO_2 emissions by considering the current average voyage speed on major routes. Moreover, the other aim is to find the optimal voyage speed as a solution for maximizing the reduction of CO_2 emissions at the lowest operating cost in order to satisfy IMO's reduction target. The third is to analyze the impact of voyage optimization on operating costs and the amount of GHG emissions while considering slow steaming effects on a loop. Moreover, the final aim is to establish the optimum alternatives for shipping lines with considering their major current strategic goals and suggest it to them.

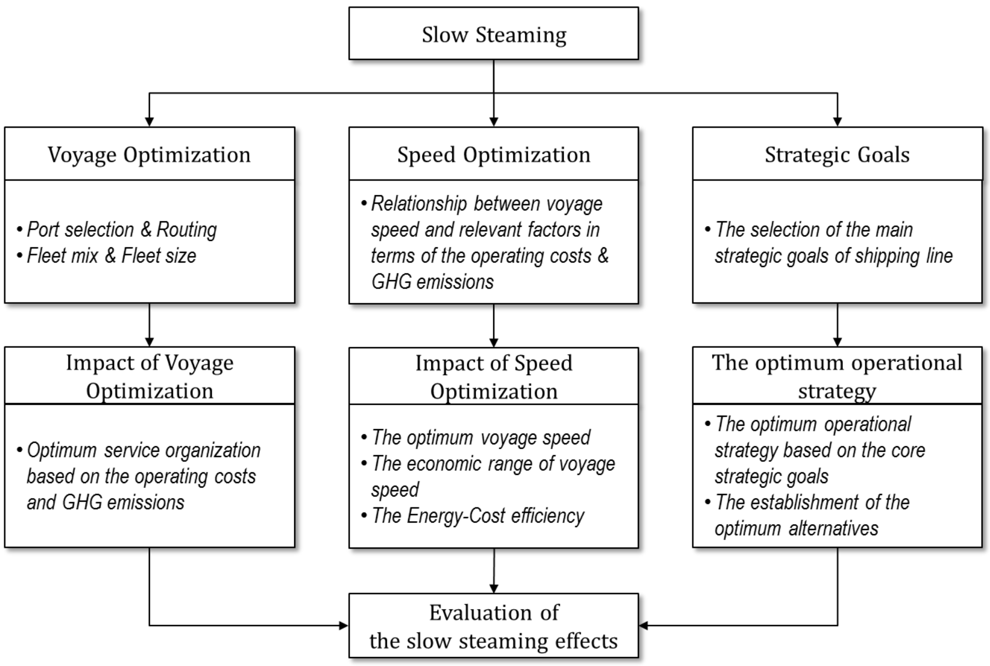


Figure 2 - Thesis objectives

1.3. Thesis Scope

The main objective of this study is to investigate the slow steaming effects on the liner shipping industry. Liner shipping is the transport service that operated by a fleet of ships and provides a fixed service, at regular intervals, between named ports (Stopfold, 2007). Therefore, voyage speed is one of the key factors to influence not only on the fleet organization but also on the transport capacity in a loop. Moreover, it is closely related with the efficiency of ship operation (Stopfold, 2009) and the profits of shipping line. For this reason, liner shipping is sensitive to the changes of voyage speed rather than other shipping service such as bulk, tanker and passenger service.

Moreover, from the environmental viewpoint, even though liner shipping is the most energy efficient transport mode in world trade however it is one of the major contributors to produce greenhouse gas (GHG) emissions. According to the research of IMO, 27% of GHG emissions are occurred by liner shipping in international shipping. Therefore, the better energy efficiency and effective emission control has been emphasized as one of the essential operational strategies, in particular, in liner shipping industry. For this reason, this study chooses the liner shipping industry as the best analysis target in shipping industry to investigate the slow steaming effects.

Table 2 - Thesis scope

	Thesis Scope	Exception
Geographical Scope	Far East-North Europe Route	
Service Scope	Loop	
Time Scope	Single voyage, Annual voyages	
Analysis Scope	The operating costs and its structure The amount of GHG emissions The level of service quality The external cost	Financial cost Some technical aspects

On the other hand, geographically, this study choices Far East-North Europe route as the analysis target service route. Far East-North Europe route is one of the major routes in the world with Trans Pacific route and Atlantic route (Drewry, 2011). Total traffic volume in this route was 18,929 thousand TEU in 2008 (it was 29.5 % of the world traffic volume), and average vessel size is the largest (8,300 TEU degrees in 2012) of the world international shipping routes. Moreover, this route has a highly competitive structure (Wang and Cullinane, 2004; Notteboom, 1997) and is sensitive to changes in market conditions in comparison with other major routes (Drewry, 2011). Hence, this route is a suitable route to analyze the impacts of slow steaming rather than other major routes.

Moreover, from the analysis scope, this study focuses on the impacts of slow steaming on the liner service organization and patterns, operating costs and GHG emissions in order to find the optimal voyage speed and establish the optimum operational strategy for shipping line in the short-term perspective. To accomplish this, this thesis utilized various actual market data published by shipping lines, major consulting companies and relevant international institutes. However, some factors such as imperfect combustion of bunker fuel and financial costs are not considered in this study.

1.4. Data and Methodology

This thesis consists of four main sections: introduction and literature review, voyage optimization, speed optimization and the optimum operational strategy. To achieve the aim, diverse methodologies were utilized in each section. In first section, this thesis conducts a literature review in terms of voyage optimization, operating strategies of shipping lines and environmental issues to define and analyze the impacts of slow steaming on operating costs and GHG emissions.

To identify voyage optimization, an Integer Programming (IP) Model and an Integration Cost Model were established in order to attempt to the route optimization and fleet optimization using an Integer Programming modeling approach. Moreover, a dynamic simulation model (Dynamic Slow Steaming Evaluation Model: DSSEM) was designed to analyze the relationship between voyage speed and various slow steaming effects such as the changes of service organization, operating costs and the level of environmental performance. In three models, actual market data published by shipping lines, major consulting companies such as Drewry Shipping Consultant, Ocean Shipping Consultant and Alpha liner and relevant international institutes such as IMO, UNCTAD and OECD was utilized.

On the other hand, to define the current strategic goals of shipping lines, a survey was conducted to investigate the awareness of experts in terms of slow steaming and the current strategic goals of shipping lines targeting shipping lines, terminal operators and logistics companies and experts working at the University in each region, consulting companies and government. Moreover, the factor analysis and Analytic Hierarchy Process (AHP) were utilized to select the core current strategic goals. Moreover, to establish the optimum operational strategy, Experiment of Design (EOD) technique and Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) were utilized to design the optimum alternatives as the optimum operational strategy based on selected strategic goals through the factor analysis and AHP.

1.5. Thesis Structure

This study consists of eight chapters. Chapter 1 contains the background, the aim of the thesis, main methodologies and thesis structure. Chapter 2 presents the definition of slow steaming and its effects and the major previous studies in terms of voyage optimization, slow steaming and operational strategies of shipping lines. In Chapter 3, both models, Integer Programming Model and Integration Cost Model, are established for route optimization and fleet optimization. Moreover, Chapter 3 provides the results of analysis in terms of the impacts of route optimization and fleet optimization on operating costs and GHG emissions and their main implications.

Chapter 4 provides the concept of a dynamic simulation model (Dynamic Slow Steaming Evaluation Model: DSSEM) with main assumptions, and the major results of a simulation are presented in Chapter 5. Moreover, in Chapter 6, the results of factor analysis and AHP are presented, and the optimum operational strategy is designed using Experiment of Design (EOD) technique and Technique for Order

Performance by Similarity to Ideal Solution (TOPSIS) in Chapter 7. Finally, Chapter 8 provides a summary of the thesis and conclusions with the future research plans.

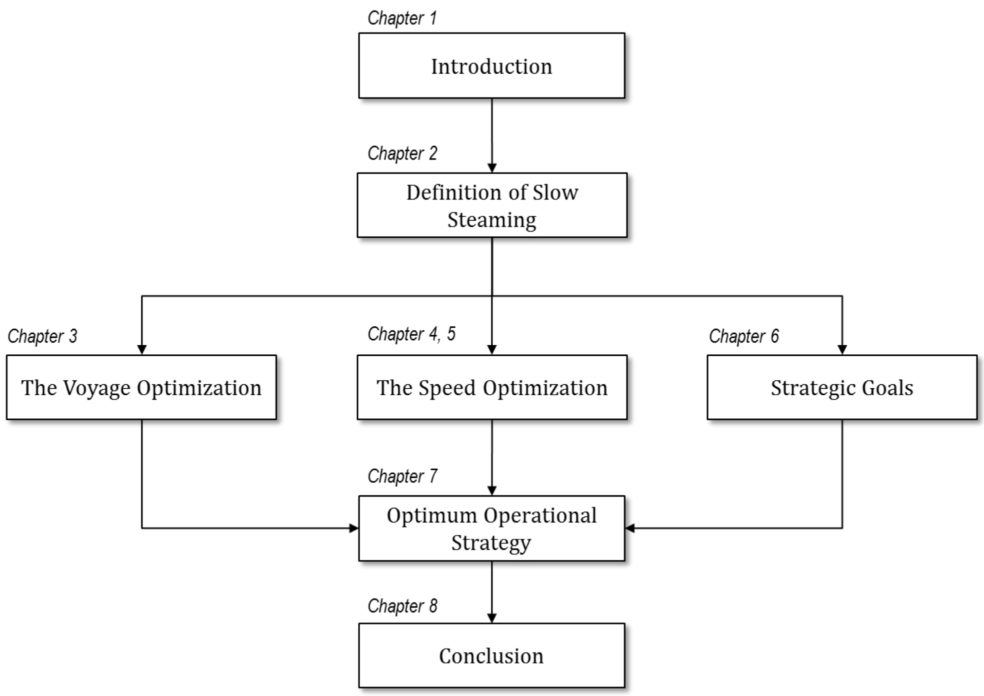


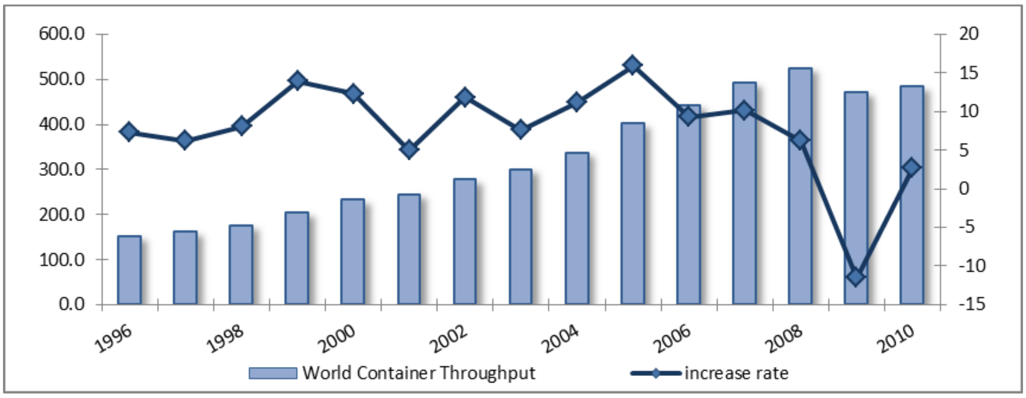
Figure 3 - Thesis structure

2. SLOW STEAMING AND LINERS' STRATEGY

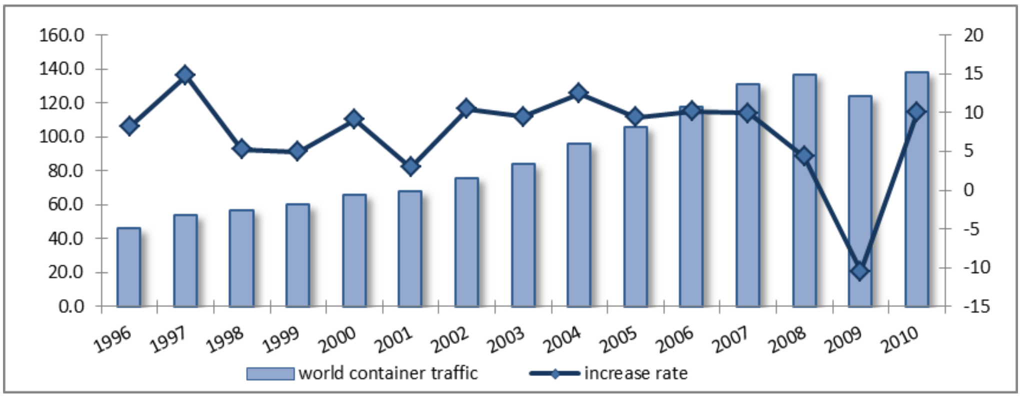
2.1. Introduction

During the last five decades, the liner shipping industry has grown more rapidly than any other major industry. Historically, notwithstanding several economic crises and recessions, world container traffic increased from 46 million TEU in 1996 to 138 million TEU in 2010, and world container throughput increased from 150.8 million TEU to 483.4 million TEU in the same period (Drewry, 2011). Moreover, the container fleet capacity exceeded 10 million TEU in 2008, and it will reach 17 million TEU in 2012 (Alphaliner, 2012) as shown in Figure 4. In spite of the recent global financial crisis and economic slump, major international organizations and consulting companies expect world container transport demand to increase by an average of 7-8% per year until 2015 (Deutsch Bank, 2012).

Trends of world container throughput and increase rate (1996-2010)



Trends of world container traffic and increase rate (1996-2010)



Trends of world container fleet capacity (2008-2012)

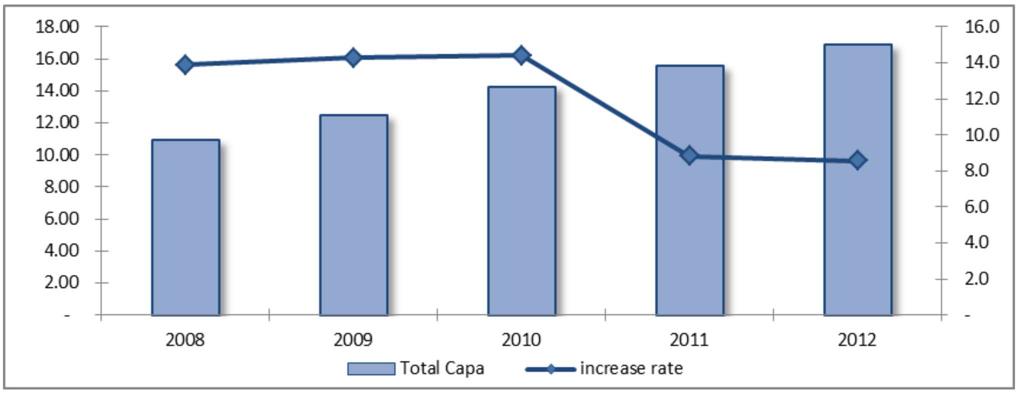


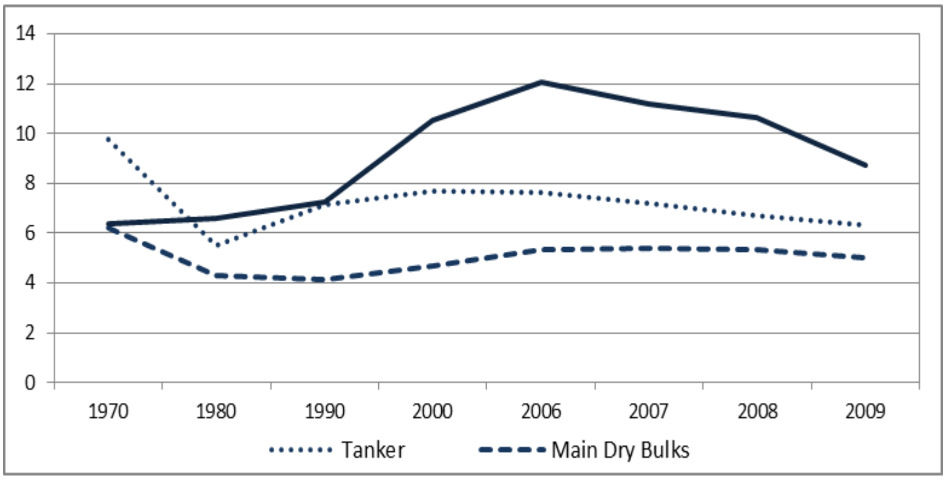
Figure 4 - Trends in world container activity

Source: Drewry. (2000-2010). *Container Market, Annual Review and Forecast, 2000-2010.* Drewry Shipping Consultants Ltd.

According to Basta and Morchio (2008), the success of the liner shipping industry is directly traceable to three aspects as follows. "Firstly, the evolution of the world economy, both in terms of enlargements of the market, due to globalization trends and to institutional reasons, and growth of the world production influences the world trade, and transport. Secondly, the dimensional growth of industrial firms and the restructuring process of their logistics and distribution strategies, in accordance to the continuous attempts to gain rationale and efficiency as to products and processes. Moreover, thirdly, the development of new technologies, applied to communication and information processes and to the transport sector itself, especially the maritime mode. These innovations have further contributed to the steady reduction of transport costs, which on its turn represents one of the key factors in the intensification of competition among ports."

Regarding this, Stopford (2009) argued that the main reason for the success of liner shipping results from the high operational efficiency and regularity of the liner shipping service. A liner shipping service provides a fixed service, at regular intervals, between ports, for any cargoes with reasonable freight rates. For this reason, liner shipping is recognized as the most competitive transport mode, considering its efficiency and function compared with other transport modes. According to UNCTAD (2010), the productivity of liner shipping is more than 30-50% higher than another shipping (tanker and dry bulk shipping) as shown in Figure 5. Moreover, these advantages of liner shipping service promote the development and improvement of inter-modal transport, value-added logistics services and relevant business and service industries (Kim and Gunther, 2006; Mangan and Lalwani, 2008).

Unit: Percentage



*Productivity=fleets size/transport volume
**Dry cargoes are the sum of annual transport volume of general cargoes and container

Figure 5 - Estimated productivity of tanker, bulk and container shipping
Source: United Nation (2010), *Review of Maritime Transport 2010*, UNCTAD.

However, recently, the operational strategy of shipping lines has fundamentally changed. Presently, they have adopted slow steaming as their basic operational strategy, and have decelerated their voyage speed to 15-18 knots in major routes.

Moreover, some leading shipping lines have announced their plans to reduce voyage speed to below 12 knots. This phenomenon can be explained by the fact that the strategic goals of shipping lines have changed from high productivity to cost reduction and environmental friendly performance due to the changes in market conditions.

On the other hand, According to previous studies, slow steaming has a close relationship with operating costs, service structure and the amount of greenhouse-gas emissions. As well, it can lead the changes in the fundamental principles of liner shipping service. In this chapter, the author attempts to define the concept of slow steaming as one of the operating techniques from the economic and shipping lines' viewpoints. Moreover, the main reasons why slow steaming has spread rapidly in the liner shipping market are analyzed using three approaches: the viewpoint of shipping cycle, operating costs and environmental performance. The results of these analyses will be used to build the theoretical concept of this thesis and to design the simulation model.

2.2. The definition of slow steaming

2.2.1. Concept of Liner Shipping and Slow Steaming

In general, liner shipping is defined as the maritime transport services that are provided on a regularly scheduled basis to pre-determined ports in each market. According to the definition of Dinger (2003), liner shipping is "the shipping services that operated by a provision of regular service between specified ports based on the advertised schedule and freight tariff". Moreover, Stopford (2009) presents a detail definition from the functional and systematic viewpoints as follows.

"A liner service is a fleet of ships, with a common ownership or management, which provide a fixed service, at regular intervals, between named ports, and offer transport to any goods in the catchment area served by those ports and ready for transit by their sailing dates. A fixed itinerary, inclusion in a regular service, and the obligation to accept cargo from all comers and to sail, whether filled or not, on the date fixed by a published schedule is what distinguish the liner from the tramp."

A shipping line operates a fleet of ships to provide a fixed liner shipping service, at regular intervals, between ports, and offers transport services for any cargoes in the catchment area served by those ports that are ready for transport by the sailing dates (Lawrence, 1972; Ronen, 1983; Christiansen *et al.*, 2004) Moreover, Lun and Browne (2009) define the primary functions of shipping liner as;

"a) shipping lines offer a regular service for cargo consignments and process the associated shipping documentation; b) shipping lines charge individual consignments; c) shipping lines load containers onto ships and discharge containers from ships; d) shipping lines run a shipping service on a fixed shipping schedule; and e) shipping lines plan the tonnage availability to serve the shipping demand, which may require building new vessels and chartering additional vessels to meet the demand requirements".

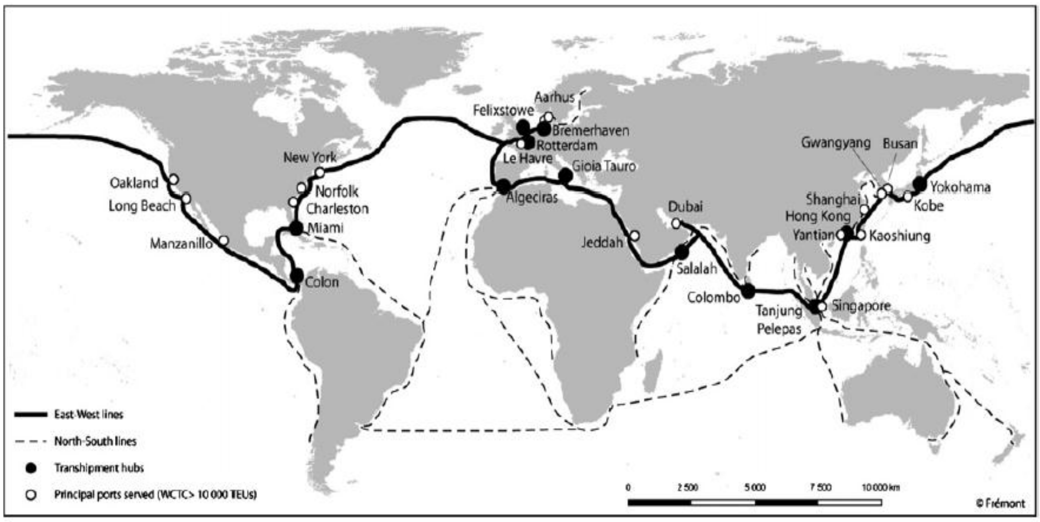


Figure 6 - Major international liner shipping networks
Source: Fremont (2007). Global maritime networks: the case of Maersk. *Journal of Transport Geography*, 15, 431–442

Liner shipping has some distinguishing characteristics itself through the fundamental principle of a liner service as described in the above definitions. Firstly, liner shipping has a specific feature of being a very capital intensive industry

(Notteboom, 2004; Fusillo, 2004) because liner shipping requires an extensive infrastructure, i.e. expensive container ship and relevant logistics facilities, and a more complex administrative overhead than tanker and bulk shipping (UN, 1998; Brooks, 2000). Secondly, liner shipping provides a systematic and standardized transport service, and it leads to the increase of efficiency and productivity. Therefore, liner shipping can provide fast, frequent and reliable service for almost any cargo to almost any foreign destination at a steady freight charge.

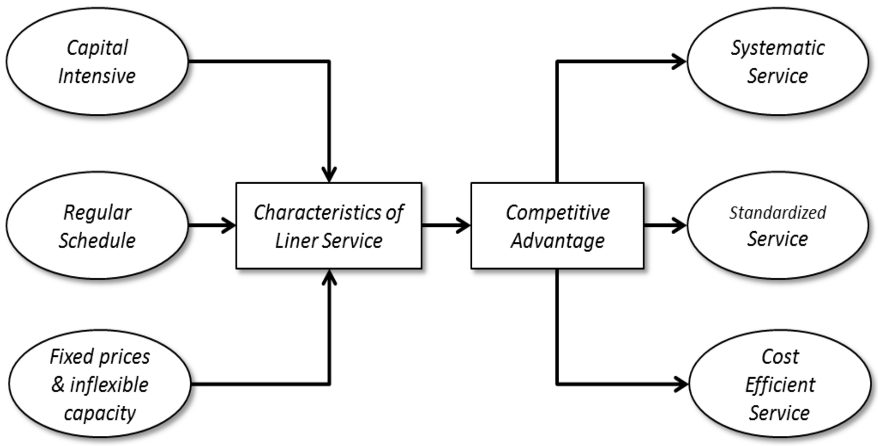


Figure 7 - Characteristics of liner shipping and its advantages

Moreover, the principal of liner service, *i.e.* scheduled weekly service patterns, causes some difficulties for the management of the transport capacity. Shipping lines have to operate the required number of vessels to run a weekly service regardless of whether the ship is full, the market situation and the vessel size. Therefore, network design and managing an optimum capacity on a route are important to liner shipping companies. Fourthly, liner shipping has a close relationship with container terminals, so liner shipping service is influenced directly by the productivity and accessibility of container terminals in major markets (Basta and Morchio, 2008; Maloni and Jackson, 2005; OSC, 2004). These unique characteristics of liner shipping create a competitive advantage, and play an important role in accelerating the development and growth of inter-modal transport and global supply chains (Mangan and Lalwani, 2008).

Slow steaming is one of the operational techniques to reduce voyage speed by close to half of the designed voyage speed or the previous level (Alphaliner, 2010). From the viewpoint of shipping line, slow steaming means stretching out a service by one, two or more weeks, leading to the deployment of more transport capacity (number of vessels or space to transport) for the same volume of cargo, and a reduction in the annual voyage distance for each vessel (UNCTAD, 2010). In these senses, this thesis defines slow steaming as an operational technique to reduce voyage speed of ships, and it necessitates employing a larger number of vessels to transport the same transport volume and to maintain the same frequency or to serve the same level of demand.

Table 3 - Classification of voyage speed

Classification	Voyage Speed	Special Feature
Normal Speed	20-25 knots	Represents the optimal cruising speed a containership and its engine have been designed to travel at
Slow Steaming	18-20 knots	Running ship engines below capacity to save fuel consumption, but at the expense of additional travel time, particularly over long distances
Super Slow Steaming	15-18 knots	A substantial decline in speed for the purpose of achieving a minimal level of fuel consumption while still maintaining a commercial service
Minimal Cost	12-15 knots	The lowest speed technically possible, since lower speeds do not lead to any significant additional fuel economy

Source: Rodrigue, J.P., Comtois, C. and Slack, B. (2009). *The Geography of Transport Systems; Second Edition*. New York: ISBN 978-0-415-48324-7.

Slow steaming was adopted by shipping lines during the financial crisis of 2008-2009. In 2009, due to the sudden decrease of transport demand, shipping lines began to decelerate their voyage speed to downsize their transport capacity or utilize their idle capacity. And they started to adopt slow steaming from 2010 as their main operational strategy to reduce operating costs and the amount of GHG emissions in the condition of high fuel prices and low freight rates. Generally, the voyage speed can be classified by four classes: normal speed, slow steaming, super slow steaming and minimal cost as shown in Table 3.

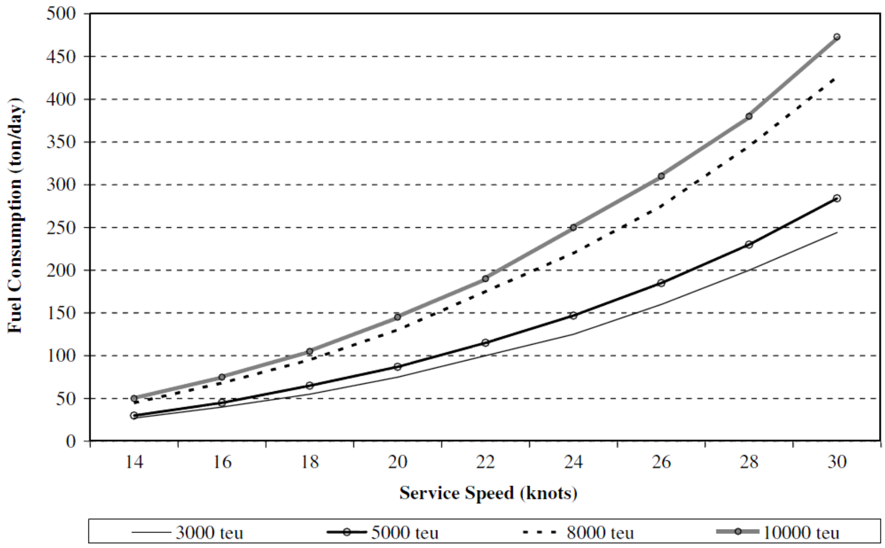


Figure 8 - Daily fuel consumption for four types of container ships at different voyage speeds.

Source: Notteboom, T. and Vernimmen, B. (2008). The impact of fuel costs on liner service design in container shipping. *Proceedings of the 2008 International Association of Maritime Economists (IAME) Conference*, April, Dalian, China.

Shipping lines can enjoy two kinds of main potential advantages from slow steaming. Firstly, shipping lines can reduce their operating costs by the reduction of fuel consumption. The amount of fuel consumption is decided by three factors, engine power, engine load and voyage speed. So, when type of vessel is equal, the amount of bunker consumption can be reduced by the deceleration of voyage speed. According to the analysis of Notteboom and Vernimmen (2008), when the voyage speed is decelerated, fuel consumption can be reduced in every type of container vessel as shown in Figure 8. According to the A.P. Moller Maersk Group (APMM), when voyage speed is reduced by 20%, bunker fuel consumption and CO_2 emissions can be reduced by 40% and 20% respectively. Moreover, according to Germanischer Lloyd (GL), when voyage speed is reduced from 25 knots to 19 knots, fixed costs (11%) and capital costs (29%) can be reduced (Matthew, 2011).

Secondly, slow steaming is an efficient method to reduce the amount of GHG emissions. The amount of GHG emissions that occurred by ships is proportional to the amount of fuel consumption, and it has a strong correlation with vessel size (engine size and power) and voyage speed (engine load). Therefore, when shipping lines decelerate voyage speed, they can reduce the fuel consumption and the amount of GHG emissions together by the reduction of engine load. In this sense, slow steaming is one of the efficient operational techniques used by shipping lines to reduce GHG emissions and/or to improve the level of environmental performance.

Thirdly, slow steaming provides operational flexibility to shipping lines from the strategic perspective. Shipping lines have been improving and/or changing their fleet mix and its size to cope with changes in business and market conditions every quarter and/or year. So, when transport demand is increased rapidly, shipping lines accelerate voyage speed to increase their transport capability to maximize their profits, and, in the contrary situation, they decelerate voyage speed to downsize their transport capacity to reduce their losses and maintain the level of freight rates.

However, in the former case, there are some limitations to increasing transport capacity using just acceleration of voyage speed without additional vessels. Moreover, the additional employment of a new vessel through new order requires a couple of years. However, shipping lines which have a lot of vessels for slow steaming can control their transport capability flexibly through changes in voyage speed without additional investment and/or the lay-up cost. In this sense, slow steaming is a useful strategy to manage the transport supply, *i.e.* transport capacity, and maintain the strategic position of shipping lines.

Moreover, slow steaming is helpful to minimize changes in freight rates through the control of transport capacity. When the liner shipping markets are in oversupply due to a decrease of transport demand or an excessive increase of transport supply, if shipping lines reduce their transport capacity by the reduction of the number of employed vessels on a loop, they can suffer losses related to the increase of lay-up costs and financial costs. In this sense, slow steaming is a useful solution to minimize the decrease of freight rates while fully utilizing fleets.

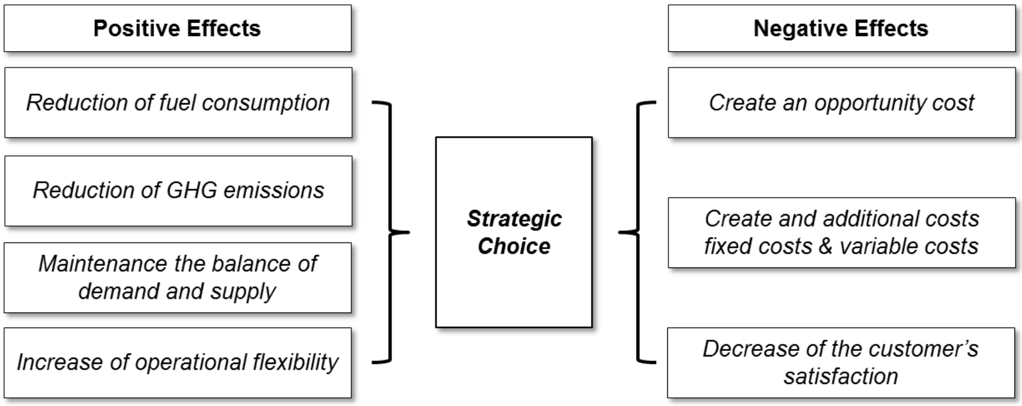


Figure 9 - Advantages and disadvantages of slow steaming

However, slow steaming creates some negative effects also. Firstly, slow steaming requires the additional employment of vessels on a loop and route. Liner shipping service is operated by a provision of regular service between specified ports based on the advertised schedule and freight tariff. Therefore, when the voyage speed is decreased, the number of vessel has to be increased to maintain transport capacity on a loop. This leads to an increase in fixed costs, financial cost, and some variable costs, excluding fuel cost. Secondly, when the voyage speed is decreased, the operational productivity on a loop and a route is reduced. As discussed above, when the voyage speed is decreased, shipping lines have to employ additional vessels to transport the same transport volume. Therefore, the slot utilization rate per unit of cargo is decreased. This decreased slot utilization rate involves the concept of an opportunity cost. Because, reduced slot utilization means the amount of the abandoned transport capacity by the deceleration of voyage speed.

Thirdly, slow steaming can negatively influence the customer's satisfaction. Nowadays, customers and shippers are demanding more complex and sophisticated services such as global coverage that distributes their resources and products globally, high frequency and fast transit time, while maintaining the lowest possible cost and highest possible quality of service (Wang and Cullinane, 2006). However, from the customer's perspective, the extension of transit time by slow steaming increases their inventory costs directly, and it negatively affects their cash flow and supply chain continuously. During the economic downturn, customers are not too concerned about it because they are mostly aiming to reduce their inventory. However, as the economy is recovered, they may no longer accept the longer transit time. Therefore, it is required to find the optimum transit time that fulfills the goals of both parties.

2.2.2. Main Cause of the Adoption of Slow Steaming

During the last three decades, shipping lines have been focusing on the improvement of operational efficiency and productivity to the maximum level by the acceleration of voyage speed and the enlargement of vessel size on major routes. However, nowadays, an obvious operational strategy in liner shipping industry is slow steaming. By the sudden decrease of transport demand, shipping lines began to decelerate their voyage speed to downsize their transport capacity or utilize the idle capacity in 2009. Moreover, they started to adopt slow steaming as their main operational strategy from 2010 (Drewry, 2010; Alphaliner, 2011).

This is because economic and market condition was changed totally by the financial crisis and economic recession. For this reason, today, shipping lines are focusing on the minimization of operating costs to survive in uncertain markets. The main reason for the adoption of slow steaming can be explained by three perspectives such as the theory of shipping cycle, the generation of profits and the growth of pressure on environmental performance.

2.2.2.1. Shipping Cycle (Market Balance)

The shipping cycle is an economic concept that explains how shipping lines and freight rates respond to supply and demand (Stopford, 2009). It can be divided into four stages such as trough, recovery, peak and collapse based on conditions of transport supply and demand as shown in Figure 10. In Stage 1 (Peak), the transport demand exceeds transport supply in the markets. Therefore, freight rates are quite high with charter rates and new order prices compared to other stages. At the same time, shipping lines try to increase their operational efficiency to the maximum level by acceleration of voyage speed and reduction of the number of calling ports and port time.

In Stage 2 (Collapse), the transport supply begins to exceed the transport demand due to the decrease of transport demand. Hence, freight rates begin to drop along with charter rates and new order prices in this stage. Shipping lines start to reduce their investment, firstly, and if transport demand is not recovered as much as present degrees of transport supply, they start to reduce their transport capability and operational efficiency gradually by the control of voyage speed and number of employed vessels in major routes. This leads to a decrease of profit and to an increase of financial costs.

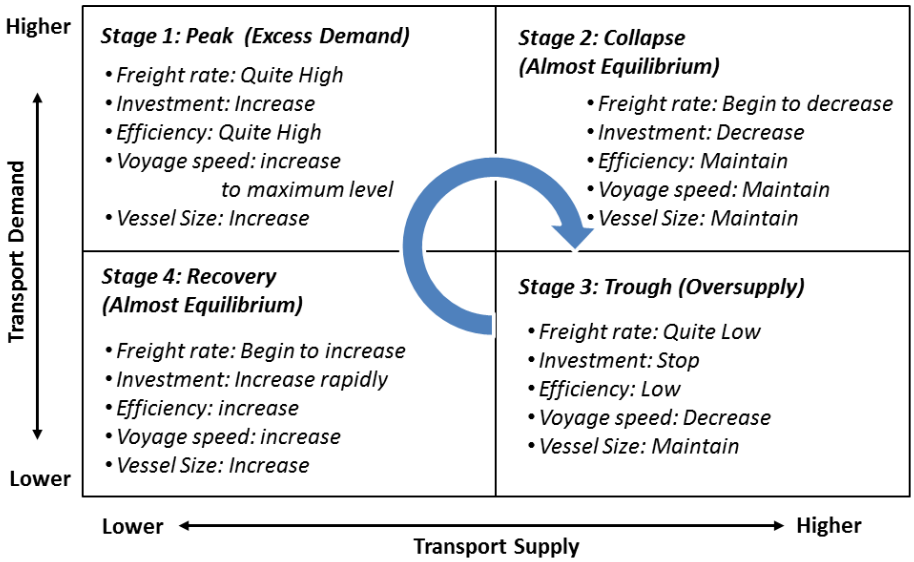


Figure 10 - The shipping cycle (Four Stages)

In Stage 3 (Trough), the transport supply exceeds the transport demand in this market. Therefore, freight rates are quite low with relevant indexes such as charter rate, second hand vessel price and new order price. Moreover, shipping lines try to decrease their operation efficiency through a reduction in employed vessels and vessel size and the deceleration of voyage speed on a loop and a route. However, in 'Stage 4 (Recovery)', due to an increase in the growth rate of transport demand, freight rates and relevant market indexes begin to increase gradually. Hence, shipping lines start to increase their operational efficiency through an increase in voyage speed and investment.

According to the theory of a shipping cycle, the main reasons for the spread of slow steaming can be found from the changes of market balance of transport demand and supply. For example, from 2000 to 2005, the liner shipping industry experienced a serious shortage of transport supply due to a rapid growth in transport demand. In this period, the growth rate of transport demand was higher than the growth rate of transport supply as shown in Figure 11, and relevant indicators such as time charter rates, second-hand prices and new-building prices are at a higher level than the following years as shown in Tables 4 and 5.

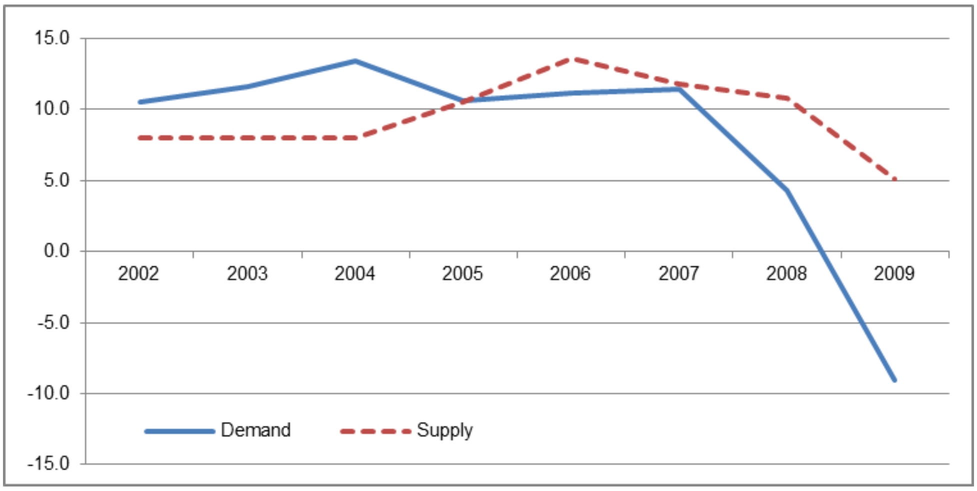


Figure 11 - Trends in growth rate of demand and supply (2002-2009)
Source: UNCTAD. (2011). *Review of Maritime Transport 2010.* United Nations Conference on Trade and Development, Geneva.

This period has unique characteristics of Stage 1 (Peak). However, the growth rate of transport supply began to exceed transport demand from 2006, and its difference was increased from 2009 due to a sharp drop in transport demand. In this period, market indicators began to go down rapidly as shown in Tables 4, 5, and 6. In these senses, we can divide this period (2000-2009) into three phases based on the theory of a shipping cycle such as Stage 1 (Peak: 2000-2005), stage 2 (Collapse: 2005-2007) and Stage 3 (Oversupply: 2008- 2009).

Table 4 - Trends in time charter rates in Container ships (2000-2010)

Unit: US$/ slot/day

Ship type (TEU)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
200-299	17.8	17.8	17.0	18.9	27.0	35.4	28.0	29.8	32.1	16.7	16.9
300-500	14.6	14.9	13.4	15.6	22.2	28.8	22.0	21.3	21.4	9.8	10.2
600-799	-	-	9.3	12.3	19.6	23.7	16.6	16.1	15.6	6.6	7.7
700-999	-	-	9.1	12.1	18.4	22.0	16.7	16.9	15.4	6.0	7.2
800-999	-	-	-	-	-	-	-	-	-	4.9	6.3
1,000-1,260	11.9	8.8	6.9	11.6	19.1	22.6	14.3	13.7	12.2	4.0	4.8
1,261-1,350	-	-	-	-	-	-	-	-	-	3.7	4.3
1,600-1,999	10.4	8.0	5.7	10.0	16.1	15.8	11.8	12.8	10.8	3.1	4.0

Source: UNCTAD. (2011). *Review of Maritime Transport 2010*. United Nations Conference on Trade and Development, Geneva.

Table 5 - Trends in second-hand prices and new-building prices (2003-2010)

Unit: millions of US$

		2003	2004	2005	2006	2007	2008	2009	2010
Second-hand prices	Geared, 500 TEU	5	7	11	10	9	13	4	4
	Geared, 2,500 TEU	20	29	39	41	24	36	18	15
	Geared, 3,500 TEU	25	34	43	44	43	45	24	18
New-building prices	Geared, 500 TEU	13	18	18	16	16	21	14	10
	Geared, 6,500 TEU	67	86	101	98	97	108	87	74
	Geared, 12,500 TEU					154	164	114	105

*Second-hand prices; five years old vessels
Source: UNCTAD. (2011). *Review of Maritime Transport 2010*. United Nations Conference on Trade and Development, Geneva.

On the other hand, during the same period, shipping lines changed their operational strategy to cope with the rapid changes in market conditions in each stage. In the case of west-bound service in the Europe-Far East route, the average transport utilization rate was 91.5% in Stage 1 (Peak: 2000-2005), and it reached 97.4% in

2004 as shown in Table 6. Therefore, shipping lines focused on the increase of their transport capability to the maximum level through two kinds of strategies. Firstly, they tried to increase their transport capability through new-building orders and/or merger & acquisition (M&A). For these reasons, the transport capacity increased rapidly until 2008, and there were various M&As, which led to changes in the market structure in this period.

Table 6 - Trends in transport demand and supply in a Far East/Europe route

Unit: Thousand TEU

Classification		2002	2003	2004	2005	2006	2007	2008	2009
East bound	Traffic Volume	2,987	3,255	3,708	3,838	4,003	4,218	4,101	3,789
	Transport Capacity	4,128	4,782	5,211	5,988	6,760	7,380	8,110	6,544
	Utilization Rate	72.4	68.1	71.2	64.1	59.2	57.2	50.6	57.9
West Bound	Traffic Volume	4,432	5,206	6,238	6,852	7,805	9,101	9,074	7,817
	Transport Capacity	5,139	5,905	6,406	7,355	8,441	9,545	10,819	9,255
	Utilization Rate	86.2	88.2	97.4	93.2	92.5	95.3	83.9	84.4
Sum	Traffic Volume	7,419	8,461	9,946	10,690	11,808	13,319	13,175	11,606
	Transport Capacity	9,267	10,687	11,617	13,343	15,201	16,925	18,929	15,802
	Utilization Rate	80.1	79.2	85.6	80.1	77.7	78.7	69.6	73.4

Source: Drewry (2000-2011). *Container Market; Annual Review and Forecast*. Drewry Shipping Consultants Ltd.

Table 7 - Major acquisitions in liner shipping industry (2000-2009)

Classification	Acquisitor	Target
2000	CSAV	Norasia
2002	Hamburg Sud	Ellerman services to Med/lndia
2003	Hamburg Sud	Kien Hung Shipping Co.
2005	Maersk	P&O Nedlloyd
2005	CMA-CGM	Bollore (Delmas)
2005	Hapag-Lloyd	CP Ships
2007	Hamburg Sud	Costa Container Lines

Source: Woo, J. K. (2009). The effects of M&A on the future container markets: Maersk case. *KMI Global Shipping & Logistics.* 248. 12-27.

For example, Maersk Sealand (the largest liner company in 2005) acquired P&O Nedlloyd (third largest liner company in 2005) in 2005. Thereby the transport capacity of Maersk Sealand increased from 103.6 thousand TEU to 129.7 thousand TEU, and they secured enough transport capability to attain strong competitiveness. Moreover, by this acquisition, P&O Nedlloyd withdrew from Grand Alliance, which consists of four liners, Hapag-Lloyd, NYK, OOCL and P&O Nedlloyd, which led to changes in the structure of alliances in the liner shipping industry as shown in Table 7 and Figure 12.

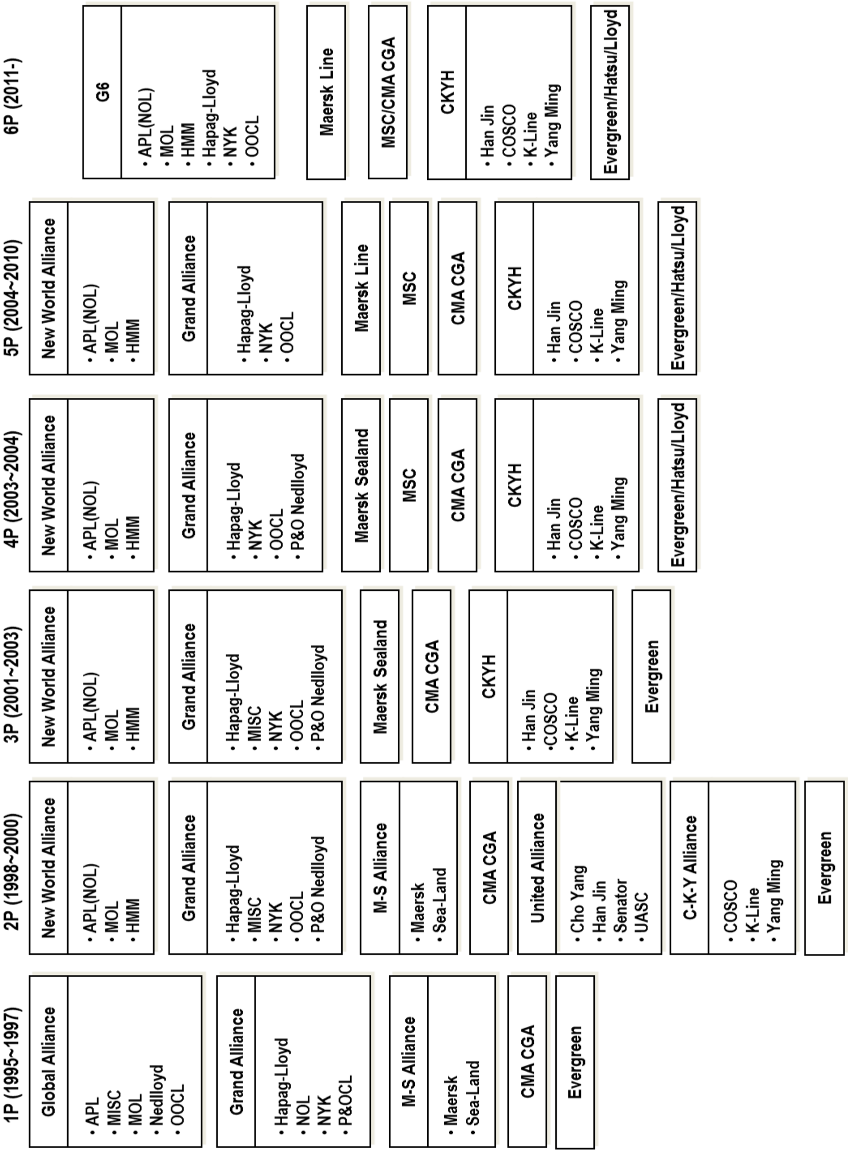


Figure 12 - Change of strategic alliance structure (1995-2012)

Secondly, shipping lines focused on the maximization of transport capacity in major markets. In the case of west-bound service in the Europe-Far East route, shipping lines reduced the number of employed vessels and calling ports on a loop as shown as Figure 13. The average number of vessels on a loop was decreased from 9 vessels in 2003 to 8.6 vessels in 2008, and the average number of calling ports was decreased from 19 ports (2000) to 10 ports (2008). This means that shipping lines increased their turnover rate (or annual number of round-trips) by the acceleration of voyage speed and reduction of port time.

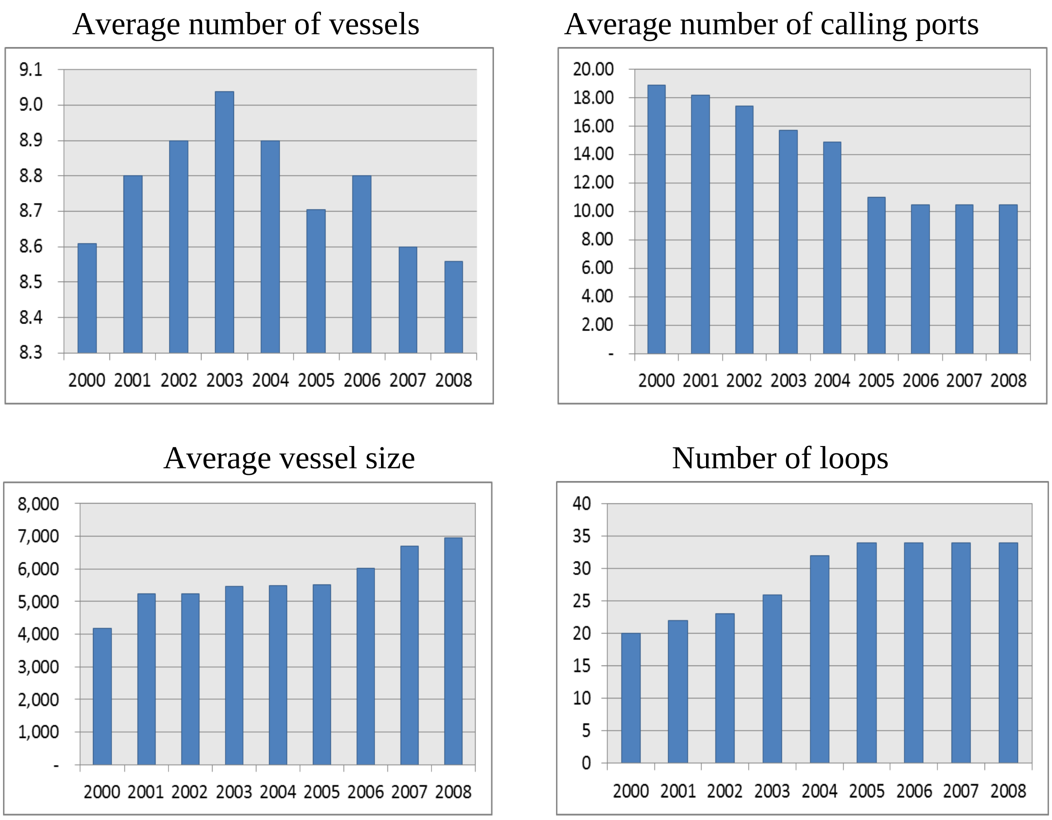


Figure 13 - Trends in liner's operational indicators (2000-2008)
Source: Drewry. (2000-2011). *Container Market, Annual Review and Forecast.* Drewry Shipping Consultants Ltd.

However, in Stage 3 (Oversupply: 2008-2009), shipping lines changed their operating strategy to cope with the rapid changes in market conditions. They, despite the increase of employed vessel size, increased the average number of employed vessels on a loop from 8.3 vessels in 2008 to 9.4 vessels in 2009, and the average number of calling port from 10 ports (2008) to 16 ports (2009). Moreover, at the same time, they reduced the number of services (loops) from 34 loops to 30 loops in the same period. This means that shipping lines decreased their operational efficiency through the reduction of the average number of employed vessels and the deceleration of voyage speed on a loop.

As discussed, shipping lines changed their operating strategy following changes in market conditions, *i.e.* balance of transport demand and supply, in the viewpoint of the theory of a shipping cycle. In this sense, it can be explained that slow steaming is a rational operating strategy to cope with changes in market conditions. In other words, shipping lines adopted slow steaming not only to reduce their operating costs but also to minimize their financial burden (Vernimmen *et al*, 2007). Therefore, in the viewpoint of the theory of a shipping cycle, slow steaming is one of the passing phases in the liner shipping cycle. In this sense, if transport demand is showing signs of recovery, shipping lines would change their operating strategy to increase their operational capability and efficiency by the increase of voyage speed and investment.

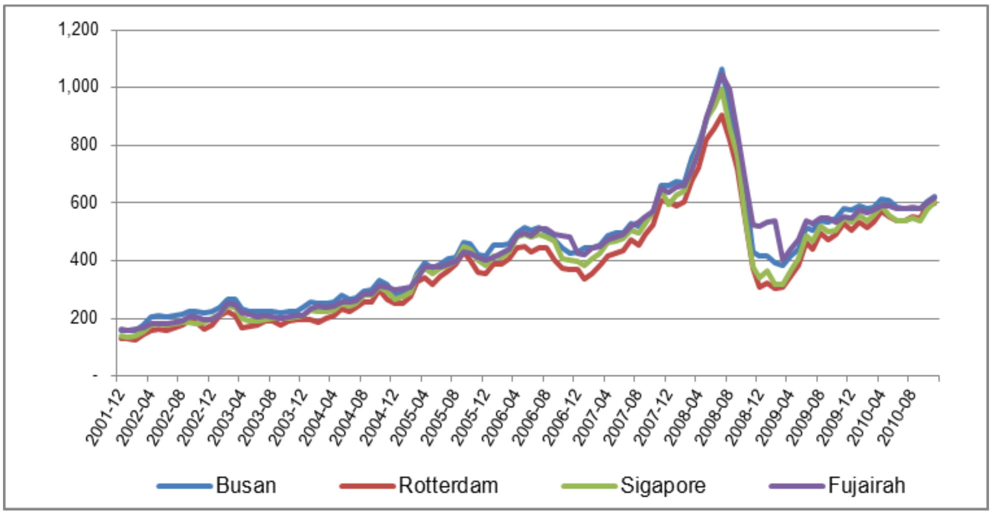
2.2.2.2. The Generation of Profits

The second reason for the spread of slow steaming can be found from the deterioration of profits due to high bunker fuel prices and low freight rates. During the last 10 years, bunker fuel price has been moving upward continuously. The average bunker fuel price of 380 CST (Intermediate Fuel Oil) was 105 US$/ton in January 2002. However, it exceeded 300 US$/ton in April 2006, and it reached 680 US$/ton in July 2008 as shown in Figure 13. At the end of 2008, the price dropped sharply as a result of the global financial crisis and subsequent economic recession, but it began to increase again from the middle of 2009 gradually.

High fuel price is a heavy burden in the liner shipping business. The effects of high fuel price on shipping lines are larger than on bulk carriers given that, in general, container ships require faster speed to fit their schedule (Notteboom, 2004). Moreover, by the international conventions, *i.e.* MARPOL 73/78, and the restrictions regarding vessel fuel of major markets such as Northern Europe and North America, shipping lines have to use high-quality fuel, which is more expensive than normal bunker fuels. Hence, shipping lines charge the Bunker Adjustment Factor (BAF) to customers to offset their burden.

However, today, the fuel price is too high to cover the burden of the shipping line. The proportion of fuel cost in total operating costs was 13% in the 1970s, and it increased to 34% in 1980s (Stopford, 2009). In the case of a 12,000 TEU vessel, annual bunker fuel cost, where bunker fuel price is 210 US$/ton, represents about 40% of annual operating costs (Yang, *el al.*, 2002). However, its proportion increased by 60~65% in 2008 and more than 75% in 2011 (Alphaliner, 2011). Hence, today, shipping lines focus on the reduction of fuel cost.

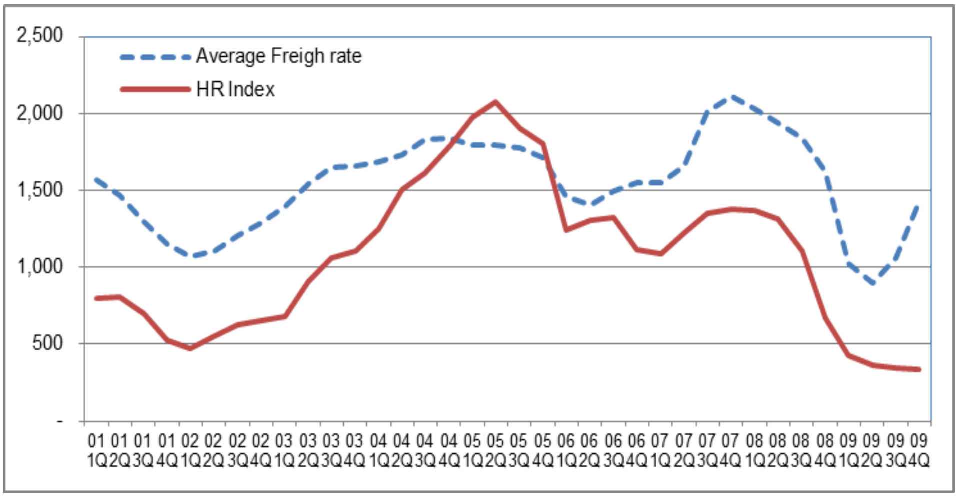
Unit: US$/ton



*Average price of 380CST and MDO in major four ports in each market

Figure 14 - Trends in bunker fuel price in four main ports (2001- 2010)
Source: Clarkson, Shipping Review Outlook, Clarkson, each month & Reuters, each month

Furthermore, the freight rates in major routes started to drop in the first quarter of 2008 due to the decrease of transport demand. In the case of the Howe Robinson Container Index (HR Index), it reached by 2,071 points in the second quarter of 2005. However, it dropped to 334 points by the end of 2009. Therefore, this situation, *i.e.* high bunker fuel prices and low freight rate degree, is too problematic with the decrease of transport demand for shipping lines to maintain their operating systems. For these reasons, shipping lines adopted slow steaming to reduce their bunker fuel costs from the middle of 2009.



*Average fright rates in west-bound service in Europe-Far East route

Figure 15 - Trends in the average freight rates* and HR Index

Source: Containerization International (2001-2010) & The Howe Robinson Container Index (2001-2010)

2.2.2.3. The Pressure of Environmental Performance

The other reason for the spread of slow steaming can be explained by the high pressure on the reduction of GHG emissions. Even though international shipping is the most environmental-friendly transportation mode, it is one of the main contributors to the production of marine pollution and atmosphere pollution such as Carbon dioxide (CO_2), Sulfur dioxide (SO_2) and Nitrogen oxides (NO_x) as shown in Table 8.

According to the definition of Eyring et al. (2009), international shipping is one of the major contributors to produce the GHG emissions, and causes of significant climate warming. Moreover, According to the research of IMO (2009), if there is no active countermeasure to control the amount of GHG emissions, the amount of GHG will be doubled by 2015. In this sense, IMO started to produce various international treaties, conventions and agreements for the prevention of pollution and the control of GHG emissions from ships from the beginning of the 1970s.

Table 8 - Main Pollutants in international shipping industry

Classification		Main Pollutants
Pollution from ships	Marine Pollution	• Oil • Chemicals and liquefied gases in bulk • Dangerous goods (bulk and packaged) • Garbage and sewage • Ballast water • Bio-fouling • Anti-fouling paints
	Atmosphere Pollution	• Exhaust gases • Cargo vapour emissions • Ozone depleting substances • Noise

Source: IMO (2009). *Second IMO GHG Study 2009*. The International Maritime Organization 4 Albert Embankment, London SE1 7SR.

Table 9 - Major International Environmental Conventions (IMO)

Conventions	Adopted in	Entered into Force from
International Convention for the Prevention of Pollution from Ships (1973), as modified by the Protocol of 1978 relating thereto (consist of 6 Annexes)	1973/1978	1983, 1998, 1992, 2000, 2005
International Convention for the management and intervention on the High Seas in Cases of Oil Pollution Casualties	1969	1975
International Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter	1972	1975
International Convention on Oil Pollution Preparedness, Response and Co-operation	1990	1995
Protocol on Preparedness, Response and Co-operation to pollution Incidents by Hazardous and Noxious Substances	2000	2007
International Convention on the Control of Harmful Anti-fouling Systems on Ships	2001	2008
International Convention for the Control and Management of Ships' Ballast Water and Sediments	2004	-

Source: IMO. (2009). *Second IMO GHG Study 2009*. The International Maritime Organization 4 Albert Embankment, London SE1 7SR.

The major environmental issues in international shipping are emissions to the atmosphere, energy wastage, discharges/dumping to the sea, discharge to shore and recycling. In general, pollution from ships can be divided into two categories; marine pollution and atmospheric pollution. The main marine pollution is oil, chemicals and liquefied gases in bulk, garbage and sewage and ballast water; and the major atmospheric pollution is exhaust gases and Ozone.

During the last three decades, IMO produced seven international conventions regarding marine environment protection. Among them, six conventions have entered into force as shown in Table 9 and one, i.e. International Convention for the Control and Management of Ships' Ballast Water and Sediments, is not in force. One of the main international conventions to cover prevention of pollution of the marine environment by ships from operational or accidental causes is the International Convention for the Prevention of Pollution from Ships (MARPOL). It was, firstly, adopted on 2 November 1973 at IMO and consisted of six annexes to cover oil, chemicals, harmful substances in packaged from sewage and garbage. In 1978, it was modified into MARPOL 73/78 adding a new Annex (*Annex VI*[1]) to govern various air pollutants from ships, and it entered into force on the 19 May 2005 as shown in Table 10.

Annex VI contains six regulations in terms of the emissions from ozone-depleting substances from refrigerating plants and fire-fighting equipment (*Regulation 12*), Emissions from shipboard incinerators (*Regulation 16*), Fuel Oil quality (*Regulation 16*) and related greenhouse-gas emissions such as Nitrogen Oxide (NOx) (*Regulation 13*), Sculpture Oxide (SOx) (*Regulation 14*) and Volatile Organic compounds emissions from cargo oil tanks of oil tankers (*Regulation 15*). In addition to this, IMO adopts new technical and operational measures for the reduction of CO_2 emissions from international shipping in Annex *VI*. It includes three main regulations:

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[1] It applies to all ships (fixed and floating drilling rigs and other platforms) but the certification requirements are depending on size of the vessel and when it is constructed. Ships of 400 gross tons and above engaged in international voyages involving countries that have ratified the conventions, or ships flying the flag of those countries, are required to have an International Air Pollution Prevention Certificate (IAPP Certificate). The IAPP certificate will be issued following an initial survey carried out by the Flag Administration or by a recognized organization (*e.g.* Det Norske Veritas) on behalf of the Flag Administration, confirming compliance with MARPOL Annex VI. For ships with the flag of an Administration that have not yet ratified Annex VI, a Certificate of Compliance with Annex VI may be issued by DNV.

a) An Energy Efficiency Design Index (EEDI) for application to new specified ship types; b) A review clause such that the application of the EEDI to future new ships can be tested against efficiency expectations and for any unforeseen impact prior to each implementation of the EEDI reduction stages; and c) A requirement for each ship to have a ship specific Ship Energy Efficiency Management Plan (SEEMP).

Table 10 - Structure and main contents in MARPOL 73/78

Annex		*Main contents*	*Entered into Force from*
I	*Regulations for the Prevention of Pollution by Oil*	*It covers prevention of pollution by oil from operational measures as well as from accidental discharges*	*October 2, 1983*
II	*Regulations for the Control of Pollution by Noxious Liquid substances in Bulk*	*It details the discharge criteria and measures for the control of pollution by noxious liquid substances carried in bulk.*	*October 2, 1983*
III	*Regulations for the dangerous goods*	*It contains general requirements for the issuing of detailed standards on packing, marking, labelling, documentation, stowage, quantity limitations, exceptions and notifications for preventing pollution by harmful substances*	*July 1, 1992*
IV	*Prevention of Pollution by Sewage from ships*	*It contains requirements to control pollution of the sea by sewage*	*September 27, 2003*
V	*Prevention of Pollution by Garbage from Ships*	*It deals with different types of garbage and specifies the distances from land and the manner in which they may be disposed of*	*December 31, 1988*
VI	*Prevention of Air Pollution from Ships*	*The regulations in this annex set limits on sulphur oxide and nitrogen oxide emissions from ship exhausts as well as particulate matter and prohibit deliberate emissions of ozone depleting substances.*	*May 19, 2005*

Source: IMO. (2009). *Second IMO GHG Study 2009*. The International Maritime Organization 4 Albert Embankment, London SE1 7SR.

Moreover, IMO suggests nine principles for efficient enforcement such as; a) effectively reduce CO2 emissions; b) be binding and include all flag States; c) be cost effective; d) not distort competition; e) be based on sustainable development without restricting trade or growth; f) be goal based and not prescribe particular methods; g) stimulate technical research and development in the entire maritime sector; h) take into account new technology; i) be practical, transparent, free of fraud and easy to administer.

IMO adopted the Energy Efficiency Operational Indicator (EEOI) through MEPC 53 in July 2005. EEOI is a measure to analyze the amount of greenhouse-gas emissions per ton/mile (or TEU/mile), and the unit for the EEOI is grams of CO_2 per capacity-mile (or TEU/mile), where capacity is an expression of the actual amount of cargo that the ship is carrying. Therefore, EEOI is focused on the relationship between the amount of greenhouse-gas emissions and operational conditions. Unlike EEOI, EEDI is a measure to analyze the amount of greenhouse-gas emissions per transport utility. Thereby, it is focused on the relationship between the amount of greenhouse-gas emissions and total transport capability. EEDI and EEOI can be calculated by the following formulas:

$$EEDI = \frac{Engine\ Power(kW) \times SFC(g/kWh) \times Cf}{Capacity\ (DWT) \times Speed(kt)}$$

$$EEOI = \frac{\sum_i (FCi \times Cf)}{\sum_i (Mi \times Di)}$$

Where,

FC_i: fuel consumption on voyage i

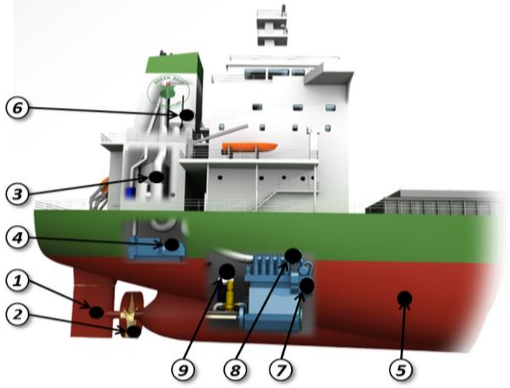
Cf: carbon content of the fuel used

M_i: mass of cargo transported on voyage i

D_i: distance of voyage i

In this sense, technical policy instruments are based on the EEOI and operational policy instruments are based on the EEDI (IMO, 2010). Moreover, to achieve this, IMO provides three basic strategic approaches to improve the energy efficiency of ships such as DWT enlargement, voyage speed reduction and application of new technologies (MEPC 60/4/35, 15 January 2010). These three approaches influence the efficiency of ships in markets by the increase of a denominator of the EEDI formula, *i.e.* transport capability, and the decrease of a numerator, *i.e.* the amount of GHG emissions that occurred by marine transportation as shown in Table 11.

Table 11 - Major technologies to improve the efficiency of ships



Technologies	Reduction
1. Advanced rudder and propeller system	*Fuel (4%)*
2. Speed Nozzle	*Fuel (5%)*
3. Exhaust gas scrubber system	*SOx (98%)*
4. LNG auxiliary engines	*CO_2 (20%), NOx (35%), SOx (100%)*
5. Hull Paint	*Fuel (3-8%)*
6. Waste Heat Recovery system (WHR)	*Fuel (7-14%)*
7. Water In Fuel system (WIF)	*NOx (30-35%)*
8. Exhaust Gas Recirculation system (EGR)	*NOx (80%)*
9. Pump and cooling water optimization	*Fuel (1.5%)*

Source: Green Ship

In the case of DWT enlargement, although larger DWT requires larger engine power, DWT enlargement can improve efficiency (reduction of the EEDI value). This is because the necessary engine power increase in proportion to the DWT increase is powered by two-thirds, and therefore, the increase of the denominator outweighs that of the numerator. Moreover, in the case of speed reduction, lowering the voyage speed would reduce the necessary engine power considerably as the engine power is in proportion to the speed powered by three. So, speed reduction is very effective in improving efficiency. Finally, in the case of application of new technologies, new technology means one which can be considered as technically achievable and be applicable to a particular ship type from an engineering viewpoint. Its advantage is that it can improve the EEDI value without changing DWT or ship speed; the improvement in efficiency would not cause any changes to, or constraints on, the operation patterns of the ship.

In addition, IMO provides the Development of a Ship Energy Efficiency Management Plan (SEEMP) (IMO MEPC 59 INF. 10), and it contains the basis for technical and operational methods for increasing energy efficiency. The amount of greenhouse-gas emissions that occur by the ship is determined by the level of activity and efficiency of the ship. Therefore, in order to reduce greenhouse-gas emissions, a regulatory framework as a guide line should aim to minimize the activity and/or improve the efficiency of the ship. In this sense, various technical methods include the improvement of ship/hull design to reduce drag and rudder, propulsion systems and maintenance technologies including hull coating are being developed and improved continuously.

On the other hand, IMO adopted the Energy Efficiency Design Index (EEDI) and Energy Efficiency Operational Indicator (EEOI) as technical and operational measures for the reduction of CO_2 emissions from international shipping. In addition, they provide a plan, as a guideline, to improve efficiency. In this plan, the energy efficiency of the ship can be improved by three basic approaches, namely, DWT enlargement, voyage speed reduction and new technologies as shown in Figure 16.

As shown in this diagram, slow steaming is one of the important strategies to reduce the CO_2 emissions in this plan. Moreover, according to this plan, if shipping lines increase the vessel size and adopt new technologies rapidly, the energy efficiency of ships can be improved by 25-75%. According to IMO's Marine Environment Protection Committee (MEPC), CO_2/ton-mile can be reduced by 10-50% through the improvement of vessel design and relevant technologies, and 10-50% by the improvement of the operating system as shown in Table 12. In the case of the improvement of the operating system, there is a plan to reduce the CO_2/ton-mile by the improvement of fleet management (5-50%), voyage optimization (1-10%) and energy management (1-10%).

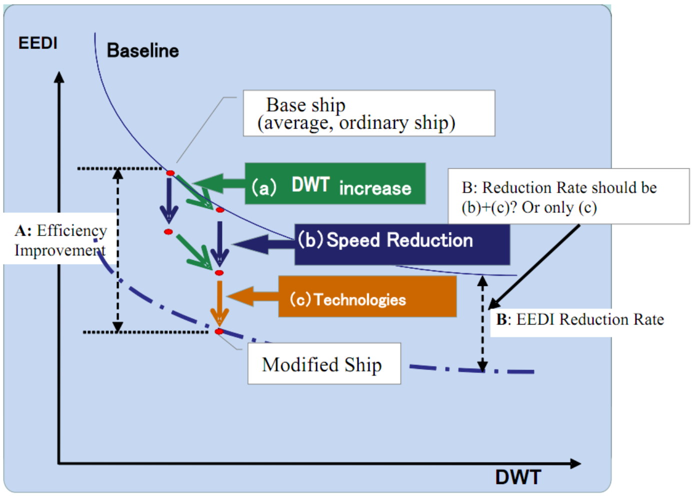


Figure 16 - Three approaches to improve the energy efficiency based on EEDI

Source: IMO. (2010). *MEPC 60/4/35. IMO*, 15 January 2010.

Table 12 - Assessment of potential reductions of CO_2 emissions from ships

Classification		Saving of CO_2/ton-mile	Combined	Combined
Design (New ships)	Concept, speed and capability	2% to 50%	10% to 50%	25% to 75%
	Hull and superstructure	2% to 20%		
	Power and propulsion systems	5% to 15%		
	Low-carbon fuels	5% to 15%		
	Renewable energy	1% to 10%		
	Exhaust gas CO_2 reduction	0%		
Operation (All ships)	Fleet management, logistics	5% to 50%	10% to 50%	
	Voyage optimization	1% to 10%		
	Energy management	1% to 10%		

Source: IMO. (2009). *Second IMO GHG Study 2009*. The International Maritime Organization 4 Albert Embankment, London SE1 7SR.

In this sense, we can find one of the important reasons for the spread of slow steaming in recent environmental issues and relevant international conventions. From the viewpoint of shipping lines, slow steaming is an important operational technique (method) to improve the efficiency of ships and their environmental performance through the reduction of greenhouse-gas emissions on a route. According to the assessment of IMO, shipping lines can improve the efficiency of their ship operation by 10-50% and reduce GHG emissions to the same degree by the improvement of fleet management and the optimization of their operating system (Notteboom, 2008; Ben, 2009; IMO, 2009; Ronen, 2010).

As discussed above, one of the main reasons for the spread of slow steaming is the change of the value proposition of shipping lines. Slow steaming is an important strategy to improve a liner's energy efficiency and operational efficiency, and the value proposition moves from high operational efficiency based on the productivity of ships and service to high operational and energy efficiency based on environmental performance.

2.3. Literature Review

During the last five decades, much scholarly work has been done on the topic of the liner shipping industry. These studies have been inclined to consider three categories: the definition of liner shipping, routing and scheduling and strategy of shipping lines, including safety and environmental issues. Especially, the literature on liner shipping has been dominated by a focus on routing and scheduling problems. This is because great attention has been shown to the question of how shipping lines can improve their operational efficiency and reduce their operating costs following the rapid growth of transport demand during the last five decades.

Therefore, relatively little attention has been paid to the relationship between voyage speed and liner shipping, and there is limited literature on this topic. However, in recent years, much interest has been aroused in the relationship between voyage speed and the strategies of shipping lines and the relationship between voyage speed and greenhouse-gas emissions by the rapid spread of slow steaming. In this thesis, the author attempts to examine the major research related with voyage speed from the viewpoint of the liner strategy, strategic planning and environmental issues.

2.3.1. Strategy of Shipping Lines

According to Porter (1980), when a firm sustains profits that exceed the average for its industry, this firm is said to possess a competitive advantage over its rivals. He identifies two types of competitive advantage of the firm, specifically, cost advantage and differentiation advantage. He explains when a firm can deliver the same benefits as competitors but at a low-cost or deliver benefits that exceed those of competing products (differentiation advantage) this firm can get a competitive advantage.

Moreover, he emphasizes the importance of strategic positioning, and he explains that a firm will be able to secure its competitive advantage through strategic positioning using three types of strategy: cost leadership, differentiation and focus on the complex competitive structure. In other words, the success of a firm and, therefore, its choices of competitive strategy are deeply rooted in the structure of the industry in which it operates and its position in the industry and its proximate environment.

Regarding the competitive structure of industry, he explains it using the ‘Five Forces Model’. This model consists of five forces (three horizontal and two vertical forces) that affect competition in the market and there are related considerable factors in each area as shown in Figure 17. In addition to the five forces, as a sixth force, governmental policies are added to his model because of their influence on all the other forces. On the other hand, Porter also emphasizes productivity growth as the focus of national strategy. According to this theory, firms can create competitive advantage by perceiving or discovering new and better ways to compete in an industry and bringing them to market, which is ultimately an act of innovation. In addition, he identifies five sources of innovation; a) new technology; b) new or shifting buyer needs; c) emergence of new industry segment; d) shifting input costs or availability; e) changes in government regulation.

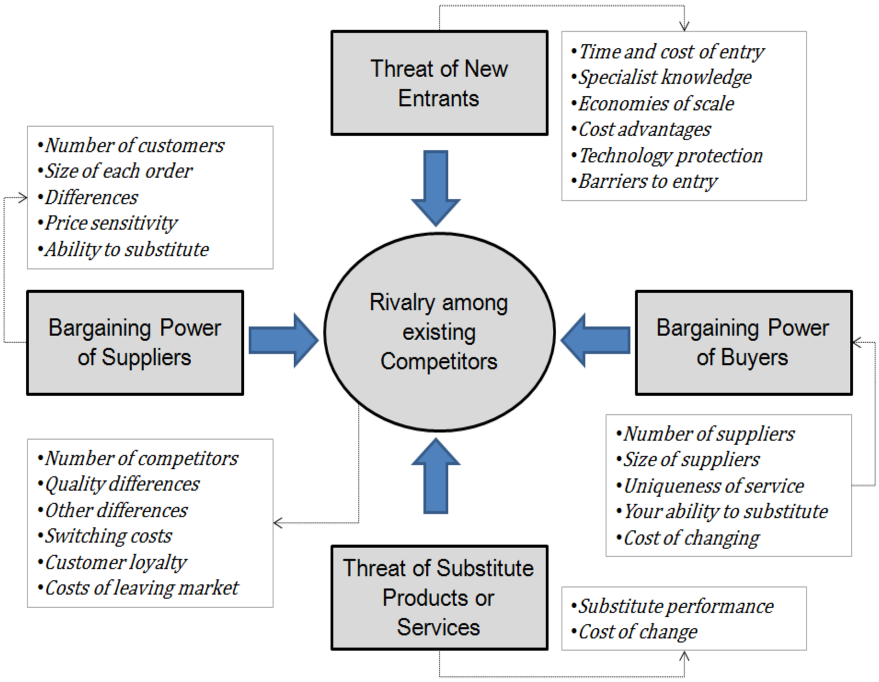
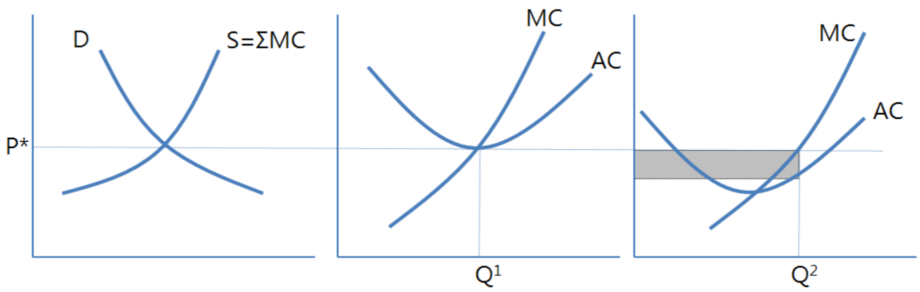


Figure 17 - Five forces model

Source: Michael E. Porter (1980). *Competitive Strategy: Techniques for Analyzing Industries and Competitors*. Free Press, 1980.

On the other hand, from the viewpoint of 'Resources Based View (RBV)', if a firm has superior resources, and its resources are protected by some form of isolating mechanism in industry, the firm can earn sustainable super normal returns. Barney (1991) argues that the superior resources are the root to create or to strengthen the firm's competitive advantage. In addition to this, he identifies four indicators of the potential of firm resources to create sustainable competitive advantage as follows; (a) valuable: when they enable a firm to conceive or implement strategies that improve its efficiency or effectiveness; (b) rare; valuable firm resources possessed by large numbers of competing firms cannot be sources of either a competitive advantage or a sustainable competitive advantages; (c) imperfectly imitable; because of a combination of three reasons such as unique historical conditions, causally ambiguous and social complex; and (d) substitutability; there must not be strategically equivalent valuable resources that are themselves either not rare or imitable. Therefore, if firms have superior resources, these firms have lower average costs than other firms (Mahoney and Pandian, 1992). Moreover, according to the research of Peteraf (1993), firms which have a low average cost, a low-cost firm, have somewhat inelastic supply curves, so they can produce their goods more cheaply than the equilibrium price in the market. In equilibrium, industry demand and supply are in balance, a high-cost firm's breakeven point is P (P=AC), so low-cost firms earn super normal profits in the form of rents to their scarce resources (P>AC) as shown in Figure 18.



P* = Equilibrium Price, □ = Rents to Efficient Producer

Figure 18 - Scarcity rents with heterogeneous factors

Source: Peteraf, R. (1993). The Cornerstones of Competitive Advantage: A Resource -Based View. *Strategic Management Journal*, 14. 179-191.

Moreover, the low-cost firms can maintain their competitive advantage when their resources cannot be expanded freely or imitated by other firms. If production in this market increased by low-cost firms (efficient producers), the supply curve shifts from S_1 to S_2, and the equilibrium price m, moves from P_1 to P_2 as shown in Figure 19. In this case, high-cost firm groups (Firms A) leave the market, and low-cost firms (Firms B) will produce at the point where price equals both marginal cost and average cost. As a result, rents will be dissipated and only normal returns will be earned by efficient (now homogeneous) producers. For this reason, the precise strategy is important to shipping lines also. This is because shipping lines face the challenges of developing strategies that give them an advantage in better serving their customers through changes of the business environment with technological, economic, and political developments (Lun, Lai and Cheng, 2010).

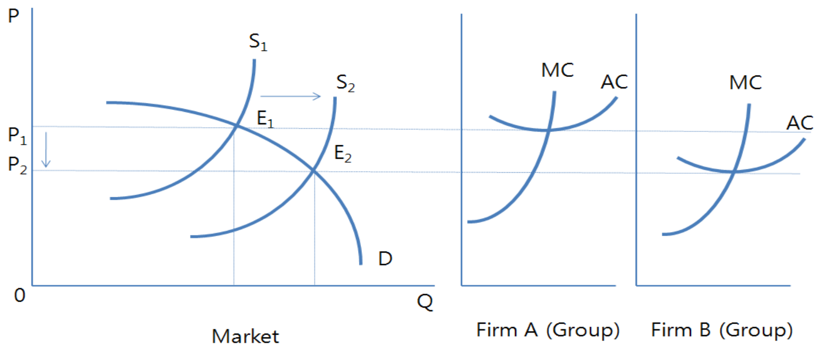


Figure 19 - Market changes by the change of production and price level

Source: Peteraf. R. (1993). The Cornerstones of Competitive Advantage: A Resource -Based View. *Strategic Management Journal*, 14. 179-191.

On the other hand, Jawkins and Gray (2000) explain the importance of liner strategy and they define the principles of strategic management for shipping lines as follows; a) help shipping firms identify and prioritize business opportunities; b) give shipping firms an objective view to solve business problems; c) provide shipping firms with a management framework to improve their internal and external collaborations; d) minimize the negative effects on shipping firms when threats arise; e) help shipping firms make better decisions to support predefined organizational goals and objectives; f) guide shipping firms in the effective allocation of resources to improve their overall efficiency and effectiveness; and g) provide shipping firms with methods and ways to manage changes in a dynamic business environment. Especially, they emphasize that strategy can give an objective view to solve business problems, assist in controlling business activities, minimize negative effects when threats arise, and help make better decisions to allocate resources efficiently.

In these senses, Walker *et al.* (2003) define the development process of formulating and implementing the operational strategies of shipping line as shown in Figure 20. According to their definition, formulating and implementing a shipping strategy involves many interrelated decisions, such as what to do, when to do it, as well as how to do it. Objectives and strategies must be achievable with the liner shipping company's available resources and capabilities, and must be consistent with the direction and allocation of resources based on their corporate and business strategies. Formulation of strategies should reflect transport demand and the competitive situation in a market. In addition, they explain that in order to build a successful strategy it is necessary to consider: a) internal resources, capabilities, and strategies; b) the environmental context, such as political, economic, and technological trends in the shipping industry; c) the relative strengths and weakness of competitors; and d) the needs, wants, and characteristics of current and potential customers.

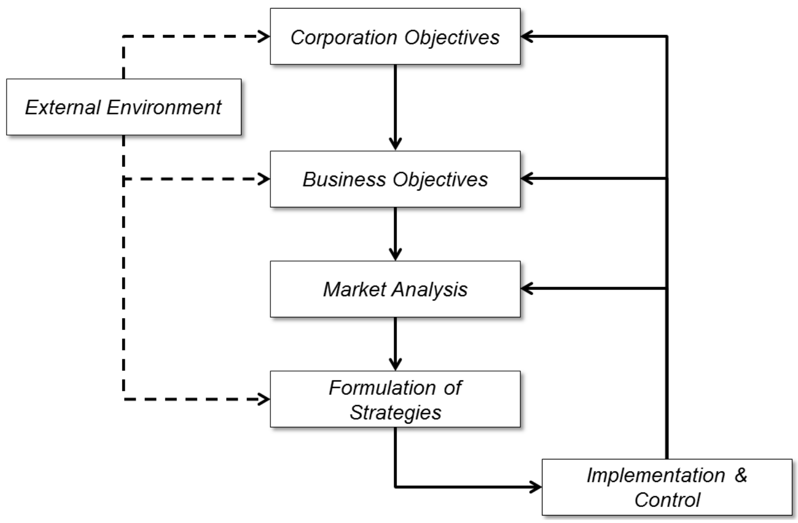


Figure 20 - Development process of strategies in shipping lines

Source: Walker *et al.* (2003). *Marketing Strategy*. McGraw-Hill, Boston.

On the other hand, Pepall *et al.* (2005) refine the strategy formulation process in liner shipping markets, and they argue that there is a direct relationship among the market structure, conduct, and performance as shown in Figure 21. In this model, the economic and political conditions affect the market structure, and the market structure influences the conduct of shipping lines with the political condition. In the conduct phase, shipping lines build their pricing policy and capacity level based on their own policy and strategies.

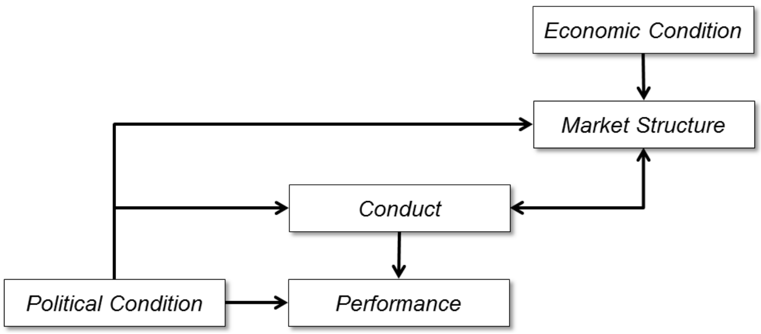


Figure 21 - Strategic decision-making process of shipping lines

Source: Pepall, Richards and Norman. (2005). *Industrial organization, contemporary theory and practice*, Thomson South-Western, Cincinnati.

Moreover, the performance of service depends on the conduct, and their competitiveness should be decided by the performance in this market. In the viewpoint of Resource Based View (RBV), the concept of conduct means the technical and industrial innovation. In this phase, shipping lines build or improve their strategies such as transport capacity, transport schedule (transit time, number of employed vessels and calling ports and vessel size) and freight rates using their resources. Shipping lines provide their transport service, and their competitiveness should be decided by the competition in this market.

Brooks (2000) builds a model to analyze the framework of a liner's strategic decision-making process based on the concept of RBV. In this model, shipping lines improve or change their existing strategy and service structure based on changes in the business environment and their competitiveness. In this process, the liner's competitiveness is a result of competition with rivals in the market, and it influences the strategic decision-making process directly. In the new strategy and structure phase, shipping lines rebuild and/or reorganize their transport capacity level and service network. Moreover, they focus on the improvement of operational efficiency and reduction of operating costs to strengthen their competitiveness. Shipping lines can improve their strategies and build optimal service structures through this feedback process. In this sense, precise business environment analysis and monitoring systems are important to shipping lines to achieve their strategic goals.

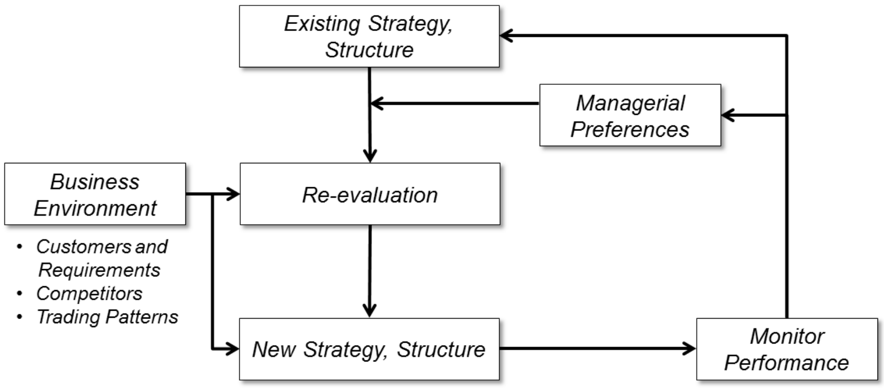


Figure 22 - Strategy formulation in liner companies

Source: Brooks, M. R. (2000). *Sea Change in Liner Shipping: Regulation and Managerial Decision-Making in a Global Industry*. Oxford: Pergamum Press.

According to the definition of Christiansen *et al.* (2004), shipping lines build their strategies based on the mechanism of transport planning in the viewpoint of long-term, medium-term and short-term as shown in Figure 23. It consists of three levels, which are the strategic planning, the tactical planning and the operational planning levels, and each level is connected with the others. At the level of strategic planning, shipping lines select the target market, and they analyze and forecast it based on the market size, potential growth rate, competition and expected profit. The decision of fleet size and composition will be highly dependent on the overall service strategy as well as the forecast market share and planned network. They select calling ports and build a network plan by considering the interchange points between the different trade routes, their connectivity as well as the network scale in terms of geographical coverage. Based on the above decisions, shipping lines determine their fleet mix (vessel and fleet size).

A vessel deployment plan is concerned with the allocation of vessels to routes with the objective of maximizing the utilization and efficiency of the service. The deployment plan takes into account the expectations for transport demand (freight volume) on the routes as well as possible restrictions (physical or regulatory) of the types of vessels that can operate on a certain route. Furthermore, shipping lines take into account various problems from the viewpoint of the operational level. They decide the optimum voyage speed by the considering the market condition (balance between transport demand and supply) and the port conditions (productivity and cost information in calling ports).

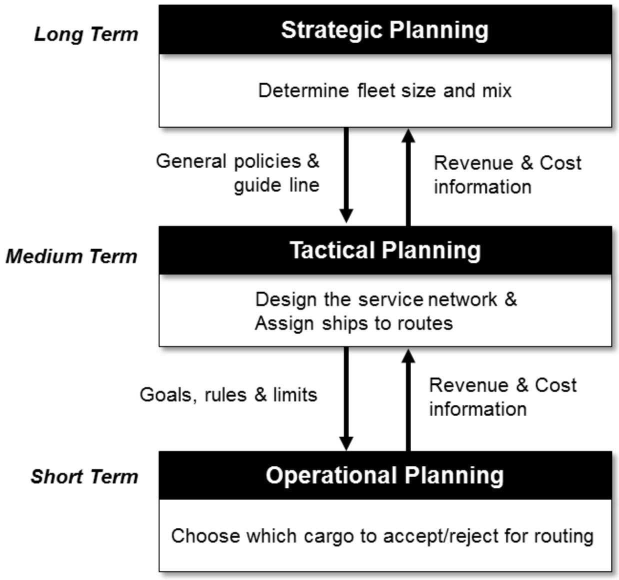


Figure 23 - Mechanism of transport planning

On the other hand, shipping lines have been conducting various strategies actively to achieve their strategic goals such as the increase of employed vessel size, control and management of transport capability, business integration, strategic alliance, acquisitions and joint venture. These strategies can be divided into two categories: the operational option and structure option (Lun and Browne, 2009). The operational option is one of the liner's strategic methods to improve their operational efficiency using their own resources and operating system, and its representative strategies are enlargement of vessel size, management of capability and strategic alliance. The structural option is the lines' strategy to expand their transport networks and business areas and to strengthen their competitiveness through co-operation with rivals, and its main strategies are strategic alliance, joint venture and business integration.

Shipping lines have been improving and/or changing their strategies continuously to cope with the changes of economic and market conditions (Porter, 1980; Utterback and Afuah, 1995; Brooks, 2000; Walker *et al*., 2003; Richards and Norman, 2005) based on their own strategic goals (Barney, 1991; Peteraf, 1993). Regarding this, Bergantino and Veenstra (2002) defined the main strategic goals of shipping lines. According to their definition, shipping lines build and/or improve their strategies based on the following strategic goals; a) the improvement of transport ability to provide better transport services and make them more attractive to shippers; b) the expansion of the services and network to more markets in an inexpensive way; c) the improvement of the operational efficiency and cost efficiency by increasing revenues and reducing costs; d) the decrease the financial risk by strategic investment planning; e) the increase of market share by stimulating growth in acquiring new cargo; f) the improvement of the service quality.

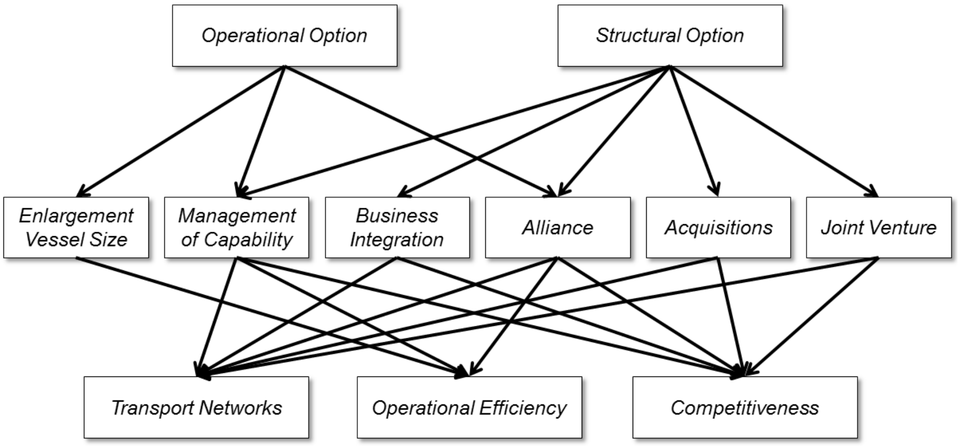


Figure 24 - Strategy of shipping lines

2.3.2. Voyage Speed and Strategic Planning

During the last five decades, shipping lines have been increasing their transport capacity actively following the rapid growth of transport demand. However, in the short and medium term, shipping lines have been controlling their transport capacity flexibly to achieve their strategic goals in line with changes in the economic environment and market conditions. Voyage speed is one of the key methods to manage the transport capacity and operational efficiency of shipping lines. This is because it has a fast and accurate ripple effect, while its financial burden is smaller than other methods such as the reduction of the loop and/or number of employed vessels, decrease in vessel size or changes of transport networks.

In this sense, during the last three decades, many studies have attempted to analyze the optimum voyage speed from economic and business viewpoints. Stopford (2009) explains that the liner shipping industry is concerned with speed, reliability and quality of service, and he emphasizes the function of voyage speed as a key indicator of liner shipping service. Moreover, he defines the optimum voyage speed as the voyage speed that maximizes the liner's operational profit, and explains the relationship between voyage speed and relevant operational conditions using following formula:

$$s = \sqrt{\frac{R}{3 \cdot p \cdot k \cdot d}}$$

where,

s: optimum voyage speed (mile/day) *R: freight rate*

p: price of fuel *k: ship's fuel constant*

d: voyage distance

According to his definition, the optimum voyage speed depends on the freight rate, the price of fuel, the efficiency of the ship and the length of the voyage. The optimum voyage speed is directly proportional to the freight rate. However, it is inversely proportional to the price of fuel, the ship's fuel constant and voyage distance. Therefore, the more the freight rate is increased the more optimal voyage speed is increased. However, the more the fuel price is increased and/or the more the voyage distance is increased the more optimal voyage speed is decreased.

On the other hand, Min (1973) defines the concept of optimal voyage speed as the voyage speed that maximizes the liner's profit and/or the return on investment in the voyage, and he suggests the concept of the optimal voyage speed using the following formula. According to his definition, the optimal voyage speed has a positive relationship with the value of cargo (freight rate), annual interest rate (financial costs) and voyage distance. However, it has a negative relationship with fuel consumption, annual operating time and load factor. Moreover, he argues that when some specific conditions are fulfilled on a voyage, shipping lines should accelerate the voyage speed to maximize their profit and/or to strengthen their competitiveness in the market such as; a) when the value of cargo is high; b) when the freight rate is high; c) when the fuel price is low; d) when the competition with rivals is intensified; e) when vessel size is big; and f) when transport demand is higher than transport supply (shortage of transport capacity).

$$V = \sqrt[4]{\frac{P \cdot R \cdot D}{3a \cdot ap \cdot l}}$$

where,

V: optimal voyage speed | *P: the value of cargo*
R: annual interest rate | *D: voyage distance*
a: technical instant (fuel consumption) | *ap: annual operating time (day)*
l: load factor

Numerous studies point out the relationship between voyage speed and freight rates (Magirou, 1992; Stopford, 2009; Robinson, 2005; Imai, 2006, Notteboom, 2008). According to this research, there is a close relationship between the voyage speed and the freight rate. If the freight rate is above equilibrium and if carriers anticipate an upward trend in the freight market, active supply will increase as a result of the following strategies: "a) postponement of periodic surveys and maintenance; b) maximization of the possible service speed at sea; c) acceleration of the processes of loading and unloading to reduce the berthing time; d) reduction in laid-up tonnage". By contrast, if the freight rate is below equilibrium and if carriers do not anticipate an improvement in the shipping market, active supply will decrease as a result of the following incidents: “a) decrease in the average speed of vessels at sea; b) carrying quantities of cargo that is less than the maximum cargo-carrying capacity of vessels; c) slow operations in loading and discharging; and d) laying up of the vessel”.

2.3.3. Voyage Optimization

Regarding fleet size and scheduling problems, Kydland (1969) analyzes optimal port rotation using a simulation model, and Datz (1969) designs a simulation model to build an optimum schedule for shipping lines depending on limited resources (fleet size and port capacity). Rana and Vickson (1988) build a model for the determination of fleet size and routing of vessels, and Jaramillo and Perakis (1991) analyzes the optimal fleet size using three main factors such as operating costs, voyage speed and frequency of departure. Fagerholt and Lindstad (2000) build an operation research (OR) model to analyze the optimal operating system based on the Europe-Asia service route.

Sambracos *et al.* (2004) builds a model and a solution that establishes optimal feet size and routing, and they suggested that using several transshipment centres was efficient to increase the operational efficiency of shipping lines. Melkote and Daskin (2000) design an integrated model of facility location and transportation network design, and Lun and Lai (2004) analyze the framework for the operation of liner shipping networks. Jayaraman and Srivastava (2000) analyze the combined location-routing problems in the liner shipping market. Aversa *et al.* (2005) focus on the mixed integer programming model of the location of a hub port. Shintani and Mai (2005) build a simulation model to solve the problems of container shipping network design with empty container repositioning.

Regarding the optimization of service and operating costs, Jansson and Shneerson (1987) propose an economic model to analyze shipping service decisions by minimizing total shipping and inventory costs, and Lane *et al.* (1987) analyzes the most cost effective size and mix of the fleet on one fixed route based on the

Australia-North America West Coast route. Perakis and Jaramillo (1991) design a linear programming model for a routing strategy to minimize total operating and lay-out cost over a planning time horizon. Moreover, Mourao *et al.* (2002) build a 'cost minimization based optimization model' that assigns ships to a hub-and-spoke network.

Fagerholt (1999) analyzes the problem of determining the optimal fleet and liner routes based on weekly service patterns. Bendall and Stent (2001) propose a determination model for the optimal fleet configuration while taking into account the fleet deployment plan applied in a hub and spoke container shipping network. Hsu and Hsieh (2007) build a two-objective model to determine the optimal liner routing, ship size, and sailing frequency by minimizing shipping costs and inventory costs. In recent times, Notteboom and Vernimmen (2008) build a cost model to analyze the impact of changes in bunker fuel costs on the operational cost, and Ronen (2010) analyzes the effect of oil price on voyage speed and vessel size based on a single vessel.

2.3.4. Environmental Issues

In recent years, there has been much discussion about the amount of greenhouse-gas emissions from vessels and all transportation modes. In 2000, the Organization for Economic Cooperation and Development (OECD) develops the emission factors of air pollution in representative transportation modes such as road, rail and ocean to estimate the amount of air pollution in each mode. As well, the Swedish Environmental Research Institute (2002) develops the emission factor and, recently, IMO (2009) and the Netherland Environmental Assessment Agency (NEAA) (2010) develop the emission factors (fuel-based exhaust gas emission factors) based on the accumulated related data and previous major analyses.

According to IMO (IMO, 2009), totally 3,260.88 kilograms of GHG emissions are emitted per ton of fuel in ocean transportation, and the proportion of carbon dioxide accounts for more than 96% of total GHG emissions. Moreover, many studies have estimated the amount of GHG emissions using published emission factors (Corbett, 2003; Endersen, 2003; Eyring *et al.*, 2005; Faber *et al*., 2010; Cariou, 2010; Norman *et al*., 2011). Denier and Hulskotte (2010) build the methodologies for estimating shipping emissions, and the Netherland Environmental Assessment Agency (NEAA) analyzes the impact of GHG emissions that occurred by shipping and port industries in Netherlands and North Europe (NEAA, 2010).

2.3.5. The Effects of Slow Steaming

In recent times, many studies have verified the effectiveness of slow steaming in liner shipping. Notteboom and Vernimmen (2008) build an operating cost decision model to analyze the impact the reduction of voyage speed on the fuel consumption, and they argue that there is a positive correlation between voyage speed and fuel consumption in liner shipping. The relationship between fuel prices and the operating costs was discussed by Cariou and Notteboom (2011), and Ronen (2011) analyzes the relationship between the oil prices, vessel size and voyage speed. Cariou and Cheaitou (2012) analyze the effect of slow steaming on the operating costs and the amount of GHG emissions, and they argue the sustainability of slow steaming from the economic and environmental viewpoints. Woo and Moon (2012) build a dynamic simulation model not only to investigate the relationship between voyage speed and three main factors such as the service organization, operating costs and GHG emissions with external cost on a loop but also to find the optimal voyage speed that can minimize the operating costs and the amount of GHG emissions. Eide *et al.* (2011) estimated the cost for the reduction of GHG emissions using scenarios in the shipping industry.

2.3.6. Simulation Model: System Dynamics

Recently, numerous scholars have been attempting to analyze the specific phenomenon in shipping, port and logistics industries using a simulation model, especially system dynamics (SD). During the last four decades, system dynamics was commonly used in scientific experiments, industrial, construction, medical, mechanical engineering and in some parts of business administration areas, so for studies related to port competition, within the shipping and logistics industries, using system dynamics is insufficient. However, recently, many scholars have started to build a simulation model using system dynamics to simulate the market structure and its process, and to forecast future changes in main container markets. Lee and Yeo (2001) create an algorism of the simulation model using system dynamics, and they analyzed the competitive structure and development strategies in Far East major container ports. Park and Jun (2004) build a simulation model to analyze an optimal transshipment port in the Far East region.

Oh *et al.* (2001) establish an algorism of the simulation model using system dynamics, and they analyzed the relationship between port and regional economy, and Yu (2004) build a simple model to simulate the changes in bulk shipping markets and address structural changes in the global network and transport system. Moreover, Oliva (2007) simulates the relationship between economic reforms and the competitive environment of firms using system dynamics, and he discussed the change of supply chain networks, including container ports. Laio (2004) analyzes the competitive structure in the airline industry, and Woo (2008) designs a simulation model, with a dynamic algorism, to analyze and to anticipate changes in the strategy of shipping lines using system dynamics on a Far East-European container market. Løfstedt *et al.* (2010) build a simulation model to simulate minimizing fuel cost and consumption in the specific network by varying the speed of services.

2.4. Definition of slow steaming effects and Liner's strategy

As discussed above, voyage speed plays an important role as a key factor for shipping lines when they build and/or improve their strategies. Recently, shipping lines have focused on the importance of voyage speed. This is because voyage speed influences not only the fleet mix and service schedule but also the amount of greenhouse-gas emissions that occur in the voyage. From functional perspectives, voyage speed effects the transit time and turnover ratio directly, and it leads to continuous changes in transport capability.

At the same time, shipping lines control their transport capability based on market conditions (balance of transport demand and supply) and their resources, *i.e.* fleet size, employed vessel size and operational system. As the voyage speed decreases, the transit time is increased, and the turnover ratio is decreased. Moreover, the required number of vessels in a loop is decided by the annual turnover ratio and employed vessel size. Continuously, the transport capacity has influenced directly by both factors of the annual turnover ratio and the required number of vessels as shown in Figure 25.

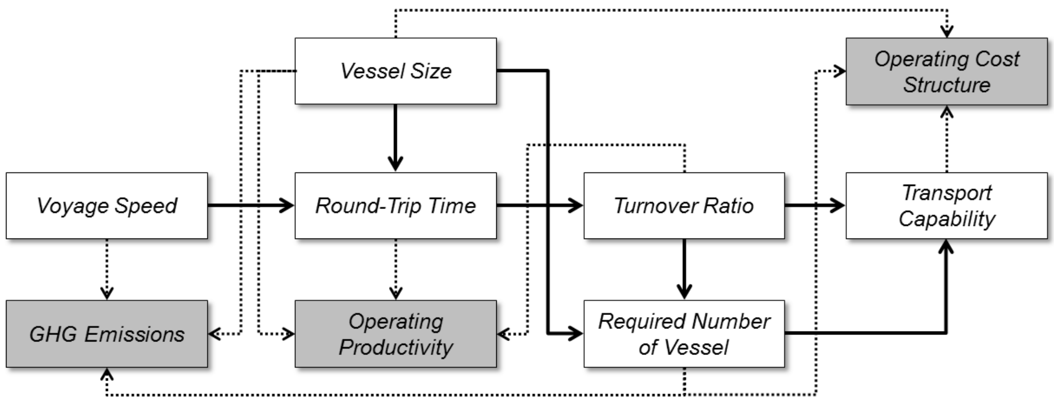


Figure 25 - The ripple effect of changes in voyage speed

Furthermore, these changes have influence on the liner's operating system and strategic goals. Firstly, the decrease in the turnover ratio brings down operational productivity and efficiency, and it leads to operational loss on a loop and route as well. This loss can be defined as the opportunity cost oriented by the operating costs. It is incurred by the abandonment of some parts of transport capability through the deceleration of voyage speed. However, at the same time, the deceleration of voyage speed is helpful to reduce the operating costs by the reduction of fuel consumption (Notteboom and Vernimmen, 2008). Therefore, the operating cost can be decided by the relationship between changes in opportunity cost and the changes in cost reduction, and it is changed at different voyage speeds.

Moreover, secondly, the deceleration of voyage speed is closely connected with the liner's environmental strategy. There is a close correlation between voyage speed and the amount of greenhouse-gas emissions that occur in the voyage. Moreover, vessel size has a direct influence on the amount of greenhouse-gas emissions. Therefore, shipping lines control and/or manage the amount of greenhouse-gas emissions through voyage speed and their fleet mix process. Hence, when shipping lines build and/or improve their strategy, they have to consider their optimum voyage speed to minimize their operating costs and to maximize their operational productivity and the reduction of greenhouse-gas emissions through the control and/or management of voyage speed and vessel size.

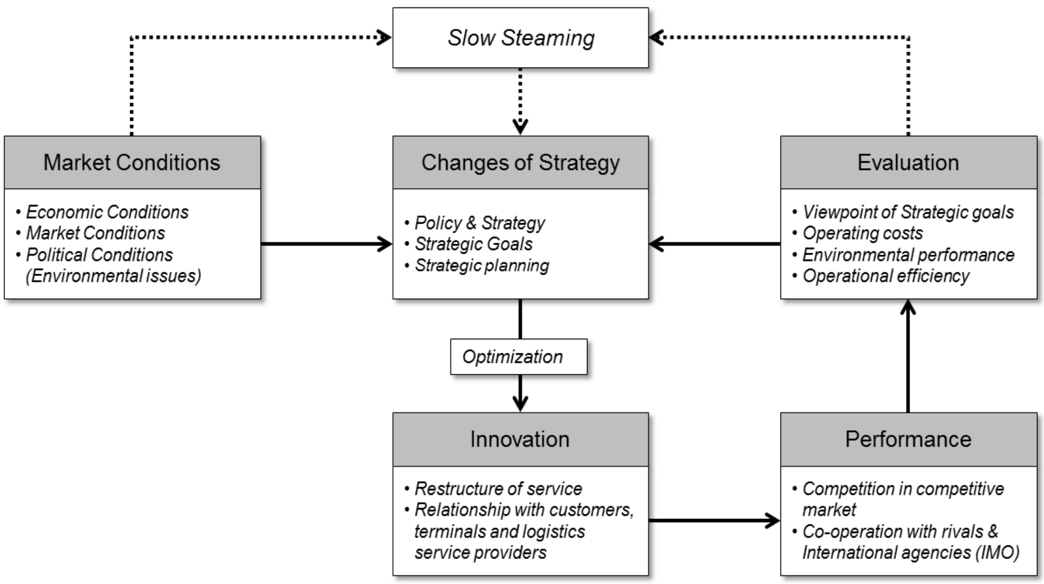


Figure 26 - Slow steaming and liner's strategic decision making process

In this sense, the liner's strategic decision-making process considering slow steaming is defined in Figure 26. In this diagram, shipping lines are improving their strategy and service continuously through the four levels: changes of strategy, innovation, performance and evaluation. In the first phase, shipping lines build their policy, strategy and strategic goals considering slow steaming based on market conditions, i.e. economic, market and political conditions. Especially, shipping lines analyze slow steaming effects and their optimal voyage speed, and they begin to decrease the voyage speed step by step based on their existing resources and resourcing plan.

In the second phase (level of innovation), they restructure and/or optimize the service to achieve their strategic goals based on their resources. Moreover, in the third phase (level of performance), they provide the transport service and come into competition with rivals to get the competitive advantage and to expand their market share based on the restructured resources, *i.e.* improved service schedule and fleet. In the fourth phase (level of evaluation), they evaluate their present strategy in the market based on the results of business performance in the viewpoint of their strategic goals. At the same time, they seek the way, *i.e.* optimal voyage speed, to improve their operational efficiency and environmental performance while maintaining their competitive advantage in the market. In fifth phase (level of changes of strategy), shipping lines modify and/or improve their strategy based on the results of evaluation again. In this sense, it is an important strategy to find their optimal voyage speed to improve their operational efficiency and environmental performance.

2.5. Chapter Conclusion

During the last couple of decades, shipping lines focused on the improvement of operational productivity to maximize the transport capability by minimized input assets using various operational strategies such as a route optimization, improvement of transport networks and enlargement of ship size. This strategy enabled to shipping lines not only to reduce the operating costs with financial risks but also to raise the quality of service. Moreover, it led to the improvement of liner service as more competitive transport mode, *i.e.* faster, organized and economic transport service, and this has contributed to growth of international trade and liner shipping industry.

However, in recent times, a strategic goal in terms of efficiency of ship operation has been changed in liner shipping. Under the intensive pressure of high fuel price and low freight rates, shipping lines focused on the efficient ship operation for minimizing the operating costs instead of improving of operational productivity to survive in uncertainty markets. Moreover, the better energy efficiency and effective emission control has been emphasized as one of the essential operational strategies in shipping industry. For these reasons, today, shipping lines adopted slow steaming as their main operational strategy in major routes.

In this chapter, the concept of slow steaming and the impacts of slow steaming on the operating costs and the amount of GHG emissions are defined. Slow steaming is helpful to reduce the operating costs and GHG emissions by the reduction of fuel consumption. However, it also creates negative effects such as an opportunity cost, additional fixed costs and in-transit inventory cost on a loop. Hence, the impacts of slow steaming are changed dynamically by the changes of voyage speed. These definitions in terms of the slow steaming effects are utilized as the basic concepts to design the models for the voyage optimization and speed optimization in chapter 3 and 4.

3. VOYAGE OPTIMIZATION

3.1. Introduction

Shipping lines provide their transport service based on an announced regular schedule with decided freight rates in major routes. They seek to make available just sufficient transport capacity on any route or at any port to cope with the variability of transport demand and maximize profits. Moreover, they normally change and/or improve their operating plans, *i.e.* calling port, fleet mix and size, every quarter and/or year to improve their operational efficiency and service quality.

During the last five decades of stable growth of transport demand, shipping lines have been focusing on voyage optimization, with fleet optimization, in order to reduce operating costs and improve operational efficiency to strengthen their competitiveness and survive in the competitive market. However, from 2009, due to the sudden decrease of transport demand, shipping lines began to utilize slow steaming to downsize their transport capacity and/or use their idle capacity. Moreover, from 2010, shipping lines started to adopt slow steaming as their major operational strategy. This is because slow steaming is useful to shipping lines in reducing operating costs and the amount of GHG emissions in the condition of high fuel prices, low freight rates and high uncertainty of the global economy.

Both strategies have the same objective of the reduction of the operating cost while the method of both strategies to achieve their goal is different. In the case of voyage optimization, it is an operational strategy to reduce operating costs by the improvement of operational efficiency, whereas slow steaming seeks a solution through the deliberate reduction of operational efficiency. For this reason, there is a trade-off between both strategies. Regarding this issue, the IMO suggested both strategies as the optimal solutions to improve the energy efficiency along with improvement of the standard of vessel design and relevant technologies (IMO, 2009). The improvement of energy efficiency has a positive influence on operating cost and the amount of GHG emissions. Hence, from the perspective of shipping lines, it is necessary to optimize the service loop through both strategies of voyage optimization and slow steaming.

In this sense, the aim of this chapter is to analyze the impact of voyage optimization and slow steaming on the operating costs on a loop. To achieve this analysis, firstly, an Integer Programming (IP) model was established to build an optimum route and estimate the impact of voyage optimization on the operating cost and the reduction of GHG emissions. Moreover, secondly, a simulation model was designed to optimize the fleet mix while considering the slow steaming effects and attempt to analyze the impact of fleet optimization and slow streaming on the operating cost and the amount of GHG emissions. Finally, this study analyzed the amount by which operating costs can be reduced by both strategies of voyage and fleet optimization and slow streaming on a loop.

3.2. Process of Route Optimization

Shipping lines normally design their new service loops and/or improve their existing service loops by following a process (Stopford, 2009) as shown in Figure 27. In the first phase in this process, a shipping line decides its service scope and route based on its policies and strategies. In phase 2 and 3, the shipping line selects its calling ports on the route, considering berth window scheduling, port productivity and cost. In phase 4 and 5, the routing and scheduling are decided with the fleet mixture and size, and the shipping line evaluates the established optimal service loop from the viewpoint of profitability, and they attempt to improve it based on their evaluation in the final phase.

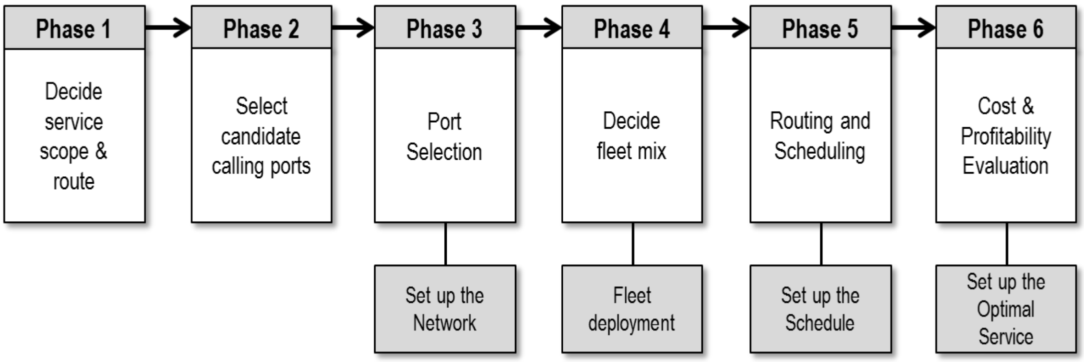


Figure 27 - Process to design a new service loop

Source: Stopford, M. (2009). *Maritime Economics: Third Edition*. London and New York.

This study set up a procedure to analyze the impact of voyage optimization and slow steaming on operating cost and the amount of GHG emissions as shown in Figure 28. In the first step, the service scope and target route are assumed, and in the second phase, this study selects calling ports and designs the network using an Integer Programming (IP) model. In step 3, the simulation model is designed by an IP model and System Dynamics to optimize the fleet deployment, considering slow steaming and weather condition from the viewpoint of the operating cost. Finally, this study evaluates the impact of both strategies on the operating cost and the amount of GHG emissions.

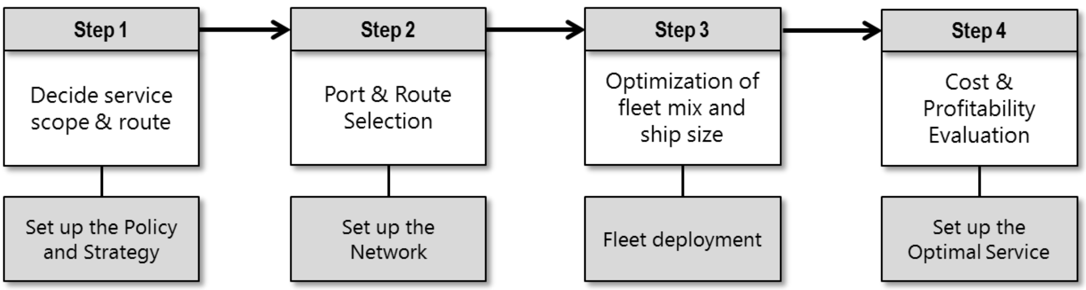


Figure 28 - Process to establish the optimal transportation model

3.3. Route Optimization: Port Selection and Routing

3.3.1. Service Scope and Route

This study assumes that the shipping line has a plan to design a new service loop in the Far East-North Europe route. It attempts to select the calling ports among nine candidate ports such as Shanghai, Ningbo, Yantian, Hong Kong, Kaohsiung, Tanjung Pelepas, Rotterdam and Bremerhaven based on their experiments, and attempts to design the optimal service loop that can minimize the voyage time, to minimize their operating cost and maximize their operational efficiency. Figure 29 slows the candidate calling ports and the voyage distance (miles) between each port in the west bound (W/B) service route. In this route, there are 20 combinations of possible routings to call when considering the departure point (Shanghai) and the destination point (Bremerhaven) as shown in Table 13.

Table 13 - Combinations of the possible routing to call in W/B service

Combination number	Sequence of calling (number of ports)						
	1	2	3	4	5	6	7
Route 1	*1*	*2*	*3*	*6*	*7*	*9*	
Route 2	*1*	*2*	*3*	*6*	*8*	*7*	*9*
Route 3	*1*	*2*	*3*	*6*	*7*	*8*	*9*
Route 4	*1*	*2*	*3*	*6*	*9*		
Route 5	*1*	*2*	*4*	*6*	*7*	*9*	
Route 6	*1*	*2*	*4*	*6*	*8*	*7*	*9*
Route 7	*1*	*2*	*4*	*6*	*7*	*8*	*9*
Route 8	*1*	*2*	*4*	*6*	*9*		
Route 9	*1*	*2*	*5*	*6*	*7*	*9*	
Route 10	*1*	*2*	*5*	*6*	*8*	*7*	*9*
Route 11	*1*	*2*	*5*	*6*	*7*	*8*	*9*
Route 12	*1*	*2*	*5*	*6*	*9*		
Route 13	*1*	*3*	*6*	*7*	*9*		
Route 14	*1*	*3*	*6*	*8*	*7*	*9*	
Route 15	*1*	*3*	*6*	*7*	*8*	*9*	
Route 16	*1*	*3*	*6*	*9*			
Route 17	*1*	*4*	*6*	*7*	*9*		
Route 18	*1*	*4*	*6*	*8*	*7*	*9*	
Route 19	*1*	*4*	*6*	*7*	*8*	*9*	
Route 20	*1*	*4*	*6*	*9*			

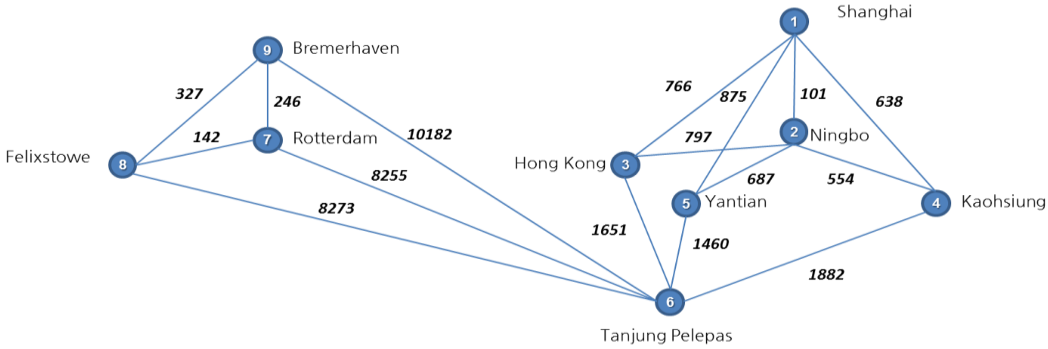


Figure 29 - Candidate calling ports in W/B service in Asia-Europe route

On the other hand, Figure 30 shows the candidate calling ports in the east bound (E/B) service route. In this route, there are 12 combinations of the possible routings with considering the order of call among target ports when considering the departure point (port of Bremerhaven) and the destination point (port of Shanghai) as shown in Table 14.

Table 14 - Combinations of the possible sequence of calling in E/B service

Combination number	Sequence of calling (number of ports)					
	1	2	3	4	5	6
Route 1	*1*	*2*	*3*	*4*	*8*	
Route 2	*1*	*2*	*3*	*4*	*7*	*8*
Route 3	*1*	*2*	*3*	*5*	*8*	
Route 4	*1*	*2*	*3*	*5*	*7*	*8*
Route 5	*1*	*2*	*3*	*6*	*8*	
Route 6	*1*	*2*	*3*	*6*	*7*	*8*
Route 7	*1*	*3*	*4*	*8*		
Route 8	*1*	*3*	*4*	*7*	*8*	
Route 9	*1*	*3*	*5*	*8*		
Route 10	*1*	*3*	*5*	*7*	*8*	
Route 11	*1*	*3*	*6*	*8*		
Route 12	*1*	*3*	*6*	*7*	*8*	

3.3.2. Model and Result

An Integer Programming (IP) model is built to design the optimum service loop and select calling ports. Firstly, the optimization model for the west bound service route is given as;

$$\begin{aligned} \text{Minimize } Z = {} & 101x_{12} + 766x_{13} + 638x_{14} + 875x_{15} + 797x_{23} + 554x_{24} + 687x_{25} + 1651x_{36} \\ & + 1882x_{46} + 1460x_{56} + 8255x_{67} + 8273x_{68} + 10182x_{69} + 142x_{78} + 246x_{79} \\ & + 246x_{87} + 327x_{89} + 246x_{97} \end{aligned}$$

subject to

$$\begin{aligned} & x_{12} + x_{13} + x_{14} = 1 \\ & x_{12} - x_{23} - x_{25} = 0 \\ & x_{13} - x_{36} = 0 \\ & x_{14} - x_{46} = 0 \\ & x_{12} + x_{15} - x_{56} = 0 \\ & x_{36} + x_{56} + x_{46} - x_{67} - x_{69} - x_{68} = 0 \\ & x_{67} - x_{79} - x_{78} = 0 \\ & x_{68} + x_{78} - x_{89} = 0 \\ & x_{69} + x_{79} = 1 \\ & x_{ij} = 0 \text{ or } 1 \end{aligned}$$

According to the result of optimization, the calling ports on the west-bound service route are selected to six ports as the target calling ports: Shanghai, Ningbo, Yantian, Tanjung Pelepas, Rotterdam and Bremerhaven, and the optimum route is designed as 'Shanghai - Ningbo - Yantian - Tanjung Pelepas - Rotterdam -Bremerhaven' as shown in Table 15 and Figure 30. Total voyage distance of this route is 10,378.8 miles, and total voyage time at sea is 415.1 hours (17.3 days).

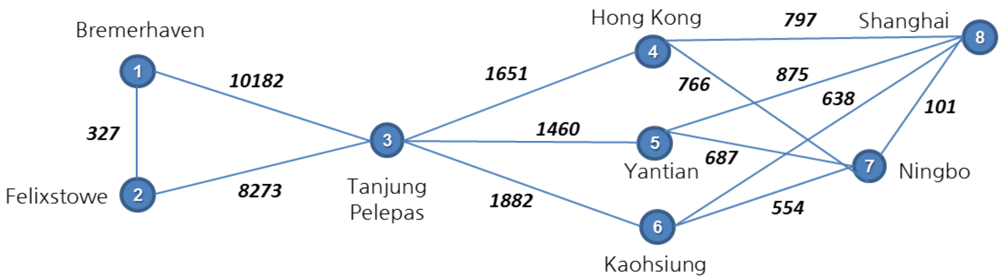


Figure 30 - Candidate calling ports in E/B service in Asia-Europe route

On the contrary, 'Shanghai - Kaohsiung - Tanjung Pelepas - Rotterdam - Felixstowe - Bremerhaven route' is selected as the most inefficient route. Its total voyage distance is 11,244 miles, and total voyage time at sea is 449.76 hours (18.74 days).

Table 15 - Result of route optimization (W/B service)

Select Voyage	*Node*	*Port i*	*Node*	*Port i+1*	*Voyage Distance (miles)*
1	*1*	*Shanghai*	*2*	*Ningbo*	*101.00*
0	*1*	*Shanghai*	*3*	*Hong Kong*	*766.12*
0	*1*	*Shanghai*	*4*	*Kaohsiung*	*626.59*
0	*1*	*Shanghai*	*5*	*Yantian*	*934.70*
0	*3*	*Hong Kong*	*6*	*Tanjung Pelepas*	*1,650.46*
0	*4*	*Kaohsiung*	*6*	*Tanjung Pelepas*	*1,863.35*
0	*2*	*Ningbo*	*3*	*Hong Kong*	*794.68*
1	*2*	*Ningbo*	*5*	*Yantian*	*761.44*
0	*2*	*Ningbo*	*4*	*Kaohsiung*	*549.17*
1	*5*	*Yantian*	*6*	*Tanjung Pelepas*	*1,474.43*
1	*6*	*Tanjung Pelepas*	*7*	*Rotterdam*	*7,715.53*
0	*6*	*Tanjung Pelepas*	*9*	*Bremerhaven*	*9,483.44*
0	*6*	*Tanjung Pelepas*	*8*	*Felixstowe*	*7,718.51*
1	*7*	*Rotterdam*	*9*	*Bremerhaven*	*326.43*
0	*7*	*Rotterdam*	*8*	*Felixstowe*	*224.98*
0	*8*	*Felixstowe*	*9*	*Bremerhaven*	*401.08*
0	*8*	*Felixstowe*	*7*	*Rotterdam*	*238.59*
0	*9*	*Bremerhaven*	*7*	*Rotterdam*	*334.44*
0	*9*	*Bremerhaven*	*8*	*Felixstowe*	*327*
				Total	*10378.8*

On the other hand, an IP model for the east bound service route is designed as shown in the following;

$$Minimize\ Z = 327x_{12} + 10182x_{13} + 8273x_{23} + 1651x_{34} + 1460x_{35} + 1882x_{36} + 797x_{48} + 766x_{47} + 687x_{57} + 875x_{58} + 554x_{67} + 638x_{68} + 101x_{78}$$

subject to

$$x_{12} = 1$$

$x_{12} - x_{23} = 0$

$x_{13} + x_{23} + x_{34} - x_{35} - x_{36} = 0$

$x_{34} - x_{48} - x_{47} = 0$

$x_{35} - x_{57} - x_{58} = 0$

$x_{36} - x_{67} - x_{68} = 0$

$x_{47} + x_{57} + x_{67} - x_{78} = 0$

$x_{48} + x_{58} + x_{57} + x_{78} = 1$

$x_{ij} = 0 \text{ or } 1$

Table 16 - Result of route optimization (E/B service)

Select Voyage	*Node*	*Port i*	*Node*	*Port i+1*	*Voyage Distance(miles)*
1	*1*	*Bremerhaven*	*2*	*Felixstowe*	*327*
0	*1*	*Bremerhaven*	*3*	*Tanjung Pelepas*	*10,182*
1	*2*	*Felixstowe*	*3*	*Tanjung Pelepas*	*8,273*
0	*3*	*Tanjung Pelepas*	*4*	*Hong Kong*	*1,651*
1	*3*	*Tanjung Pelepas*	*5*	*Yantian*	*1,460*
0	*3*	*Tanjung Pelepas*	*6*	*Kaohsiung*	*1,882*
0	*4*	*Hong Kong*	*8*	*Shanghai*	*797*
0	*4*	*Hong Kong*	*7*	*Ningbo*	*766*
0	*5*	*Yantian*	*8*	*Shanghai*	*875*
1	*5*	*Yantian*	*7*	*Ningbo*	*687*
0	*6*	*Kaohsiung*	*8*	*Shanghai*	*638*
0	*6*	*Kaohsiung*	*7*	*Ningbo*	*554*
1	*7*	*Ningbo*	*8*	*Shanghai*	*101*
				Total	*10,848*

According to the result, the calling ports on the east-bound service route are selected as the following six ports: Shanghai, Ningbo, Yantian, Tanjung Pelepas, Bremerhaven and Felixstowe, and the optimum route is designed as 'Bremerhaven-Felixstowe-Tanjung Pelepas-Yantian-Ningbo-Shanghai route' as shown in Table 16. Total voyage distance of this route is 10,848 miles, and total voyage time at sea is 433.9 hours (18.1 days). On the contrary, the 'Bremerhaven - Felixstowe - Tanjung Pelepas - Yantian - Ningbo - Shanghai route' is selected as the most inefficient route.

Its total voyage distance is 11,137 miles, and total voyage time at sea is 445.5 hours (18.6 days).

On the other hand, according to the result of both optimization processes, the optimum route on the Far East-North Europe route is decided as shown in Figure 31. Seven ports are decided as the calling ports in this route, and the rotation plan is designed as 'Shanghai-Ningbo-Yantian-Tanjung-Pelepas-Rotterdam-Bremerhaven-Felixstowe-Tanjung Pelepas-Yantian-Ningbo-Shanghai'. The total voyage distance in this route is 21,597 miles and total voyage time is 863.9 hours as shown in Table 17. In the case of the worst service route, its total voyage distance is 22,381 miles, so the shipping line reduces its voyage distance by 784 miles (31.36 hours) through the route optimization in this market.

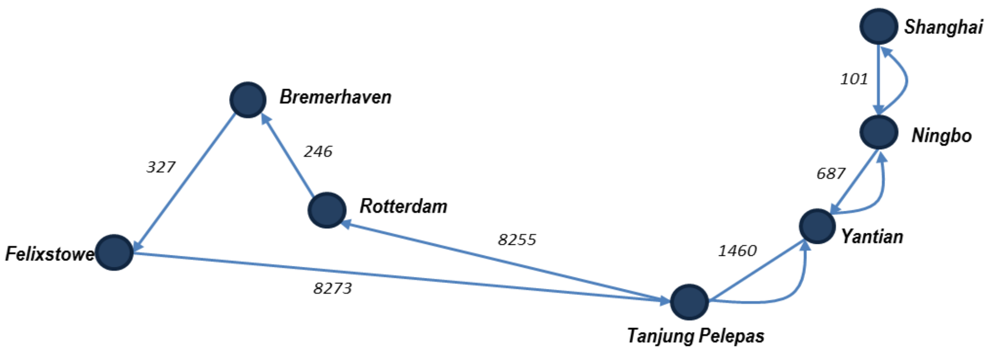


Figure 31 - Selected optimum service route

Table 17 - Comparison between the optimum route and the worst route

Classification	West-Bound		East-Bound		Total	
	Voyage distance (miles)	Voyage time at sea (hours)	Voyage distance (miles)	Voyage time at sea (hours)	Voyage distance (miles)	Voyage time at sea (hours)
Optimum route	10,749.00	430.00	10,848.00	433.90	21,597.00	863.90
Average routes *	10,996.50	439.90	10,992.50	439.70	21,989.00	879.55
The worst route	11,244.00	449.80	11,137.00	445.50	22,381.00	895.20

**The average of both routes; the optimum route and the worst route*

3.3.3. Economic Benefits of the Route Optimization

In this part, a cost analysis is conducted to evaluate the economic benefit of three cases of route; optimum route, the worst route and average of both routes. To achieve the goal, a transport operating cost model is established to estimate the operating cost on three routes as follows.

$$TOC_{knr} = \sum_{krn} \left((FC_{knr} + FU_{knr} + CP_{knr}) \cdot Nov_{knr} \right)$$

with

$$FC_{knr} = DOC_k \cdot Nv_{kr}$$

$$FU_{knr} = SFOC_k \cdot EP_k \cdot (V_3/V_1)^3 \cdot 24/10^3 \cdot FU_{price} \cdot T_{knr} \cdot Nv_{kr}$$

$$CP_{knr} = DO_k \cdot VTport_r \cdot NCport_r + HA_r \cdot 2DR_{knr} + 2CT_k$$

where,

k: the type of ship

n: the number of ship route r

r: the target route r

FC_{knr}: *the fixed costs of number of k class ship n on route r*

FU_{knr}: *the fuel cost of number of k class ship n on route r*

CP_{knr}: *the costs at port of number of k class ship n on route r*

Nov_{knr}: *the turnover ratio of number of k class ship n on route r*

T_{knr}: *the total voyage time of number of k class ship n on route r*

DOC_k: *the daily running cost of k class ship on route r*

$VTsea_{knr}$: *the voyage time at sea of number of k class ship n on route r*

$VTport_{knr}$: *the port time of number of k class ship n on route r*

Nv_{knr}: *the number of type k ships allocated to route r*

$ATport_{knr}$: *the average port time of number of k class ship n on route r*

$NCport_{knr}$: *the number of calling ports of number of k class ship n on route r*

$SFOC_{knr}$: *the specific fuel oil consumption of k class ship n on route r*

EP_k: *the engine power of a type k ship*

Nov_{knr}: *the turnover ratio (frequency) of number of k class ship n on route r*

FU_{price}: *the fuel price per ton*

DO_k: *the dockage cost at port on route r*

HA_r: the handling cost at port on route r

CT_k: the canal transit charges on route r

DR_{knr}: transport volume on route r

In the first phase, the basic service loop is designed based on the selected routes, *i.e.* voyage distance and selected calling ports with some assumptions to estimate the operating cost of each route. This analysis assumes that the shipping line has a plan to employ 8 vessels (8,000TEU class vessels) on a loop, and maintain the frequency on the level of 6.5 per year. Moreover, average port time in selected calling ports is 42 hours (1.75 days) when considering the target volume of line.

Table 18 - Comparison of basic service pattern among three cases

Classification		Unit	Optimum route	The worst route	Average routes
Basic service pattern	Voyage distance	Miles	21,597	22,381	21,989
	Average vessel size	TEU	8,000	8,000	8,000
	Number of vessel	Number	8.00	8.00	8.00
	Round trip (frequency)	Number	6.50	6.50	6.50
	Total voyage time	days	56.15	56.15	56.15
	Voyage time at sea	days	38.65	38.65	38.65
	Voyage time in port	days	17.50	17.50	17.50
	Voyage speed	Knots	23.28	24.13	23.70
	design transport capacity	TEU	416,000	416,000	416,000
Basic condition (assumption)	Number of calling port	Number	10.00	10.00	10.00
	Average port time	Hours	42.00	42.00	42.00
	Total port time	Hours	420.00	420.00	420.00
	Fuel price	US$/ton	650.00	650.00	650.00
	Value of CO2	US$/ton	20.00	20.00	20.00
	Transport demand	TEU	353,600	353,600	353,600

Total voyage time per voyage (T) is a sum of both voyage times: the voyage time at sea ($VTsea$) and the voyage time at port ($VTport$): $T = VTsea + VTport$, and it can be calculated also by the formula; $T = (365 \cdot Nv)/52$. Hence, total voyage time per voyage is 56.15 days ((365·8)/52=56.15), and total voyage time at sea can be decided as 38.65 days (56.15-17.5=38.65 days) when the port time per voyage is fixed (42·10=420 hours=17.5 days) by assumption. Voyage speed can be calculated by the formula; $V = Vdis_r/(365/VTsea_{knr})/24$, when $Vdis_r$ is the voyage distance as shown in Table 18. The decided service pattern and some assumptions adopted by this model are as shown in Table 18.

- Voyage speed at optimum route: 21,597/38.56 /24 = 23.28 knots
- Voyage speed at the worst route: 22,381/38.56/24 = 24.13 knots
- Voyage speed at average route: 21,989/38.56/24 = 23.70 knots

Table 19 - Annual transport demand on a loop and O/D table

Unit: TEU

	Shang hai	Ningbo	Yan tian	Tanjung Pelepas	Rotter dam	Felix stowe	Bremer haven	Sum
Shanghai	-	-	13,030	16,251	19,839	20,634	20,107	89,862
Ningbo	-	-	13,344	11,579	19,069	13,116	18,261	75,369
Yantian	6,568	-	-	8,663	19,246	16,710	16,955	68,142
Tanjung Pelepas	5,227	6,775	5,101	-	14,756	12,563	12,917	57,340
Rotterdam	5,174	5,112	5,334	5,826	-	-	314	21,760
Felixstowe	4,578	5,080	5,008	5,032	-	-	-	19,698
Bremerhaven	5,556	4,395	6,254	5,224	-	-	-	21,430
Sum	27,103	21,363	48,071	52,575	72,910	63,024	68,554	353,600

Source: Estimated data based on the Drewry research: Drewry (2010). *Container Market; Annual Review and Forecast 2011*. Drewry Shipping Consultants Ltd.

This model assumes that the annual transport demand of a loop is 353,600 TEU (85% of transport capacity), and the Origin/Destination flow, *i.e.* O/D table, is estimated based on the Drewry data (Drewry, 2010) as shown in Table 19. On the other hand, the port costs consist of three costs such as the dockage cost, canal transit charges and the handling cost, and can be calculated by basic tariffs in the selected route and ports.

- Dockage cost=20US$ per meter hours
- Canal transit charges=2US$ per registered TEU
- Handling cost=45US$/TEU

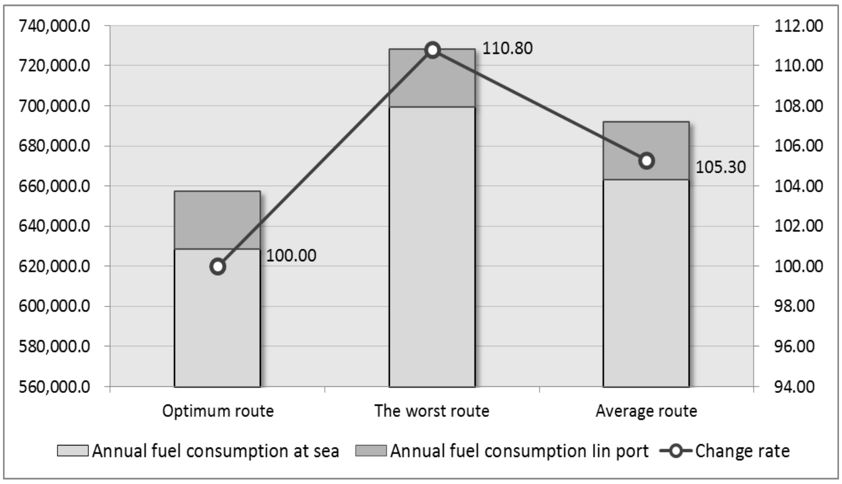


Figure 32 - Annual fuel consumption on three routes

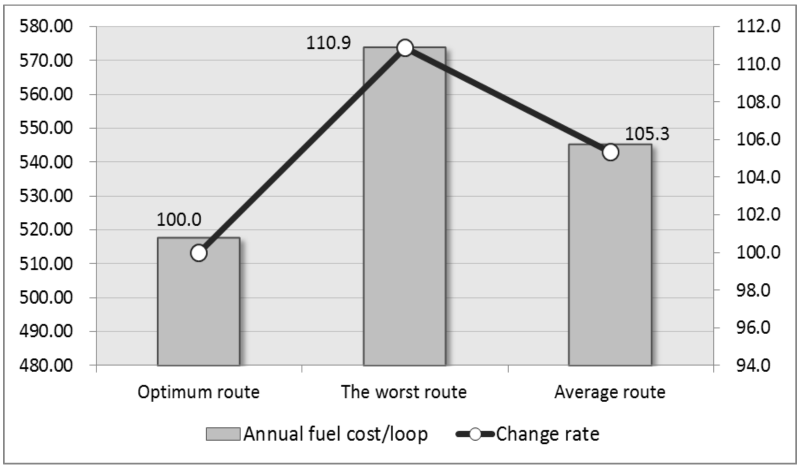


Figure 33 - Annual fuel cost on three routes

According to the result of analysis, annual fuel consumption is reduced by 10.8% and 5.3% on the optimum route in comparison with the worst route and the average route as shown in Figure 32. The estimated amount of annual fuel consumption on the optimum route is 517.72 million tons, and it is 56.27 million tones lower than the worst route (574 million tons). Moreover, annual fuel cost on the optimum route is decreased by 10.9% and 5.3% in comparison with the worst route and the average route as shown in Figure 33.

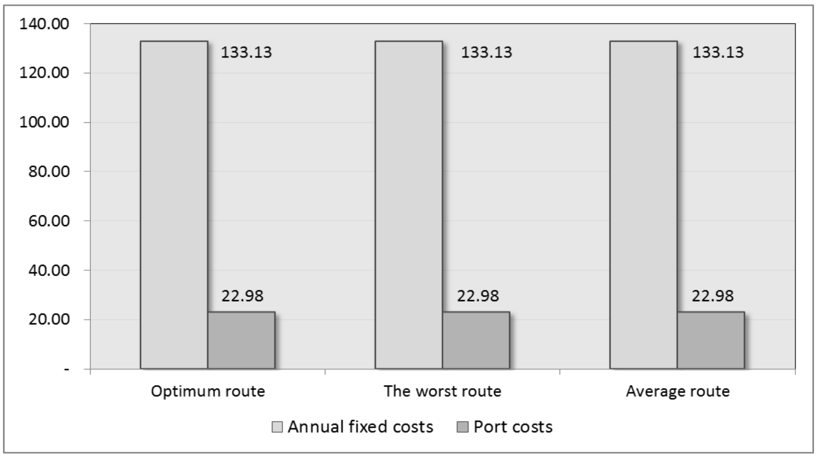


Figure 34 - Annual fixed costs and port costs on three routes

In this sense, we can conclude that voyage optimization has a positive influence on fuel consumption and fuel cost. In this analysis, 10.8% of annual fuel cost can be reduced by just voyage optimization. However, annual fixed costs and port costs are not changed in all routes as shown in Figure 34. This is because the three routes are operated by the same number of vessels (same class), and transport the same transport volume.

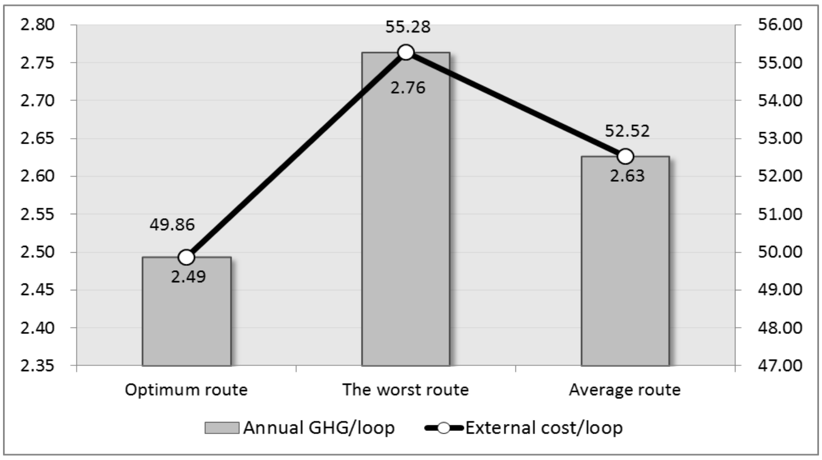


Figure 35 - Annual amount of GHG emissions on three routes

On the other hand, voyage optimization has an influence on the reduction of GHG emissions on a loop as shown in Figure 35. According to the result of analysis, shipping lines can reduce annual GHG emissions by 10.9%, *i.e.* from 55.28 to 49.86 million tons, by voyage optimization. Moreover, they can eliminate 0.27 million US$ of external cost (from 2.76 to 2.49 million US$) by the reduction of the amount of GHG emissions on a loop.

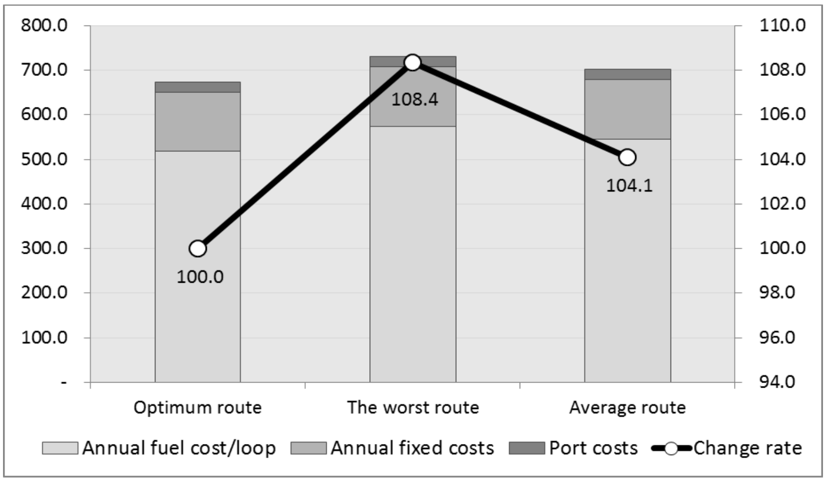


Figure 36 - Annual total operating cost on three routes

Finally, annual operating costs of three routes are derived as shown in Figure 36. In this diagram, annual operating cost of the optimum route is reduced by 8.4% and 4.1% in comparison with the worst route and the average route. The main reason for this result is the reduction of fuel cost by the minimization of voyage distance. Moreover, it leads also to the reduction of the amount of GHG emissions and the externality on a loop.

3.4. Fleets optimization

3.4.1. Objective of Model

A cost evaluation model was designed to optimize the fleet deployment on a loop, with considering slow steaming, and analyze the impacts of the fleet optimization on operating costs on a loop. The fleet deployment plan is closely connected with slow steaming. An increase in the number of employed vessels leads to an increase of frequency (annual turnover ratio) and voyage time at sea, and it influences the voyage speed and operating costs again. The aim of a cost evaluation model is to minimize the operating costs in a selected service route that decided by previous analysis (route optimization). The objective of this model is given as;

Minimize $\sum_{krn}\big((FC_{knr} + FU_{knr} + CP_{knr} + EX_{knr} + OP_{knr} + TI_{knr}) \cdot Nov_{knr}\big)$

with

$FC_{knr} = DOC_k \cdot Nv_{kr}$

$FU_{knr} = SFOC_k \cdot EP_k \cdot (V_3/V_1)^3 \cdot 24/10^3 \cdot FU_{price} \cdot T_{knr} \cdot Nv_{kr}$

$CP_{knr} = DO_k \cdot VTport_r \cdot NCport_r + HA_r \cdot 2DR_{knr} + 2CT_k$

$EX_{knr} = [(SFOC_k \cdot EP_k \cdot VAL_{GHG} \cdot (V_{3\,knr}/V_{1\,knr})^3 \cdot 24/10^3)/10^3] \cdot T_{knr} \cdot Nv_{kr}$

$OP_{knr} = \Delta Nov_{knr} \cdot \Delta Tran_{knr} \cdot DOC_k$

$TI_{knr} = Q_r \cdot (\Delta Trans_{knr}/365) \cdot (D_r/Q_r) \cdot Vg_r \cdot Iit_r$

where

k: the type of ship

n: the number of ship route r

r: the target route r

FC_{knr}: the fixed costs of number of k class ship n on route r

FU_{knr}: the fuel cost of number of k class ship n on route r

CP_{knr}: the costs at port of number of k class ship n on route r

EX_{knr}: the external cost of number of k class ship n on route r

OP_{knr}: the opportunity cost of number of k class ship n on route r

TI_{knr}: the increased in-transit inventory cost of number of k class ship n on route r

Nov_{knr}: the turnover ratio of number of k class ship n on route r

T_{knr}: the total voyage time of number of k class ship n on route r

DOC_k: the daily running cost of k class ship on route r

$VTsea_{knr}$: the voyage time at sea of number of k class ship n on route r

$VTport_{knr}$: the port time of number of k class ship n on route r

Nv_{knr}: the number of type k ships allocated to route r

$ATport_{knr}$: the average port time of number of k class ship n on route r

$NCport_{knr}$: the number of calling ports of number of k class ship n on route r

$Vdis_r$: the voyage distance on route r

V_{1knr}: the designed voyage speed of number of k class ship n on route r

V_{2knr}: the changed voyage speed of number of k class ship n on route r

V_{3knr}: the voyage speed in specific weather condition of number of k class ship n on route r

ΔV: the speed difference on route r

Nr: the number of type k ships available

Mr: the number of voyages required per year on route r

$AFCV_{knr}$: the annual fuel consumption of number of k class ship n on route r

$AFCL_{knr}$: the annual fuel consumption of number of k class ship n on route r

$SFOCv_{knr}$: the specific fuel oil consumption of number of k class ship n on route r

EP_k: the engine power of a type k ship

Nov_{knr}: the turnover ratio (frequency) of number of k class ship n on route r

$AGHG_{knr}$: the annual amount of GHG emissions of number of k class ship n on route r

EF_a: the emission factor of emission a

FU_{price}: the fuel price per ton

Qr: the transport volume (units in in-transit inventory) in each shipment on route r

Dr: the transport volume on route r

$\Delta Tran_{knr}$: the changed transit time on number of k class ship n on route r

Vgr: the average value of goods per TEU, given number

Iitr: the ratio of in-transit inventory cost to total value of goods per TEU, given number

DO_k: the dockage cost at port on route r

HA_r: the handling cost at port on route r

CT_k: the canal transit charges on route r

This model has some constraints as follows. Firstly, the maximum number of ships of type *k* employed in this loop cannot be larger than the maximum number of ships of type *k* available. This model assumed that shipping line can employ maximum 15 vessels on a loop. This constraint can be expressed by following formula.

$\sum_{r=1}^{R} Nv_{knr} < N_k^{max}$

where

N_k^{max}: *the maximum available number of ships of type k employed (15 vessels)*

Secondly, voyage speed cannot be faster than designed voyage speed (25 knots) on a loop. Voyage speed is decided by both factors of port time and number of vessels on a loop as defined in formula 4. Therefore, the shipping line has to design its fleet mix considering both factors. So,

$$V_{1knr} = Vdis_r/[(365/(52/Nv_{knr})) - VTport_{knr}]/24 > V_{2knr}$$

where

V_{1knr}: *the designed voyage speed of number of k class ship n on route r*
V_{2knr}: *the changed voyage speed of number of k class ship n on route r*
$Vdis_r$: *the voyage distance on route r*
$VTport_{knr}$: *the port time of number of k class ship n on route r*
Nv_{knr}: *the number of type k ships allocated to route r*

Thirdly, the annual turnover ratio, *i.e.* annual number of voyages, on a loop cannot be smaller than the minimum required annual turnover ratio on route *r*. So,

$$Nov_{knr} = \frac{Tk_{knr}}{T_{knr}} > Nov_p$$

where

Nov_{knr}: *the turnover ratio (frequency) of number of k class ship n on route r*
Nov_p: *the minimum required annual turnover ratio on route r*
T_{knr}: *the total voyage time (day) of number of k class ship n on route r*
Tk_{knr}: *the number of days that can provide line service on route r*

Finally, all factors that consist of the operating cost must be non-negative. Therefore,

$$FC_{knr} > 0$$

$FU_{knr} > 0$
$CP_{knr} > 0$
$EX_{knr} > 0$
$OP_{knr} > 0$
$TI_{knr} > 0$

where

FC_{knr}: *the fixed costs of number of k class ship n on route r*

FU_{knr}: *the fuel cost of number of k class ship n on route r*

CP_{knr}: *the costs at port of number of k class ship n on route r*

EX_{knr}: *the external cost of number of k class ship n on route r*

OP_{knr}: *the opportunity cost of number of k class ship n on route r*

TI_{knr}: *the increased in-transit inventory cost of number of k class ship n on route r*

3.4.2. Fleets Organization

This model assumes that the annual transport demand of a loop is 353,600 TEU, and the Origin/Destination flow (O/D table), is estimated based on the Drewry data (Drewry, 2010) as shown in Table 20. Moreover, the port throughputs per voyage and port time in each port are derived by considering the berth productivity of each port as shown in Table 21. The port time on a loop consists of both berth time for handling cargo and the in-out time for enter and departure procedures. Total port time per voyage is estimated at 434 hours (18.09 days), and the average port time in each port is 43.41 hours (1.81 days).

Table 20 - Annual transport demand on a loop and O/D table

Unit: TEU

	Shang hai	Ningbo	Yantian	Tanjung Pelepas	Rotter dam	Felix stowe	Bremer haven	Sum
Shanghai	-	-	13,030	16,251	19,839	20,634	20,107	89,862
Ningbo	-	-	13,344	11,579	19,069	13,116	18,261	75,369
Yantian	6,568	-	-	8,663	19,246	16,710	16,955	68,142
Tanjung Pelepas	5,227	6,775	5,101	-	14,756	12,563	12,917	57,340
Rotterdam	5,174	5,112	5,334	5,826	-	-	314	21,760
Felixstowe	4,578	5,080	5,008	5,032	-	-	-	19,698
Bremerhaven	5,556	4,395	6,254	5,224	-	-	-	21,430
Sum	27,103	21,363	48,071	52,575	72,910	63,024	68,554	353,600

Source: Estimated data based on the Drewry research: Drewry (2010). *Container Market: Annual Review and Forecast 2011*. Drewry Shipping Consultants Ltd.

Table 21 - Port throughput, berth productivity and port time in each port

	Throughput* (TEU)	Throughput /voyage (TEU)	Berth productivity * (TEU/hr)	Berth time (hours)	In-Out time** (hours)	Port time (hours)
Shanghai	116,965	17,995	300	60	3	63
Ningbo 1	75,369	11,595	240	48	3	51
Yantian 1	87,948	13,530	240	56	3	59
Tanjung Pelepas 1	76,730	11,805	240	49	3	52
Rotterdam	94,670	14,565	300	49	3	52
Felixstowe	82,723	12,727	300	42	3	45
Bremerhaven	89,983	13,844	300	46	3	49
Tanjung Pelepas 2	33,184	5,105	240	21	3	24
Yantian 2	28,265	4,348	240	18	3	21
Ningbo 2	21,363	3,287	240	14	3	17
Sum	707,200	108,800		404	30	434

**Calculated data from annual transport demand.*

***From OSC data: OSC. (2010). Container Terminal Management; a post crisis perspective 2010. Ocean Shipping Consultants Ltd.*

On the other hand, the characteristics of each type of container vessel are considered in this model, and are shown in Table 22. This table shows the variable information such as average vessel size, engine size and the specific fuel oil consumption (*SFOC*) for each class of container vessel.

Table 22 - Characteristics of container vessels

Containership Size Class			6,000	8,000	10,000	12,000	14,000
LOA		M	304	323	364	393	408
LBP		M	292	308	350	380	394
Breadth		M	40	43	47	52	57
Depth		M	24	25	30	32	33
Design Deadweight		Ton	61,700	82,200	114,900	140,600	165,800
Design Draft		M	12	13	15	16	16
Keel to Top of Antenna		M	62	63		76	
Designed voyage speed		Knots	25	25	25	25	25
Main Engine Size		kW	57,100	68,500	74,000	82,100	89,700
Total Installed Aux. Power		kW	12,900	12,000	12,000	14,000	16,000
SFOC	at sea	g/kW h	246	286	307	342	375
	in port	g/kW h	26	24	24	28	32

Source: Herbert Engineering Corp.

Table 23 - Fixed and variable costs in different types of vessel

Unit: Million US$

Type of Containership	6,000	8,000	10,000	12,000	14,000
Annual ship running cost	9.61	10.80	11.99	13.17	14.36
Administration fee & container costs	3.28	3.68	4.09	4.49	4.89
Maintaining costs	3.93	4.42	4.90	5.39	5.87
Employ cost	2.62	2.95	3.27	3.59	3.92
Insurance cost	2.40	2.70	3.00	3.29	3.59
Sum	21.85	24.55	27.24	29.94	32.63
Daily cost	0.06	0.07	0.07	0.08	0.09

Source: Samsung Heavy Industry data

Moreover, this model adapts annual fixed costs with its detailed contents in each type of container vessel. Annual fixed costs consist of five factors such as the annual ship running cost (charter cost), administration fees, maintenance costs, employment cost and insurance cost as shown in Table 23. In the case of the port cost, it is utilized as the same cost as the route optimization (Dockage cost=20US$ per meter hours/ Canal transit charges=2US$ per registered TEU/ Handling cost=45US$/TEU)

Table 24 - Service pattern at different number of vessels on a loop

Number of vessel	Turnover ratio (number)	Total design round-trip (days)	Port time (days)	Voyage time at sea (days)	Voyage distance (miles)	voyage speed (knots)
5	10.40	35.10	18.09	17.01	21597	52.90
6	8.67	42.12	18.09	24.03	21597	37.45
7	7.43	49.13	18.09	31.05	21597	28.98
8	6.50	56.15	18.09	38.07	21597	23.64
9	5.78	63.17	18.09	45.09	21597	19.96
10	5.20	70.19	18.09	52.11	21597	17.27
11	4.73	77.21	18.09	59.13	21597	15.22
12	4.33	84.23	18.09	66.14	21597	13.60
13	4.00	91.25	18.09	73.16	21597	12.30
14	3.71	98.27	18.09	80.18	21597	11.22
15	3.47	105.29	18.09	87.20	21597	10.32

On the other hand, the service pattern (frequency, turnover ratio, transit time) and voyage speeds are changed by the changes in the number of vessels on a loop. This relationship can be defined using formula 1, 2 and 3 as shown in Table 24. In this relationship, when the number of vessels on a loop is designated fewer than 8, voyage speed becomes higher than designed voyage speed (25 knots). Hence, when the number of vessels is designated more than 8, the shipping line can operate its service from the technical perspectives. For this reason, this study decides the range of the possible employed number of vessels as the range between 8 and 15. Moreover, the range of employed vessel size is assigned at the range between 8,000 TEU and 14,000 TEU class based on the current employed vessel size.

3.4.3. Weather Condition

The amount of fuel consumption and GHG emissions that incurred by ships on a loop have influenced directly by the weather conditions, *i.e.* waves and wind. The bad weather conditions affects to the voyage speed negatively, so, shipping lines, in this case, are forced to make up for the lost time that caused by bad weather conditions, through increasing their speeds at sea. This leads to an increase in fuel consumption, fuel cost and the amount of GHG emissions on a loop.

To define the loss of voyage speed on a loop by weather conditions, first of all, this study attempts to analyze the annual average wave height in the Far East-North Europe route. Moreover, an analysis on the estimation of the loss of voyage speed by weather conditions is conducted using three key indicators of the direction reduction coefficient, the speed reduction coefficient and the ship form coefficient based on the Kwon method (IMO, 2009). Finally, this cost evaluation model adopts the estimated loss of voyage speed to analyze the fuel consumption with fuel cost on a loop and the amount of GHG emissions.

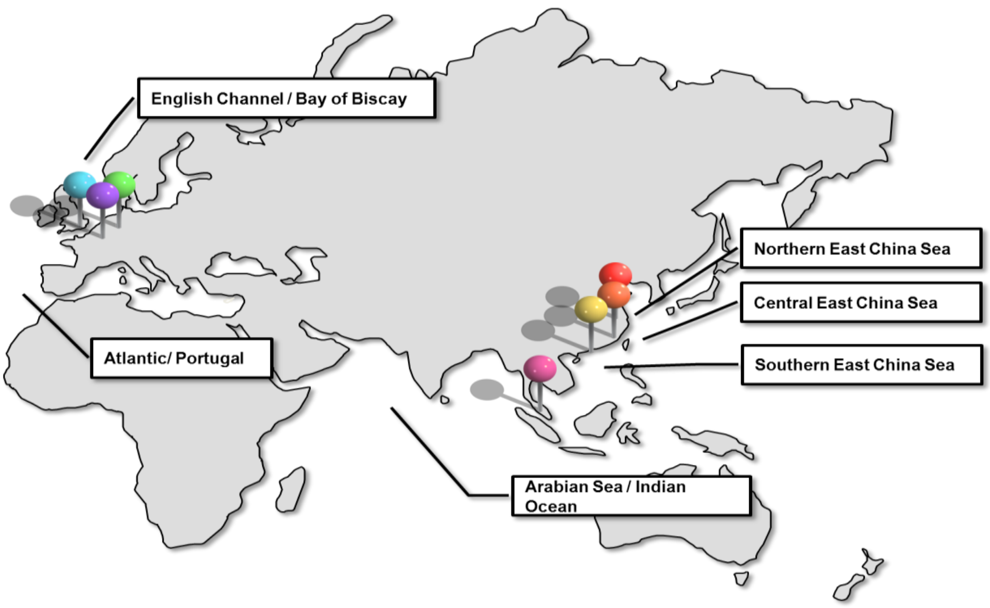


Figure 37 - Six oceans on Far East-North Europe route

In first phase, this study attempts to analyze average wave height in the Far East-North Europe route using two kinds of real market data published by Hyundai

Merchant Shipping and Hamburg Institute Für Schiffbau, in particular Georg (2006). Far East-North Europe route consists of six different routes such as Northern East China Sea, Central East China Sea, Southern East China Sea, Arabian Sea (Indian Ocean), Atlantic sea and English Channel as shown in Figure 37.

According to Hyundai Merchant Shipping, annual average wave height in each ocean is different as shown in Figure 38. Among them, the average wave height is higher in the Arabian Sea and English Channel while it is lower in the Asian routes, *i.e.* Northern East China Sea, Central East China Sea and Southern East China Sea. Moreover, the average wave height of Arabian Sea (Indian Ocean) is the highest, and Northern East China Sea is the lowest in this route. Moreover, the annual average wave height in the Far East-North Europe route was estimated by 2.4 m.

Unit: meters

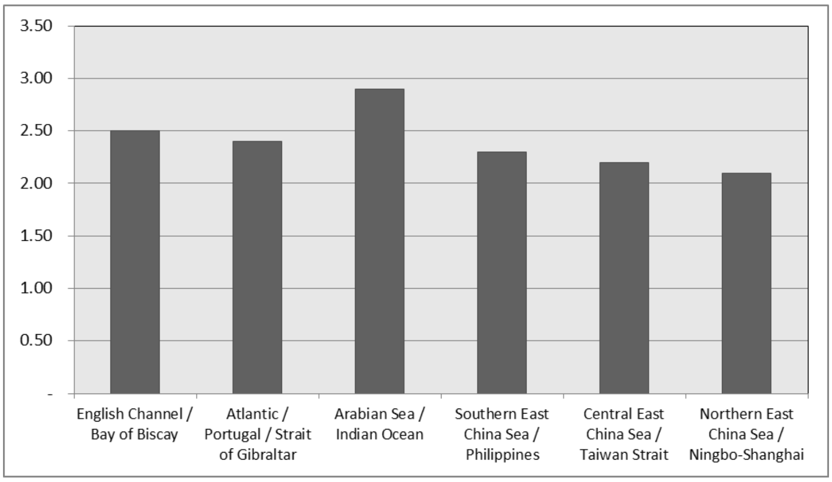


Figure 38 - Annual average wave height in Far East-North Europe route (2010)
Source: Hyundai Merchant Shipping, Co. (internal data)

On the other hand, this model utilizes real data in terms of wave height that collected by Georg (2006) from the database operated by Hamburg Institute Für Schiffbau. This data was retrieved at the observation points in each ocean in Far East-North Europe route as shown in Table 25. The average wave height in each ocean is derived by a concept of population mean (*E(X)*) based on the Beaufort number and number of observation as shown in Table 26.

Table 25 - Location of point to observe the weather condition in each route

Area of a route	Location of the observation point	
Northern East China Sea / Ningbo-Shanghai	Latitude 33, Longitude 146	Point 103
Central East China Sea / Taiwan Strait	Latitude 22, Longitude 146	Point 095
Southern East China Sea / Philippines	Latitude 14, Longitude 146	Point 088
Arabian Sea / Indian Ocean	Latitude -6, Longitude 170	Point 073
Atlantic / Portugal / Strait of Gibraltar	Latitude 38, Longitude 338	Point 116
English Channel / Bay of Biscay	Latitude 46, Longitude 338	Point 121

Source: Georg, E. (2006). *Development of a fuel oil consumption monitoring system*. Technische Universität Hamburg.

Table 26 - Average wave height in five areas in Far East-North Europe route

Northern East China Sea / Ningbo-Shanghai

Beaufort Number BF	Wave height (m)	Number of Observation (times)	Number Normalization (year)	Number Normalization	Population Mean E(X)	Population Variance $V(X)=\sigma^2$	Standard deviation
1.5	0.38	5.9	27.2	0.07	0.03	0.32	
2	0.61	6.1	28.1	0.08	0.05	0.27	
2.5	0.91	6.3	29.1	0.08	0.07	0.19	
3	1.22	6.5	30.0	0.08	0.10	0.13	
3.5	1.6	7	32.3	0.09	0.14	0.07	
4	1.98	7.4	34.1	0.09	0.19	0.02	
4.5	2.51	8	36.9	0.10	0.25	0.00	
5	3.05	8.9	41.1	0.11	0.34	0.04	
5.5	3.96	10.7	49.4	0.14	0.54	0.30	
6	4.88	12.3	56.8	0.16	0.76	0.91	
		79.1	365	1	2.47	2.25	1.50

Central East China Sea / Taiwan Strait

Beaufort Number BF	Wave height (m)	Number of Observation (times)	Number Normalization (year)	Number Normalization	Population Mean E(X)	Population Variance $V(X)=\sigma^2$	Standard deviation
1.5	0.38	5.7	26.8	0.07	0.03	0.33	
2	0.61	5.9	27.8	0.08	0.05	0.27	
2.5	0.91	6.1	28.7	0.08	0.07	0.20	
3	1.22	6.4	30.1	0.08	0.10	0.13	
3.5	1.6	6.8	32.0	0.09	0.14	0.07	
4	1.98	7.1	33.4	0.09	0.18	0.02	
4.5	2.51	7.8	36.7	0.10	0.25	0.00	
5	3.05	8.7	41.0	0.11	0.34	0.04	
5.5	3.96	10.6	49.9	0.14	0.54	0.30	
6	4.88	12.4	58.4	0.16	0.78	0.92	
		77.5	365	1	2.49	2.26	1.50

Southern East China Sea / Philippines

Beaufort Number BF	Wave height (m)	Number of Observation (times)	Number Normaliza tion (year)	Number Normaliza tion	Population Mean E(X)	Population Variance $V(X)=\sigma^2$	Standard deviation
1.5	0.38	5.3	25.8	0.07	0.03	0.31	
2	0.61	5.5	26.7	0.07	0.04	0.26	
2.5	0.91	5.8	28.2	0.08	0.07	0.19	
3	1.22	6	29.2	0.08	0.10	0.13	
3.5	1.6	6.4	31.1	0.09	0.14	0.07	
4	1.98	6.9	33.5	0.09	0.18	0.02	
4.5	2.1	7.6	36.9	0.10	0.21	0.01	
5	3.05	8.6	41.8	0.11	0.35	0.04	
5.5	3.96	10.6	51.5	0.14	0.56	0.31	
6	4.88	12.4	60.3	0.17	0.81	0.95	
		75.1	365	1	2.48	2.29	1.51

Arabian Sea / Indian Ocean

Beaufort Number BF	Wave height (m)	Number of Observation (times)	Number Normaliza tion (year)	Number Normaliza tion	Population Mean E(X)	Population Variance $V(X)=\sigma^2$	Standard deviation
1.5	0.38	5.3	26.0	0.07	0.03	0.33	
2	0.61	5.5	27.0	0.07	0.05	0.27	
2.5	0.91	5.7	28.0	0.08	0.07	0.20	
3	1.22	5.9	29.0	0.08	0.10	0.14	
3.5	1.6	6.2	30.5	0.08	0.13	0.07	
4	1.98	6.7	32.9	0.09	0.18	0.03	
4.5	2.51	7.4	36.4	0.10	0.25	0.00	
5	3.05	8.4	41.3	0.11	0.34	0.03	
5.5	3.96	10.7	52.6	0.14	0.57	0.29	
6	4.88	12.5	61.4	0.17	0.82	0.92	
		74.3	365	1	2.54	2.29	1.51

Atlantic / Portugal / Strait of Gibraltar

Beaufort Number BF	Wave height (m)	Number of Observation (times)	Number Normaliza tion (year)	Number Normaliza tion	Population Mean E(X)	Population Variance $V(X)=\sigma^2$	Standard deviation
1.5	0.38	5.4	25.5	0.07	0.03	0.33	
2	0.61	5.7	26.9	0.07	0.04	0.28	
2.5	1.9	6	28.3	0.08	0.15	0.03	
3	1.22	6.2	29.2	0.08	0.10	0.14	
3.5	1.6	6.6	31.1	0.09	0.14	0.08	
4	1.98	7.2	34.0	0.09	0.18	0.03	
4.5	2.1	8	37.7	0.10	0.22	0.02	
5	3.05	9	42.4	0.12	0.35	0.03	
5.5	3.96	10.9	51.4	0.14	0.56	0.28	
6	4.88	12.4	58.5	0.16	0.78	0.87	
		77.4	365	1	2.55	2.09	1.44

English Channel / Bay of Biscay

Beaufort Number BF	Wave height (m)	Number of Observation (times)	Number Normalization (year)	Number Normalization	Population Mean E(X)	Population Variance $V(X)=\sigma^2$	Standard deviation
1.5	0.38	6.5	28.3	0.08	0.03	0.33	
2	0.61	6.6	28.7	0.08	0.05	0.27	
2.5	0.91	6.7	29.2	0.08	0.07	0.19	
3	1.22	6.9	30.1	0.08	0.10	0.12	
3.5	1.6	7.3	31.8	0.09	0.14	0.06	
4	1.98	7.8	34.0	0.09	0.18	0.02	
4.5	2.51	8.6	37.5	0.10	0.26	0.00	
5	3.05	9.5	41.4	0.11	0.35	0.04	
5.5	3.96	11.1	48.3	0.13	0.52	0.30	
6	4.88	12.8	55.8	0.15	0.75	0.90	
		83.8	365	1	2.45	2.24	1.50

Source: Georg, E. (2006). *Development of a fuel oil consumption monitoring system*. Technische Universität Hamburg.

The average wave height in each ocean is calculated based on both data of weather condition with considering the average wave height of both data and the voyage distance in each ocean. According to the result of analysis, the annual wave height is calculated by 2.41m as shown in Table 27.

Table 27 - Average wave height on Far East-North Europe route

Unit: m

	Hamburg Institute fur Schiffbau	Hyundai Merchant Shipping	Average	Distance (Mile)	Population Mean E(X)
English Channel	2.45	2.50	2.47	202	0.02
Atlantic	2.55	2.40	2.47	1,374	0.16
Arabian Sea	2.54	2.90	2.72	2,920	0.37
Southern East China Sea	2.48	2.30	2.39	6,611	0.73
Central East China Sea	2.49	2.20	2.34	5,785	0.63
Northern East China Sea	2.47	2.10	2.28	4,705	0.50
Annual average wave height					2.41

In the second step, the loss of voyage speed that occurred due to weather conditions is analyzed using three indicators of the direction reduction coefficient, the speed reduction coefficient and the ship form coefficient based on the Kwon method (IMO, 2009). Three indicators of the direction reduction coefficient, the speed reduction coefficient and the ship form coefficient are derived by the definitions in chapter 2 as shown in Table 28.

Table 28 - The direction reduction coefficient, the speed reduction coefficient and the ship form coefficient

Ship Size (TEU)	Froude number (Fn)	Speed reduction coefficient (C_u)[a)]	Ship form coefficient (C_{form})[b)]	Direction reduction coefficient (C_b)
8,000	0.2285	-0.5184	2.2366	0.8493
10,000	0.2153	-0.3229	2.2114	0.8493
12,000	0.2071	-0.2026	2.1987	0.8493
14,000	0.2033	-0.1483	2.1895	0.8493

a) when the block coefficient is 0.75
b) when the average wave height is 2.41m

Table 29 - Changed voyage speed by the weather condition at different voyage speeds and ship types on Far East-North Europe route

Unit: knots

Planned speed	Required voyage speed			
	8,000 TEU	10,000TEU	12,000TEU	14,000TEU
25.00	25.25	25.40	25.50	25.57
24.00	24.24	24.38	24.48	24.54
23.00	23.23	23.37	23.46	23.52
22.00	22.22	22.35	22.44	22.50
21.00	21.21	21.34	21.42	21.47
20.00	20.20	20.32	20.40	20.45
19.00	19.19	19.30	19.38	19.43
18.00	18.18	18.29	18.36	18.41
17.00	17.17	17.27	17.34	17.38
16.00	16.16	16.26	16.32	16.36
15.00	15.15	15.24	15.30	15.34
14.00	14.14	14.22	14.28	14.32
13.00	13.13	13.21	13.26	13.29
12.00	12.12	12.19	12.24	12.27
11.00	11.11	11.18	11.22	11.25
10.00	10.10	10.16	10.20	10.23

Moreover, the changed voyage speed in weather conditions for different voyage speeds and ship types on the Far East-North Europe route is shown in Table 29. The changed voyage speed is the actual voyage speed needed to maintain the planned voyage speed. Hence, if the shipping line set up their target voyage speed at 23 knots on their service loop which was carried out by 8,000 TEU class vessels, it has to accelerate its voyage speed to 23.23 knots on the actual voyage due to the weather conditions (wave and wind). Moreover, if this loop is organized by 14,000 TEU class vessels, the shipping line has to increase its voyage speed to 23.52 knots. These results influence the fuel consumption, fuel cost and the amount of GHG emissions directly. As analyzed above, the weather conditions (waves and wind) are one of the important factors that influence the operating costs and the amount of GHG emissions. So, this result (the changed voyage speed) is utilized in this model to reflect the weather conditions.

3.4.4. Results

This model sets up 32 cases based on combinations of the number of vessels (8-15 vessels) and vessel types (4 types of vessels) as shown in Table 30, and the analysis is conducted based on 32 cases.

Table 30 - Combinations of the possible cases by the changes of input data (number of vessel and vessel size)

		Number of vessels							
		8	9	10	11	12	13	14	15
Vessel size	8,000	Case1	Case2	Case3	Case4	Case5	Case6	Case7	Case8
	10,000	Case9	Case10	Case11	Case12	Case13	Case14	Case15	Case16
	12,000	Case17	Case18	Case19	Case20	Case21	Case22	Case23	Case24
	14,000	Case25	Case26	Case27	Case28	Case29	Case30	Case31	Case32

3.4.4.1. Fuel consumption

According to the result of the simulation, an increase in the number of vessels on a loop is helpful in reducing the amount of annual fuel consumption and fuel cost on the same class of vessel size. As shown in Figure 39, when vessel size is fixed, as the number of vessel increases, the amount of annual fuel consumption decreases sharply.

However, increase in the vessel size is a main cause to increase the amount of fuel consumption.

Unit: Million tons

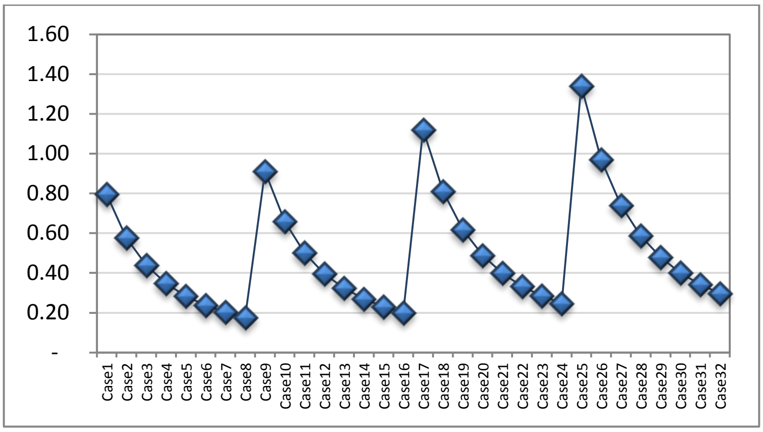


Figure 39 - Annual fuel consumption in different cases

3.4.4.2. Fuel cost and externality

Annual fuel cost and externality have positive correlations with increases in the number of vessels. According to the result of the simulation, as the number of vessels increases, annual fuel cost and external cost are decreased as shown in Figure 40 and 41. However, as vessel size increases from 8,000 TEU to 14,000 TEU, both annual fuel cost and external cost are increased. In this sense, it can be concluded that there is a negative correlation between annual fuel cost, with externality, and the increase of vessel size on a loop.

Unit: Million US$

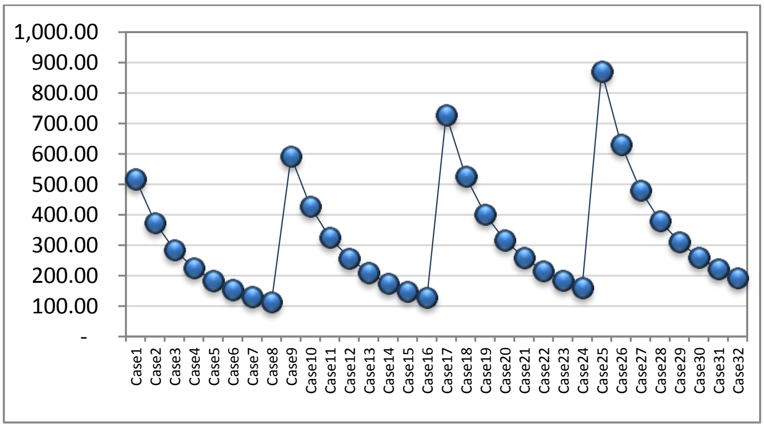


Figure 40 - Annual fuel cost in different cases

Unit: Million US$

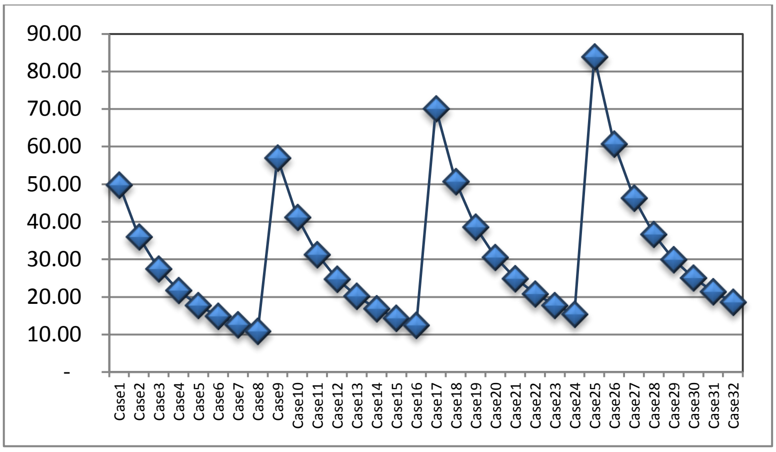


Figure 41 - Annual external cost in different cases

Unit: Million US$

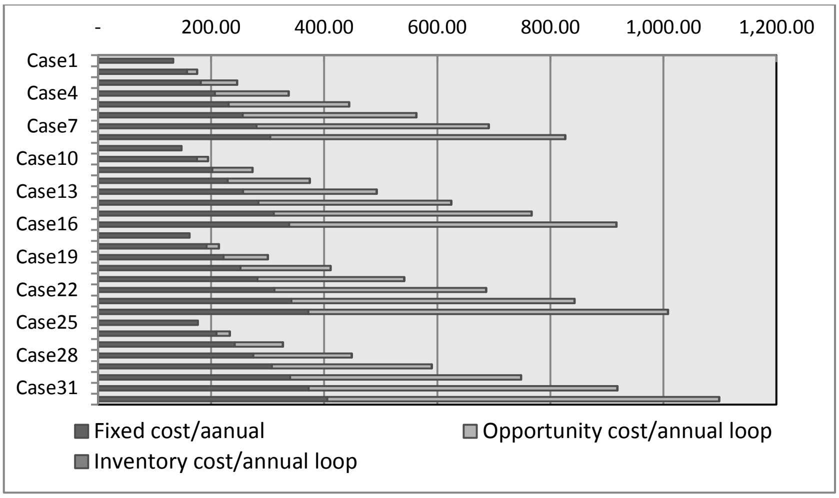


Figure 42 - Annual fixed costs, opportunity cost and inventory cost

3.4.4.3. Fixed costs, opportunity cost and inventory cost

Annual fixed costs, opportunity cost and inventory cost in each case are derived by simulation as shown in Figure 42. In this diagram, an increase in the number of vessels has a positive influence on three costs, while an increase in vessel size does not. Moreover, opportunity cost increases rapidly compared to fixed cost and inventory cost with an increase in the employed number of vessels. This means that an increase in the number of vessels on a loop leads to a decrease in operational efficiency.

3.4.4.4. Port cost

Annual port cost in each case is derived also by simulation, and it is influenced not by the vessel size but by the number of vessels as shown in Figure 43. This is because dockage charge and canal transit charge are sensitive to vessel size when the transport demand is fixed. Hence, it can be concluded that an increase in vessel size may cause an increase in port cost on a loop, and it has a negative influence on the operating cost.

Unit: Million US$

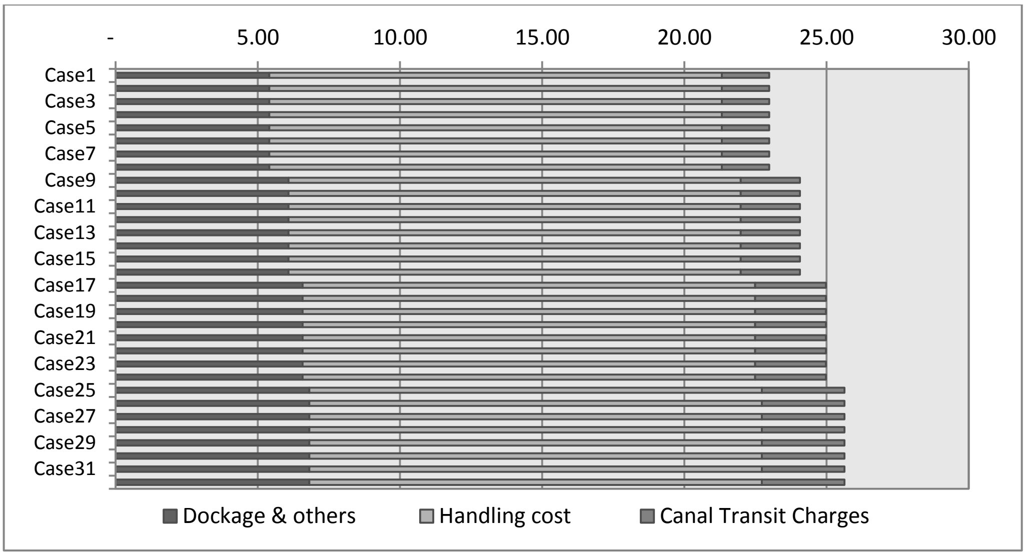


Figure 43 - Annual port costs in different cases

3.4.4.5. Net operating cost and zero-profit slot cost

Net operating cost in different cases is derived by the simulation based on the definition of this study as shown in Figures 44, and 45. Some relationships among the number of vessels, vessel size and net operating cost are derived by the results of simulation. Firstly, in each class of vessel size, until the number of vessel is increased by 10, net operating cost is decreased: however, when the number of vessel is increased by more than 10, net operating cost increases sharply. Moreover, when the number of employed vessels is controlled at 10 ships, the shipping line can minimize their operating cost. Hence, when the shipping line organizes their service loop with 10 8,000 TEU class vessels, they can optimize their fleet.

Unit: Million US$

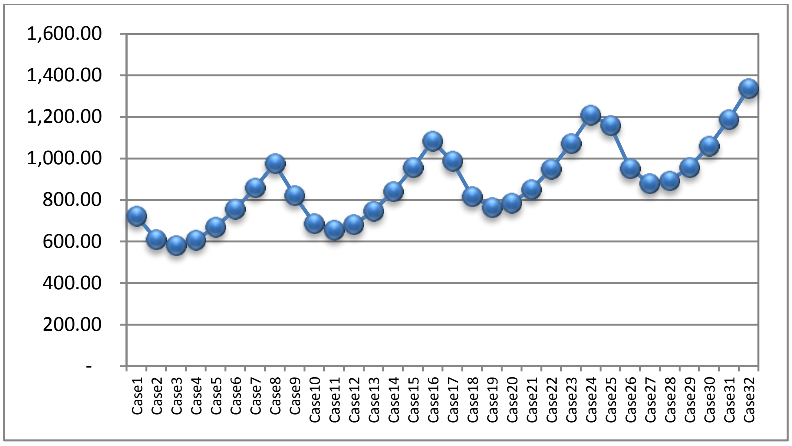


Figure 44 - Annual net operating cost in different cases

Unit: Million US$

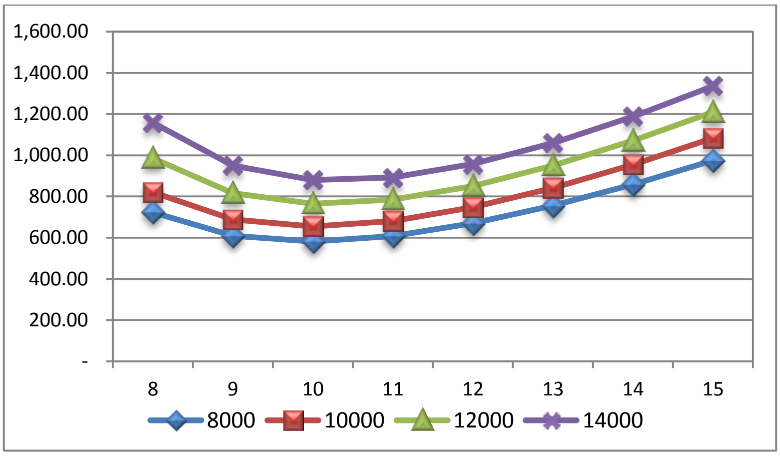


Figure 45 - Annual net operating cost for different class of vessel size

Moreover, as vessel size increases, the net operating cost curve shifts upward as shown in Figure 45. Hence, it can be concluded that there is a negative correlation between operating cost and an increase in vessel size when transport demand is fixed based on the result of the simulation. Finally, when considering the change rate of net operating cost, the shipping line can reduce its operating costs in seven cases as shown in Figure 46. In the case of 8,000 TEU class vessels, when the number of employed vessel is controlled within the range between 9 and 12 vessels, net operating cost can be reduced. Moreover, In the case of 10,000 TEU class vessels, net operating cost can be reduced within the range of 9 and 10.

Unit: Percentage

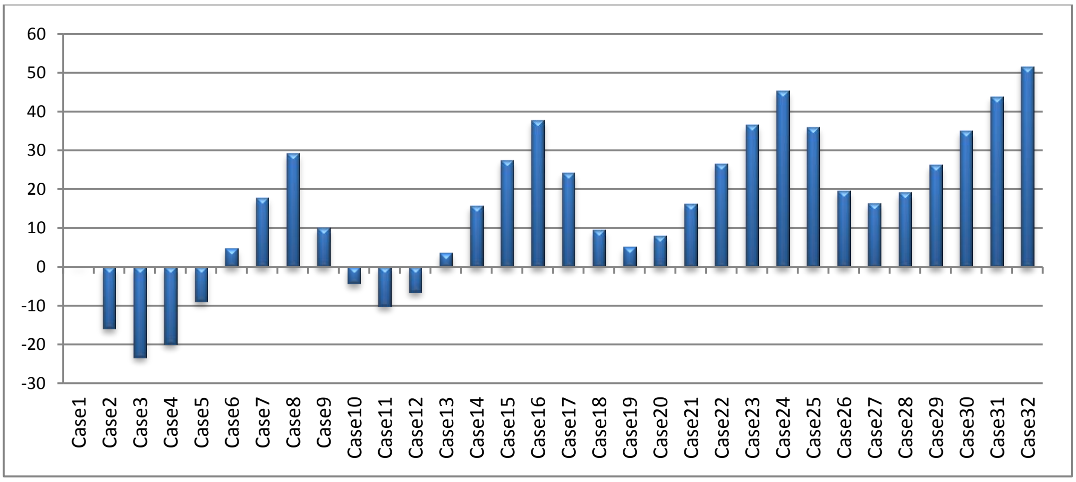


Figure 46 - Change rate of net operating cost in comparison with basic service

On the other hand, the zero-profit slot cost, *i.e.* an average cost per TEU on a loop, is changed by alterations in net operating cost as shown in Figure 47. According to the result of the analysis, the zero-profit slot cost can be reduced in seven cases (2, 3, 4, 5, 10, 11 and 12) compared to the basic case (case 1), and it is minimized in case 3 (1,399 US$). However, the zero-profit slot cost (average cost per unit) becomes higher than the basic case (case 1) in other cases.

Unit: US$

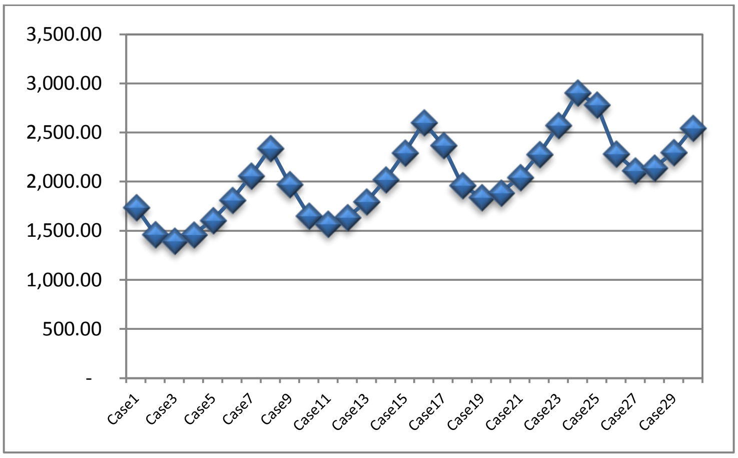


Figure 47 - Zero-profit slot cost in different cases

3.5. Chapter Conclusion

The aim of this chapter was to analyze the impact of route optimization and fleet optimization, while considering slow steaming, on the operating costs on a loop. To achieve the aim of this chapter, firstly, an Integer Programming (IP) model was established to minimize the voyage time, distance and cost on a loop. Moreover, the impact of route optimization on the operating cost and the amount of GHG emissions was analyzed. The optimum route and the worst route were selected by analysis, and this analysis found that the operating cost of the optimum route was reduced by 8.4% through route optimization in comparison with the worst route as shown in Figure 48.

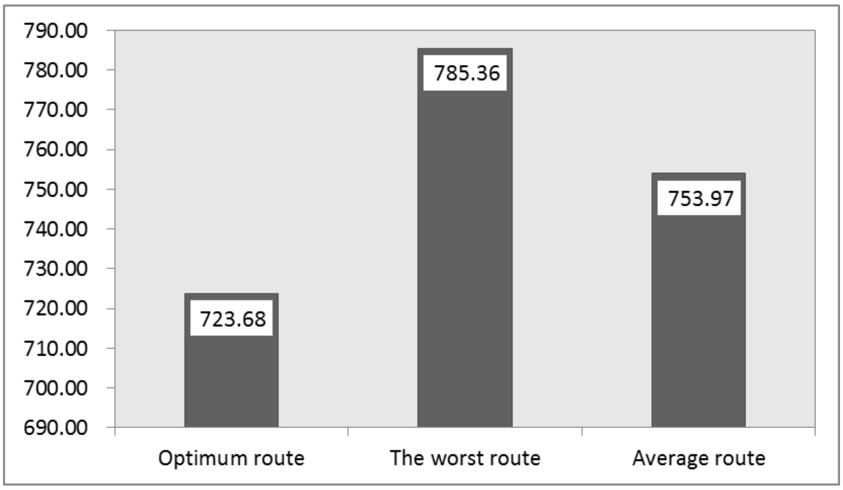
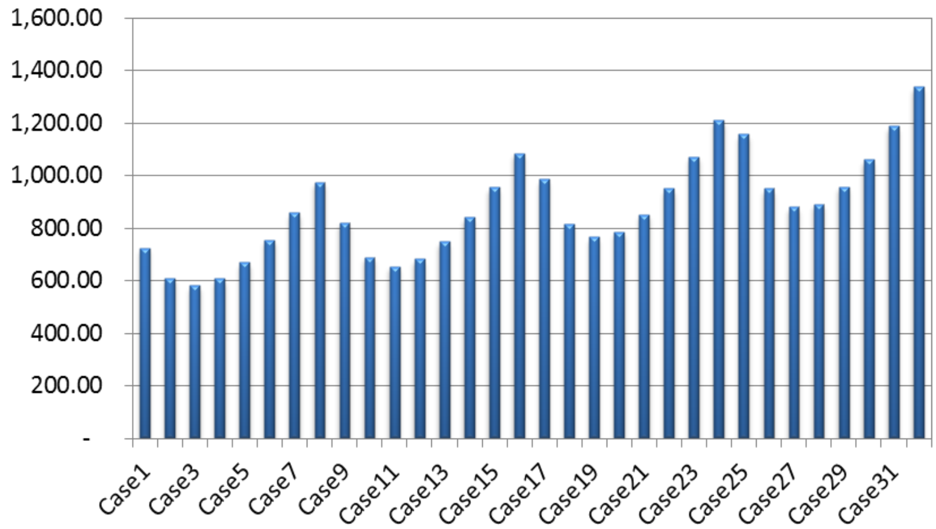


Figure 48 - Changes of the operating cost by the voyage optimization

Secondly, a cost model was designed to analyze the impact of fleet optimization on the operating cost while considering slow steaming on a fixed route. The aim of the model is to minimize the operating cost in the condition of the different number of vessels and different types of vessels. According to the result of the analysis, the operating cost is changed dynamically by changes in fleet mix and type of vessel. The operating cost was reduced in seven cases (case 2, 3, 4, 5, 10, 11 and 12), and it was minimized in case 3 (when the loop employs 10, 8,000 TEU class vessels) in this model. In case 3, the operating cost (582 million US$) was reduced by 23.26% (141.68 million US$) in comparison with the worst case (723.68 million US$).



		Number of vessel							
		8	9	10	11	12	13	14	15
Vessel size	8,000	Case1	Case2	Case3	Case4	Case5	Case6	Case7	Case8
	10,000	Case9	Case10	Case11	Case12	Case13	Case14	Case15	Case16
	12,000	Case17	Case18	Case19	Case20	Case21	Case22	Case23	Case24
	14,000	Case25	Case26	Case27	Case28	Case29	Case30	Case31	Case32

On the other hand, when considering the impacts of both analyses, the operating cost has been reduced by 8.4% through route optimization and by 23.26% through fleet optimization with slow steaming on a loop. This can be expressed clearly by diagram as shown in Figure 49. This diagram shows the impact of route optimization and the impact of fleet optimization, and by both strategies, the shipping line reduced its operating cost from 785.36 to 582 million US$ (totally 31.7%) by route optimization (61.7 million US$) and fleet optimization with slow steaming (141.7 million US$). Moreover, the amount of GHG emissions has been reduced from 2.76 to 2.49 million tons through route optimization (10.87%) and fleet optimization (55.11%) on a loop. The diagram in Figure 50 clearly shows the impact of route optimization and fleet optimization with slow steaming on the reduction of the amount of GHG emissions.

This chapter proved that both strategies, *i.e.* route optimization and fleet optimization with slow steaming, are useful in reducing operating costs and the amount of GHG emissions at the same time in liner shipping. In this sense, from the viewpoint of a shipping line, it is necessary to consider both impacts on operating cost and environmental performance when they build and/or improve their operational strategies.

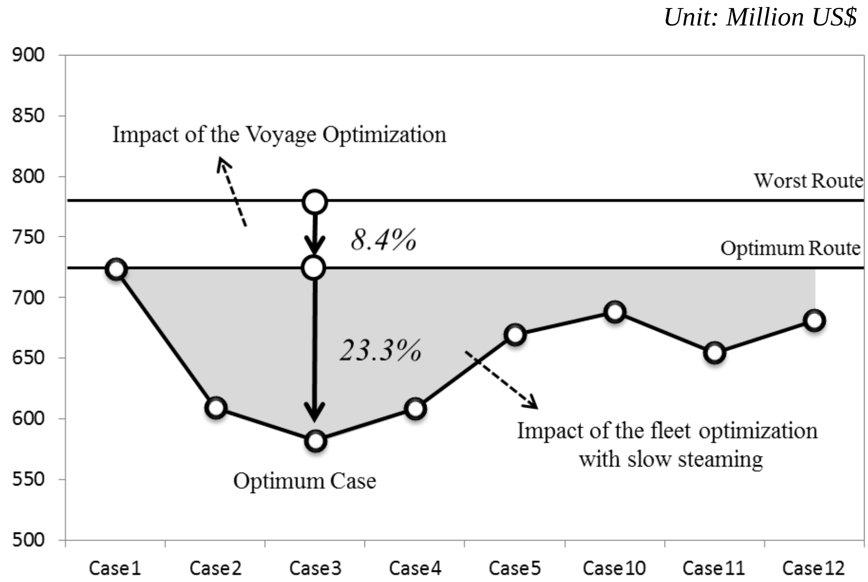


Figure 49 - The impact of the voyage optimization and the fleet optimization with slow steaming on the operating cost

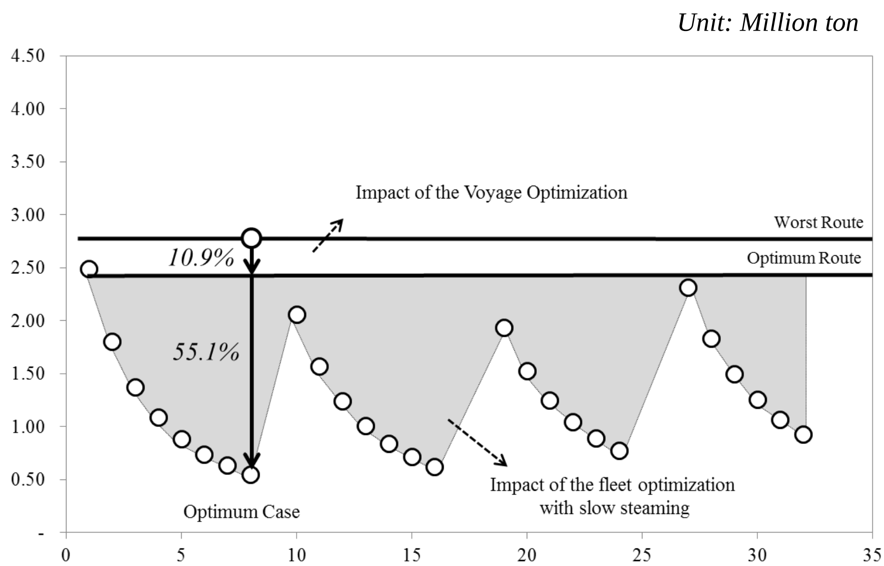


Figure 50 - The impact of the voyage optimization and the fleet optimization with slow steaming on the amount of GHG emissions

4. SPEED OPTIMIZATION 1: MODELING

4.1. Introduction

Slow steaming is helpful to reduce operating costs and the amount of GHG emissions by the reduction of bunker fuel consumption. According to A.P. Moller Maersk Group (APMM), when voyage speed is reduced by 20%, bunker fuel consumption and the amount of CO_2 emissions that occur by ship can be reduced by more than 40% and 20% respectively. According to the research of Germanischer Lloyd's Maritime Solutions (GL), slow steaming is a useful strategy for shipping lines to reduce their fixed costs and capital costs (Matthew, 2011). For this reason, presently, more than 95% of liner shipping service is operated using slow steaming, and average voyage speed has been reduced from 22-25 knots in 2008 to 15-18 knots in 2012 on the Far East-North Europe route (Alphaliner, 2012). Moreover, most shipping lines have plans to reduce their voyage speed to below 15 knots on major routes.

However, slow steaming creates additional costs also. This is because slow steaming leads to changes in the organization of a loop and its service pattern. In this chapter, this study defines the effects of slow steaming on operating cost, environmental performance and operational productivity on a loop from an economic perspective. Moreover, the definitions derived from this chapter are utilized when the simulation model is designed as the major algorithm to analyze the three main aims of operating cost, environmental performance and operational productivity on a loop.

This chapter starts with some fundamental questions about slow steaming and its effects. Firstly, how does voyage speed (slow steaming) influence the organization of liner shipping services and service patterns? Secondly, is it true that the more voyage speed is reduced the more operating cost, and the amount of GHG emissions can be reduced at the same time? Moreover, what voyage speed is the optimal speed that minimizes operating costs and maximizes the reduction of GHG emissions? Moreover, how much operating costs and what amount of GHG emissions can be reduced at the optimal voyage speed? Finally, what kind of relationship do slow steaming effects have with vessel size on operating costs and amount of GHG emissions?

As discussed, in the viewpoint of the shipping line, the main reason for the introduction of slow steaming as an operational strategy is that slow steaming is helpful to reduce their operating costs by the reduction of fuel consumption. However, slow steaming creates positive and negative effects at the same time. In this sense, this thesis attempts to analyze slow steaming effects with a focus on the changes of voyage speed from various perspectives and find the optimal voyage speed to minimize operating costs and the amount of GHG emissions. This chapter provides an analysis of the effects of slow steaming on operating costs and the amount of GHG emissions and designs a simulation model to achieve the goal of the chapter. Moreover, the simulation model designed in this chapter is utilized to simulate slow steaming effects with a focus on changes in voyage speed from various perspectives in Chapter 5.

4.2. Simulation Process

4.2.1. Scope and Methodology

A dynamic simulation model (Dynamic Slow Steaming Evaluation Model: DSSEM) was designed to analyze the relationship between voyage speed and relevant factors in terms of operating costs, and the amount of GHG emissions based on a Far East-Europe Route using a System Dynamics simulation modeling technique. In the three models, actual market data published by shipping lines, major consulting companies such as Drewry Shipping Consultant, Ocean Shipping Consultant and Alpha liner and relevant international institutes such as IMO, UNCTAD and OECD was utilized.

On the other hand, system dynamics can be defined as a methodology and computer simulation modeling technique for framing, understanding, and discussing complex issues and problems. Originally, system dynamics was developed in the 1950s to help corporate managers improve their understanding of industrial processes; however, it is currently being used throughout the public and private sectors for policy analysis and design. System dynamics is an aspect of system theory as a method for understanding the dynamic behavior of complex systems. The basis of the method is the recognition that the structure of any system, the many circular, interlocking, sometimes time-delayed relationships among its components, is often just as important in determining its behavior as the individual components themselves.

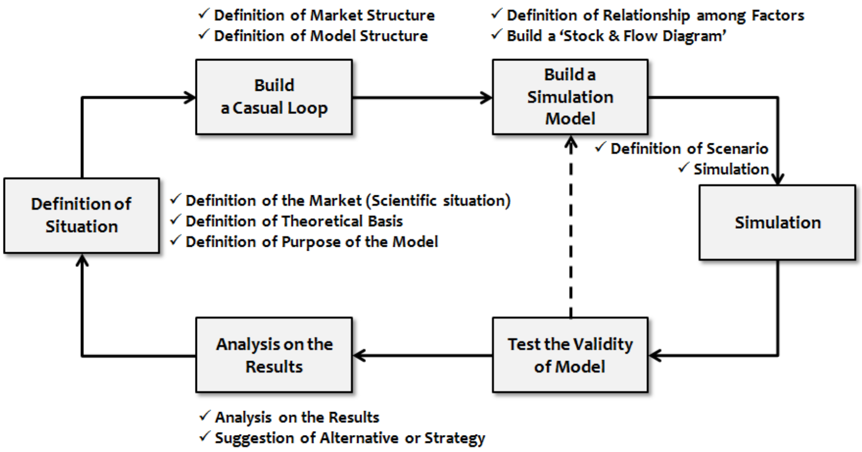


Figure 51 - Simulation modeling Process on System Dynamics Simulation

In addition, according to the system dynamics society, 'system dynamics can be defined as a methodology for studying and managing complex feedback systems, such as one finds in business and other social systems'. In fact, it has been used to address practically every sort of feedback system. While the word system has been applied to all sorts of situations, feedback is the differentiating descriptor here. Feedback refers to the situation of X affecting Y, and Y in turn affecting X perhaps through a chain of causes and effects. One cannot study the link between X and Y and, independently, the link between Y and X and predict how the system will behave. Only the study of the whole system as a feedback system will lead to correct results. The methods have been used for over thirty years (Forrester, 1961). Presently, however, numerous studies adopt it in various research fields. For this thesis, a system dynamics Simulation Model was built using 'Vensim PLS-Plus Version 5.9e'. The Vensim is one of the leading dynamic simulation modeling tools, and it was utilized in many previous studies for building simulation models.

4.2.2. Simulation Modeling Process

This simulation model was designed based on the social science analysis process of system dynamics simulation modeling technique as shown in Figure 51. Firstly, the causal loop is designed based on the definition of the relationships between voyage speed and various relevant factors concerning operating costs and its structure, the amount of GHG emissions and the level of service quality on a loop. The causal loop consists of graphical notation, and a basic idea for thinking about the basic concepts. Moreover, a simulation model was designed based on the 'Causal Loop'. A Simulation model is comprised of multiple 'Stock & Flow' that define the relationships among factors by formulas and definitions, and, in the next step, a simulation is conducted according to the established aim of the simulation. Finally, a simulation model provides various alternatives as a result of the simulation, checking the validity of a model.

4.3. Assumptions

Some assumptions were established to clarify the analysis objectives and the results of the simulation. The assumptions are adopted based on the actual market data on a Far East-North Europe Route and these are as follows.

4.3.1. Perfect Competition Market

This model assumes that the liner shipping market is a perfect competition market. In economic theory, a perfectly competitive market is one in which the number of buyers and sellers is so large that no one party can affect the market price of the good or service being exchanged. Under these conditions, sellers take the price as a given and maximize profits by producing at the point where the cost of producing one more unit is equal to the revenue received from the sale of that unit. Moreover, perfect competition describes markets in which no participants are large enough to have the market power to set the price of a homogeneous product (Mankiw, 2007). In this sense, this simulation model assumes that; a) all liner shipping companies are price takers; b) all liner shipping companies, container ports, customers and players have perfect information about the service schedule, transport capacity, freight rates, service quality and operational efficiency; and c) the liner shipping industry is characterized by freedom of entry and exit.

4.3.2. Transport Demand and Supply

Slow steaming is defined as the operational technique wherein a vessel is deliberately operated at a lower voyage speed than its designed voyage speed, making it necessary to employ more vessels to transport the same volume of cargo while maintaining the announced weekly service schedule. Based on this concept, this simulation model assumes that transport volume is fixed in spite of the changes in transport capacity by the deceleration of voyage speed. However, shipping lines can change the number of vessels on a loop freely through changes in voyage speed on a loop. This is because the aim of this simulation model is to analyze the relationships between voyage speed and various factors in terms of the organization and service pattern, operational productivity, operating costs and the amount of GHG emissions related to changes in voyage speed. In this simulation model, annual transport demand was estimated based on the Drewry data (Drewry, 2000-2010) as shown in Tables 31 and 32.

Table 31 - Trends of transport demand and supply

Unit: Thousand TEU, %

Classification		2002	2003	2004	2005	2006	2007	2008	2009
East bound	Traffic Volume	2,987	3,255	3,708	3,838	4,003	4,218	4,101	3,789
	Transport Capacity	4,128	4,782	5,211	5,988	6,760	7,380	8,110	6,544
	Utilization Rate	72.4	68.1	71.2	64.1	59.2	57.2	50.6	57.9
West Bound	Traffic Volume	4,432	5,206	6,238	6,852	7,805	9,101	9,074	7,817
	Transport Capacity	5,139	5,905	6,406	7,355	8,441	9,545	10,819	9,255
	Utilization Rate	86.2	88.2	97.4	93.2	92.5	95.3	83.9	84.4

Source: Drewry (2000-2010). *Container Market, Annual Review and Forecast.* Drewry Shipping Consultants Ltd.

Table 32 - Annual transport demand on a loop and O/D flow

Unit: TEU

	Shang hai	Ningbo	Yantian	Tanjung Pelepas	Rotter dam	Felix stowe	Bremer haven	Sum
Shanghai	-	-	13,030	16,251	19,839	20,634	20,107	89,862
Ningbo	-	-	13,344	11,579	19,069	13,116	18,261	75,369
Yantian	6,568	-	-	8,663	19,246	16,710	16,955	68,142
Tanjung Pelepas	5,227	6,775	5,101	-	14,756	12,563	12,917	57,340
Rotterdam	5,174	5,112	5,334	5,826	-	-	314	21,760
Felixstowe	4,578	5,080	5,008	5,032	-	-	-	19,698
Bremerhaven	5,556	4,395	6,254	5,224	-	-	-	21,430
Sum	27,103	21,363	48,071	52,575	72,910	63,024	68,554	353,600

Source: Estimated data based on the Drewry research: Drewry (2010). *Container Market; Annual Review and Forecast 2011.* Drewry Shipping Consultants Ltd.

4.3.3. Service Patterns and other conditions

A simulation model was designed based on the optimum service loop decided by route optimization on a Far East-North Europe Route. Moreover, this model assumes that a shipping line operates its liner service by the provision of regular service between selected calling ports based on the advertised schedule and freight tariff based on the following conditions.

- Liner shipping services are operated based on weekly service. Therefore, when a shipping line decelerates voyage speed, it has to control the number of vessels and number of calling ports to keep its announced schedule.
- The basic vessel size is 8,000 TEU class, and a shipping line can change the vessel size within the range between 8,000 and 14,000 TEU class. The average vessel size is 8,300 TEU in 2012 (Drewry, 2012). Moreover, the characteristics of container vessels are as shown in Table 33.
- The designed voyage speed on designed service is 25 knots. In this model, liner shipping companies can control their voyage speed within the range of 25 and 10 knots.
- The basic bunker fuel price is 650 US$/ton, which was the average bunker fuel price at the end of 2011 (Clarkson & Reuters, 2010; see Figure 13).
- This model adopts the fuel-based exhaust GHG factors developed by IMO (2009) to estimate the amount of GHG emissions as shown in Table 35.
- Annual fixed costs consist of five factors such as the annual ship running cost, administration fees and container management costs, maintenance costs, employment cost and insurance cost. However, this model defines bunker fuel cost as a variable cost to simulate slow steaming effects. This model utilizes internal data published by Sam Sung Heavy Industry as shown in Table 34.
- Port costs are estimated using actual market data as follows. (Dockage cost= 20US$/m·hours; Canal transit charges=2US$ per registered TEU; Handling cost =45US$/TEU).
- The weather conditions (waves and wind) and the loss of voyage speed by weather condition are adopted as one of the major factors to influence on the fuel consumption (see Chapter 3, 3.4.3 and Table 29).
- The imperfect combustion of bunker fuel is not considered in this model. This is because its amount is too small to reflect this model, and there is little evidence to explain the impacts of slow steaming on the engine operation.

- This model considers the financial cost that occurred by ship running. This model adopted real data in terms of the fixed costs that published by Sam Sung Heavy Industry as shown in Table 34, and it includes financial cost. However, this model focused on the impact of slow steaming based on one operating year so, financial analysis is not conducted.

Table 33 - Characteristics of container vessels

Containership Size Class			6,000	8,000	10,000	12,000	14,000
LOA		m	304	323	364	393	408
LBP		m	292	308	350	380	394
Breadth		m	40	43	47	52	57
Depth		m	24	25	30	32	33
Design Deadweight		ton	61,700	82,200	114,900	140,600	165,800
Design Draft		m	12	13	15	16	16
Keel to Top of Antenna		m	62	63		76	
Designed voyage speed		knots	25	25	25	25	25
Main Engine Size		kW	57,100	68,500	74,000	82,100	89,700
Total Installed Aux. Power		kW	12,900	12,000	12,000	14,000	16,000
SFOC	at sea	g/kW h	246	286	307	342	375
	in port	g/kW h	26	24	24	28	32

Source: Herbert Engineering Corp.

Table 34 – The fixed costs in different types of vessel

Unit: Million US$

	6,000	8,000	10,000	12,000	14,000
Annual ship running cost including financial costs	9.61	10.80	11.99	13.17	14.36
Administration fee & container costs	3.28	3.68	4.09	4.49	4.89
Maintaining costs	3.93	4.42	4.90	5.39	5.87
Employ cost	2.62	2.95	3.27	3.59	3.92
Insurance cost	2.40	2.70	3.00	3.29	3.59
Sum	21.85	24.55	27.24	29.94	32.63
Daily cost	0.06	0.07	0.07	0.08	0.09

Source: Samsung Heavy Industry internal data

Table 35 - Summary of Services in Far East- North Europe Route (2010)

Unit: day, TEU

Liner	Service	Voyage time	No. of vessel	Average Vessel size	Total Capacity
Grand Alliance (Hapag-Lloyd, MISC, NYK, OOCL)	EU 1	56	9	6,404	333,936
	EU 2	63	9	7,440	387,925
	EU 3	63	9	8,654	451,227
	EU 4	63	9	8,256	430,515
Maersk Line	AE 1	63	9	8,178	426,413
	AE 2	56	8	8,925	465,375
	AE 7	56	8	11,287	588,562
	AE 8	56	8	7,699	451,227
	AE 10	56	9	7,699	465,375
	AE 9	49	7	6,167	321,558
New World Alliance (APL,HMM,MOL)	Japan Exp. JEX(MOL)	56	8	6,381	332,737
	Asia Exp. AEX(HMM)	56	8	6,800	354,571
	China EXP. CEX(APL)	56	8	5,751	299,900
	South China Exp. (APL/MOL)	49	7	5,582	291,061
CMA CGM	FAL 1	63	8	8,510	394,455
	FAL 3	56	8	6,680	348,321
CMA CGM/CSCL	FAL 2/AEX 7	56	8	9,497	495,227
CSAV NORASIA	AME	56	8	6,287	327,848
CKYH COSCO / K Line / Yang Ming / Han Jin/Senator	JES/AE 2	56	8	5,613	292,704
	AE 1/AES	56	8	8,622	449,576
	Loop 1/NCX	56	8	8,982	468,354
	Loop 2/AEX	56	8	5,582	291,081
	Loop 3/FEX	56	8	6,166	321,500
	Loop 4/SCX	49	7	6,713	350,013
United Arab (UASC)	AEC	70	10	3,876	202,127
Evergreen	CES	56	8	6,937	361,741
	CEM	56	8	8,073	420,949
Mediterranean Shipping Co (MSC)	Silk Express	63	9	9,178	478,567
	Lion service	70	10	8,595	448,157
	Australia service	91	13	3,162	164,856
China Shipping	AEX 1	56	8	8,741	455,794
	PIL/Wan Hai	56	8	4,252	221,737
	Hapag-Lloyd	84	12	2,351	122,584
	CAM CGM/DAL NEMO	91	10	2,719	109,071

Source: Drewry. (2011). *Container Market, Annual Review and Forecast.* Drewry Shipping Consultants Ltd.

Table 36 - Fuel-based exhaust greenhouse-gas emission factors (IMO, NEAA)

Unit: Kg emitted/ton of fuel

Emission	IMO	NEAA*
CO	7.4	12.2
NMVOC	2.4	-
CH_4	0.3	-
N_2O	0.08	-
CO_2	3,130	3.173
SO_2	54	20
NO_X	60	68.1
PM_{10}	6.7	2.1

*the case of Medium-speed engine

Source: 1) IMO. (2009). *Second IMO GHG Study 2009*. IMO.

2) Denier R. and Hulskotte H. (2010). *Methodologies for estimating shipping emissions in the Netherlands*. Netherland Environmental Assessment Agency.

4.4. Definition of the Effects of Slow Steaming

Voyage speed is one of the fundamental factors in shipping lines when networks are designed and service routes are built (network design and fleet mix). This is because the deceleration of voyage speed has a direct influence on the service organization, net operating costs and the amount of GHG emissions that occur by ships as shown in Figure 52. In this diagram, the deceleration of voyage speed leads to changes in service organization such as transit time, turnover ratio and the required number of vessels employed on a loop. These changes affect the cost structure, service quality and level of environmental performance.

Deceleration of voyage speed leads to a decrease in fuel consumption along with the amount of GHG emissions. This has a positive influence on operating cost (*Positive effect 1*), and reduces external costs (*Positive effect 2*) in terms of the amount of GHG emissions. However, at the same time, slow steaming creates various additional costs such as increased fixed and variable costs (*Negative effect 1*), an opportunity cost (*Negative effect 2*) and increased in-transit inventory cost (*Negative effect 3*). Therefore, slow steaming creates two kinds of positive effects and three kinds of negative effects from the viewpoint of operating costs as shown in Figure 52.

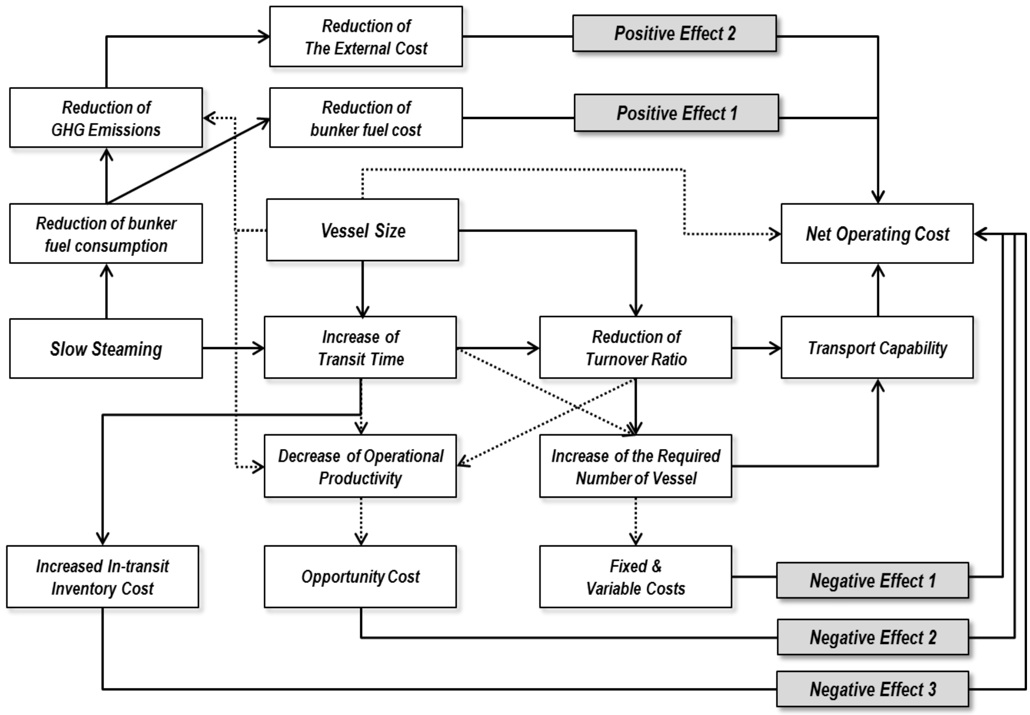


Figure 52 - The effects of slow steaming on the operating costs

As discussed above, slow steaming influences various aspects of liner shipping. In this sense, this study classifies these effects into three parts, and defines these effects using a mathematical approach from the economic perspective.

- The effects of slow steaming on the service pattern and vessel productivity
- The effects of slow steaming on the amount of GHG emissions
- The effects of slow steaming on the operating costs

4.4.1. The Effects of Slow Steaming on the Service Pattern

Total designed voyage time per voyage (*T*) is a total sum of the voyage time at sea (*VTsea*) and the voyage time at port (*VTport*), and it can be calculated by formula 1. In this formula, total designed voyage time (*T*) is sensitive to changes in the number of vessels on a loop (*Nv*). When the voyage time at port (*VTport*) is fixed, total designed voyage time (*T*) is decided by the number of vessels (*Nv*) as shown in formula 4. Therefore, as the number of vessels on a loop increases, total designed voyage time (*T*) is increased by the increase of the voyage time at sea (*VTsea*).

$$T = VTsea + VTport = 365/(52\ /\ Nv) = (365 \cdot Nv)/52 \tag{1}$$

$$VTport = ATport \cdot NCport \tag{2}$$

$$VTsea = T - VTport \tag{3}$$

$$V = Vdis_r/[(365/(52/Nv_{knr})) - VTport_{knr}\ ]\ /24 \tag{4}$$

where,

T: total designed voyage time per voyage (day)

VTsea: the voyage time at sea (days)

VTport: the voyage time at port (days)

Nv: the number of vessel (numbers)

ATport: the average port time (days)

NCport: the number of calling ports (number)

Vdis: the voyage distance (miles)

V: the voyage speed (knots)

On the other hand, when the number of vessel on a loop is fixed, the voyage time at sea (*VTsea*) is changed by the changes of voyage time at port (*VTport*). As the voyage time at port (*VTport*) decreases, the voyage time at sea (*VTsea*) is increased. Moreover, voyage speed (*V*) is sensitive to changes in the voyage time at sea (*VTsea*). When voyage distance (*Vdis*) is fixed, voyage speed (*V*) is decided by changes in the voyage time at sea (*VTsea*). Hence, the basic service factors such as turnover ratio, transit time and voyage speed can be decided by the decision of the number of vessels.

On the other hand, changes in service pattern and loop organization have a direct influence on the operational productivity of the vessels employed on a loop. In general, it is defined as a ratio of a total output of one unit to a total input (Mankiw, 2007). In the transportation sector, operational efficiency refers to the maximization of transport capability in order to deliver quality products and services to customers. In the shipping sector, vessel productivity is one of the major indexes used to evaluate the operational performance of a vessel, and it is defined as the transport volume per deadweight ton (ton/dwt) (UNCTAD, 2010). This study defines vessel productivity as the ratio of the transport volume (TEU) to the transport capacity (TEU). By the definition of slow steaming in chapter 2, the deceleration of voyage speed leads to an increase in the required number of vessels; however, total transport capacity is fixed. Hence, the transport capacity on a loop is changed by an alteration in voyage speed or an increase in the number of the vessel on a loop. Vessel productivity at different voyage speeds can be derived from the annual transport volume on a loop divided by annual transport capability at different voyage speeds on a loop, and this relationship can be expressed by formula 5.

$$VP = ATD/ATC = ATD/(Vs \times Nv \times NOv) \quad (5)$$

where,

VP: the vessel productivity (%)

ATD: annual transport demand on a loop (TEU)

ATC: annual transport capability at different voyage speeds on a loop (TEU)

Vs: vessel size (TEU)

Nv: the number of vessel on a loop (number)

Nov: the turnover ratio at specific voyage speed (number)

4.4.2. The Effects of Slow Steaming on the amount of GHG Emissions

There is a strong correlation between slow steaming and the amount of fuel consumption in liner shipping. Deceleration of voyage speed reduces bunker fuel consumption through a decrease in engine load, and it leads to a decrease in bunker fuel cost and amount of GHG emissions at the same time (Notteboom and

Vernimmen, 2008; IMO, 2009). Bunker fuel consumption is directly influenced by the main conditions of engine operation such as engine size and power, type of bunker fuel, engine load and voyage speed, and it can be derived by formula 6. Moreover, the amount of annual fuel consumption on a loop can be derived by multiplying the amount of annual fuel consumption on a single vessel by the number of employed vessels on a loop, and it can be expressed by formula 7.

$$AFCV = SFOCv \cdot EP \cdot (V_2/V_1)^3 \cdot 24/10^6 \cdot\ T \cdot Nov \qquad (6)$$

$$AFCL = SFOCv \cdot EP \cdot (V_2/V_1)^3 \cdot 24/10^6 \cdot\ T \cdot Nov \cdot Nv \qquad (7)$$

where;

AFCV: annual fuel consumption on a single vessel (ton)

AFCL: annual fuel consumption on a loop (ton)

SFOCv: the specific fuel oil consumption at specific voyage speed V (ton/knots/day)

EP: engine power (Kw)

V_2*: the changed voyage speed (10-25knots)*

V_1*: the designed voyage speed (25 knots)*

T: total designed voyage time per voyage (day)

Nov: the turnover ratio at specific voyage speed (numbers)

Nv: the number of vessel on a loop (numbers)

Changes in the amount of fuel consumption lead to changes in the amount of GHG emissions in liner shipping. The amount of GHG emissions is decided by the amount of fuel consumption on a loop and the fuel-based exhaust greenhouse-gas emission factors. During the last ten years, major international agencies and research institutes have developed emission factors based on actual data, and many scholars have attempted to estimate the amount of greenhouse-gas emissions using the emission factors (Corbett, 2003; Endersen, 2003; Eyring *et al*., 2005; Faber *el al*., 2010; Pierre, 2010; Norman *et al*., 2011). This study adopts the fuel-based exhaust greenhouse-gas emission factors developed by IMO (IMO, 2009) as shown in Table 35. The amount of GHG emissions that occur from ships at specific voyage speeds on a loop can be derived by formula 8.

$$AGHG = EF_a \cdot AFCL = EF_a \cdot \ SFOCv \cdot EP \cdot (V_2/V_1)^3 \cdot 24/10^3 \cdot \ T \cdot Nov \cdot Nv \qquad (8)$$

where;

AGHG: annual amount of GHG emissions on a loop (ton)

EFa: the emission factor of emission a (Kg emitted/tons of fuel)

AFCL: annual fuel consumption on a loop (ton)

SFOCv: the specific fuel oil consumption at specific voyage speed V (kg/hours)

EP: engine power (Kw)

V_2: the changed voyage speed (10-25 knots)

V_1: the designed voyage speed (25 knots)

T: total designed voyage time per voyage (day)

Nov: the turnover ratio at specific voyage speed (numbers)

Nv: the number of vessel on a loop (numbers)

The amount of fuel consumption and GHG emissions that occur from ships on a loop is directly influenced by weather conditions (irregular waves and wind). It is a major factor increasing the engine load and the amount of fuel consumption on a voyage. The percentage of loss of speed due to added resistance due to weather conditions can be expressed by formula 9, from which, by using the relationship ($\Delta V = V_1 - V_2$), the required voyage speed of ships in specific weather conditions (V_3) can be calculated using the following formulas. Moreover, the relationships among the three indicators of the direction reduction coefficient, the speed reduction coefficient and the ship form coefficient are as follow in Tables 37, 38 and 39 (IMO, 2009).

$$(\Delta V/V_1)100\% = \left(C_b \cdot C_u \cdot C_{form}\right) \qquad (9)$$

$$V_3 = V_1 - \left(\frac{\Delta V}{V_1} \cdot 100\%\right) \cdot \frac{1}{100\%} \cdot V_1 = V_1 - (C_b \cdot C_u \cdot C_{Form}) \cdot \frac{1}{100\%} \cdot V_1 \qquad (10)$$

where,

V_1*: the designed operating speed in clam water condition (knots, m/s), (1knots= 0.5144444 m/s)*

V_2*: the changed voyage speed (10-25knots)*

V_3*: the voyage speed in specific weather condition (m/s) (1knots=0.5144444 m/s)*

$\Delta V = V_1 - V_2$*: the speed difference (knots, m/s)*

C_b*: the direction reduction coefficient, dependent on the weather direction angle (with respect to the ship's angle) and the Beaufort number BN (Bft).*

C_u*: the speed reduction coefficient, dependent on the ship's block coefficient* C_b*, the loading condition Froude number Fn.*

C_{Form}*: the ship form coefficient, it dependent on the ship type, the Beaufort numbers BN (Bft) and the ship displacement.*

Table 37 - Relationship between weather direction and the direction reduction coefficient (C_b)

Weather direction	Direction angle (with respect to the ship's bow)	Direction reduction coefficient C_b
Head sea (irregular waves) and wind	*0*	$2C_b=2$
Bow sea (irregular waves) and wind	*30 to 60*	$2C_b=1.7-0.03(BN-4)^2$
Beam sea (irregular waves) and wind	*60 to 150*	$2C_b=0.9-0.06(BN-6)^2$
Following sea (irregular waves) and wind	*150 to 180*	$2C_b=0.4-0.03(BN-8)^2$

Source: IMO. (2009). *Second IMO Greenhouse Gas Study 2009*. IMO.

Table 38 - Relationship between the block coefficient C_B and Speed reduction coefficient (C_u)

Block coefficient C_B	Ship loading conditions	Speed reduction coefficient C_u
0.55	Normal	*1.7 - 1.4Fn - 7.4(Fn)^2*
0.60	Normal	*2.2 - 2.5Fn - 9.7(Fn)^2*
0.65	Normal	*2.6 - 3.7Fn - 11.6(Fn)^2*
0.70	Normal	*3.1 - 5.3Fn - 12.4(Fn)^2*
0.75	loaded or normal	*2.4 - 10.6Fn - 9.5(Fn)^2*
0.80	loaded or normal	*2.6 - 13.1Fn - 15.1(Fn)^2*
0.85	loaded or normal	*3.1 - 18.7Fn + 28.0(Fn)^2*
0.75	Ballast	*2.6 - 12.5Fn - 13.5(Fn)^2*
0.80	Ballast	*3.0 - 16.3Fn - 21.6(Fn)^2*
0.85	Ballast	*3.4 - 20.9Fn + 31.8(Fn)^2*

Source: IMO. (2009). *Second IMO Greenhouse Gas Study 2009*. IMO.

Table 39 - Ship form coefficient (C_{form})

Type of (displacement) ship	Ship form coefficient C_{form}
All ships (except container ships) in loaded loading conditions	$0.5BN + BN^{6.5}/(2.7\nabla^{2/3})$
All ships (except container ships) in ballast loading conditions	$0.7BN + BN^{6.5}/(2.7\nabla^{2/3})$
Container ships in normal loading conditions	$0.5BN + BN^{6.5}/(22.0\nabla^{2/3})$

Source: IMO. (2009). *Second IMO Greenhouse Gas Study 2009*. IMO.

Hence, when considering weather conditions such as the direction reduction coefficient, speed reduction coefficient and ship form coefficient, the amount of annual fuel consumption and GHG emissions on a loop at specific voyage speeds can be calculated using the formula 11 and 12. In this formula, the changed voyage speed is replaces planned voyage speed for slow steaming operation (V_2) with the voyage speed in specific weather conditions (V_3).

$$AFCL = SFOCv \cdot EP \cdot (V_3/V_1)^3 \cdot 24/10^3 \cdot T \cdot Nov \cdot Nv \quad (11)$$

$$AGHG = EF_a \cdot AFCL = EF_a \cdot SFOCv \cdot EP \cdot (V_3/V_1)^3 \cdot 24/10^3 \cdot T \cdot Nov \cdot Nv \quad (12)$$

where;

AGHG: annual amount of GHG emissions on a loop (ton)

EFa: the emission factor of emission a (Kg emitted/tons of fuel)

AFCL: annual fuel consumption on a loop (ton)

SFOCv: the specific fuel oil consumption at specific voyage speed V (kg/hours)

EP: engine power (Kw)

V1: the designed voyage speed (25 knots)

V2: the changed voyage speed (10-25knots)

V3: the voyage speed in specific weather condition (knots, m/s) (1knots=0.5144444.m/s)

T: total designed voyage time per voyage (day)

Nov: the turnover ratio at specific voyage speed (numbers)

Nv: the number of vessel on a loop (numbers)

4.4.3. The effects of slow steaming on the operating costs

The deceleration of voyage speed is helpful in reducing not only annual fuel cost but also the external costs in terms of the amount of GHG emissions by the decrease of fuel consumption. The concept of reduced annual fuel cost is defined as the difference between the annual fuel cost that occurs at designed voyage speed (V_1) and annual fuel cost that occurs at different voyage speeds (V_2). It can be expressed by formula 13, and in this formula, the voyage speed in specific weather conditions (V_3) is adopted to consider the weather conditions on a route. Moreover, annual saved fuel cost ($RFUC_V$) can be defined by multiplying the amount of annual saved fuel consumption ($ASFC$) by the fuel price per ton (FU_{price}), and it can be expressed by formula 14.

$$ASFC = AFCL_{V1} - AFCL_{V2}$$

$$= \left[\langle SFOCv \cdot EP \cdot \frac{24}{10^3}\rangle - \langle SFOCv \cdot EP \cdot (V_3/V_1)^3 \cdot \frac{24}{10^3}\rangle\right] \cdot T \cdot Nov \cdot Nv \qquad (13)$$

where;

ASFC: the amount of annual saving fuel consumption/loop (US$)

$AFCL_{v1}$: annual fuel consumption on a loop at designed voyage speed (ton)

$AFCL_{v2}$: annual fuel consumption on a loop at specific voyage speed V_2 (ton)

SFOCv: the specific fuel oil consumption at specific voyage speed V (kg/hours)

EP: engine power (Kw)

V_1: the designed voyage speed (25 knots)

V_2: the changed voyage speed (10-25knots)

V_3: the voyage speed in specific weather condition (knots, m/s) (1 knots=0.5144444.m/s)

T: total designed voyage time per voyage (day)

Nov: the turnover ratio at specific voyage speed (numbers)

Nv: the number of vessel on a loop (numbers)

and

$$RFUC_V = AFCL \cdot FU_{price} \qquad (14)$$

where;

$RFUC_V$: the amount of annual saved fuel cost (US$)

ASFC: the amount of annual saved fuel consumption/loop (US$)

FU_{price}: fuel price per ton (US$)

On the other hand, slow steaming can reduce external costs by the reduction of the amount of GHG emissions. In economics, the cost of externality is defined as a negative externality or external cost, while the benefit of an externality is defined as a positive externality or an external benefit (Mankiw, 2007). The amount of external cost can be calculated by multiplying the amount of GHG emissions that occur at specific voyage speed by the value of GHG emissions per ton on a loop, and it can be expressed by formula 15.

$$EXcost_{V_3} = (AGHG \cdot VAL_{GHG})/10^3$$
$$= \{[SFOCv \cdot EP \cdot VAL_{GHG} \cdot 24/10^3]/10^3\} \cdot T \cdot Nov \cdot Nv \qquad (15)$$

where;

$EXcost\_v_3$: external cost at specific voyage speed V_3 (US$)

$AGHG_{V3}$: annual amount of GHG emissions at specific voyage speed V_3 (ton)

Val_{GHG}: the value of CO_2 emissions per ton (US$)

SFOCv: the specific fuel oil consumption at specific voyage speed V (ton/knots/day)

EP: engine power (Kw)

T: total designed voyage time per voyage (day)

Nov: the turnover ratio at specific voyage speed (numbers)

Nv: the number of vessel on a loop (numbers)

Moreover, the reduced amount of external cost by slow steaming at specific voyage speed is calculated by the designed external cost that occurs at designed voyage speed minus the changed external cost that occurs at different voyage speeds, and this study expresses this relationship by formula 16.

$$REX_V = [(EF_a \cdot AFCL_{V1} \cdot VAL_{GHG}) - (EF_a \cdot AFCL_{V3} \cdot VAL_{GHG})] / 10^3$$
$$= \{[\langle SFOCv \cdot EP \cdot VAL_{GHG} \cdot 24/10^3 \rangle - \langle SFOCv \cdot EP \cdot VAL_{GHG} \cdot (V_3/V_1)^3 \cdot 24/10^3 \rangle]/10^3\} \cdot T \cdot Nov \cdot Nv \qquad (16)$$

where;

REX_V: the reduced amount of external cost at specific voyage speed (US$)

EFa: the emission factor of emission a (Kg emitted/tons of fuel)

$AFCL_{v1}$: annual fuel consumption on a loop at designed voyage speed (ton)

$AFCL_{v2}$: annual fuel consumption on a loop at specific voyage speed V_2 (ton)

SFOCv: specific fuel oil consumption at specific voyage speed V (ton/knots/day)

EP: engine power (Kw)

V_1: the designed voyage speed (25 knots)

V_2: the changed voyage speed (10-25knots)

V_3: the voyage speed in specific weather condition (knots, m/s) (1knots=0.5144444.m/s)

T: total designed voyage time per voyage (day)

Nov: the turnover ratio at specific voyage speed (numbers)

Nv: the number of vessel on a loop (numbers)

Val_{GHG}: the value of CO_2 emissions per ton (US$)

On the other hand, slow steaming also creates additional costs on a loop. The first costs to consider are fixed and variable costs. As the voyage speed is decelerated, the fixed costs and variable costs, except fuel cost, are increased (*Negative effect 1*). This is because slow steaming requires an increase in the number of vessels on a loop to keep its fixed and tight organized service schedule. Moreover, slow steaming creates an opportunity cost (*Negative effect 2*). This occurs because transport capability is given up through the deceleration of speed. Hence, as voyage speed decreases, opportunity cost will increase. In addition to this, slow steaming leads to an increase in in-transit inventory cost by the increase of transit time (*Negative effect 3*).

The changes in the amount of fixed costs and variable costs on a loop (*ADOP*; *Negative effect 1*) can be derived by multiplying the annual designed operating cost on a single vessel (*DOCv*) by the differences between the number of employed vessels at designed voyage speed (N_{V1}) and specific voyage speed (N_{V2}). This relationship can be formulated by formula 17.

$$ADOP_V = (N_{v1} - N_{v2}) \cdot DOC_v \quad (17)$$

where,

$ADOP_V$: the changed amount of fixed and variable costs at specific voyage speed V (US$)

DOCv: the annual designed operating cost on a single vessel (US$)

N_{v1}: the required number of vessel at designed voyage speed V_1 (number)

N_{v2}: the required number of vessel at specific voyage speed V_2 (number)

Moreover, an opportunity cost on a loop (OPP_{loop}; *Negative Effect 2*) can be calculated by multiplying an opportunity cost on a single vessel (OPP_{single}) by the required number of vessels at specific voyage speed V_2 (N_{v2}). An opportunity cost on a single vessel (OPP_{single}) is derived by multiplying changes in annual operating time (CH_{ot}) by the daily designed operating cost on a single vessel (DOC_d). Moreover, changes in annual operating time (CH_{ot}) can be calculated by multiplying the changes of turnover ratio (ΔNov) by the changes of voyage time ($\Delta Tran_{time}$) between designed voyage speed (V_1) and specific voyage speed (V_2). These relationships can be formulized by formulas 18 and 19.

$$OPP_{lv} = OPP_{single} \cdot N_{v2} \quad (18)$$

$$OPP_{sv} = CH_{ot} \cdot DOC_d = [(\Delta Nov \cdot \Delta Tran_{time}) \cdot DOC_d] \quad (19)$$

where,

OPP_{lv}: an opportunity cost on a loop at specific voyage speed (US$)

OPP_{sv}: an opportunity cost on a shingle vessel at specific voyage speed (US$)

CH_{ot}: the changes of annual operating time

ΔNov: the changes of turnover ratio by the changes of voyage speed (V_1-V_2) (number)

$\Delta Tran_{time}$: the changes of transit time by the changes of voyage speed (V_1-V_2) (days)

DOCd: the daily designed operating cost on a single vessel (US$)

Moreover, changes in the in-transit inventory cost (*IAIC*: *Negative Effect 3*) can be defined as the difference between the in-transit inventory cost at a designed voyage speed (AIC_{V1}) and the in-transit inventory cost at specific voyage speeds (AIC_{V2}), and it can be derived by formula 20.

$$IAIC = AIC_{V1} - AIC_{V2}$$
$$= Q \cdot (Tran_{V1} - Tran_{V2})/365 \cdot (D/Q) \cdot Vg \cdot Iit \quad (20)$$

where;

IAIC: the increased annual in-transit inventory cost per voyage (US$)

AIC_{V1}: annual in-transit inventory cost at designed voyage speed V_1 (US$)

AIC_{V2}: annual in-transit inventory cost at specific voyage speed V_2 (US$)

Q: the transport volume (units in in-transit inventory) in each shipment (TEU)

D: annual transport volume (TEU)

$Tran_{V1}$: the transit time at designed voyage speed V_1 (day)

$Trans_{V2}$: the transit time at specific voyage speed V_2 (day)

Vg: average value of goods per TEU (US$)

Iit: the ratio of in-transit inventory cost to total value of goods per TEU (percentage)

4.4.4. Net slow steaming effects

Slow steaming has influence on three main aspects, the service pattern and vessel productivity, the amount of GHG emissions and the operating cost directly. In particular, slow steaming creates two kinds of positive effects and three kinds of negative effects. This study defined these as the slow steaming effects in liner shipping, and classified them into two categories, the direct slow steaming effects and the indirect slow steaming effects as shown in Figure 53. The effectiveness of the slow steaming effects can be evaluated by comparison with the sum of both effects.

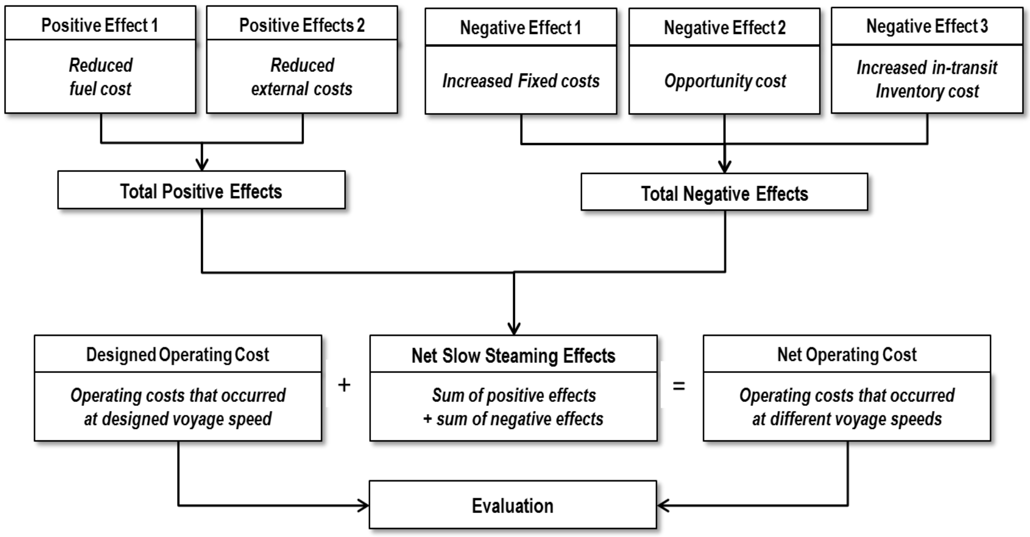


Figure 53 - Impact of slow steaming in liner shipping

Firstly, the positive effects of slow steaming on operating costs in liner shipping can be defined as the sum of the amount of annual saved fuel cost and the reduced amount of external cost by the definitions of both positive effects, and it can be expressed by formula 21 using formula 14 and 15.

$$POSI_{slow} = RFUC_V + REX_V$$
$$= \left|[\langle SFOCv \cdot EP \cdot 24/10^3\rangle - \langle SFOCv \cdot EP \cdot (V_3/V_1)^3 \cdot 24/10^3\rangle] \cdot T \cdot Nov \cdot Nv \cdot FU_{price}\right| + |\{[\langle SFOCv \cdot EP \cdot VAL_{GHG} \cdot 24/10^3\rangle - \langle SFOCv \cdot EP \cdot VAL_{GHG} \cdot (V_3/V_1)^3 \cdot 24/10^3\rangle]/10^3\} \cdot T \cdot Nov \cdot Nv| \qquad (21)$$

where;

$POSI_{slow}$: the sum of positive effects at specific voyage speed V

RFUCV: the amount of annual saved fuel consumption (US$)

REXV: the reduced amount of external cost at specific voyage speed (US$)

FU_{price}: the fuel price per ton (US$)

SFOCv: the specific fuel oil consumption at specific voyage speed V (ton/knots/day)

EP: engine power (Kw)

V_1: the designed voyage speed (25 knots)

V_2: the changed voyage speed (10-25knots)

V_3: the voyage speed in specific weather condition (knots, m/s) (1knots=0.5144444.m/s)

T: total designed voyage time per voyage (day)

Nov: the turnover ratio at specific voyage speed (numbers)

Nv: the number of vessel on a loop (numbers)

Val_{GHG}: the value of CO_2 emissions per ton (US$)

On the other hand, the negative effects of slow steaming on operating costs in liner shipping can be defined as the sums of the increased fixed and variable costs (*Negative effect 1*), annual opportunity cost (*Negative effect 2*) and the increased in-transit inventory cost (*Negative effect 3*), and it can be formulated by formula 22 using formula 17, 18 and 20.

$$\begin{aligned} NEGA_{slow} &= ADOP_V + OPP_{lv} + IAIC_{lv} \\ &= [(N_{v1} - N_{v2}) \cdot DOC_v] + [(\Delta Nov \cdot \Delta Tran_{time}) \cdot DOC_d \cdot N_{v2}] + \\ &\quad [Q \cdot (Tran_{V1} - Tran_{V2})/365 \cdot (D/Q) \cdot Vg \cdot Iit] \end{aligned} \tag{22}$$

where,

$NEGA_{slow}$: total negative effects on liner shipping by slow steaming (US$)

$ADOP_V$: the changed amount of fixed on a loop at specific voyage speed V (US$)

OPP_{lv}: an opportunity cost on a loop at specific voyage speed (US$)

$IAIC_{lv}$: the increased annual in-transit inventory cost per voyage (US$)

DOCv: the annual designed operating cost on a single vessel (US$)

N_{v1}: the required number of vessel at designed voyage speed V_1 (number)

N_{v2}: the required number of vessel at specific voyage speed V_2 (number)

ΔNov: the changes of turnover ratio by the changes of voyage speed (V_1-V_2) (number)

$\Delta Tran_{time}$: the changes of transit time by the changes of voyage speed (V_1-V_2) (days)

DOCd: the daily designed operating cost on a single vessel (US$)

Q: the transport volume (units in in-transit inventory) in each shipment (TEU)

D: annual transport volume (TEU)

$Tran_{V1}$: the transit time at designed voyage speed V_1 (day)

$Tran_{V2}$: the transit time at specific voyage speed V_2 (day)

Vg: average value of goods per TEU (US$)

Iit: the ratio of in-transit inventory cost to total value of goods per TEU (percentage)

The effectiveness of slow steaming effects can be evaluated by a comparison between the sum of the positive effects and negative effects. This study defines the difference between the positive and negative slow steaming effects, *i.e.* $POSI_{slow} - NEGA_{slow}$, as net slow steaming effect. When the positive effect of slow steaming is higher than the negative effect of slow steaming (*net slow steaming effect is higher than 0*): $POSI_{slow} - NEGA_{slow} > 0$, the operating cost can be reduced by deceleration of voyage speed on a loop. Hence, in this case, a shipping line can enjoy the slow steaming effects by the reduction of operating costs on a loop. However, in the opposite case, i.e. net slow steaming effect is lower than 0: $POSI_{slow} - NEGA_{slow} \leq 0$, the operating cost is increased by the deceleration of voyage speed on a loop. Therefore, in this case, a shipping line can be suffer losses, or maintain their operating costs, by slow steaming.

Table 40 - Net slow steaming effects

Condition of net slow steaming effects		Impact of slow steaming on the operating cost
Case 1	$POSI_{slow} - NEGA_{slow} > 0$	The operating cost is reduced by slow steaming
Case 2	$POSI_{slow} - NEGA_{slow} \leq 0$	The operating cost is increased by slow steaming

On the other hand, changes in the operating cost can be evaluated by comparison between net operating cost and the designed operating cost as shown in Figure 54. The designed operating cost is an operating cost that occurs at designed voyage speed, so it is fixed when all other conditions are equal (*ceteris paribus*). Net operating cost is an operating cost that occurs at different voyage speeds, so it is changed dynamically by changes in voyage speed. Net operating cost can be defined as the designed operating cost minus net slow steaming effects, and it can be expressed by formula 23.

$$NOC = DECO - (POSI_{slow} - NEGA_{slow}) \tag{23}$$

where,

NOC: the net operating cost at specific voyage speed (US$)

DECO: the designed operating cost that occurred at designed voyage speed (US$)

Therefore, when net slow steaming effect is higher than 0 ($POSI_{slow} - NEGA_{slow} > 0$), net operating cost can be reduced. However, when net slow steaming effect is lower than 0 ($POSI_{slow} - NEGA_{slow} < 0$), net operating cost becomes higher than designed operating cost as shown in Figure 54. Moreover, this study defines the range on the condition of $POSI_{slow} - NEGA_{slow} > 0$ as the economic range of voyage speed that can reduce operating cost by slow steaming.

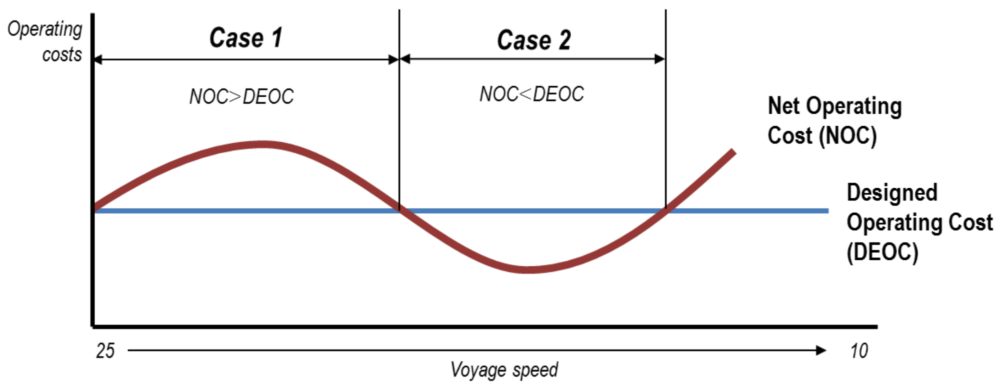


Figure 54 - Effectiveness of the slow steaming in liner shipping

4.5. Modeling

To establish a simulation model, firstly, a causal loop is designed based on the definition of slow steaming effects as shown in Figure 55. In this model, voyage speed is the fundamental factor in liner shipping service to decide the loop organization and the relationships between voyage speed and relevant factors in terms of operating costs and amount of GHG emissions. In a causal loop, the short descriptive phrases mean the elements which make up the sector and/or function, and the arrows represent the causal influences between these elements. In this causal loop, the flows of influence are connected with each other by the following mechanism.

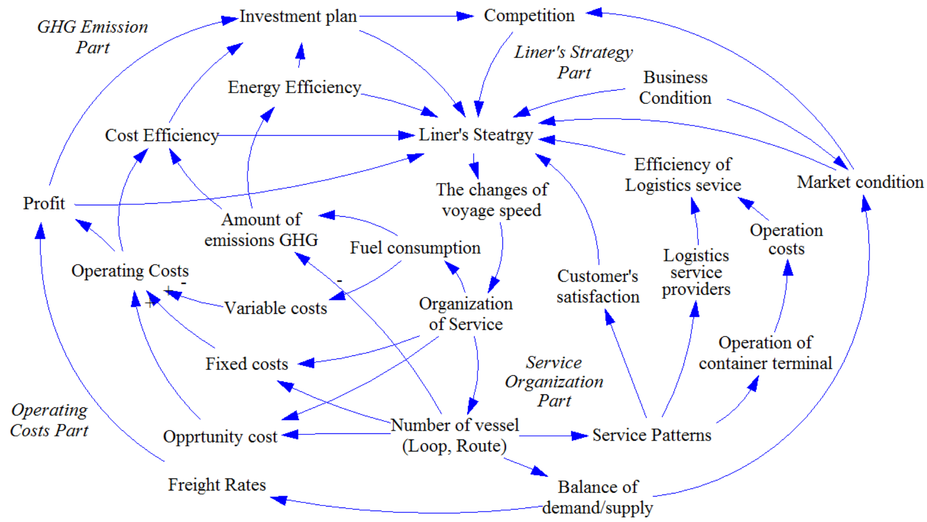


Figure 55 - Causal Loop of the slow steaming effects

In a causal loop firstly, changes in voyage speed have a direct influence on the organization of transport service such as number of vessels, turnover ratio and transit time, and it affects operating costs including fixed costs, opportunity cost and fuel cost. Changes in operating costs have influence on the revenue and profits of a shipping line, and affect, continuously, the long-term and/or mid-term policy and operational strategy of the shipping line including its investment plan. Secondly, the deceleration of voyage speed influences the amount of bunker fuel consumption positively and the amount of GHG emissions on a loop is decreased by the reduction in bunker fuel consumption. Moreover, it leads to the reduction of external cost, continuously. However, an increase in the number of employed vessels on a loop leads to increases in bunker fuel consumption, fuel cost and the external costs.

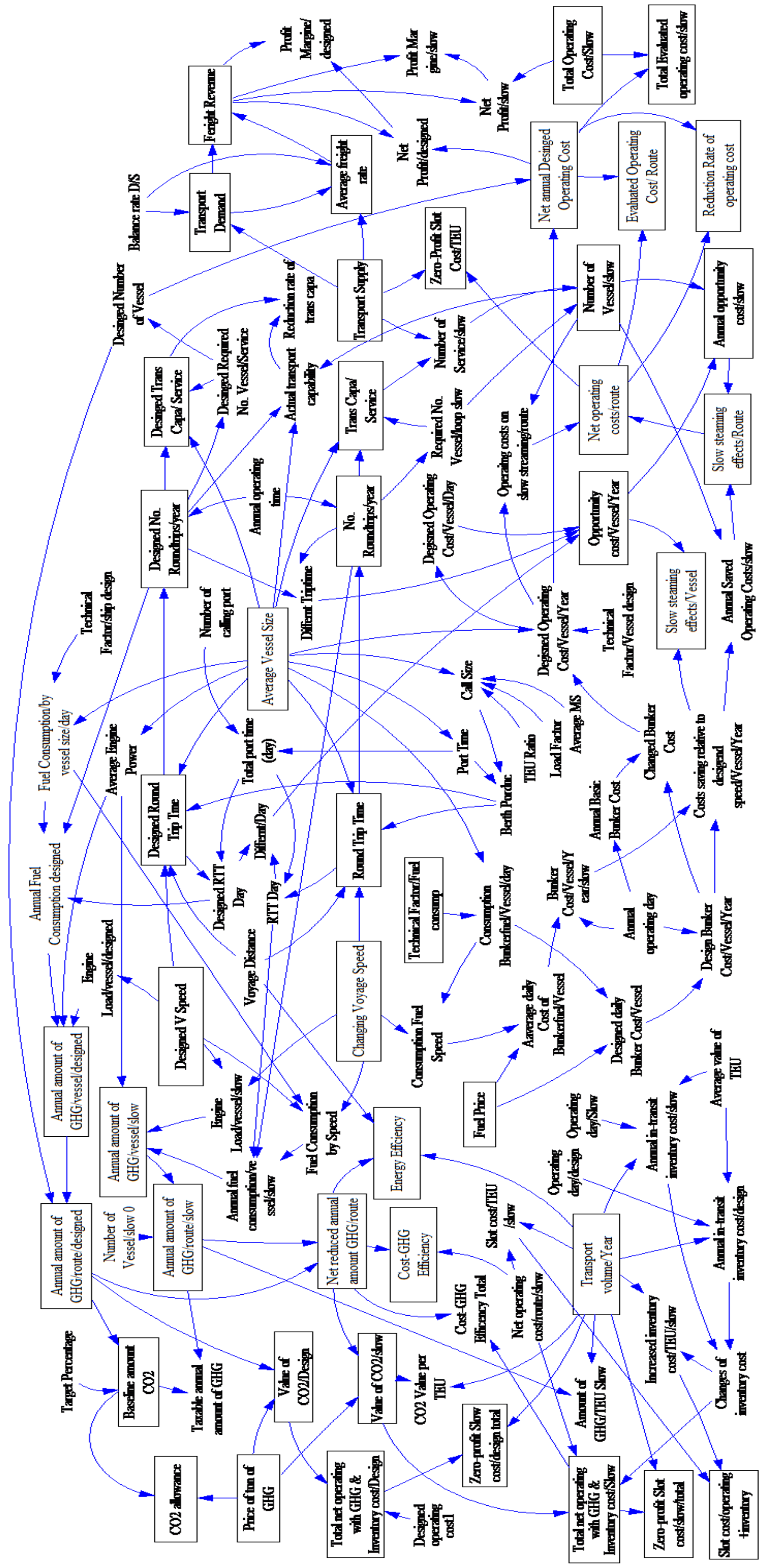


Figure 56 - Dynamic Slow Steaming Evaluation Model (DSSEM)

A dynamic simulation model (Dynamic Slow Steaming Evaluation Model: DSSEM) was designed based on a causal loop and the definition of slow steaming effects as shown in Figure 56. This model consists of 156 formulas and variables (functions and data). The aim of the simulation model is to minimize operating costs using the deceleration of voyage speed in a selected service route. The objective of this model is given as;

$$Minimize \ \sum_{krv}(DOC_{krv1} - SSE_{krv})$$

with,

$$DOC_{krv1} = \sum_{krv1}(FIC_{krv1} + FUC_{krv1} + CP_{krv1} + EX_{krv1})$$

where,

$$FIC_{krv1} = N_{v1} \cdot DOC_{krv1}$$

$$FUC_{\mathrm{krv1}} = SFOC_k \cdot EP_k \cdot 24/10^3 \cdot FU_{price} \cdot T_{\mathrm{krv1}} \cdot Nv_{krv1} \cdot Nov_{krv1}$$

$$EX_{krv1} = SFOC_k \cdot EP_k \cdot VAL_{GHG} \cdot 24/10^3 \cdot T_{\mathrm{krv1}} \cdot Nv_{krv1} \cdot Nov_{krv1}$$

$$CP_{krv1} = (DO_k \cdot VTport_r \cdot NCport_r + HA_r \cdot 2DR_{krv1} + 2CT_k) \cdot T_{krv1} \cdot Nv_{krv1}$$

and,

$$SSE_{krv} = \sum_{krv}(CHFIC_{krv} + CHFUC_{krv} + CHEX_{krv} + CHOP_{krv} + CHTI_{krv} + \mathrm{CH}CP_{\mathrm{krv}})$$

where,

$$CHCP_{krv} = (DO_k \cdot VTport_r \cdot NCport_r + HA_r \cdot 2DR_{krv} + 2CT_k) \cdot T_{krv} \cdot Nv_{kr}$$

$$CHTI_{krv} = Q_r \cdot \left((\Delta Trans\_V1_{krv} - \Delta Trans\_V2_{krv})/365\right) \cdot (D_r/Q_r) \cdot Vg_r \cdot Iit_r \cdot T_{\mathrm{krv}} \cdot Nv_{kr}$$

$$CHOP_{krv} = \Delta Nov_{krv} \cdot \Delta Tran_{krv} \cdot DOC_k \cdot T_{\mathrm{krv}} \cdot Nv_{kr}$$

$$CHFIC_{krv} = (N_{v1} - N_{v2}) \cdot DOC_{kr}$$

$$CHEX_{krv} = \{[\langle SFOC_k \cdot EP_k \cdot VAL_{GHG} \cdot 24/10^3\rangle - \langle SFOC_k \cdot EP_k \cdot VAL_{GHG} \cdot 24/10^3\rangle]/10^3\} \cdot T_{krv} \cdot Nv_{kr} \cdot Nov_{krv}$$

$$CHFUC_{krv} = \left[\langle SFOC_k \cdot EP_k \cdot \frac{24}{10^3}\rangle - \langle SFOC_k \cdot EP_k \cdot (V_3/V_1)^3 \cdot \frac{24}{10^3}\rangle\right] \cdot FU_{price} \cdot T_{krv} \cdot Nv_{kr} \cdot Nov_{krv}$$

where

k: the type of ship

l: the selected loop on route r

v: the voyage speed on route r

v1: the designed voyage speed on route r

FC_{krv}: the fixed costs on route r

FU_{krv}: the fuel cost on route r

CP_{krv}: the costs at port on route r

EX_{krv}: the external cost on route r

OP_{krv}: the opportunity cost on route r

TI_{krv}: the increased in-transit inventory cost on route r

Nov_{krv}: the turnover ratio on route r

T_{krv}: the total voyage time on route r

DOC_k: the daily running cost of k class ship on route r

$VTsea_{krv}$: the voyage time at sea on route r

$VTport_{krv}$: the port time on route r

Nv_{krv}: the number of type k ships allocated to route r

$ATport_{krv}$: the average port time on route r

$NCport_{krv}$: the number of calling ports on route r

$Vdis_r$: the voyage distance on route r

V_{1krv}: the designed voyage speed on route r

V_{2krv}: the changed voyage speed on route r

V_{3krv}: the voyage speed in specific weather condition on route r

ΔV: the speed difference on route r

Nr: the number of type k ships available

Mr: the number of voyages required per year on route r

$AFCV_{krv}$: the annual fuel consumption on route r

$AFCL_{krv}$: the annual fuel consumption on route r

$SFOCv_{krv}$: the specific fuel oil consumption on route r

EP_k: the engine power of a type k ship

Nov_{krv}: the turnover ratio (frequency) on route r

$AGHG_{krv}$: the annual amount of GHG emissions on route r

EF_a: the emission factor of emission a

FU_{price}: the fuel price per ton

Qr: the transport volume (units in in-transit inventory) in each shipment on route r

Dr: the transport volume on route r

$\Delta Tran_{krv}$: the changed transit time on on route r

Vgr: the average value of goods per TEU, given number

Iitr: the ratio of in-transit inventory cost to total value of goods per TEU, given number

DO_k: the dockage cost at port on route r

HA_r: the handling cost at port on route r

CT_k: the canal transit charges on route r

4.6. Chapter Conclusion

In Chapter 4, the effects of slow steaming on operating costs and GHG emissions were defined. Slow steaming is helpful in reducing the fuel cost and external cost by the reduction of fuel consumption. Voyage speed is an important factor in shipping service, directly influencing operating costs and GHG emissions. Deceleration of voyage speed affects the service organization with its service pattern, net operating costs and the amount of GHG emissions that occur from ships.

Slow steaming creates twin effects of positive effects and negative effects at the same time. Slow steaming leads to a decrease in fuel consumption along with the amount of GHG emissions. This influences operating costs (*Positive effect 1*) and the external costs (*Positive effect 2*) in terms of the amount of GHG emissions. However, at the same time, slow steaming creates various additional costs such as increased fixed and variable costs (*Negative effect 1*), opportunity cost (*Negative effect 2*) and increase in-transit inventory cost (*Negative effect 3*).

Therefore, net slow steaming effects are decided by the sum of both effects. Moreover, when total positive effects are higher than total negative effects, a shipping line can reduce its operating costs using slow steaming. If not, the shipping line can suffer losses due to slow steaming. On the other hand, net operating cost is decided by the net slow steaming effects. When net slow steaming effects are positive, net operating costs can be reduced. These relationships were presented by mathematic models in this chapter, and a simulation model was established using System Dynamics. In Chapter 5, various simulations are conducted using this simulation model with a focus on operating costs, the amount of GHG emissions and organization of service loops.

5. SPEED OPTIMIZATION 2: SIMULATION

5.1. Introduction

In this chapter, three aims are established. The first aim is to simulate the effects of slow steaming by changes in voyage speed with a focus on three perspectives, the loop organization (operating system) and service pattern, operating costs and the amount of GHG emissions, using a Dynamic Slow Steaming Evaluation Model (DSSEM) as shown in Figure 57.

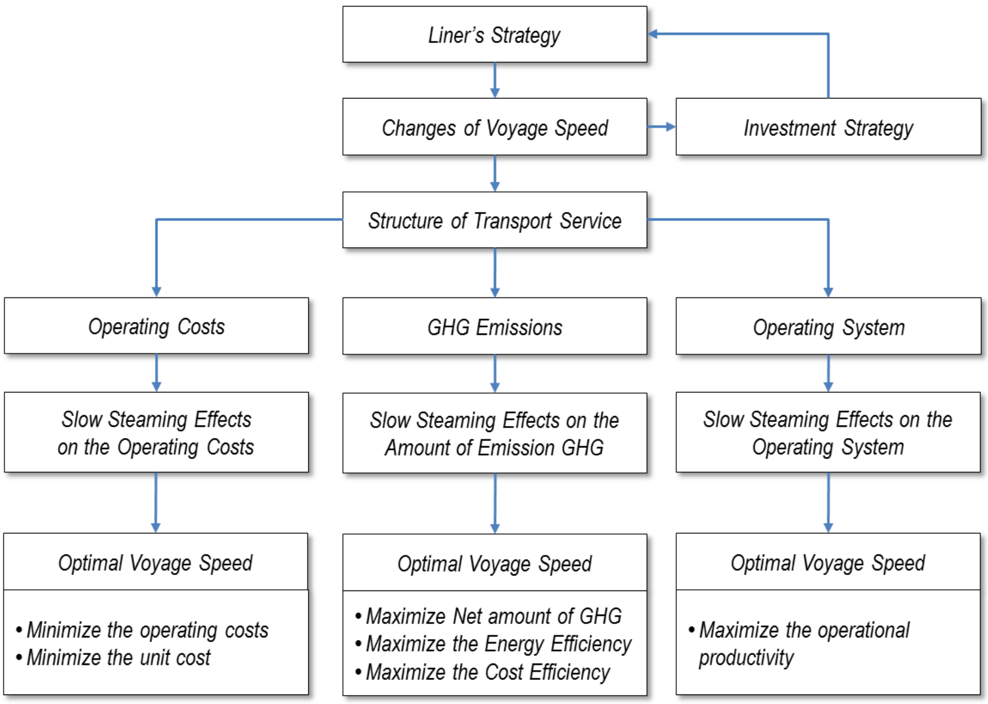


Figure 57 - Aim of simulation

The second is to find the optimum voyage speed to minimize the operating costs while considering the changes of net slow steaming effects which consist of fixed costs, fuel cost, opportunity cost, in-transit inventory cost and external cost. The third is to simulate changes in the main results by changes to the main factors such as a vessel type, fuel prices and port time through a sensitive analysis. This chapter consists of three parts. In the first part, the relationship between voyage speed and operating costs was simulated, and the relationship between voyage speed and the amount of GHG emissions was simulated in the second part. Moreover, in the third part, various sensitive analyses were conducted and provided the main results and their effects.

5.2. Simulation 1: Slow Steaming and Operating System

5.2.1. Voyage Speed and Loop Organization

Voyage speed is one of the fundamental determinants when shipping lines builds their operational strategies, and it directly affects the loop organization and service pattern on a loop. Deceleration of voyage speed influences the transit time and annual turnover ratio (frequency) on a loop. Based on these changes, the employed number of vessels on a loop can be decided considering the weekly service patterns. According to the result of the simulation, total voyage time per voyage, which consists of the voyage time at sea and port time, is increased with an increase in the voyage time at sea as shown in Figure 58. Moreover, the required number of vessels on a loop is increased while annual frequency is decreased as shown in Figure 58.

Based on the result of the simulation, the relationship between the voyage speed and the loop organization and service pattern is derived as shown in Table 48. As discussed above, by the deceleration of voyage speed, the total voyage time per voyage, transit time and required number of employed vessels are increased. However, annual frequency (turnover ratio) is decreased by the deceleration of voyage speed on a loop. These results have a direct influence on operating costs and operational productivity.

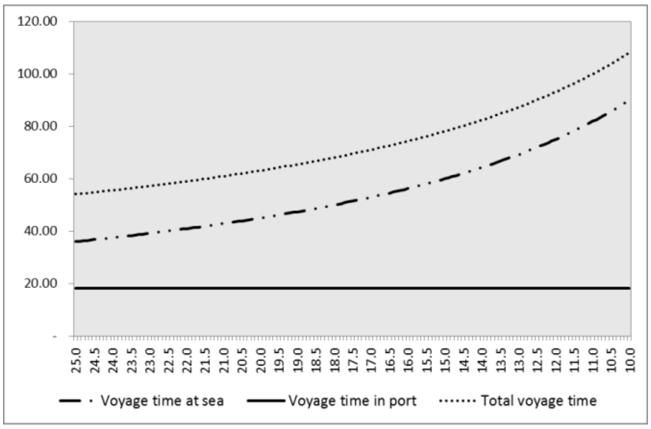


Figure 58 - Total voyage time at each voyage speed

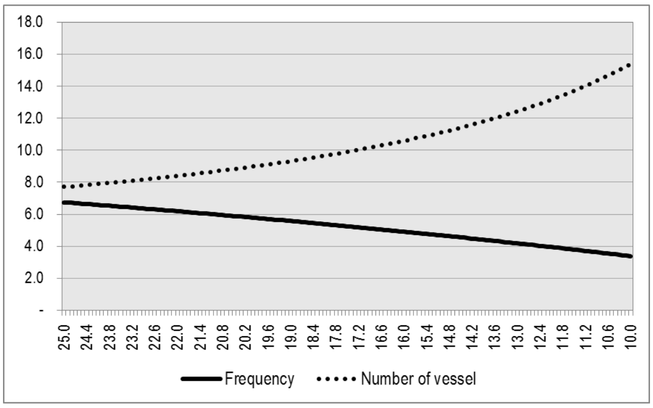


Figure 59 - Required number of vessels and frequency at each voyage speed

Table 41 - Changes of the service structure by the slow steaming on a route

	Voyage time at sea (days)	Voyage time in port (days)	Total design round-trip (days)	Frequency (times)	Required no. vessel loop (Number)
25.0	36.00	18.09	54.08	6.75	7.70
24.0	37.49	18.09	55.58	6.57	7.92
23.0	39.13	18.09	57.21	6.38	8.15
22.0	40.90	18.09	58.99	6.19	8.40
21.0	42.85	18.09	60.94	5.99	8.68
20.0	44.99	18.09	63.08	5.79	8.99
19.0	47.36	18.09	65.45	5.58	9.32
18.0	49.99	18.09	68.08	5.36	9.70
17.0	52.93	18.09	71.02	5.14	10.12
16.0	56.24	18.09	74.33	4.91	10.59
15.0	59.99	18.09	78.08	4.67	11.12
14.0	64.28	18.09	82.36	4.43	11.73
13.0	69.22	18.09	87.31	4.18	12.44
12.0	74.99	18.09	93.08	3.92	13.26
11.0	81.81	18.09	99.89	3.65	14.23
10.0	89.99	18.09	108.08	3.38	15.40

5.2.2. Voyage Speed and Vessel Productivity

In this part, the relationship between voyage speed and vessel productivity was simulated. The vessel productivity is one of the important factors in evaluating operational performance on a loop. During the last five decades, shipping lines have been focusing on the improvement of operational efficiency to reduce their operating costs and strengthen their competitiveness. So, there is a necessity to analyze the impact of slow steaming on vessel productivity to evaluate operational efficiency. In general, vessel productivity can be defined as the transport volume per deadweight ton (ton/dwt) (UNCTAD, 2010), and this study defines it as the ratio of transport volume (TEU) to transport capacity (TEU) as shown in formula 5 in chapter 4.

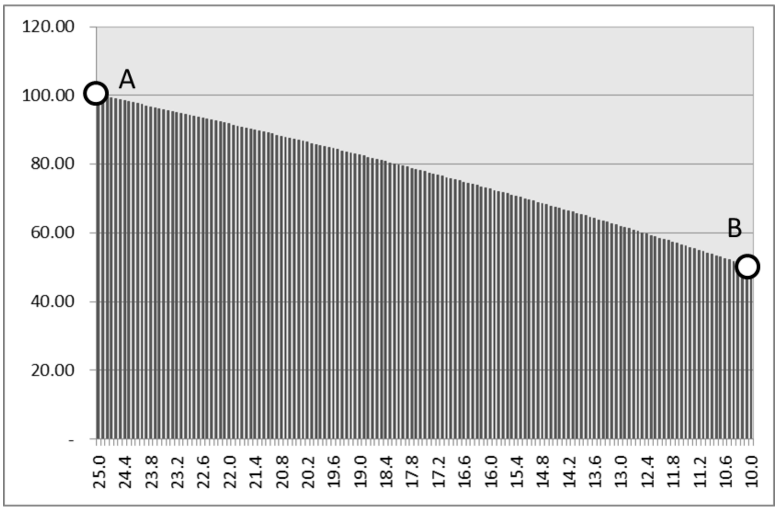


Figure 60 - Vessel productivity at the different voyage speed

According to the result of the simulation, the vessel productivity is decreased by deceleration in voyage speed as shown in Figure 60. At the highest voyage speed (25 knots, point A), the vessel productivity is maximized (the maximum vessel productivity=100) whereas, when voyage speed is decelerated by 10 knots, it is reduced by 53% (point B) in comparison with the highest voyage speed. Based on the result of the simulation, it can be defined that slow steaming is an operational technique to reduce operating costs through the deliberate reduction of operational efficiency in the condition of high fuel prices and low freight rates. Therefore, from the viewpoint of operational efficiency, there is a negative correlation between slow steaming and operational efficiency.

5.3. Simulation 2: Slow Steaming and Operating Costs

In this section, the relationship between voyage speed and operating costs is analyzed based on five effects influenced by the deceleration of voyage speed, namely, fuel cost, external cost, fixed cost, opportunity cost and inventory cost. Moreover, net slow steaming effects are simulated to evaluate net operating costs.

5.3.1. Relationship between Voyage Speed and Cost Factors

5.3.1.1. Fuel Consumption and Fuel Cost: Positive Effect 1

Annual amount of fuel consumption is sensitive to changes in voyage speed, and it is reduced by the deceleration of voyage speed as shown in Figure 61. When a service loop is operated at designed voyage speed (25 knots), 911.5 thousand tons of bunker fuel is required on a loop. However, when voyage speed is reduced from 25 knots to 18 and 10 knots, annual fuel consumption on a loop can be reduced by 47.9% (475 thousand tons) and 83.5% (150.2 thousand tons) respectively.

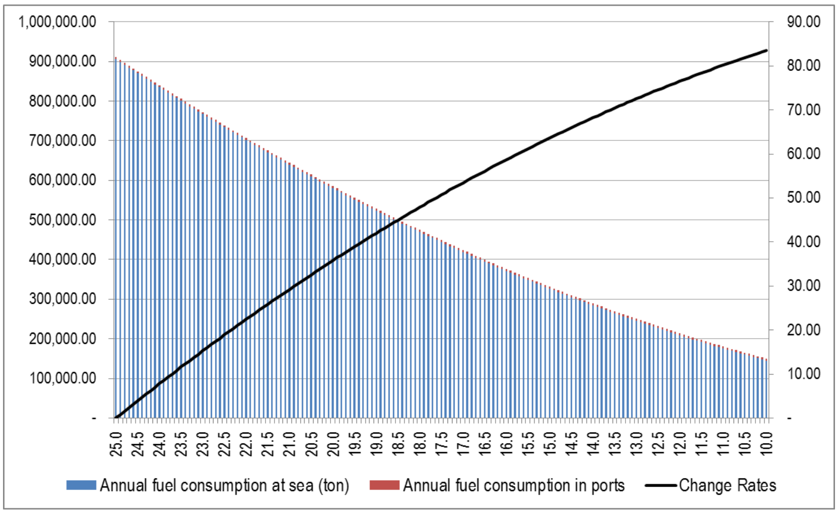


Figure 61 - Relationship between voyage speed and Fuel consumption

A reduction in annual fuel consumption leads to a reduction in annual fuel cost, directly. According to the result of the simulation, when voyage speed is reduced from 25 knots to 18 knots, annual fuel cost can be reduced from 592.5 million US$ to 308.8 million US, and its reduction rate is 47.9% as shown in Figure 62. Moreover, when voyage speed is reduced by 10 knots, annual fuel cost can be reduced by 83.52% (97.6 million US$) in comparison with annual cost at designed voyage speed. Therefore, it can be defined that there is a strong correlation between slow steaming and the reduction of fuel cost based on the result of the simulation.

Unit: Million US$/%

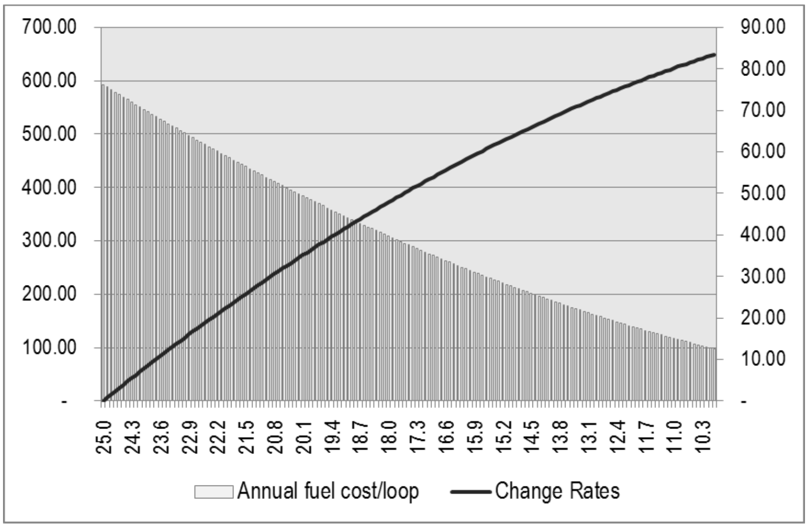


Figure 62 - Relationship between voyage speed and annual fuel cost

5.3.1.2. The external Cost: Positive Effects 2

Slow steaming has a positive influence on annual external cost as shown in Figure 64. Annual external cost is reduced by 80.2% when voyage speed is reduced from 25 knots to 18 knots, and, in this situation, the total reduced amount of external cost is 47.1 million US$ (58.7→11.6 million US$). Moreover, when voyage speed is decelerated to 10 knots, annual external cost is reduced by 98.4% (0.9 million US$). Hence, it can be defined that there is a strong correlation between slow steaming and annual external cost based on the result of the simulation.

Unit: Million US$/%

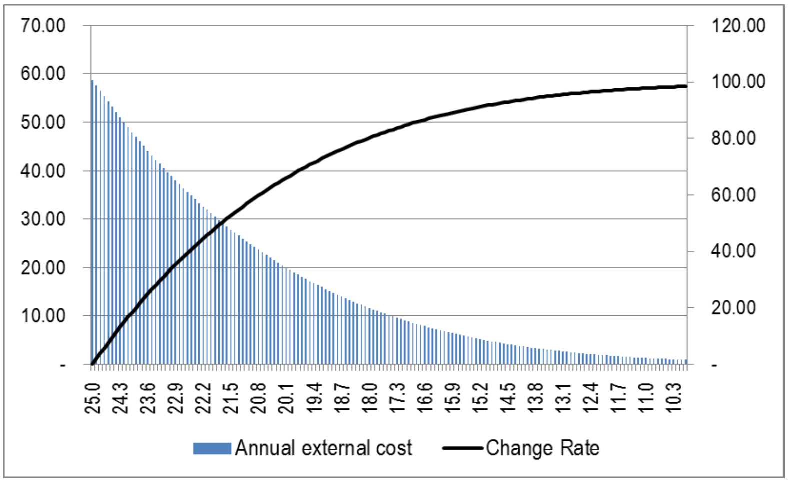


Figure 63 - Relationship between voyage speed and annual external costs

Unit: Million US$/%

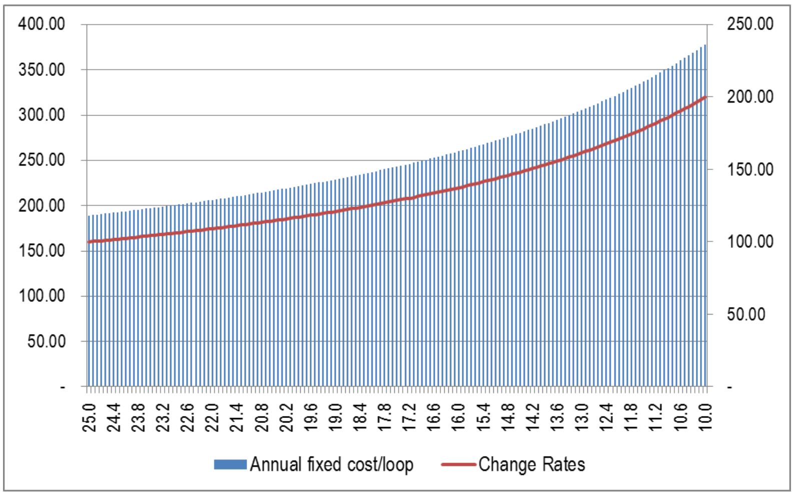


Figure 64 - Relationship between voyage speed and annual fixed costs

5.3.1.3. The Fixed Costs: Negative Effect 1

According to the result of the simulation, annual fixed costs increase rapidly with the deceleration of voyage speed as shown in Figure 63. This is because an increase in the number of vessels on a loop leads to an increase in fixed costs. When voyage speed is reduced from 25 knots to 18 knots, annual fixed costs increase from 189 million US$ to 238.1 million US$, and its increase rate is 25.9%. Moreover, when voyage speed is reduced by 10 knots, annual fixed costs increase by around 200%

(377.9 million US$) in comparison with annual cost at designed voyage speed. Hence, it can be defined that deceleration of voyage speed has a negative influence on the fixed costs.

5.3.1.4. Opportunity Cost and Inventory Cost: Negative Effect 2 and 3

Slow steaming creates an opportunity cost on a loop by the decrease of operational efficiency of fleet of ships as shown in Figure 64. According to the result of simulation, when voyage speed is reduced from 25 knots to 18 knots, an annual opportunity cost increases to 48.9 million US$. Moreover, when voyage speed is reduced by 10 knots, it increases to around 189% (188.9 million US$) in comparison with annual operating cost at designed voyage speed (25 knots).

On the other hand, the annual in-transit inventory cost is also increased by the increase of transit time on a loop. In the same condition, the annual in-transit inventory cost increases to 64.9 and 250.1 million US$ respectively. Therefore, as voyage speed decreases, the in-transit inventory cost is increased and it leads to the drop of the level of service quality from the viewpoint of customers. Hence, it can be defined that slow steaming is negative correlation between an opportunity cost and in-transit inventory cost based on the result of simulation.

Unit: Million US$

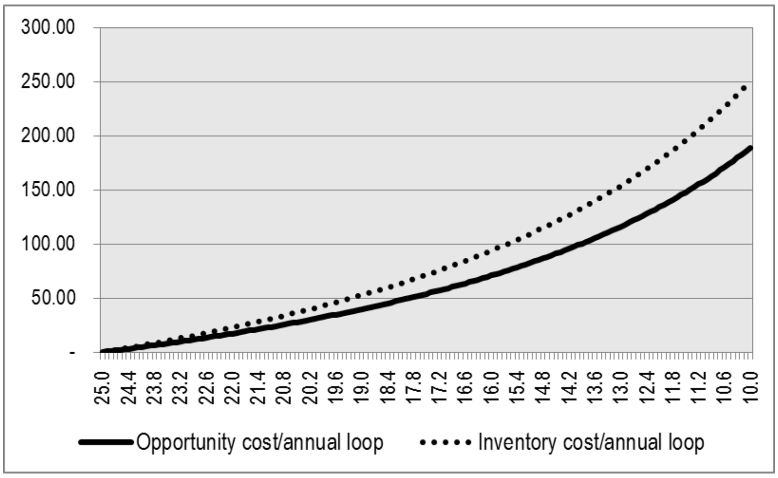


Figure 65 - Relationship between voyage speed and an opportunity cost and in-transit inventory cost

5.3.1.5. Port Cost

Port cost consists of three costs such as a dockage charge, handling charge and canal transit fee, and it is decided by three factors such as the port time, ship size and transport volume on a loop. According to the result of the simulation, when port time is fixed, port cost has not influenced by voyage speed as shown in Figure 66. This is because this model assumes that total transport volume on a loop is fixed with the organization of a loop, *i.e.* number of vessels, frequency and voyage time per voyage.

Unit: Million US$

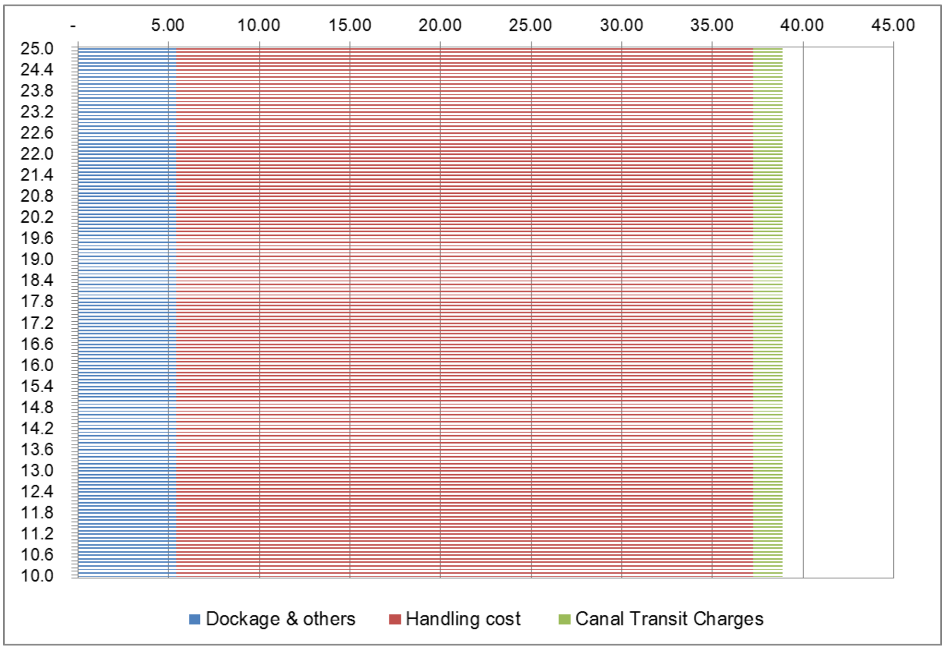


Figure 66 - Relationship between voyage speed and port cost

5.3.2. Net Slow Steaming Effects and Net Operating Cost

5.3.2.1. Net Slow Steaming Effects

Net slow steaming effects can be defined as the sum of total positive effect and total negative effect, and influence net operating costs directly. According to the result of the simulation, total positive effect is higher than total negative effect within the range of voyage speed between 25 and 11 knots, but becomes lower below 11 knots as shown in Figure 67. Therefore, it can be concluded that slow steaming is helpful to reduce operating costs only within the speed range of 25 and 11 knots based on the result of the simulation.

Unit: Million US$

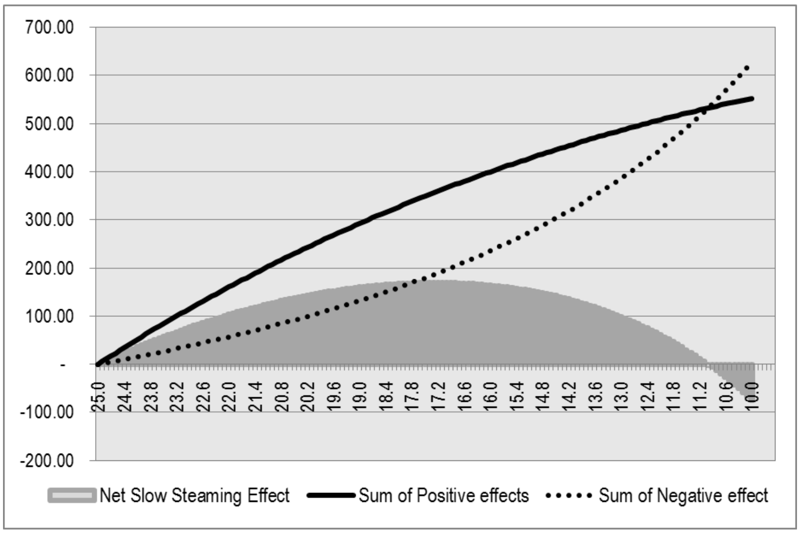


Figure 67 - Net Slow Steaming Effects in each Voyage Speed

5.3.2.2. Net Operating Cost

The designed operating cost curve and net operating cost curve were derived to verify the effectiveness of slow steaming and to find the optimum voyage speed. According to the result of the simulation, the designed operating cost is fixed, and the net operating cost curve is 'U' shaped as shown in Figure 68. In this diagram, net operating cost is lower than the designed operating cost within the range between point A and point C (25-11 knots), whereas it becomes larger in another range between point C and point D (11-10 knots).

Based on the results of the simulation, some definitions can be derived as follows. Firstly, it can be defined that slow steaming is not always helpful in reducing operating costs on a loop. Secondly, the economic range of voyage speed is decided within the range between 25 and 11 knots. Therefore, a shipping line can reduce its operating cost just within this range of voyage speed using slow steaming. On the contrary, when shipping lines control their voyage speed to below 11 knots, slow steaming may cause an increase in their operating cost on a loop. Thirdly, the optimum operating cost on a loop is decided at point B, and the optimum voyage speed is also decided at 17.2 knots. Point B is the lowest point of the net operating cost curve on the condition of *NOC-DEOC* ≤ 0. Therefore, when shipping lines control their voyage speed at 17.2 knots, they can minimize their operating cost on a loop using slow steaming.

Unit: Million US$

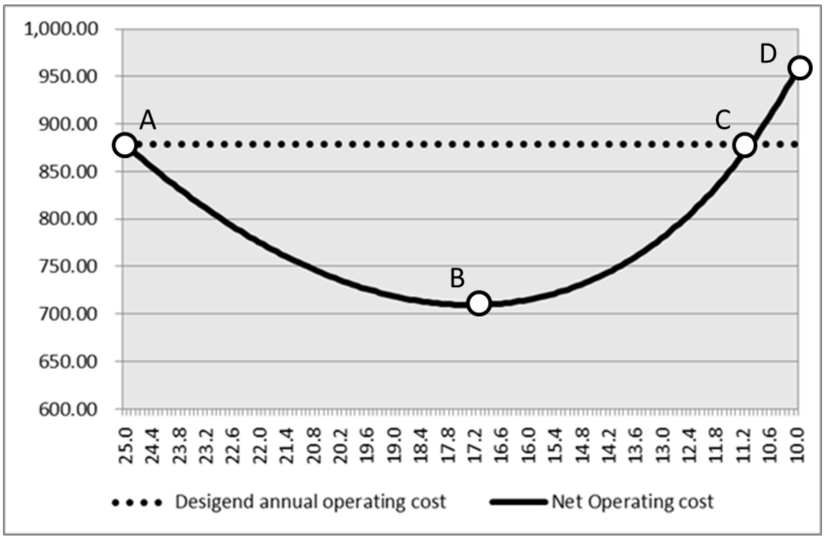


Figure 68 - Designed operating cost and net operating cost

Unit: US$

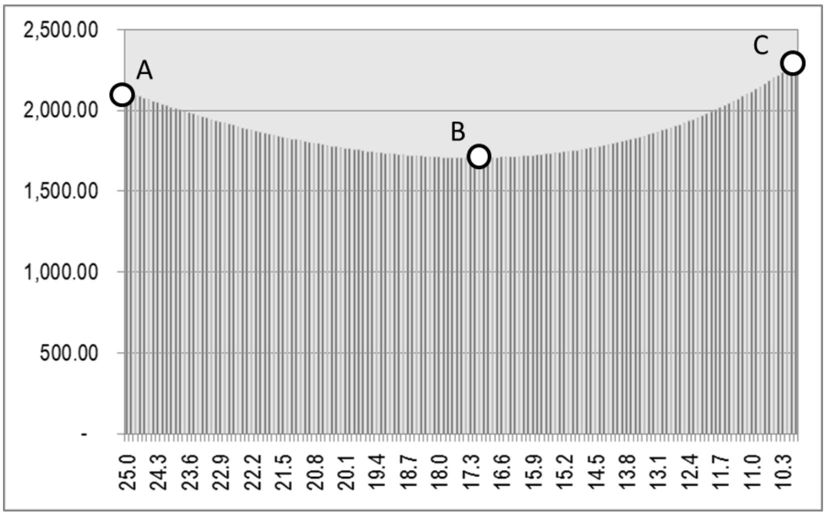


Figure 69 - Zero-profit slot cost

Reduced operating cost leads to a decrease in zero-profit slot cost as shown in Figure 69. The zero-profit slot cost is the cost per slot in the condition of zero profit, so it means an average cost per unit (TEU). The zero-profit slot cost is minimized at point B (17knots) and it is 1,705 US$. Hence, if the freight rate is lower than the zero-profit slot cost, a shipping line can suffer losses. This shows why shipping lines have experienced huge losses during the last three years.

5.3.3. Sensitivity Analysis

A sensitive analysis was conducted using the system dynamics game approach to analyze how much the slow steaming effects are influenced by the changes of related factors of the increase of ship size and the changes of value of CO_2 emissions on a loop. The basic aim of a sensitive analysis is to find the special feature of the slow steaming effects through the changes of related factors in terms of the operating costs and environmental performance in liner shipping.

5.3.3.1. Sensitive analysis 1: the slow steaming effects and ship size

Nowadays, shipping lines adopted slow steaming as their major operating strategy on major routes, and they have successively increased their employed vessel size focusing on the Super Post-Panamax ship. According to the research of Alphaliner (Alphaliner, 2012), the proportion of Super Post-Panamax Ships (larger than 10,000 TEU) in all container ships will rise from 6.2% in 2010 to 17.4% in 2014 based on capacity. Moreover, it will exceed the proportion of the Post-Panamax Ship (17.2%; larger than 7,500 TEU) in 2014. Therefore, if there is a positive correlation between both effects, as vessel size increases, the positive effects of slow steaming will be increased. However, if there is a negative correlation, it is required that liners change or improve their strategies.

In sensitive analysis 1, the changes of operating costs by the increase of vessel size have been simulated. This analysis assumes that shipping line can increase their vessel size from 8,000 TEU to 14,000 TEU, and other condition is fixed. According to the result of the simulation, as the average vessel size on a loop increases, the total positive effect curve and the total negative effect curve shift upward at the same time as shown in Figure 70. Moreover, it leads not only to an increase in the scale of net slow steaming effects but also to the expansion of the economic range of voyage speed as shown in Figure 71.

Unit: Million US$

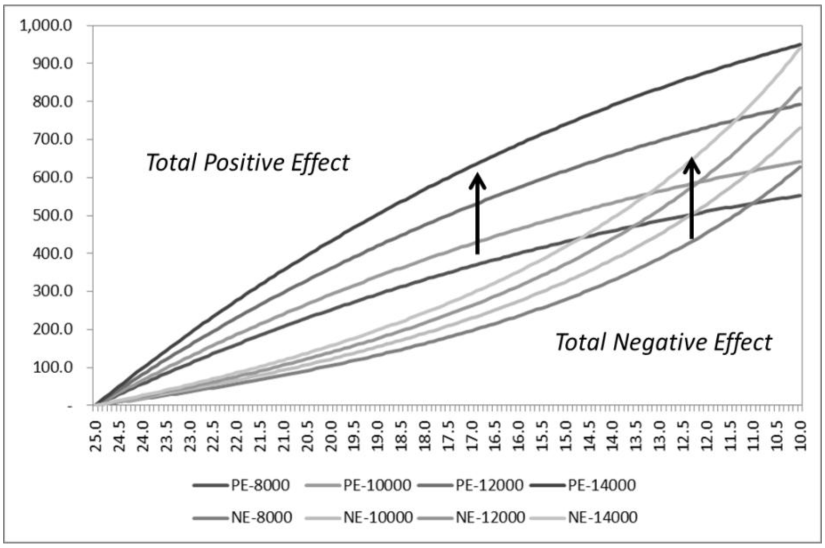


Figure 70 - The changes of positive & negative effects

Unit: Million US$

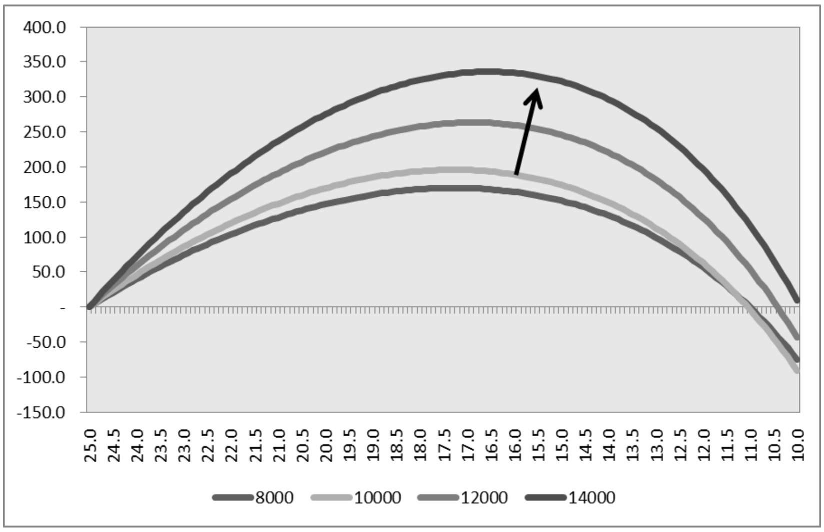


Figure 71 - The changes of net slow steaming effects at different types of vessels

The result of first analysis (Figure 70) shows us that the increase of vessel size, with the transport volume and service schedule are fixed, leads to the increase of both effects, *i.e.* positive effect and negative effects, at the same time. Moreover, the second diagram (Figure 71) shows us there is a positive correlation between the increase of vessel size and net slow steaming effects on a loop. However, the enlargement of vessel size has a negative influence on the operating cost on a loop. According to the result of the simulation, as the average vessel size increases, the net operating cost is also increased as shown in Figure 72. In this diagram, when the vessel size is increased from 8,000 to 14,000 TEU, the net operating cost curve shifts upward, and the optimum operating cost is increased by 18% (from point F to point E).

Moreover, the economic range of voyage speed is reduced from the range between point A and point D (25-11 knots) to the range between point B and point C (22.5-14.8 knots). However, when the vessel size is increased more than 12,000 TEU degrees, net operating cost becomes larger than the designed operating cost at all different voyage speeds (*NOC–DEOC* > 0). Hence, it can be defined that there is a negative correlation between the enlargement of vessel size and net operating cost on a loop based on the result of the simulation.

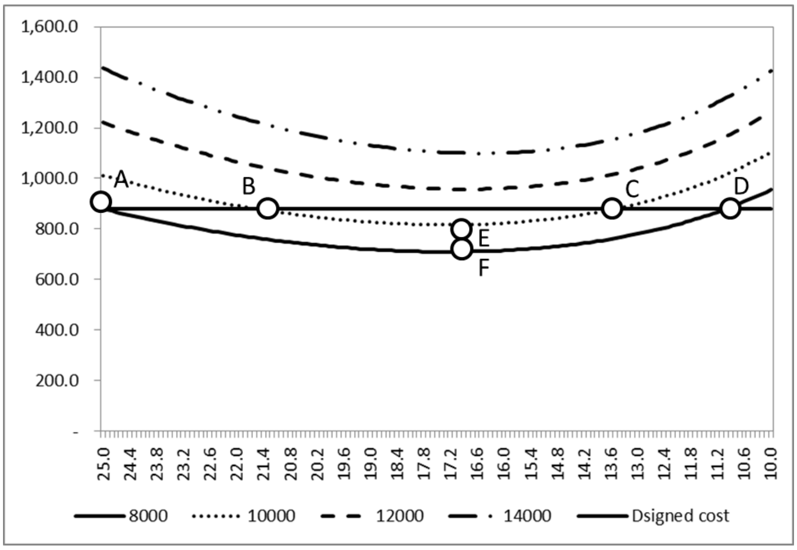


Figure 72 - Changes of net operating cost at different types of vessel

5.3.3.2. Sensitive analysis 2: the slow steaming effects and value of CO_2 emissions

The aim of sensitive analysis 2 is to analyze how much the operating cost is changed by the changes of the value of CO_2 emissions. Regarding the value of CO_2 emissions, many relevant institutes of government in each country and scholars estimated the value of CO_2 emissions in order to calculate the amount of carbon credit in 'Cap and Trade'. The U.S. House Energy and Commerce Committee estimated the value of CO_2 emissions as 10US$/Ton in 2012, and they have a plan to increase it to 17US$/Ton in 2015 (Lomax, 2009). In the case of EU Committee, they estimated the value of CO_2 emissions as 23 Euros/Ton in 2008, and they announced that it is possible to increase it to 26-40 Euros/Ton in 2015.

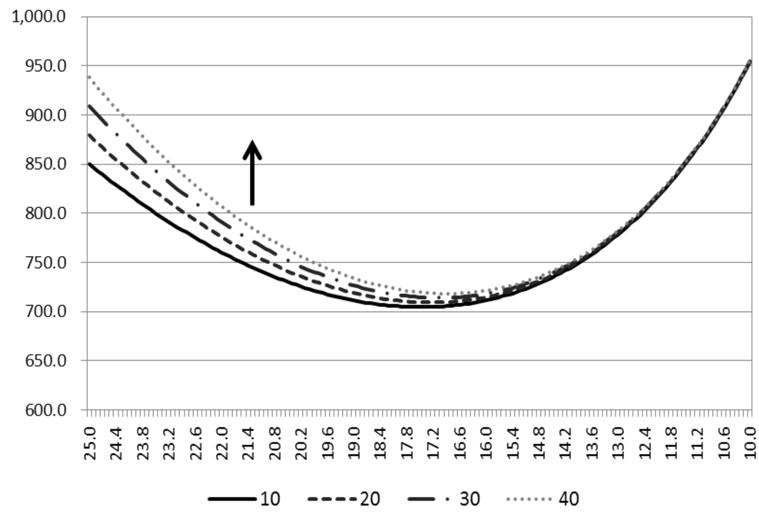


Figure 73 - Changes of net operating cost in each value of CO_2 emissions

A sensitive analysis 2 focused on how much the operating cost is changed by the changes of the value of CO_2 emissions, and assumed that the value of CO_2 emissions is changes within the range between 10~40US$/Ton. According to the result of analysis, as the value of CO_2 emissions increases, the operating cost is increased also as shown in Figure 73. Moreover, when the value of CO_2 emissions is increased from 10 to 40 US$/Ton, the optimal voyage speed became lower from 17.5 knots to 16.8 knots. This result shows us the increase of the value of CO_2 emissions is one of the causes of the increase of operating cost. Moreover, the increase of operating cost by the increase of the value of CO_2 emissions leads to the reduction of optimal voyage speed. Therefore, if the value of CO_2 emissions is increased, shipping line has to decelerate the voyage speed in order to minimize their operating cost.

5.3.4. Decision of operational strategy

Recently, leading shipping lines have been increasing their fleet sizes on major routes by charter and new order based on the Super Post Panamax Ship, and preparing to reduce voyage speed to 15 knots. The main objectives of this strategy are to achieve the three goals of the economies of vessel size, the slow steaming effects and the reduction of GHG emissions at the same time. However, according to the results of the simulation in this study, it is not an efficient strategy because operating costs can be reduced just within the economic range of voyage speed (25-11knots) using slow steaming. Moreover, the slow steaming effects have a negative correlation with increase in vessel size. Then, how does a shipping line establish or improve its fleet mix, considering both strategies of slow steaming and enlargement of vessel size?

According to the results of the simulation, when the average vessel size on a route is 8,000 TEU, the optimal voyage speed is decided at 17.2 knots. Moreover, when the voyage speed is controlled within the economic range of voyage speed (25-11 knots), shipping lines can reduce their operating costs using slow steaming. By contrast, if liner companies control the voyage speed outside of the economic range of voyage speed (11-10 knots), their operating cost is increased by the slow steaming. This relationship can be illustrated by the diagram in Figure 74. Moreover, there is a negative correlation between operating costs and increase in vessel size. According to the result of the simulation, in spite of the economies of vessel size, the more vessel size is increased the more the operating costs and the unit costs are increased on a route. This relationship is expressed by the diagram in Figure 75.

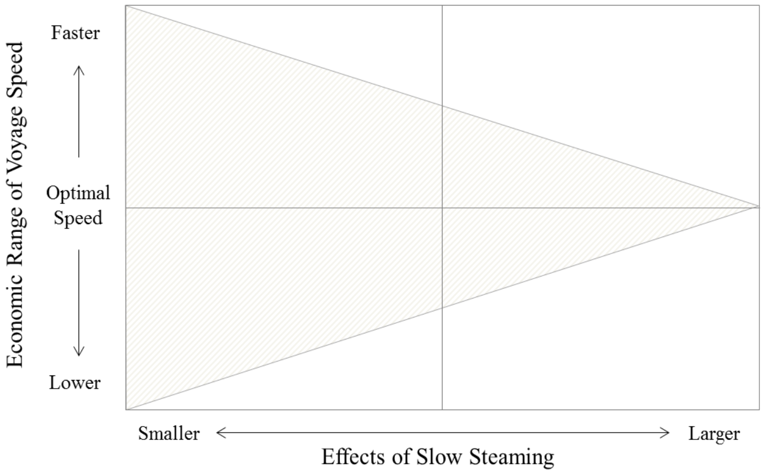


Figure 74 - Relationship between voyage speed and net operating cost

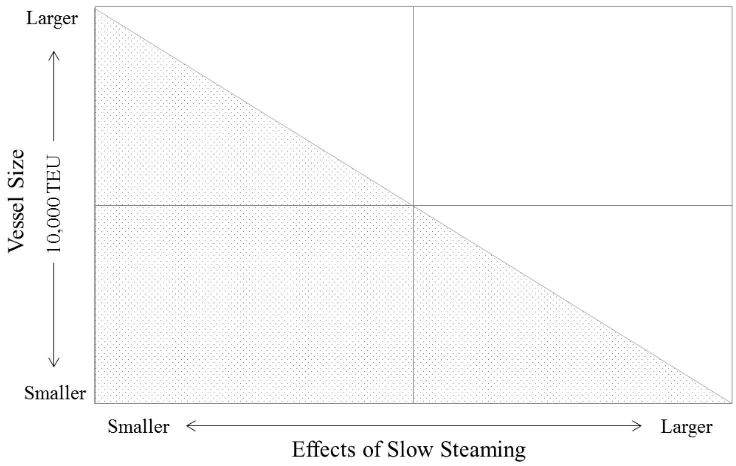


Figure 75 - Relationship between net operating cost and vessel size

To find the best strategy in terms of the relationship between voyage speed and vessel size, two diagrams, Figures 74 and 75, are combined, and the practicable strategy of shipping lines is classified in four combinations based on the voyage speed, the vessel size and the operating costs as shown as Figure 76. The area that overlaps the two diagrams represents the benefit to shipping lines of slow steaming effects and the economies of vessel size.

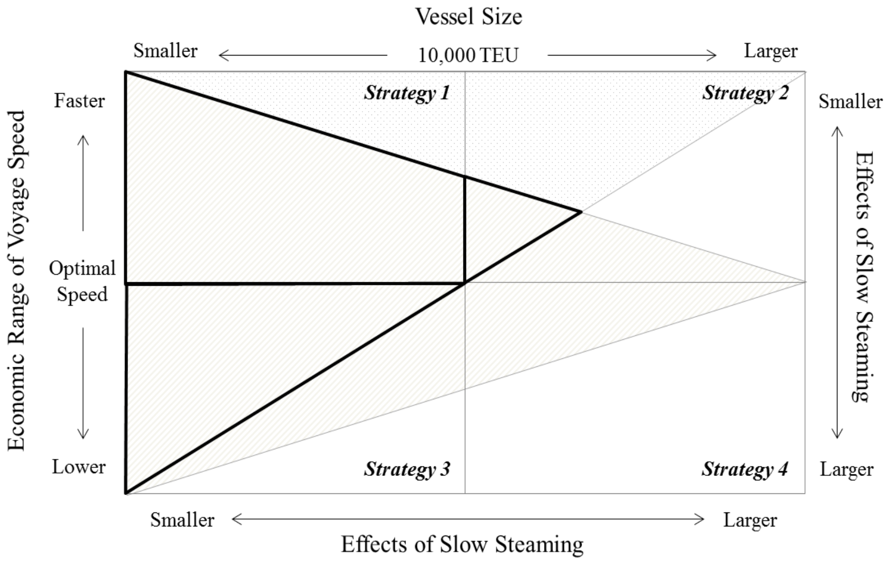


Figure 76 - Alternatives of operating strategies for liners

In this diagram, the best strategy in terms of voyage speed and vessel size for shipping lines is 'Strategy 1', and the second best strategy is 'Strategy 3'. Therefore, when shipping lines control their voyage speed within the range of voyage speed (25-17.2 knots) and vessel size within the range between 8,000 and 10,000 TEU class, shipping lines can organize the best service for minimizing the operating costs and unit cost. Moreover, when shipping lines decelerate the voyage speed to the range of 17.2-10 knots and employ the ships that within the range between 8,000 and 10,000 TEU class (strategy 4), they can reduce their operating costs however its amount is smaller than strategy 1. On the contrary, when shipping lines decelerate the voyage speed to the range of 17.2-10 knots and increase the employed vessel size to more than 10,000 TEU (strategy 4), it is difficult to enjoy benefits by using slow steaming.

5.4. Simulation 3: Slow Steaming and GHG Emissions

This section started with three basic questions about the impact of slow steaming as follows. The first question was how much can CO_2 emissions be reduced by slow steaming? If slow steaming is really helpful in reducing the amount of CO_2 emissions, there is a need to evaluate how much CO_2 emissions can be reduced by slow steaming in liner shipping. This is because the estimation of the amount of CO_2 emissions in the market is important to liners and policy makers, *i.e.* IMO and governments, as basic information for developing operating strategies and relevant emission policies.

Secondly, is it true that, as voyage speed reduces the operating costs, the amount of CO_2 emissions can be reduced at the same time? If this is true, liners will definitely decelerate their voyage speed as far as possible as to increase their profits and improve the level of environmental performance. However, if not, liners will concentrate on increasing their profits and not consider the environmental factors. Moreover, IMO cannot force liners to reduce CO_2 emissions without taking into consideration their economic situation. Finally, with the slow steaming strategy, how can liners reduce the amount of CO_2 emissions to the maximum level while minimizing their operating costs?

Unit: million Tons

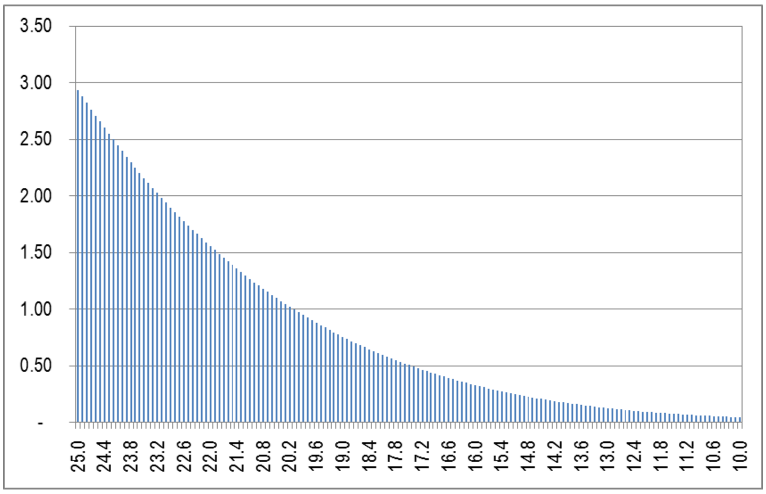


Figure 77 - Relationship between voyage speed and CO_2 emissions

5.4.1. Relationship between slow steaming and GHG emissions

In this section, the environmental impact of slow steaming on liner shipping is analyzed using SDEEM. Firstly, the relationship between the voyage speed and the amount of CO_2 emissions was derived as shown in Figure 77. According to the result of the simulation, as voyage speed is decelerated, the amount of CO_2 emissions is decreased rapidly on a loop. The outcome shows that there is a strong correlation between slow steaming and a reduction of the amount of CO_2 emissions, and it is remarkably consistent with previous findings.

5.4.2. GHG emissions elasticity of voyage speed

The amount of CO_2 emissions is not reduced in proportion to the changes of voyage speed. This means that the amount of CO_2 emission elasticity of voyage speed is different at each voyage speed. Hence, in this section, the amount of CO_2 emission elasticity of voyage speed at each voyage speed is simulated. According to the result of the simulation, the amount of the CO_2 emission's elasticity of the voyage speed is different at each voyage speed as shown in Figure 78. In the voyage speed range between 25 knots and 14 knots (25 *knots<voyage speed<14 knots*), the elasticity of each point is elastic (*e>1*), and it becomes unit elastic (*e=1*) at 14 knots.

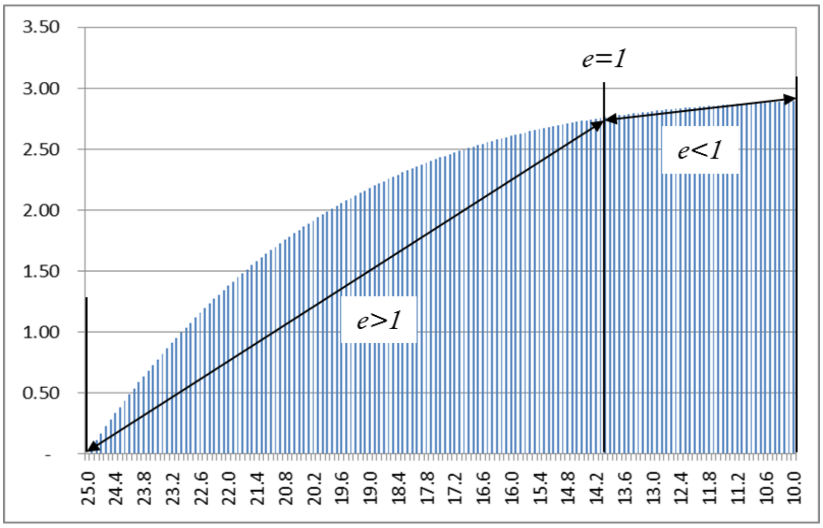


Figure 78 - The amount of CO_2 emissions elasticity of voyage speed

However, it is changed to inelastic (*e<1*) between 14 knots and 10 knots (*14 knots<voyage speed<10 knots*). Therefore, in the elastic range and at the point of unit elastic, the amount of CO_2 emissions can be reduced sharply on a loop by slightly decelerating the voyage speed. On the contrary, in the range of inelastic, even if liners reduce the voyage speed by the same degree as in the above case, they cannot reduce the amount of CO_2 emissions as much as in the elastic range. Hence, the amount of CO_2 emissions can be reduced efficiently by slow steaming within the range of 25-14 knots. In this sense, this study defines this range of voyage speed (25-14 knots) as the efficient range of voyage speed (EFRVS) that can reduce the amount of CO_2 emissions efficiently on a loop through slow steaming.

5.4.3. Evaluation of the changes of CO_2 emissions

On the other hand, a decreasing rate of the amount of CO_2 emissions at different voyage speeds was derived as shown in Figure 79. According to the result of the simulation, the amount of CO_2 emissions is not decreased in direct proportion to changes in voyage speed. Moreover, when voyage speed is controlled at lower than 22 knots, the carbon emissions reduction target of IMO can be fulfilled (point A). In this sense, when considering an average voyage speed on the Asia-North Europe route (15-18 knots), 89-97% of CO_2 emissions, *i.e.* between point B and point C, have been reduced already by slow steaming on this route. Hence, it can be estimated that liners have contributed significantly to reducing the amount of CO_2 emissions by introducing slow steaming on major routes. Hence, this study defines the specific range of voyage speed (22-10 knots) as the political range of voyage speed (PRVS) that can fulfill the carbon emissions reduction target of IMO.

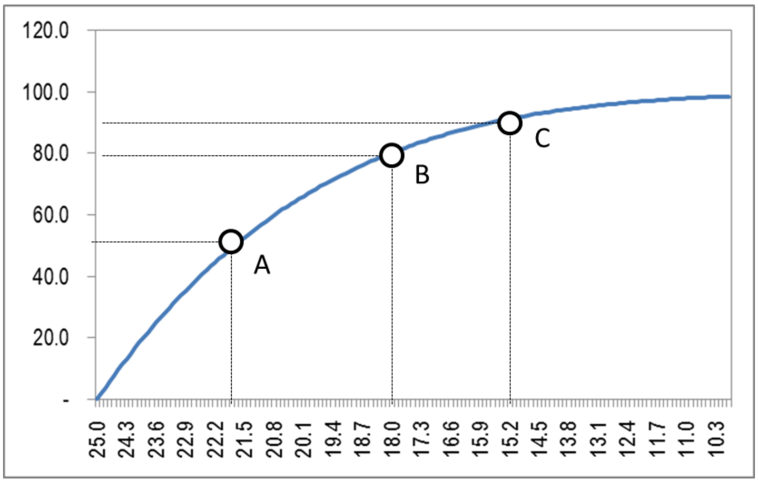


Figure 79 - Decreasing rate of CO_2 emissions at different voyage speeds

5.4.4. Selection of the optimal voyage speed

As discussed above, slow steaming influences the amount of CO_2 emissions positively on a loop. However, the net operating cost is not always reduced by the deceleration of voyage speed on a loop, and the amount of CO_2 emissions elasticity of voyage speed is not always elastic. However, from the liner's perspective, the ultimate goal of the adoption of slow steaming is the maximization of their profits by the reduction of operating costs while fulfilling the minimum level of the carbon emissions reduction target of IMO. For this reason, the aim of this section was established to find the optimal voyage speed as a solution to maximize the reduction of CO_2 emissions at the lowest operating cost while satisfying the carbon emissions reduction target of IMO.

To achieve this aim, firstly, the concept of the strategic range of voyage speed (SRVS) was introduced as a condition of speed range for selecting the optimal voyage speed. This can be defined as the specific speed range that fulfills the economic, political and efficiency conditions, and it can be decided at the range of voyage speed that covers all three ranges which are the economic range of voyage speed (ECRVS: 25-11 knots), the political range of voyage speed (PRVS: 22-10 knots) and the efficient range of voyage speed (EFRVS: 25-14 knots). Hence, SRVS was decided at the range between 22 knots and 14 knots as shown in Figure 80.

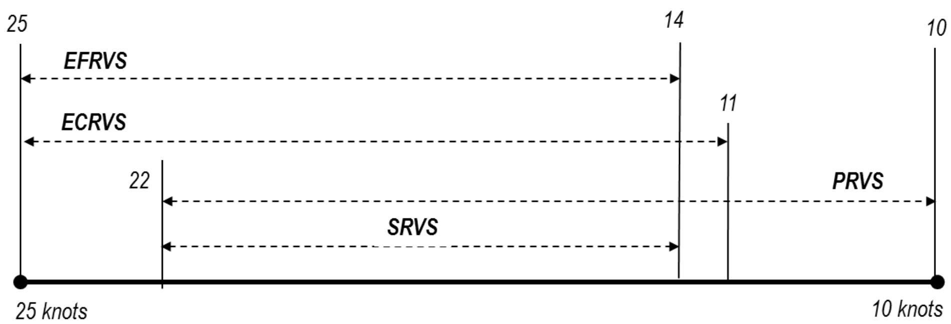


Figure 80 - Strategic range of voyage speed (SRVS)

On the other hand, the concept of the Cost-Energy Efficiency Indicator (CEEI) was established. This can be defined as the ratio of the annual net reduced amount of

CO_2 emissions to the annual net operating cost on a loop. Hence, the higher the CEEI index, the more the cost-energy efficiency increases on a loop, and liners can maximize the reduction of the amount of CO_2 emissions by minimizing the operating cost on a loop at the highest CEEI index. The CEEI index can be expressed by the following formula.

$$CEEI = \frac{\left[\left(\left(SFOCV \cdot EP \cdot Od \cdot 52 \cdot 24/10^6\right) - \left(SFOCV \cdot EP \cdot \left({}^{AVS}/_{DVS}\right)^3 \cdot Od \cdot 24/10^6 \cdot 52\right)\right) \cdot \left(2 \cdot \left[\left(\frac{VD}{CVS}\right) + \frac{2 \cdot AVS}{ABP}\right]\right)\right]}{\left[(365 \cdot 24) \cdot \left(DEOC + (CFC - ADOP - OPCL)\right)\right]}$$

where;

NRMC: annual net reduced amount of CO_2 emissions on a loop (M ton)

NOC: annual net operating cost on a loop (M US$)

SFOCv: specific fuel oil consumption at different voyage speed (ton/knots/day)

EP: engine power (Kw)

OD: the proportion of in-transit inventory cost in value of cargo (TEU)

AVS: changed voyage speed (10-25knots)

DVS: designed voyage speed (25 knots)

VD: voyage distance (mile)

AVS: average vessel size (TEU)

ABP: average berth productivity (TEU/Hr)

The CEEI indexes at different voyage speeds were derived by simulation, and expressed as the '∩' shaped curve with the strategic range of voyage speed (SRVS) as shown in Figure 81. In this diagram, the optimal voyage speed was decided at point B (17.4 knots). Hence, when liners decelerate voyage speed from 25 knots to 17.4 knots, they can minimize the amount of CO_2 emissions at the lowest operating cost thus satisfying the reduction target of IMO on a loop. On the other hand, when liners control their voyage speed to 18.6 knots (point A), even though the net reduced amount of CO_2 emissions decreases, they can minimize their operating cost thus satisfying the reduction target of IMO on a loop. Moreover, liners can reduce the maximum level of CO_2 emissions at 14 knots.

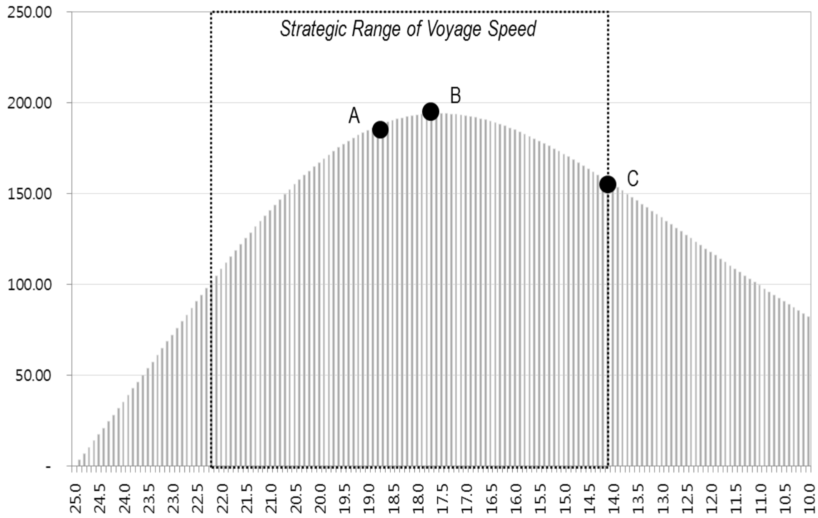


Figure 81 - CEEI curve at different voyage speeds

5.4.5. Sensitive Analysis

In this part, a sensitive analysis was conducted using the system dynamics game approach to analyze the relationship between slow steaming and the enlargement of vessel size in respect of three factors, namely, the amount of CO_2 emissions, net operating cost and the CEEI index. As discussed above, in recent times liners have been focusing on two different strategies, *i.e.* slow steaming and the enlargement of vessel size, as their operating strategies to reduce operating costs and to improve the level of environmental performance. Hence, if there is a positive correlation between both strategies, it would be to their advantages to achieve their goals. However, if not, it is required that liners consider changes and/or improvements to their operating strategies.

According to the results of the simulation, from an environmental perspective, both strategies were helpful in reducing the amount of CO_2 emissions as shown in Figure 82. In this diagram, the net reduced amount of CO_2 emissions curve shifted upwards, which means that as the vessel size increases and as voyage speed decreases, the net reduced amount of CO_2 emissions increased at all different voyage speeds. However, in the case of the net operating cost, the net operating cost curve shifted upwards also, which shows that the enlargement of vessel size influenced the operating cost negatively at all the different voyage speeds.

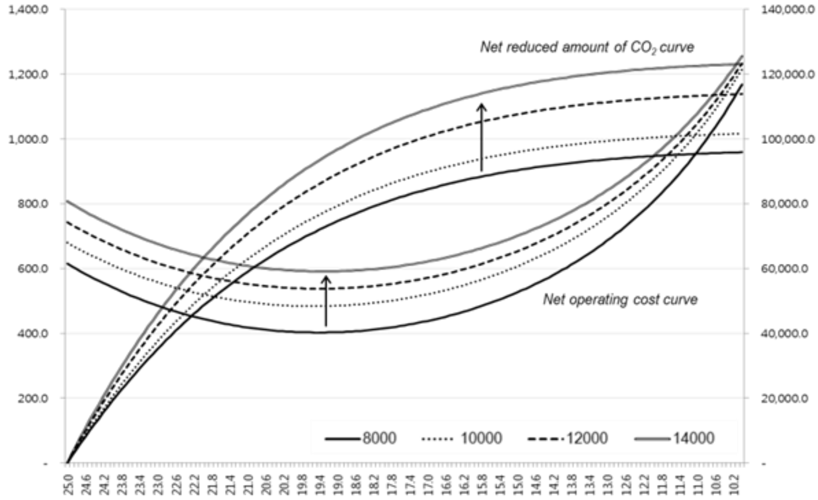


Figure 82 - The impact of the enlargement of vessel size at different voyage speeds

On the other hand, the relationship between the employed vessel size and the CEEI index at different voyage speeds was derived as shown in Figure 83. In this diagram, by the increase of the employed vessel size on a loop (from 8,000 to 14,000 TEU), the CEEI index curve shifted downwards, and the highest index moved from point A to point B. In this sense, it can be defined that there is a negative correlation between the enlargement of vessel size and cost-energy efficiency on a loop. This is because there is a trade-off between the amount of CO_2 emissions and operating costs when the employed vessel size is increased, and the change rate of the operating costs is higher than the change rate of the net reduced amount of CO_2 emissions.

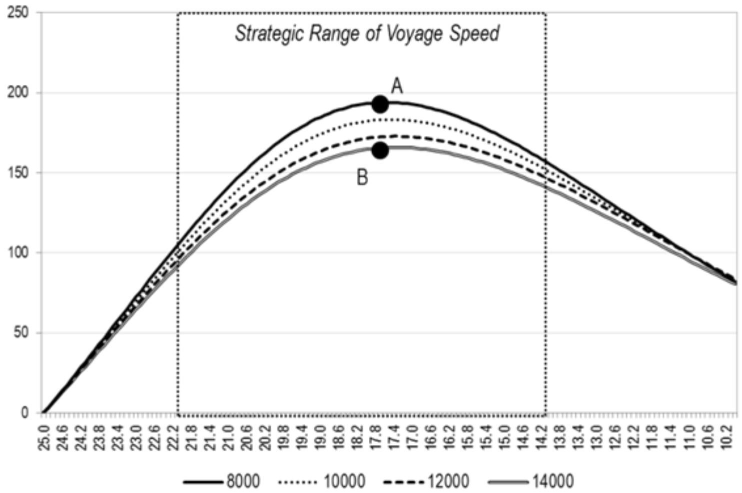
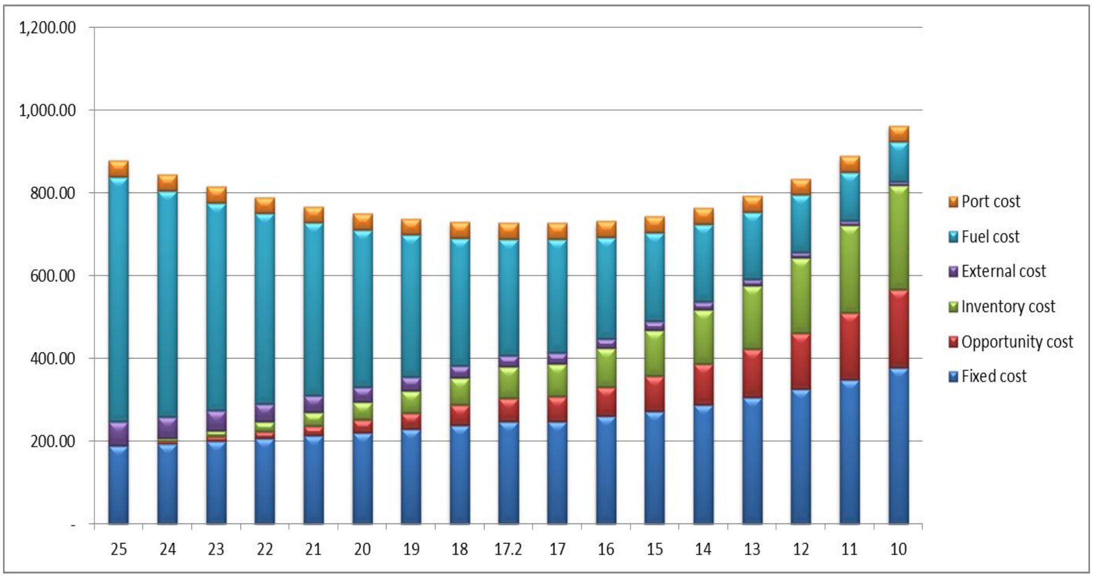


Figure 83 - The CEEI index curve at different vessel sizes

5.5. Chapter Conclusion

The aim of this chapter was to simulate the effects of slow steaming by the changes of voyage speed with focusing three perspectives such as the loop organization (operating system) and service pattern, operating costs and the amount of GHG emissions using a Dynamic Slow Steaming Evaluation Model (DSSEM). Some results were derived through various simulations, and it can be summarized as following.

According to the result of simulation, slow steaming is helpful to reduce the operating costs and the amount of GHG emission. However, in the case of the operating cost, it is not reduced always by slow steaming. Net operating cost can be reduced just within the economic range of voyage speed. The economic range of voyage speed was defined as the range of voyage speed that can reduce net operating cost. On the other hand, by the deceleration of voyage speed, the fuel cost and external cost are decreased while the fixed costs, opportunity cost and inventory cost are increased. This leads to the changes of net operating cost. For this reason, net operating cost was reduced within the range between 25 and 17.2 knots, and it began to increase. Moreover, the economic range of voyage speed was decided at the range of 25 and 11 knots, and the optimum voyage speed is selected at 17.2 knots. Hence, when shipping line control their service speed between 25 and 11 knots, they can enjoy the slow steaming effects. Moreover, when the service loop is organized by 10 vessels of 8,000 TEU class, shipping line can minimize the operating cost.



In the case of the amount of GHG emissions, as voyage speed decelerates, total amount of GHG emissions is decreased. However, the amount of GHG emissions is not reduced in direct proportion to the changes of the voyage speed. The other word, the amount of GHG emissions elasticity of voyage speed is different in each voyage speed. Moreover, the amount of GHG emissions elasticity of voyage speed is elastic just within the range between 25 and 14 knots. Hence, when shipping line control their voyage speed within the range between 25 and 14 knots, they can reduce the amount of GHG emissions efficiently from the viewpoint of elasticity.

Moreover, the cost-energy efficiency was suggested to find the optimum voyage speed that maximizes the reduction of the amount of GHG emissions and minimizes net operating cost. According to the result of simulation, the optimal voyage speed was decided at 17.4 knots. Hence, when liners decelerate voyage speed from 25 knots to 17.4 knots, they can minimize the amount of CO_2 emissions at the lowest operating cost thus satisfying the reduction target of IMO on a loop. On the other hand, when liners control their voyage speed to 18.6 knots, even though the net reduced amount of CO_2 emissions decreases, they can minimize their operating cost thus satisfying the reduction target of IMO on a loop. Moreover, liners can reduce the maximum level of CO_2 emissions at 14 knots.

6. OPTIMUM OPERATIONAL STRATEGY

6.1. Introduction

The aim of this chapter is to define the strategic goals of shipping lines, and select the current core strategic goals to build the optimum operational strategy for shipping lines. Shipping lines have various strategic goals according to their own policies, and they build and/or improve the operational strategies based on their strategic goals, considering their own resources and market conditions. When shipping lines build their operational strategies, it is necessary to consider many interrelated decisions such as what to do, when to do it, as well as how to do it. Moreover, their objectives and strategies must be achievable with the shipping line's available resources and capabilities (Walker *et al.*, 2003).

According to Bergantino and Veenstra (2002), there are eight main strategic goals in shipping lines as follows; the first goal is the improvement of transport ability to provide better transport services and make them more attractive to shippers. The second is the expansion of the services and networks to more markets in an inexpensive way. The third and fourth strategic goals are the improvement of operational productivity and cost efficiency by reducing costs. The fifth is the decrease of financial risk through a strategic investment plan, and the sixth is to increase market share by stimulating growth in acquiring new cargo. Moreover, the seventh and eighth goals are to improve their service quality and environmental performance.

This study adopts the definition of Bergantino and Veenstra (2002) as the main strategic goals of shipping lines. To identify the current main strategic goals of shipping lines, a survey was conducted as a first step to investigate the awareness of experts who work in shipping and relevant fields such as the terminal and logistics & transport industries, research institutes and scholars and government officers. In the second phase, a factor analysis was conducted to identify the structure of relationships among variables and select the valuable factors as the strategic goals of shipping lines.

Moreover, an Analytical Hierarchy Process (AHP) was utilized to analyze the relative importance of selected variables by a factor analysis and select the core strategic goals of shipping lines. Moreover, in the final step, the optimum operating strategy was established using the Experiment of Design (EOD) technique and the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) method in chapter 7. The results of the survey and analyses are utilized as the fundamental factors to build a simulation model and to establish the optimum strategy for shipping lines.

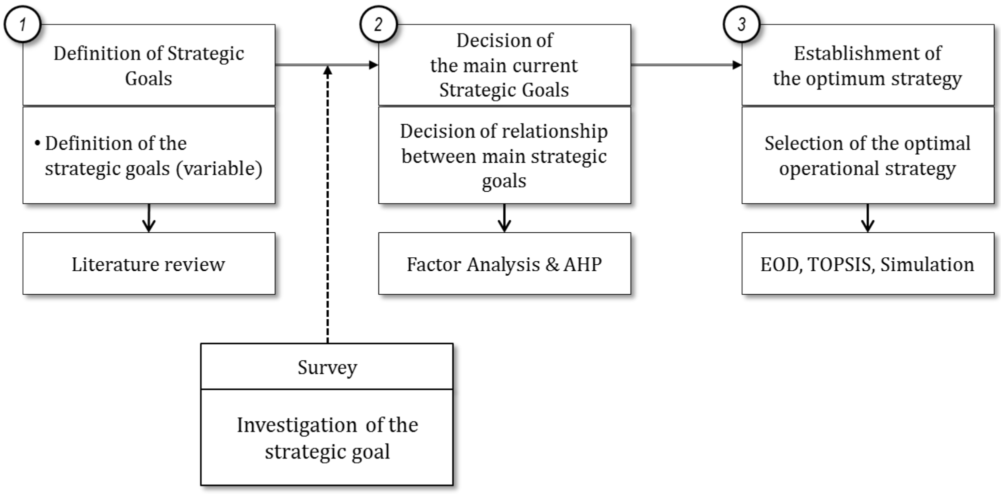


Figure 84 - The process of the building the optimum operational strategy

6.2. Survey

A survey was conducted to investigate the current main strategic goals in the liner shipping industry based on the eight selected strategic goals defined by Bergantino and Veenstra (2005). This survey was carried out using the questionnaire and interview. The questionnaire consisted of 36 questions (nine scale answers), and the reply rate was 72% (144/200). The outline of the survey is as follows.

Table 42 - Summary of survey

	Classification	Answer	Proportion (%)
Working Field	Shipping line	59	41
	Terminal Operator	14	10
	Logistics company	16	11
	Scholar (consultants & professor)	19	13
	Government officer	29	20
	Others (Manufacturer)	7	5
Residence Region	Asia	60	42
	Europe	43	30
	Middle East	20	14
	North America	11	7
	Other (Africa, South America)	10	7

A reliability analysis was conducted to verify the validity of the answers using SPSS Version 18. According to the result of the analysis as shown in Figure 43, the degree of freedom between people is *143* (*df=142*), and the degree of freedom between items is *7* (*df=7*). F-value is *308.697* and the significance is smaller than *0.05*. Moreover, according to the result of the Hotelling's T-Squared Test, the significance is smaller than *0.05* so, the data (variables) and the results of the analysis are statistically significant also.

Table 43 - Results of Reliability Analysis

ANOVA

		Sum of Squares	df	Mean Square	F	Sig
Between People		88.228	143	.617		
Within People	Between Items	1163.944	7	166.278	308.697	.000
	Residual	539.181	1001	.539		
	Total	1703.125	1008	1.690		
Total		1791.353	1151	1.556		

Grand Mean = 4.7613

Hotelling's T-Squared Test

Hotelling's T-Squared	F	df1	df2	Sig
2678.798	366.629	7	137	.000

Item Statistics

	Mean	Std. Deviation	N
CAPA	3.4306	.79906	144
NET	3.6458	.77069	144
COST	6.1181	.68446	144
MS	5.5625	.74532	144
SQ	5.3125	.71418	144
GHG	5.8681	.61731	144
HVI	3.8333	.69965	144
SAFE	4.3194	.86625	144

6.3. Factor Analysis

6.3.1. Definition of data

A factor analysis was conducted to identify the structure of relationships between variables and select the core strategic goals using SPSS Version 18. To do this, this thesis adopted the eight strategic goals of shipping lines defined by Bergantino and Veenstra (2005) as the variables (factor) as shown in Table 44.

Table 44 - Basic strategic goal of shipping line

Strategic Goals (Factor)	Factor Name
The expansion of the transport capacity	CAPA
The expansion of the services network	NET
The improvement of the cost efficiency by reducing costs	COST
The increase of market share	MS
The improvement of the service quality	SQ
The improvement of environmental performance	GHG
The diversification of the business (horizontal/vertical Integration)	HVI
The improvement of the operational productivity	OPRO

Source: Bergantino, A.S. and Veenstra, A.W. (2005). Interconnection and co-ordination: an application of network theory to liner shipping. *International Journal of Maritime Economics* 4(3), 231-248.

6.3.2. Correlation Coefficient and Communalities

The Correlation Matrix was derived by a factor analysis as shown below in Table 45. The highest correlation coefficient is 'cost efficiency' and its correlation coefficient is 0.418. The second and third highest correlation coefficients are 'market share' and 'environmental performance' and their correlation coefficients are 0.342 and 0.295 respectively. These results are consistent with the current market situation. In other words, as discussed in chapter 2, shipping lines are currently focused on the reduction of operating costs and the improvement of environmental performance while maintaining their service quality in the condition of high fuel prices, low freight rates and high pressure for reduction of GHG emissions.

Table 45 - The Correlation Matrix

Correlation Matrix[a]

		CAPA	NET	COST	MS	SQ	GHG	HVI	SAFE
Correlation	CAPA	1.000	.000	.073	.295	.020	-.054	.117	.093
	NET	.000	1.000	-.066	.021	.342	-.011	-.214	-.311
	COST	.073	-.066	1.000	.033	.110	.418	.071	.077
	MS	.295	.021	.033	1.000	.167	-.385	-.047	-.107
	SQ	.020	.342	.110	.167	1.000	-.064	.035	-.230
	GHG	-.054	-.011	.418	-.385	-.064	1.000	.078	.001
	HVI	.117	-.214	.071	-.047	.035	.078	1.000	.135
	SAFE	.093	-.311	.077	-.107	-.230	.001	.135	1.000
Sig. (1-tailed)	CAPA		.498	.193	.000	.406	.260	.082	.134
	NET	.498		.216	.403	.000	.449	.005	.000
	COST	.193	.216		.345	.095	.000	.200	.178
	MS	.000	.403	.345		.023	.000	.288	.101
	SQ	.406	.000	.095	.023		.221	.339	.003
	GHG	.260	.449	.000	.000	.221		.176	.496
	HVI	.082	.005	.200	.288	.339	.176		.054
	SAFE	.134	.000	.178	.101	.003	.496	.054	

a. Determinant = .388

On the other hand, the commonalities are derived as shown in Table 46. The commonalities measure the percentage of variance in a given variable explained by all the factors. Communality (h^2) is the squared multiple correlation for the variable as dependent using the factors as predictors. The communality, 'initial' will be 1.0 and the 'extracted' commonalities are the percentage of variance in a given variable explained by the factors which are extracted, which will usually be fewer than all the possible factors, resulting in coefficients less than 1.0. This explains how the factors that were chosen by the covariance analysis affect the other variables. According to the result, the highest extraction (the percentage of variance) is 'environmental performance', and the second and third are 'cost efficiency' and 'market share'.

Table 46 - Communalities

Communalities

	Initial	Extraction
CAPA	1.000	.544
NET	1.000	.601
COST	1.000	.682
MS	1.000	.685
SQ	1.000	.559
GHG	1.000	.766
HVI	1.000	.299
SAFE	1.000	.487

Extraction Method: Principal Component Analysis.

6.3.3. Total Variance Explained and Scree Test

The Total Variance Explained is derived as shown in Table 47, and it shows the eigenvalue which is the proportion of total variance in all the variables that are accounted for by that factor. A factor's eigenvalue may be computed as the sum of its squared factor loadings for all the variables. The ratio of eigenvalue is the ratio of explanatory importance of the factors with respect to the variables. If a factor has a low eigenvalue, then it is contributing little to the explanation of variances in the variables and may be ignored as redundant with more important factors. In this table, only the first three are extracted for analysis because, under the Extraction options, the statistic software (SPSS) was told to extract only factors with eigenvalue of 1.0 or higher. In this phase, three components which are larger than 1 are selected in this analysis.

Moreover, the result of Cattell Scree Test is represented by Figure 85. In this diagram, the X axis plots the components and the Y axis is the corresponding eigenvalue. When one moves to the right, to the next components, in the X axis, the eigenvalue is dropping. When the drop ceases and the curve makes an elbow towards a less steep decline, Cattell Scree test says to drop all further components after the one starting the elbow. There are alternative criteria for deciding how many factors to retain.

Table 47 - Total Variance Explained

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.770	22.119	22.119	1.770	22.119	22.119	1.668	20.845	20.845
2	1.498	18.728	40.847	1.498	18.728	40.847	1.495	18.688	39.533
3	1.356	16.951	57.798	1.356	16.951	57.798	1.461	18.264	57.798
4	.947	11.831	69.629						
5	.798	9.980	79.609						
6	.751	9.390	88.999						
7	.499	6.244	95.243						
8	.381	4.757	100.000						

Extraction Method: Principal Component Analysis.

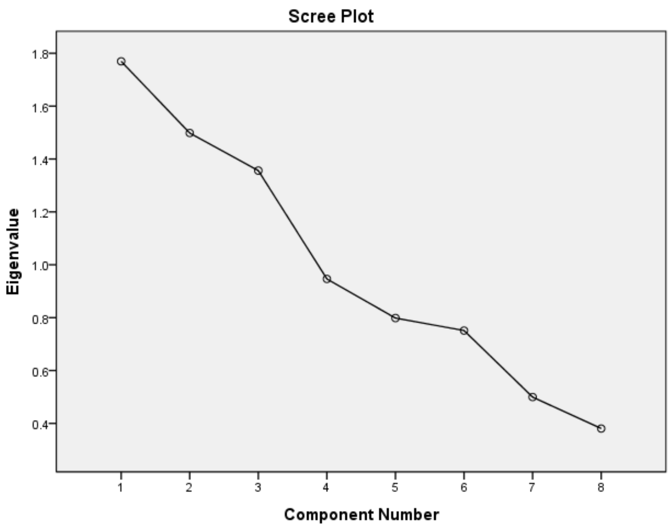


Figure 85 - The result of Scree Test

6.3.4. Component Matrix

Two kinds of ‘Component Matrix’ are derived, and these matrixes show the correlation coefficients of variables as shown in Tables 48 and 49. The correlation coefficient of variables is the relationship between the variables (rows) and factors (columns), and if it is higher than 0.6, it is usually considered ‘high’ and those below 0.4 are ‘low’. The un-rotated components matrix is derived as shown in Table 48, and it shows the correlation coefficients of the variables. In this matrix, a positive value means that each variable affects each factor influence while a negative value means that its effect is not large.

Table 48 - Component Matrix: un-rotated solution

Component Matrix[a]

	Component		
	1	2	3
NET	.612	.475	.013
SAFE	-.562	-.410	.048
SQ	.540	.320	.407
MS	.523	-.489	.415
GHG	-.532	.648	.252
COST	-.320	.367	.667
CAPA	.101	-.415	.602
HVI	-.344	-.190	.381

Extraction Method: Principal Component Analysis.
a. 3 components extracted.

Table 49 - Component Matrix: rotated solution

Rotated Component Matrix[a]

	Component		
	1	2	3
NET	.773	-.032	-.045
SAFE	-.689	.085	.069
SQ	.656	.190	.304
HVI	-.354	.327	.259
COST	.026	.812	.147
GHG	-.009	.781	-.395
MS	.156	-.232	.779
CAPA	-.117	.141	.715

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 5 iterations.

According to the un-rotated components matrix, group 1 and group 2 have one component each (the expansion of networks and the improvement of environmental performance, respectively). Group 3 has two components (the improvement of cost efficiency and the expansion of transport capacity) as shown in Table 48. Moreover, in the case of the rotated components matrix, group 1 has two components (the expansion of networks and the improvement of service quality). Group 2 has two components (the improvement of cost efficiency and the environmental performance), and group 3 has two components also (the improvement of market share and the expansion of transport capacity) as shown in Table 49.

6.3.5. Component Score Coefficient Matrix

The Component Pilot in Rotated Space and the Component Score Coefficient Matrix are derived as shown in Figure 86 and Table 50. The Component Pilot in Rotated Space shows the correlation coefficients of the variables in space. Each variable is plotted according to its factor loadings of the first three factors. This is simply a graphical way of presenting the same information as was contained in the "rotated component matrix" of factor loadings.

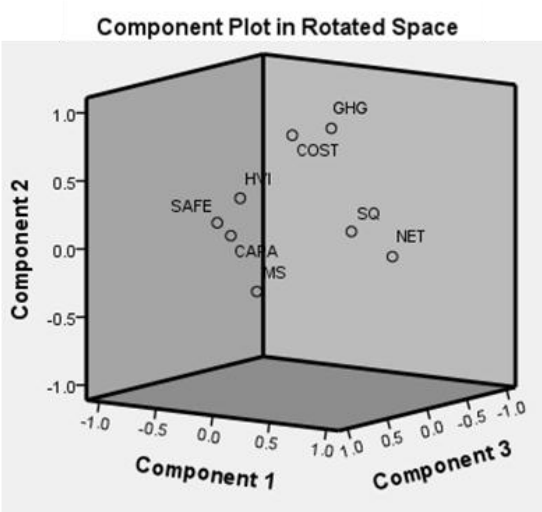


Figure 86 - Component Pilot in Rotated Space

On the other hand, the Component Score Coefficient Matrix shows the factor score, the factor score refers to the scores of each case on each factor. According to the Component Score Coefficient Matrix, two factors (the improvement of service quality and the expansion of networks) are selected in group 1, and two factors (the improvement of cost efficiency and the improvement of environmental performance) are selected in group 2. Moreover, in group 3, two factors (the expansion of transport capacity and the expansion of market share) are selected also. In conclusion, six factors are selected as the current main strategic goals based on a factor analysis.

Table 50 - Component Pilot in Rotated Space

Component Score Coefficient Matrix

	Component		
	1	2	3
CAPA	-.083	.128	.504
NET	.466	.009	-.053
COST	.047	.558	.144
MS	.064	-.109	.521
SQ	.397	.173	.203
GHG	.039	.507	-.231
HVI	-.206	.219	.205
SAFE	-.414	.031	.069

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Component Scores.

Component Score Covariance Matrix

Component	1	2	3
1	1.000	.000	.000
2	.000	1.000	.000
3	.000	.000	1.000

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Component Scores.

6.4. AHP Analysis

6.4.1. Objective and Hierarchy

The aim of the Analytical Hierarchy Process (AHP) is to select the core current strategic goals of shipping lines and to set priorities of the selected factors for establishing the optimum operational strategy. To conduct the AHP, a Hierarchy of AHP was established based on the result of a factor analysis. The objective of AHP is to find the optimal operational strategy based on three criteria, the improvement of the service and networks, improvement of cost efficiency and environmental performance and improvement of transport ability, as shown in Figure 87. Moreover, each criterion has two alternatives such as the improvement of networks, the improvement of service quality, the improvement of cost efficiency, the improvement of environmental performance, the expansion of transport capacity and the expansion of market share.

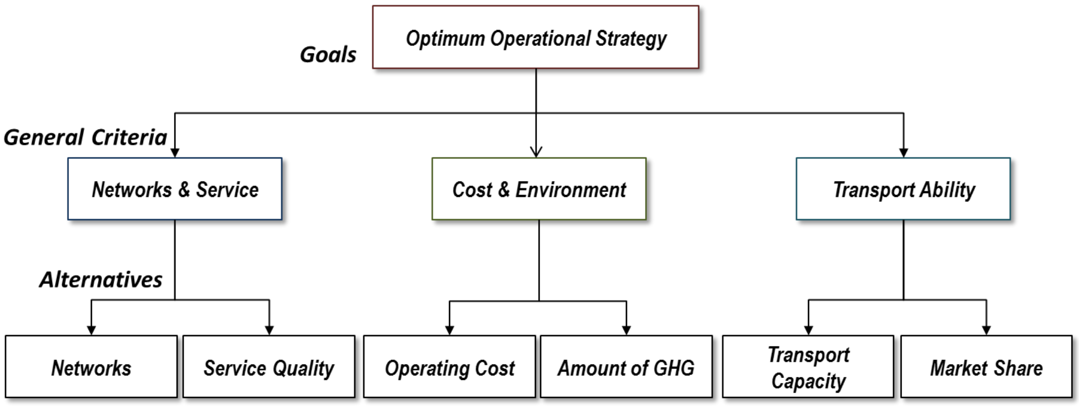


Figure 87 - Hierarchy of AHP

*It is designed based on the result of factor analysis

AHP is a widely used multi-criteria decision making tool. Unlike the conventional methods, AHP uses pair-wise comparisons, which allow verbal judgments and enhance the precision of the results. The pair-wise comparisons are used to derive accurate ratio and scale priorities. The AHP is aimed at integrating different measures into a single overall score for ranking decision alternatives. Its main characteristic is that it is based on pair-wise comparison judgments (Rangone, 1996). The description is developed through three phases (Saaty, 1980) as follows. In first phase, a pair-wise comparison decision matrix (A) is built as follows.

$$A = [a_{im}] = \begin{bmatrix} 1 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \cdots & 1 \end{bmatrix}$$

where, i, m=1, 2, 3,…., n.

Let C_1, C_2, . . . , C_n denote the set of elements, while the aim represents a quantified judgment on a pair of elements, C_i and C_m. Saaty (1980) constitutes a measurement scale for pair-wise comparison. Hence, verbal judgments can be expressed by degree of preference: Equally preferred with 1, Moderately preferred with 3, Strongly preferred with 5, Very strongly preferred with 7 and Extremely preferred with 9; 2, 4, 6 and 8 are used for compromise between the above values.

In the second phase, normalization of the decision matrix is established. Each set of column values is summed. Then, each value is divided by its respective column total value. Finally, the average of rows is calculated and the weights of the decision-maker's objectives are obtained. A set of numerical weights w_1, w_2, . . . , w_i is obtained. In the third phase, a consistency analysis is conducted.

$$A \times w_i = \lambda_{max} \times w_i,$$
Where $i=1,2,3,....,n$

Then the consistency index (*CI*) is calculated as:

$$CI = (\lambda_{max}-n)/(n-1)$$

The consistency index of a randomly generated reciprocal matrix shall be called to the random index (*RI*), with reciprocals forced. An average *RI* for the matrices of order 1-15 was generated by using a sample size of 100. The table of random indexes of the matrices of order 1-15 can be seen in Saaty (1980). The last ratio that has to be calculated is *CR* (consistency ratio). Generally, if *CR* is less than 0.1, the judgments are consistent, so the derived weights can be used. The formulation of CR is $CR=CI/RI$.

6.4.2. Result of AHP

The pairwise comparison matrix-1, and the normalized matrix-1 are derived based on the result of survey 1, and the score (priority) of all alternatives is analyzed using consistency analysis as shown in the table below. According to the result of the analysis, *λmax* is *6.14256*, a consistency index (*CI*) is *0.02851* and a consistency ratio (*CR*) is *0.02299*. Therefore, because a consistency ratio (*CR*) is smaller than *0.1*, this result of AHP can be accepted.

Table 51 - Pairwise Comparison Matrix-1

	CAPA	COST	GHG	MS	SQ	NET	SUM	AVERAGE
CAPA	1.0000	0.8151	0.7819	1.2394	0.8997	0.7676	5.5036	0.9173
COST	1.2268	1.0000	1.3315	1.0592	1.0550	1.3509	7.0234	1.1706
GHG	1.2790	0.7510	1.0000	1.4982	0.8979	1.2259	6.6520	1.1087
MS	0.8069	0.9441	0.6674	1.0000	1.3244	1.2729	6.0158	1.0026
SQ	1.1114	0.9479	1.1137	0.7550	1.0000	1.3439	6.2720	1.0453
NET	1.3028	0.7402	0.8157	0.7856	0.7441	1.0000	5.3885	0.8981
SUM	6.7269	5.1984	5.7103	6.3374	5.9211	6.9612	36.8554	6.1426

Table 52 - Normalized Matrix-1

	CAPA	COST	GHG	MS	SQ	NET	**SUM**	Average
CAPA	0.1487	0.1568	0.1369	0.1956	0.1520	0.1103	0.9002	0.1500
COST	0.1824	0.1924	0.2332	0.1671	0.1782	0.1941	1.1473	0.1912
GHG	0.1901	0.1445	0.1751	0.2364	0.1516	0.1761	1.0739	0.1790
MS	0.1199	0.1816	0.1169	0.1578	0.2237	0.1829	0.9828	0.1638
SQ	0.1652	0.1823	0.1950	0.1191	0.1689	0.1931	1.0237	0.1706
NET	0.1937	0.1424	0.1429	0.1240	0.1257	0.1437	0.8722	0.1454
Sum	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	6.0000	1.0000

Table 53 - Score of alternatives

	SCORE		
CAPA	0.15078	*λmax*	6.142562
COST	0.19186	*n*	6
GHG	0.17769	*R.I*	1.24
MS	0.16423		
SQ	0.17096	*C.I*	0.028512
NET	0.14448	*C.R*	0.022994

This study selects three factors such as the improvement of cost efficiency (*COST*), the improvement of environmental performance (*GHG*) and the improvement of service quality (*SQ*) as the current core strategic goals of shipping lines to establish the optimum operational strategy based on the result of AHP as shown in Figure 88. The result of AHP corresponds to the market situation. As discussed in chapter 2, shipping lines are presently focused on the strategic minimization of operating costs in the condition of high fuel prices, low freight rates and a sluggish growth in transport demand to survive in the uncertain market. Moreover, they are trying to reduce the amount of GHG emissions, while considering the service quality under high pressure to improve environmental performance.

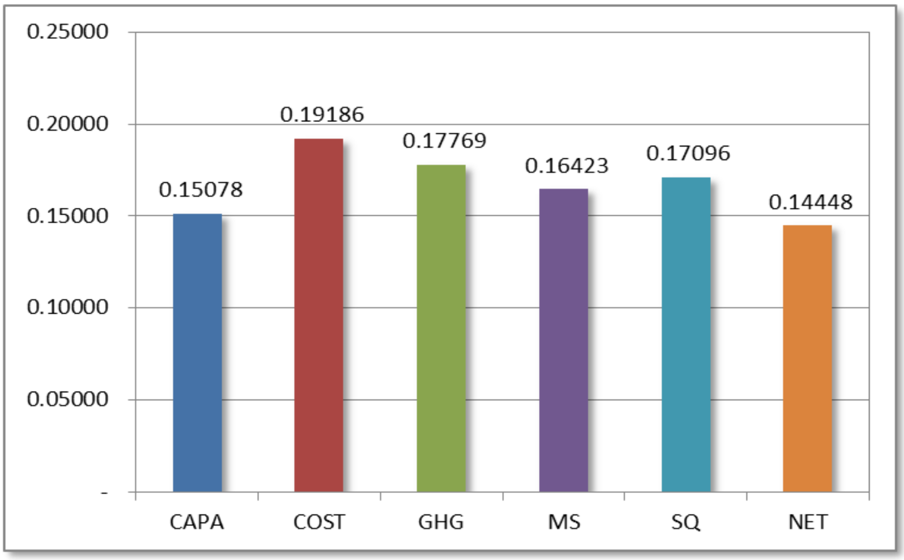
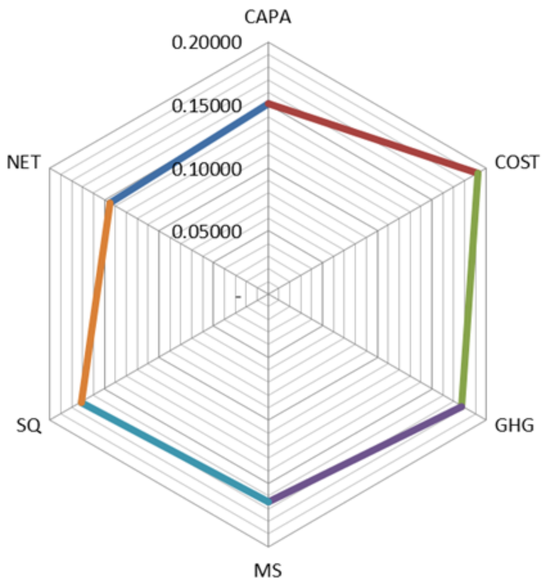


Figure 88 - Score of alternatives

6.5. Chapter Conclusion

The aim of this chapter was to define the strategic goals of shipping lines, and select the current core strategic goals to build the optimum operational strategy. Shipping lines have various strategic goals to maximize their profits and strengthen their competitiveness in the markets. Moreover, there are various strategic goals according to their own policies. This chapter conducted a survey to investigate the awareness of experts in terms of the relative importance of eight main strategic goals defined by Bergantino and Veenstra (2005).

- The expansion of the transport capacity
- The expansion of the services network
- The improvement of cost efficiency by reducing costs
- The increase of market share
- The improvement of service quality
- The improvement of environmental performance
- The diversification of the business (horizontal/vertical Integration)
- The improvement of operational productivity



To identify the structure of relationships between the main strategic goals (variables) and select the core strategic goals, a factor analysis was conducted. According to the results of the factor analysis, three groups were built, and six components (factors) that have a high correlation coefficient relatively were selected as the current main strategic goals of shipping lines. Continuously, three core strategic goals, namely, the improvement of service quality, the improvement of cost efficiency and the improvement of environmental performance were selected by

Analytical Hierarchy Process (AHP). Moreover, the results of analyses such as the reliability analysis, factor analysis and AHP are statistically significant.

This result corresponds with the current market situation. Presently, shipping lines are focused on the reduction of operating costs in the condition of high fuel prices and low freight rates to survive in the markets. Moreover, shipping lines have begun to introduce various strategies to maintain their service quality to cope with the weaknesses of slow steaming, *i.e.* longer transit time. For example, Maersk Line introduced a new service pattern, *i.e.* Daily Maersk as shown in Figure 89. Its core concept is introducing a virtual conveyor belt between Asia and Europe based on fixed transit time. Customers can deliver their cargoes on time, every day of the week, so they can manage their supply chain on time.

Figure 89 - The concept of Daily Maersk

Moreover, shipping lines have been trying to reduce the amount of GHG emissions under the strong pressure regarding environmental performance. IMO established a goal to reduce the amount of GHG emissions by 50% in existing vessels, and prepared various policies such as a carbon tax and emissions trading scheme (*ETS*). Moreover, the level of environmental performance of each shipping line is currently recognized as one of the main factors in deciding the service quality of a shipping line from the environmental viewpoint. Thus, the improvement of environmental performance, *i.e.* the reduction of GHG emissions, is one of the important strategic goals in the liner shipping industry. The results of this chapter are utilized to make a questionnaire and build the optimum operational strategy as the basic factors in chapter 7.

7. OPTIMAL STRATEGY FOR SHIPPING LINES

7.1. Introduction

Presently, shipping lines have greater difficulties building their operational strategy due to the high level of uncertainty in the markets. The liner shipping industry is in overcapacity because of the decrease of the growth rate of transport demand and the continuous increase of transport capacity by new order. Moreover, the degeneration of profits has continued following the increase of costs and decrease of revenue in the condition of high fuel prices and low freight rates. For this reason, during the last three years, shipping lines have experienced greater losses in the liner shipping sector. In the case of the world Top 10 shipping lines, they suffered losses averaging 15% in 2011 in comparison with 2010 as shown in Figure 90. In this sense, some scholars have defined the current liner shipping market as a 'zero-marine competition market' (Fairplay, 2012). For this reason, most shipping lines have been focusing on slow steaming to reduce losses by the minimization of the operating costs to survive in the uncertain market.

This thesis analyzed the impacts of voyage optimization and speed optimization on the operating cost and the amount of GHG emissions in chapter 3 and 5, and presented optimum loop organization and the optimum voyage speed. However, when considering the complex market conditions in the liner shipping markets, it is necessary to establish an operational strategy from various and strategic perspectives, considering the strategic goals and strategic planning of shipping lines. Strategic planning is an organization's process of defining its strategy and making decisions on allocating its resources to pursue this strategy (Wikipedia, 2012). In order to determine the direction of the organization, it is necessary to understand its current position and the possible avenues through which it can pursue a particular course of action. Moreover, a strategic goal is the target of a company when planning a strategy.

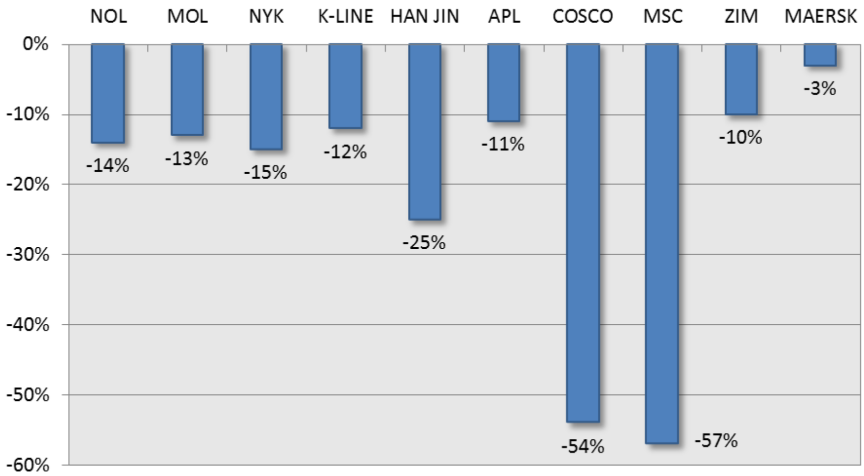


Figure 90 - Losses of shipping line in 2011 in comparison with 2010

Source: Lloyd-List, American shippers' Journal, CI-online, Fairplay.

The aim of this chapter is to establish the optimum operational strategy, considering the core strategic goals of shipping lines selected by a factor analysis and AHP. During the last five decades, shipping lines have pursued the optimal solution to achieve the twin goals of the global expansion of transport networks and the reduction of operating costs. For this reason, they have been focusing on the improvement of their operational efficiency through voyage optimization, enlargement of vessel size and acceleration of voyage speed. However, as discussed, shipping lines adopted slow steaming as their main operational strategy to reduce their operating costs, which resulted in a decrease in their operational efficiency. This is because slow steaming is an operational technique to reduce operating costs by the deliberate reduction of operational efficiency through the deceleration of voyage speed.

In this chapter, the optimum operational strategy of shipping lines is defined as the operational strategy that should be fulfilled to achieve their strategic goals, considering the fleet mix, voyage speed and operating costs. The process of building the optimum operational strategy of shipping lines consists of three main steps as shown in Figure 91. In the first step, the experiment data was collected using a simulation model (DSSEM). The Pareto-Design was selected among experiment data using the Experiment of Design (EOD) in the second step. In the final step, the optimum operational strategy was built using the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) method.

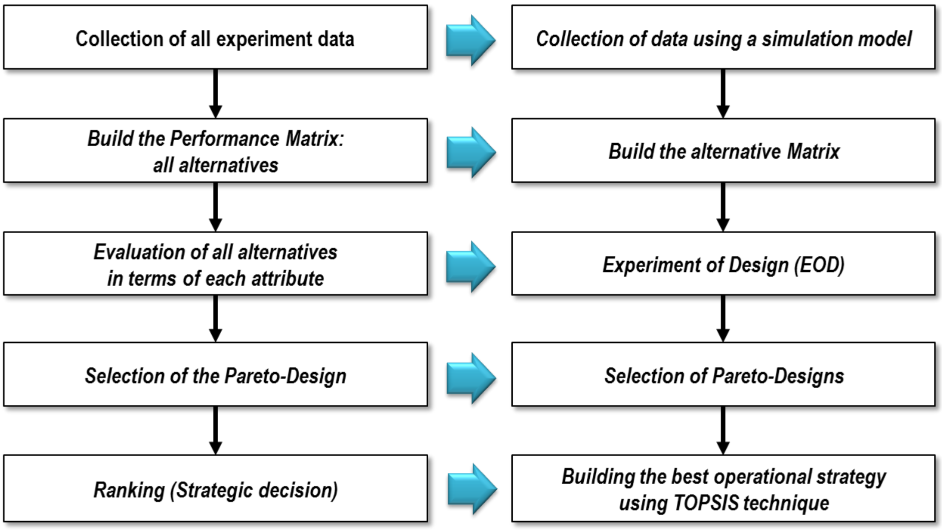


Figure 91 - The process of building the optimum operational strategy

7.2. Building the Pareto Design

7.2.1. Collection of Experiment Data

Experiment data is produced using a simulation model (DSSEM). The input data was designed by the combination of the number of factors and its change range. This thesis considered five factors: voyage speed, vessel size, the value of CO_2 emissions, average port time and number of calling ports, and the change range of each factor is as shown in Table 54. Thus, total number of input data was 16,308 *(=151× 4× 3× 3× 3)* and the total number of output was 48,924 *(=16,308 × 3 (three strategic goals).*

Table 54 - Summary of input data

Factor	voyage speed (knots)	vessel type (TEU)	Value of CO2 (US$)	Number of calling ports (number)	Average Port time (Hours)
Change range of a factor	25.0	8,000	18.0	18.0	39.0
	24.9	10,000	20.0	20.0	43.0
	24.8	12,000	22.0	22.0	48.0
	.	14,000			
	.				
	.				
	10.2				
	10.1				
	10.0				
Sum	151	4	3	3	3

Experiment data of three main strategic goals are derived using a simulation model as shown in Figures 92, 93 and 94. The three diagrams show the distribution of experiment data in terms of the improvement of cost efficiency, the improvement of environmental performance and the improvement of service quality, and each diagram consists of 16,308 outputs.

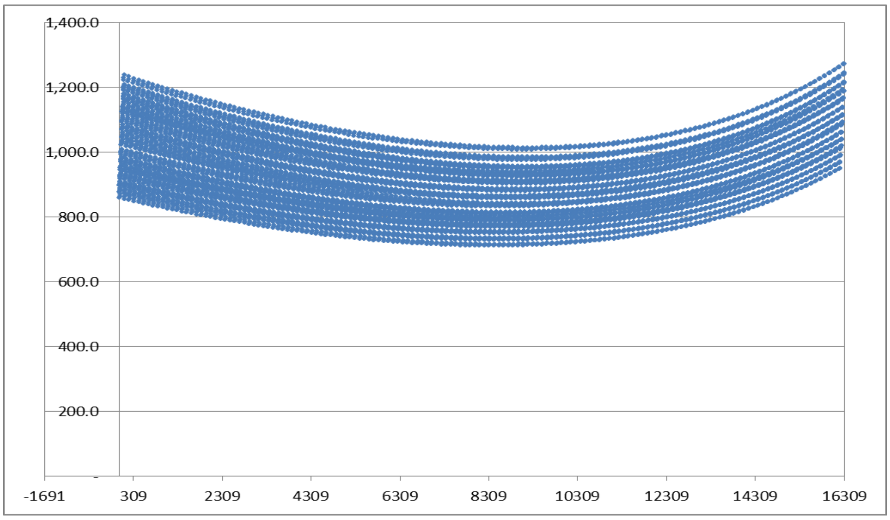


Figure 92 - Experiment data of the improvement of cost efficiency

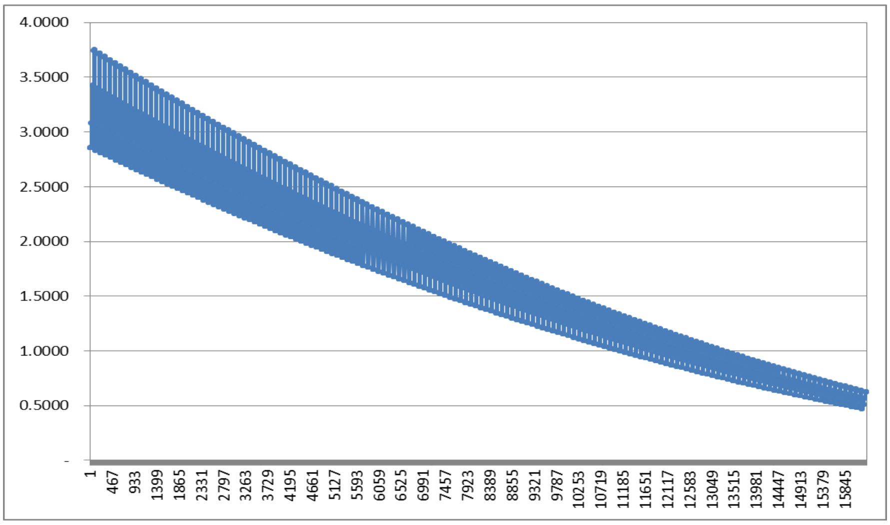


Figure 93 - Experiment data of the improvement of environmental performance

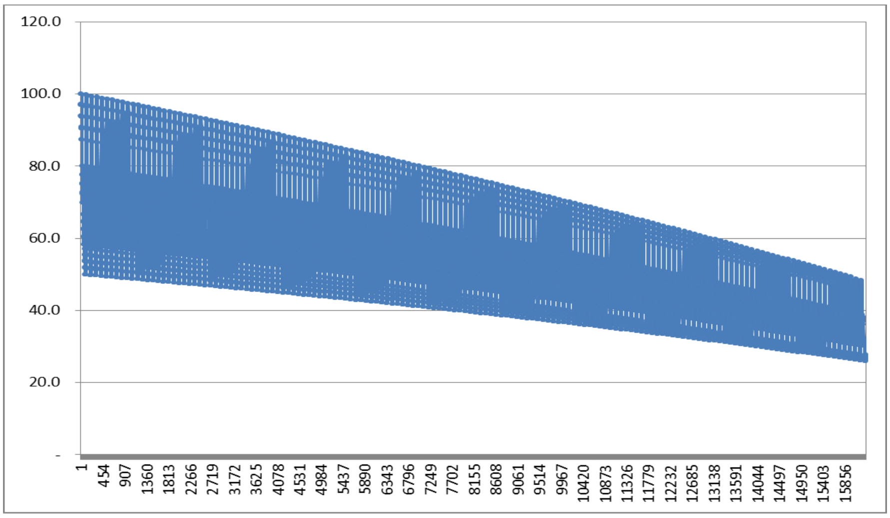


Figure 94 - Experiment data of the improvement of service quality

7.2.2. Selection of the Pareto-Design

In the second step, the process of selection of Pareto-Design was conducted using the Experiment of Design (EOD). The Experiment of Design is an advanced and powerful analysis technique and is defined as the systematic procedure carried out under controlled conditions in order to discover an unknown effect to illustrate a known effect. EOD is used to compare alternatives and determine simultaneously the individual and interactive effects of many factors that could affect the output results in any design (experiment data), while filtering out noise, and discover significant process factors as shown in Figure 95.

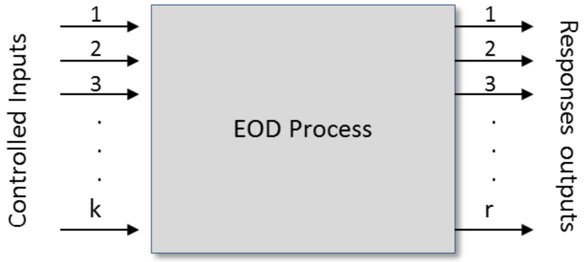


Figure 95 - Process of Experiment of Design

The Pareto-design was selected using the Experiment of Design (EOD) technique. EOD process follows the principle of non-dominance of solutions and produces the Pareto-design such that there are no other designs superior in all criteria. It can be expressed by the polynomial equation as the response variable Y as a function of the input factors X is

$$Y = \beta_0 + \sum_{i=1}^{\rho} \beta_i X_i + \sum_{i=1}^{\rho}\sum_{j=1}^{\rho} \beta_{ij} X_i X_j + \sum_{i=1}^{\rho}\sum_{j=1}^{\rho}\sum_{k=1}^{\rho} \beta_{ijk} X_i X_j X_k + \cdots,$$

where

β_0 *= the overall mean response,*

β_i *= the main effect for factor (i = 1,2, … , p),*

β_{ij} *= the tow-way interaction between the ith and jth factors, and*

β_{ijk} *= the three-way interaction between the ith, jth, and kth factors*

The selected response variable in the total response variable is a Pareto-Design which is isolated with other experiment data. This analysis defines a Pareto-Design as the optimum alternative in this model, thus the selected Pareto-Design can be defined as the optimum operational strategy selected from 48,924 experiment data. By Experiment of Design (EOD) technique, eleven Pareto-Designs were selected as shown in Tables 52 and 53. Table 52 shows the number of selected Pareto-Designs and the value of three response outputs which were derived by simulation based on the three strategic goals: the operating cost, the amount of GHG emissions and the level of service quality. Moreover, Table 53 shows the fleet mix (vessel size and number of vessels), voyage speed and service patterns (voyage time and frequency) in each optimum situation (Pareto-Design). Hence, when the shipping line builds and/or improves its operational strategy, considering the three strategic goals, they can select one optimum alternative (Pareto-Design) among the eleven alternatives.

Table 55 - Selected Pareto-Design and the value of three strategic goals

Unit: million US$, Million tons, percentage

Pareto-Design	COST	GHG	SQ
1	835.7	2.6	97.1
2	827.3	2.6	96.8
3	807.2	2.5	95.4
4	812.2	2.5	95.4
5	753.1	2.1	88.7
6	757.2	2.1	88.7
7	761.3	2.1	88.7
8	735.7	1.8	84.9
9	710.6	1.4	75.6
10	732.3	1.0	66.7
11	796.3	0.7	58.4

Table 56 - Selected Pareto-Design and its organization of service loop

Pareto-Design	voyage speed	Vessel type	Number of vessel	Total voyage time	Voyage time at port	Voyage time at sea	frequency
	knots	TEU	number	days	days	days	number
1	25.0	8000	7	37.5	14.6	52.1	7.0
2	23.9	8000	8	37.7	14.6	52.3	7.0
3	23.4	8000	8	38.5	16.3	54.7	6.7
4	23.4	8000	8	38.5	14.6	53.1	6.9
5	21.2	8000	8	42.4	14.6	57.1	6.4
6	21.2	8000	8	42.4	14.6	57.1	6.4
7	21.2	8000	8	42.4	14.6	57.1	6.4
8	20.0	8000	8	45.0	14.6	59.6	6.1
9	17.2	8000	10	52.3	14.6	66.9	5.5
10	14.7	8000	11	61.2	14.6	75.8	4.8
11	12.5	8000	12	72.0	14.6	86.6	4.2

7.3. Building the Optimum Operational Strategy

7.3.1. Principal of the decision of the optimum operational strategy

The optimum alternative of shipping lines is decided by the relative importance in terms of the three strategic goals of shipping lines. Each relative importance can be decided in the range between 0 and 1, and the grand sum of the relative importance of the three strategic goals is 1, and it is defined as the combined strategic goal of shipping lines. Hence, the optimum alternative is decided depending on the combined relative importance of the three strategic goals. For instance, if a shipping line decides to focus on the reduction of operating cost, and it allocates 80% (0.8) of relative importance to it, it can allocate just 20% (0.2) of its relative importance to the improvement of GHG emissions and service quality. This relationship can be expressed by following equation:

$$RI_{COST} + RI_{GHG} + RI_{SQ} = 1$$

when

$$0 \le RI_{COST} \le 1$$

$$0 \le RI_{GHG} \le 1$$

$$0 \le RI_{SQ} \le 1$$

On the other hand, when assuming that each relative importance can be changed by 10% (0.1), 66 kinds of combined strategic goals were derived by the combination of different relative importance assigned to each strategic goal as shown in Table 54. Moreover, the combination of each relative importance would directly influence the optimum operational strategy.

7.3.2. The optimum operational strategy

In this section, the optimum alternatives (the optimum operational strategy) were established based on the derived combined strategic goals for shipping. As discussed, the optimum operational strategy is changed depending on changes in the combined strategic goals. Thus, from the viewpoint of shipping lines, they have to select different operational strategies to achieve their strategic goals.

Table 57 - 66 kinds of combined strategic goals

Combined strategic goal	Reduction of operating cost	Reduction of GHG	Improvement of Service Quality	Combined strategic goal	Reduction of operating cost	Reduction of GHG	Improvement of Service Quality
C1	*0.0*	*0.0*	*1.0*	C34	*0.3*	*0.2*	*0.5*
C2	*0.0*	*0.1*	*0.9*	C35	*0.3*	*0.3*	*0.4*
C3	*0.0*	*0.2*	*0.8*	C36	*0.3*	*0.4*	*0.3*
C4	*0.0*	*0.3*	*0.7*	C37	*0.3*	*0.5*	*0.2*
C5	*0.0*	*0.4*	*0.6*	C38	*0.3*	*0.7*	*0.0*
C6	*0.0*	*0.5*	*0.5*	C39	*0.4*	*0.0*	*0.6*
C7	*0.0*	*0.6*	*0.4*	C40	*0.4*	*0.1*	*0.5*
C8	*0.0*	*0.7*	*0.3*	C41	*0.4*	*0.2*	*0.4*
C9	*0.0*	*0.8*	*0.2*	C42	*0.4*	*0.3*	*0.3*
C10	*0.0*	*0.9*	*0.1*	C43	*0.4*	*0.4*	*0.2*
C11	*0.0*	*1.0*	*0.0*	C44	*0.4*	*0.5*	*0.1*
C12	*0.1*	*0.0*	*0.9*	C45	*0.4*	*0.6*	*0.0*
C13	*0.1*	*0.1*	*0.8*	C46	*0.5*	*0.0*	*0.5*
C14	*0.1*	*0.2*	*0.7*	C47	*0.5*	*0.1*	*0.4*
C15	*0.1*	*0.3*	*0.6*	C48	*0.5*	*0.2*	*0.3*
C16	*0.1*	*0.4*	*0.5*	C49	*0.5*	*0.3*	*0.2*
C17	*0.1*	*0.5*	*0.4*	C50	*0.5*	*0.4*	*0.1*
C18	*0.1*	*0.6*	*0.3*	C51	*0.5*	*0.5*	*0.0*
C19	*0.1*	*0.7*	*0.2*	C52	*0.6*	*0.3*	*0.1*
C20	*0.1*	*0.8*	*0.1*	C53	*0.6*	*0.0*	*0.4*
C21	*0.1*	*0.9*	*0.0*	C54	*0.6*	*0.1*	*0.3*
C22	*0.2*	*0.7*	*0.1*	C55	*0.6*	*0.2*	*0.2*
C23	*0.2*	*0.0*	*0.8*	C56	*0.6*	*0.4*	*0.0*
C24	*0.2*	*0.1*	*0.7*	C57	*0.7*	*0.2*	*0.1*
C25	*0.2*	*0.2*	*0.6*	C58	*0.7*	*0.0*	*0.3*
C26	*0.2*	*0.3*	*0.5*	C59	*0.7*	*0.1*	*0.2*
C27	*0.2*	*0.4*	*0.4*	C60	*0.7*	*0.3*	*0.0*
C28	*0.2*	*0.5*	*0.3*	C61	*0.8*	*0.0*	*0.2*
C29	*0.2*	*0.6*	*0.2*	C62	*0.8*	*0.1*	*0.1*
C30	*0.2*	*0.8*	*0.0*	C63	*0.8*	*0.2*	*0.0*
C31	*0.3*	*0.6*	*0.1*	C64	*0.9*	*0.0*	*0.1*
C32	*0.3*	*0.0*	*0.7*	C65	*0.9*	*0.1*	*0.0*
C33	*0.3*	*0.1*	*0.6*	C66	*1.0*	*0.0*	*0.0*

To establish the optimum operational strategy, the TOPSIS method (Technique for Order Preference by Similarity to Ideal Solution), which has broad and high acceptability in various problem domains, is utilized in this study. It was developed by Hwang and Yoon (1998) based on the intuitive principle that the chosen alternative should have the shortest distance from the positive-ideal solution and the longest distance from the negative-ideal solution. TOPSIS is a useful Multi Attribute Decision Making technique, and it is used when the user prefers a simpler weighting approach (Ball and Korukoğlu, 2009). Moreover, according to Olson (2004), the TOPSIS method uses an *n*-dimensional Euclidean distance that by itself could represent some balance between total and individual satisfaction. It assumes that there exists a performance matrix obtained by the evaluation of all the alternatives in terms of each attribute.

The TOPSIS method assumes that an alternative that is more like an ideal alternative (the best that could be imagined) and less like a negative-ideal alternative (the worst that could be imagined) should be preferred. In the TOPSIS method, the ideal alternative is constructed out of exclusively the best attribute values attainable and, therefore, it is usually an invented alternative. The negative-ideal alternative is also usually an invented alternative that is constructed out of exclusively the worst attribute values attainable. The relative closeness (similarity) of each alternative to the ideal alternative is rated on the basis of its distances from both the ideal and the negative-ideal alternatives simultaneously (Ölcer and Majumder, 2006). This study adopts the concept and method of the TOPSIS defined by Ölcer and Majumder (2006) and Ball and Korukoğlu (2009). A TOPSIS analysis was conducted by the following steps.

7.3.2.1. Calculation of the normalized ratings

This step tries to transform various attribute dimensions into a non-dimensional attribute, which allows comparison across the attributes. The vector normalization technique is used for computing the element (r_{ji}) of the normalized decision matrix, which is given as

$$r_{ji} = \frac{x_{ji}}{\sqrt{\sum_{j=1}^{N} x_{ji}^2}} \ , \ j = 1, 2, \ldots, N; i = \ 1, 2, \ldots, K \qquad (1)$$

where x_{ji} *is the value of alternative j with respect to attribute i.*

7.3.2.2. Calculation of the weighted normalized ratings

A set of attribute weights assessed from the decision maker is accommodated to the normalized decision matrix in this step. The weighted normalized decision matrix can be calculated by multiplying each row of the normalized decision matrix with its associated attribute weight w_i. An element of the weighted normalized decision matrix is calculated as

$$v_{ji} = w_i \, r_{ji} \ , \ \ j = 1, 2, \ldots, N; i = 1, 2, \ldots, K \qquad (2)$$

Where w_i *is the weight of the i th attribute.*

Moreover, the normalization of the relative importance, $\{rl_1, rl_2, \ldots, rl_K\}$ is conducted to obtain the weights $\{w_1, w_2, \ldots, w_K\}$. The standard normalization is

$$w_i = \frac{rl_i}{\sum_{i=1}^{K} rl_i} \ , \ \ i = 1, 2, \ldots, K \qquad (3)$$

where, $0 \le w_i \le 1$ *and* $\sum_{i=1}^{K} w_i = 1.$

7.3.2.3. Identify positive-ideal solutions (PIS) and negative-ideal solutions (NIS)

Firstly, the TOPSIS method defines A^+ and A^- as the positive-ideal solution (PIS) and the negative-ideal solution (NIS) in terms of the weighted normalized values.

$$A^+ = \{v_1^+, v_2^+, \ldots, v_i^+, \ldots, v_K^+\},$$

where $v_i^+ = \{max_j \, v_{ji} \, , i \in J_1; \ min_j \, v_{ji} \, , i \in J_2\}$ *(4)*

$$A^- = \{v_1^-, v_2^-, \ldots, v_i^-, \ldots, v_K^-\},$$

where $v_i^- = \{max_j \, v_{ji} \, , i \in J_1; \ min_j \, v_{ji} \, , i \in J_2\}$ *(5)*

where J_1 *is the set of benefit attributes and* J_2 *is the set of cost attributes.*

Moreover, Separation (distance) between alternatives is measured by the *n*-dimensional Euclidean distance. Separation of each alternative from the PIS is then given by

$$S_j^+ = \sqrt{\sum_{i=1}^{K} (v_{ji} - v_i^+)^2}, \ j = 1, 2, \dots, N \qquad (6)$$

and, separation from the NIS is then given by

$$S_j^- = \sqrt{\sum_{i=1}^{K} (v_{ji} - v_i^-)^2}, \ j = 1, 2, \dots, N \qquad (7)$$

7.3.2.4. Calculate similarities to PIS

Relative closeness (or similarity) of A_j with respect to A^+ is defined as

$$C_j^+ = \frac{S_j^-}{S_j^+ + S_j^-}, \ 0 < C_j^+ < 1; j = 1, 2, \dots 2\ N \qquad (8)$$

When C_j^+ is close to 1, the alternative is regarded as ideal; and when C_j^+ is close to 0, the alternative is regarded as non-ideal.

7.3.2.5. Rank preference order

Choose an alternative with the maximum C_j^+ or rank alternatives according to C_j^+ in descending order. It is clear that an alternative A_j is closer to A^+ than to A^- as C_j^+ approaches 1. The optimum operational strategy and the second best operational strategy in each combined strategic goal are derived by TOPSIS method as shown in Table 58. In this table, the optimum and the second best strategy are expressed by the number of Pareto-design selected by EOD technique. Moreover, the optimum and the second best strategy are different in each case. Hence, this thesis selected some cases as example cases to explain the relationship between the strategic goal and the optimum operational strategy.

Table 58 - The optimum operational strategy in each combined strategic goal

Case	Combined strategic goal			The Optimum Strategy		The Second Best Strategy	
	Reduction of operating cost	Reduction of GHG	Improvement of Service Quality	Pareto design	Value (Cci_1)	Pareto design	Value (Cci_2)
C1	0	0	1	1	1.00	2	0.99
C2	0	0.1	0.9	2	0.81	3	0.81
C3	0	0.2	0.8	3	0.66	2	0.66
C4	0	0.3	0.7	8	0.56	6	0.56
C5	0	0.4	0.6	10	0.60	9	0.59
C6	0	0.5	0.5	10	0.68	11	0.68
C7	0	0.6	0.4	11	0.76	10	0.76
C8	0	0.7	0.3	11	0.83	10	0.80
C9	0	0.8	0.2	11	0.89	10	0.83
C10	0	0.9	0.1	11	0.95	10	0.85
C11	0	1	0	11	1.00	10	0.86
C12	0.1	0	0.9	2	0.96	1	0.96
C13	0.1	0.1	0.8	3	0.79	4	0.79
C14	0.1	0.2	0.7	3	0.63	4	0.63
C15	0.1	0.3	0.6	9	0.56	8	0.54
C16	0.1	0.4	0.5	10	0.64	11	0.62
C17	0.1	0.5	0.4	11	0.72	10	0.72
C18	0.1	0.6	0.3	11	0.81	10	0.78
C19	0.1	0.7	0.2	11	0.88	10	0.83
C20	0.1	0.8	0.1	11	0.94	10	0.85
C21	0.1	0.9	0	11	0.99	10	0.86
C22	0.2	0.7	0.1	11	0.93	10	0.85
C23	0.2	0	0.8	2	0.92	3	0.92
C24	0.2	0.1	0.7	3	0.77	4	0.77
C25	0.2	0.2	0.6	5	0.60	6	0.60
C26	0.2	0.3	0.5	9	0.58	10	0.58
C27	0.2	0.4	0.4	10	0.68	11	0.67
C28	0.2	0.5	0.3	11	0.77	10	0.76
C29	0.2	0.6	0.2	11	0.86	10	0.82
C30	0.2	0.8	0	11	0.97	10	0.86
C31	0.3	0.6	0.1	11	0.91	10	0.85
C32	0.3	0	0.7	3	0.88	4	0.88
C33	0.3	0.1	0.6	3	0.73	4	0.73
C34	0.3	0.2	0.5	8	0.58	5	0.57
C35	0.3	0.3	0.4	10	0.63	11	0.61
C36	0.3	0.4	0.3	10	0.73	11	0.73
C37	0.3	0.5	0.2	11	0.83	10	0.81
C38	0.3	0.7	0	11	0.95	10	0.86
C39	0.4	0	0.6	3	0.83	4	0.83
C40	0.4	0.1	0.5	5	0.68	6	0.68
C41	0.4	0.2	0.4	9	0.58	8	0.56
C42	0.4	0.3	0.3	10	0.69	11	0.66
C43	0.4	0.4	0.2	11	0.79	10	0.79
C44	0.4	0.5	0.1	11	0.88	10	0.84
C45	0.4	0.6	0	11	0.93	10	0.86

Table 59 - The optimum operational strategy in each combined strategic goal

Case	Combined strategic goal			The Optimum Strategy		The Second Best Strategy	
	Reduction of operating cost	Reduction of GHG	Improvement of Service Quality	Pareto design	Value (Cci_1)	Pareto design	Value (Cci_2)
C46	0.5	0	0.5	3	0.77	5	0.77
C47	0.5	0.1	0.4	5	0.65	6	0.65
C48	0.5	0.2	0.3	9	0.62	10	0.62
C49	0.5	0.3	0.2	10	0.75	11	0.73
C50	0.5	0.4	0.1	11	0.84	10	0.83
C51	0.5	0.5	0	11	0.89	10	0.86
C52	0.6	0.3	0.1	10	0.82	11	0.78
C53	0.6	0	0.4	5	0.75	6	0.74
C54	0.6	0.1	0.3	8	0.64	9	0.62
C55	0.6	0.2	0.2	10	0.70	9	0.67
C56	0.6	0.4	0	10	0.86	11	0.85
C57	0.7	0.2	0.1	10	0.79	9	0.72
C58	0.7	0	0.3	5	0.73	8	0.73
C59	0.7	0.1	0.2	9	0.70	8	0.64
C60	0.7	0.3	0	10	0.85	11	0.79
C61	0.8	0	0.2	8	0.76	9	0.73
C62	0.8	0.1	0.1	9	0.78	10	0.75
C63	0.8	0.2	0	10	0.85	9	0.74
C64	0.9	0	0.1	9	0.85	8	0.79
C65	0.9	0.1	0	9	0.84	10	0.83
C66	1.0	0	0	9	1.00	10	0.83

7.4. Case study

A case study was conducted in order to clearly the relationship between the derived optimal alternatives, *i.e.* the optimum strategy, and the strategic goals of shipping line. With considering the proportion of strategic goals, six cases were selected as shown in Table 60. In the case of C1, C11 and C66, shipping line focused on just one strategic goal of the three goals of the reduction of the operating costs, the reduction of GHG emissions and the improvement of service quality, so the results show the optimum operational strategy targeting just one strategic goal. On the contrary, in the case of C27, C 41 and C43, it was assumed that the shipping lines tried to build their operational strategy considering all three strategic goals. These six cases can show the relationship between the combined strategic goal and the optimum operational strategy.

Table 60 - Selected cases of the optimum operational strategy

Case	Combined strategic goal			The Optimum Strategy		The Second Best Strategy	
	Reduction of operating cost	Reduction of GHG	Improvement of Service Quality	Pareto design	Value (*Cci_1*)	Pareto design	Value (*Cci_2*)
C1	0	0	1	1	1.00	2	0.99
C11	0	1	0	11	1.00	10	0.86
C66	1	0	0	9	1.00	10	0.83
C27	0.2	0.4	0.4	10	0.68	11	0.67
C41	0.4	0.2	0.4	9	0.58	8	0.56
C43	0.4	0.4	0.2	11	0.79	10	0.79

7.4.1. Case 1: When a liner focuses only on the improvement of service quality

Case 1 is defined as the situation whereby a shipping line is focusing just on the improvement of service quality without considering other strategic goals, *i.e.* the reduction of operating costs and the improvement of environmental performance. According to the result of the TOPSIS analysis, its operational goal can be achieved when it organizes and operates its loop based on Pareto-design 1 (alternative number 1) as shown in Figure 96.

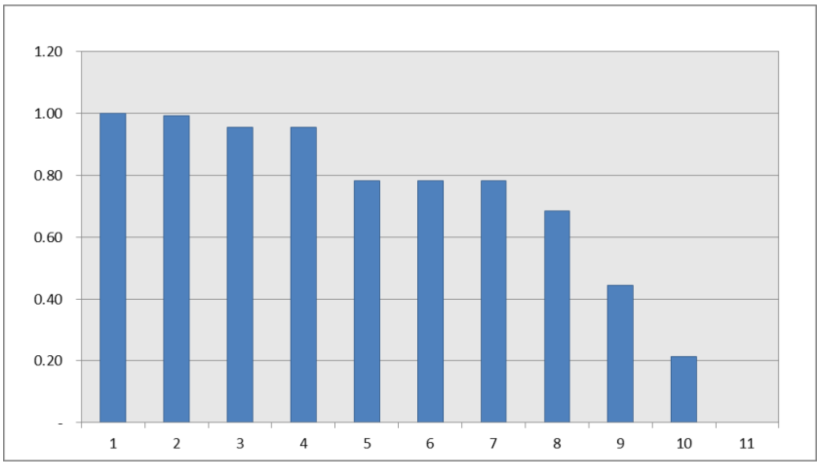


Figure 96 - The optimum operational strategy in case 1

In other words, from the viewpoint of shipping lines, when they organize their service loop with eight vessels of 8,000 TEU class, and control voyage speed to 25 knots, they can accomplish their strategic goal, *i.e.* the improvement of the service quality. However, in this situation, net operating cost and the amount of GHG emissions are at a higher level than in the other alternatives as shown in Figure 97. So, in this case, even though the shipping line can improve its service quality by the modification of loop organization and service pattern, it is inevitable that net operating cost is increased and the level of environmental performance is decreased sharply.

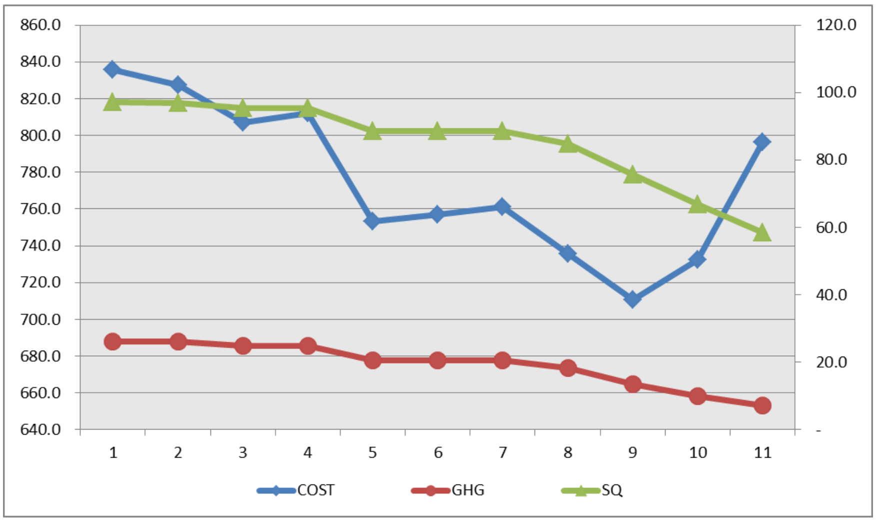


Figure 97 - Comparison of net operating cost, GHG emissions and Service Quality in each alternative

7.4.2. Case 11: When a liner focuses only on reducing GHG emissions

Case 11 can be defined as a situation whereby a shipping line is focusing 100% on the improvement of the level of environmental performance. According to the result of the TOPSIS analysis, its operational goal can be achieved when it organizes and operates its loop based on Pareto-design 11 (alternative number 11) as shown in Figure 98. Thus, when shipping lines organize their service loop with twelve vessels of 8,000 TEU class, and control voyage speed to 12.5 knots, they can achieve their strategic goal, *i.e.* the improvement of the service quality.

However, in this situation, net operating cost is at a high level and the level of service quality is at the lowest level as shown in Figure 97. Therefore, in this case, even though the shipping line can improve the level of environmental performance, this strategy leads to an increase in operating costs and a decrease in the level of service quality.

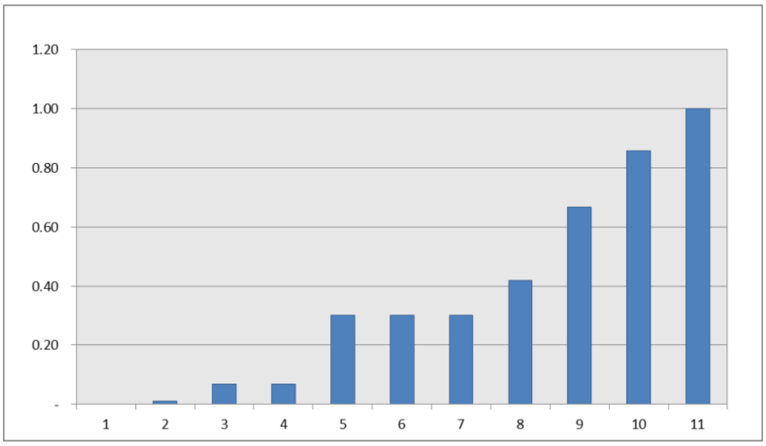


Figure 98 - The optimum operational strategy in case 11

7.4.3. Case 66: When a liner focuses only on reducing operating cost

In the situation of case 66, it is defined that the shipping line is focusing on the reduction of its operating cost regardless of other strategic goals. In this strategy, its operational goal can be achieved when it organizes and operates its loop based on Pareto-design 9 (alternative number 9) as shown in Figure 99. Therefore, when shipping lines build and/or improve their service loop with ten vessels of 8,000 TEU class, and control voyage speed to 17.2 knots, they can accomplish their strategic goal, *i.e.* the reduction of operating cost.

This result corresponds with the result of voyage optimization and speed optimization. Namely, when the shipping line decreases the vessel size and decelerates voyage speed to 17.2 knots, it can minimize its operating cost using slow steaming. Moreover, although the service quality declines, the amount of GHG emissions can be reduced by around 70% in comparison with the amount that occurs at 25 knots.

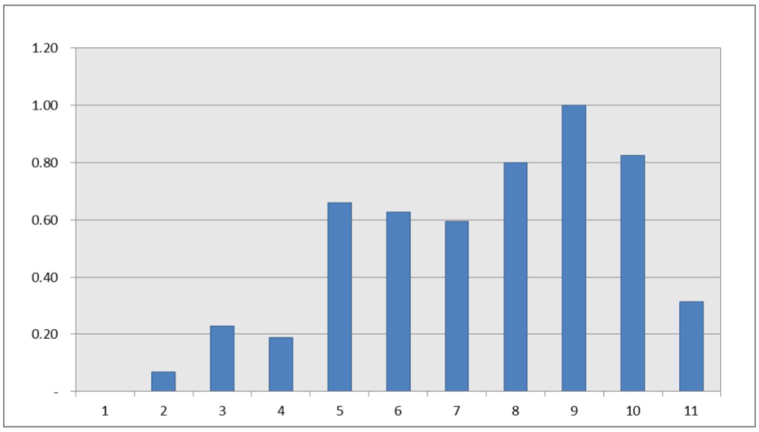


Figure 99 - The optimum operational strategy in case 66

7.4.4. Case 27: When a liner distributes its strategic goals (20:40:40)

Case 27 can be defined as the situation whereby a shipping line is focusing on three strategic goals with the ratio 0.2:0.4:0.4 (cost; environment; service quality). In other words, in this situation, the shipping line has a plan to place more importance on the level of environmental performance (40%) and service quality (40%) rather than the reduction of operating cost (20%). In this situation the shipping line can achieve its strategic goal when it builds its loop based on Pareto-design 10 (alternative number 10) as shown in Figure 100. Therefore, when a shipping line builds and/or improves its service loop with 11 vessels of 8,000 TEU class, and controls voyage speed to 12.5 knots, it can achieve its strategic goal in proportion to the ratio of each strategic goal.

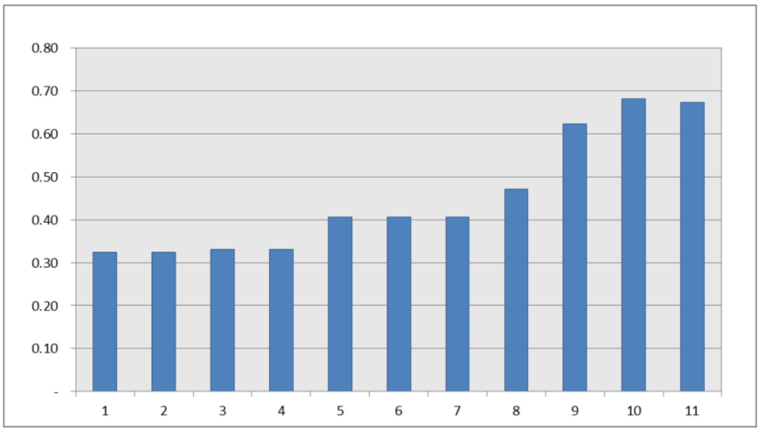


Figure 100 - The optimum operational strategy in case 27

7.4.5. Case 41: When a liner distributes its strategic goals (40:20:40)

Case 41 is the situation whereby a shipping line has a plan to focus on tree strategic goals such as the reduction of operating cost (40%), the improvement of the level of environmental performance (20%) and service quality (40%) each other. Therefore, when shipping line organizes its service loop based on Pareto-design 9 (alternative number 9), it can accomplish its goals as shown in Figure 101. Namely, when a shipping line builds and/or improves its service loop with 10 vessels of 8,000 TEU class, and controls voyage speed to 17.2 knots, it can achieve its strategic goal in proportion to the ratio of each strategic goal. In this situation, net operating cost is minimized, and the amount of GHG emissions is also reduced considerably, whereas the service quality is at a low level as shown in Figure 98.

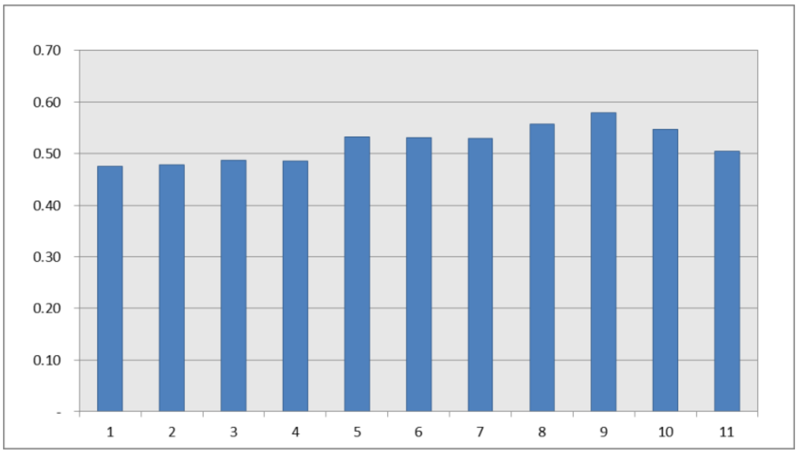


Figure 101 - The optimum operational strategy in case 41

7.4.6. Case 43: When a liner distributes its strategic goals (40:40:20)

Case 43 can be defined as the situation whereby a shipping line is focusing on the reduction of operating cost (40%) and the amount of GHG emissions (40%) rather than the improvement of service quality (20%). In this situation, the shipping line can accomplish its strategy goal when it builds its loop based on Pareto-design 10 (alternative number 10) as shown in Figure 102. Therefore, when a shipping line builds and/or improves its service loop using 11 vessels of 8,000 TEU class, and controls voyage speed to 12.5 knots, it can achieve its strategic goal.

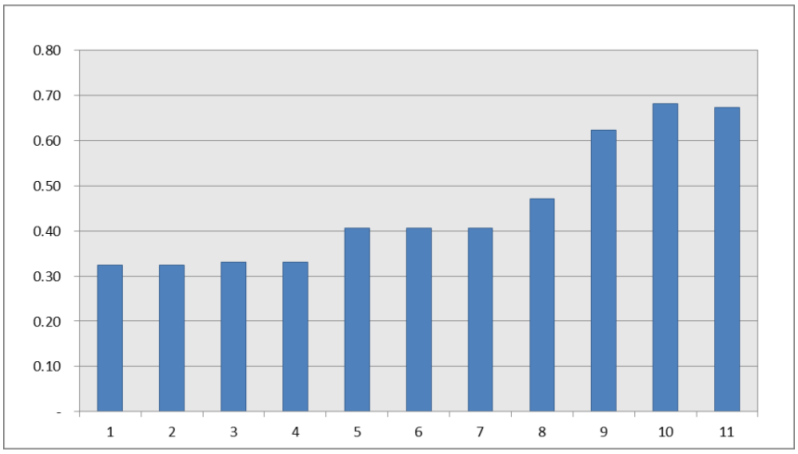


Figure 102 - The optimum operational strategy in case 43

7.5. Chapter Conclusion

In chapter 3 and 5, the impacts of voyage optimization and the impacts of speed optimization on the operating cost and the amount of GHG emissions were analyzed. Moreover, the optimum service (fleet fix) and optimum voyage speed were provided using an IP model and a simulation model each other. In this chapter, the optimum alternatives (the optimum operational strategy) that allow the achievement of various strategic goals of shipping line was established using the Experiment of Design (EOD) technique and the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) method.

The optimum operational strategy is decided by the combination of strategic goal of the shipping line. In other words, the optimum operational strategy is changed by the shipping line’s own strategic goal, which is established based on the three main strategic goals of improvement of cost efficiency, environmental performance and level of service quality. For example, if a shipping line is focusing on the reduction of operating cost regardless of other strategic goals, when it improves its service loop with ten vessels of 8,000 TEU class, and controls voyage speed to 17.2 knots, it can accomplish its strategic goal at Pareto-design 9. These relationships between the combination of strategic goals and the optimum operational strategy were presented in this chapter as shown in Tables 61.

Table 61 - The simple optimum operational strategy in each combined strategic goal

Case	Combined strategic goal			The Optimum Strategy		The Second Best Strategy	
	Reduction of operating cost	Reduction of GHG	Improvement of Service Quality	Pareto design	Value (Cci_1)	Pareto design	Value (Cci_2)
C1	0	0	1	1	1.00	2	0.99
C2	0	0.1	0.9	2	0.81	3	0.81
C3	0	0.2	0.8	3	0.66	2	0.66
C4	0	0.3	0.7	8	0.56	6	0.56
C5	0	0.4	0.6	10	0.60	9	0.59
C7	0	0.6	0.4	11	0.76	10	0.76
C23	0.2	0	0.8	2	0.92	3	0.92
C24	0.2	0.1	0.7	3	0.77	4	0.77
C25	0.2	0.2	0.6	5	0.60	6	0.60
C26	0.2	0.3	0.5	9	0.58	10	0.58
C27	0.2	0.4	0.4	10	0.68	11	0.67
C30	0.2	0.8	0	11	0.97	10	0.86
C39	0.4	0	0.6	3	0.83	4	0.83
C40	0.4	0.1	0.5	5	0.68	6	0.68
C41	0.4	0.2	0.4	9	0.58	8	0.56
C42	0.4	0.3	0.3	10	0.69	11	0.66
C43	0.4	0.4	0.2	11	0.79	10	0.79
C52	0.6	0.3	0.1	10	0.82	11	0.78
C53	0.6	0	0.4	5	0.75	6	0.74
C54	0.6	0.1	0.3	8	0.64	9	0.62
C55	0.6	0.2	0.2	10	0.70	9	0.67
C56	0.6	0.4	0	10	0.86	11	0.85
C61	0.8	0	0.2	8	0.76	9	0.73
C62	0.8	0.1	0.1	9	0.78	10	0.75
C63	0.8	0.2	0	10	0.85	9	0.74
C66	1	0	0	9	1.00	10	0.83

Based on the results of the analysis, shipping lines can select their suitable operational strategy by considering their resources, market share and their own policy from the mid-term and long-term perspective, flexibly. This thesis suggests alternative 9 as the optimum operational strategy. In this strategy, when a shipping line builds its service loop using 10 vessels of 8,000 TEU class, and decelerates target voyage speed to 17.2 knots, it can minimize operating costs and fulfill the reduction target of IMO (50% reduction). However, in this case, the level of service quality is decreased due to the increase of transit time. Thus, from the viewpoint of the shipping line, it is necessary to improve its service pattern using route optimization and routing like ‘Daily Maersk’.

8. CONCLUSION

8.1. Summary of Study

8.1.1. Background and Objective

Shipping lines have always pursued a high efficiency of ship operation in order to strengthen their competitiveness and maximize the profits in competitive markets. To achieve this goal, during the last couple of decades, shipping lines focused on the improvement of operational productivity to maximize the transport capability by minimized input assets using various operational strategies such as a route optimization, improvement of transport networks and enlargement of ship size. This is because liner shipping is capital-intensive and very sensitive to the changes of economic and market conditions. This strategy enabled to shipping lines not only to reduce the operating costs with financial risks but also to raise the quality of service. Moreover, it led to the improvement of liner service as more competitive transport mode, *i.e.* faster, organized and economic transport service, and this has contributed to growth of international trade and liner shipping industry.

However, in recent times, a strategic goal in terms of the high efficiency of ship operation has been changed in liner shipping. Under the intensive pressure of high fuel price and low freight rates, shipping lines focused on the efficient ship operation for minimizing the operating costs instead of improving of operational productivity to survive in uncertainty markets. In addition to this, the better energy efficiency and effective emission control has been emphasized as one of the essential operational strategies in shipping industry. This is because even though international shipping is the most energy efficient transport mode in world trade, it is one of the major contributors to a group of pollutant together with greenhouse gas (GHG) emissions. For this reason, IMO set up a goal to reduce the amount of GHG emissions by maximum 75% on existing and new ships through technical and operational measures by 2050.

With both strategic goals of the improvement of cost and energy efficiency, shipping lines adopted slow steaming as their main operational strategy in major routes. In the case of the Asia-Europe route, around 93% of liner services have already adopted slow steaming, and average voyage speed has reduced to 15-18 knots in 2012. This is because, even though slow steaming has influence on the productivity and service quality negatively, it is effective at reducing the operating costs and GHG emissions and at the same time.

The objective of this study is to analyze the impacts of slow steaming on the operating costs and environmental performance in liner shipping and find the optimal voyage speed that can minimize the operating costs and the amount of GHG emissions with considering the various business environments. Moreover, another objective is to establish the optimum alternatives as the long-term and mid-term operational strategy for shipping line in accordance with the current strategic goals of shipping lines. To achieve it, three models were established. The Integer Programing (IP) Model and Integration Cost Evaluation Model were established to investigate the impact of voyage optimization on the operating costs and the amount of GHG emissions with considering slow steaming.

Moreover, the Dynamic Simulation Model (Dynamic Slow Steaming Evaluation Model) was designed to analyze the impact of voyage optimization using System Dynamics. Moreover, this thesis established the optimum operational strategy based on the selected three main strategic goals of improvement of cost efficiency, improvement of the level of environmental performance and improvement of service quality, using the Experiment of Design (EOD) and the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS).

8.1.2. Main Results

The impact of voyage optimization

According to the result of the voyage optimization, both strategies of route optimization and fleet optimization are helpful in reducing operating costs and the amount of GHG emissions on a loop. More precisely, when both strategies are connected with slow steaming, a shipping line can reduce its operating cost and improve its level of environmental performance by the reduction of GHG emissions.

In the case of route optimization, the reduced voyage distance by optimization can provide the chance to reduce voyage speed while maintaining the service schedule of the shipping line, leading to a reduction in operating costs. Moreover, in the case of fleet optimization, an increase in the employed number of vessels leads to an increase in voyage time at sea for each vessel, so the shipping line can decelerate its target voyage speed while maintaining its weekly service pattern for each calling port. Hence, shipping lines can enjoy slow steaming effects.

Moreover, when considering the impacts of both analyses, operating cost has been reduced by 8.4% through route optimization and by 23.26% through fleet optimization with slow steaming on a loop. In other words, a shipping line can reduce its operating cost from 785.36 to 582 million US$ (totally 31.7%) by route optimization (61.7 million US$) and fleet optimization with slow steaming (141.7 million US$). In the case of the amount of GHG emissions, it has been reduced from 2.76 to 2.49 million tons through route optimization (10.87%) and fleet optimization (55.11%) on a loop.

The impact of speed optimization

According to the result of the simulation, the economic range of voyage speed was decided at the range of 25 and 11 knots, and the optimum voyage speed was decided at 17.2 knots. Hence, when a shipping line controls its service speed between 25 and 11 knots, it can enjoy the effects of slow steaming. Moreover, when the service loop is organized with 10 vessels of 8,000 TEU class, a shipping line can minimize its operating cost.

On the other hand, as voyage speed decelerates, the total amount of GHG emissions is decreased. However, the amount of GHG emissions is not reduced in direct proportion to the changes in voyage speed. In other words, the amount of GHG emissions elasticity of voyage speed is different at each voyage speed. Moreover, the amount of GHG emissions elasticity of voyage speed is elastic just within the range between 25 and 14 knots.

The optimum operational strategy

A survey was conducted to investigate the current strategic goals targeting shipping lines, scholars and relevant experts who work in shipping, port and logistics sectors. Moreover, the three current major strategic goals of reduction of operating costs, improvement of environmental performance and improvement of service quality were selected using a factor analysis and AHP.

On the other hand, this thesis produced 48,927 experiment data using a simulation model (16,308 input data), and selected eleven Pareto-Designs through EOD technique. Moreover, the optimum operational strategy based on three current major strategic goals was designed using the TOPSIS method. This thesis provided various alternatives as the optimum operational strategies for shipping lines. Hence, shipping lines can select their optimum operational strategy by considering their own policy and strategic goals in each market.

8.2. Main Implications and Suggestions

In this study, from the economic and environmental viewpoint, the impacts of slow steaming effects on liner shipping were analyzed, and some implications were derived from the results of analyses.

Firstly, slow steaming is not helpful always in reducing the operating costs. The operating costs can be reduced just within the economic range of voyage speed (25-11 knots), and it is minimized at the optimum voyage speed (17.2 knots). Especially, according to the result of simulation, when shipping lines organizes the service loop with 10 vessels of 8,000 TEU class, shipping lines can control the voyage speed to the optimum voyage speed and minimize the operating cost in Asia-North Europe route. Hence, from the viewpoint of shipping lines, it is required to improve their operating strategies with considering the optimal voyage speed and the strategic range of voyage speed to secure the economic and political advantages by slow steaming. This is because, even if slow steaming is useful to reduce the operating costs, the excessive reduction of voyage speed can reduce the positive effects of slow steaming on the operating costs.

Secondly, there is a negative correlation between the slow steaming effects and the increase of ship size. According to the result of a sensitive analysis, as the ship size increases, the net operating cost is increased also. Nowadays, shipping lines focused on two strategies *i.e.* slow steaming and the enlargement of vessel size, to enjoy the slow steaming effects and the economies of vessel size at the same time. However, this result shows us, shipping lines have to choice one of both strategies of slow steaming and the enlargement of ship size in order to reduce their operating costs. Hence, there is a necessity to reconsider their fleet mix and investment plan. This is because, according to the result of simulation, when shipping lines employ the 8,000 TEU class ships on a loop, they can maximize the positive slow steaming effects.

Thirdly, as voyage speed decelerates, the amount of GHG emissions on a loop is decreased. However, the amount of GHG emissions is not reduced in direct proportion to the changes in voyage speed. In other words, the amount of GHG emissions elasticity of voyage speed is different at each voyage speed. Moreover, the amount of GHG emissions elasticity of voyage speed is elastic just within the range between 25 and 14 knots. Hence, when a shipping line controls its voyage speed within the range between 25 and 14 knots, they can reduce the amount of GHG emissions efficiently from the viewpoint of elasticity.

Fourthly, from the viewpoint of shipping lines, it is necessary to optimize their service route to reduce their operating costs and the amount of GHG emissions. According to the result of voyage optimization, the reduction of voyage distance by route optimization is helpful in reducing the operating costs together with the amount of GHG emissions. Hence, shipping lines have to improve their service networks with considering the voyage distance of single service and cargo flow in the market.

Fifthly, there is a positive correlation between the amount of GHG emissions and the increase of ship size. According to the result of a sensitive analysis, as the ship size increases, the reduced amount of GHG emissions is increased also. It means as ship size increases, the energy efficiency is increased also. However, as discussed above, the increase of ship size leads to the increase of operating costs. This shows us, even though the increase of energy efficiency is helpful in reducing the amount of GHG emissions, it is not useful to reduce the operating costs. Hence, if shipping lines have a plan to increase the energy efficiency and cost efficiency at the same time, they have to choice one of both strategic goals.

Sixthly, from the viewpoint of IMO, it is needed to improve the relevant environmental policies in the liner shipping industry. It is evaluated that a lot of amounts of CO_2 emissions, which exceeded the reduction target of IMO had reduced already by slow steaming in liner shipping based on the result of simulation. Moreover, when considering other relevant regulations of IMO for the reduction of carbon emissions, it is expected that the more amount of CO_2 emissions could be reduced in liner shipping.

In this sense, it is needed to establish another measure that can reflect the amount of CO_2 emissions and the economic situations of liners at the same time. Moreover, it is necessary to improve the direction of environmental policies to support liner shipping companies which reduced the amount of CO_2 emissions by slow steaming with utilizing the market-based instruments such as a carbon tax, emissions trading and cap-and-trade at the same time. In this sense, the cost-energy efficiency indicator

(CEEI), with EEOI, is expected to play an important role to control the amount of CO_2 emissions with considering the economic situation of liners.

8.3. Special Feature of Thesis

This thesis has analyzed the impact of voyage optimization and slow steaming on operating costs and the amount of GHG emissions on the liner shipping industry. Moreover, this thesis provided not only an optimum voyage speed with an economic range of voyage speed from the viewpoint of operating costs but also the optimum alternatives as the optimal operational strategy for shipping lines. The results of this thesis have some differentiations with previous studies.

Firstly, this thesis proved that slow steaming is not always helpful in reducing operating costs. The operating cost can be reduced just within the economic range of voyage speed (25-11 knots), and it is minimized at the optimum voyage speed (17.2 knots). Hence, from the viewpoint of shipping lines, it is necessary to consider the economic range of voyage speed and the optimal voyage speed when they build and/or improve their operational strategy.

Secondly, this study provided various relationships between voyage speed and various factors in terms of the operating costs and the amount of GHG emissions. In the short or mid-term, these results derived by a simulation can provide significant information for strategic decisions. For example, according to the result of simulation, there is a negative correlation between slow steaming and the economies of vessel size. This means that shipping lines need to choice one strategy of twin strategies of slow steaming and the enlargement of vessel size to reduce their operating costs and average cost.

Thirdly, this thesis offered multiple alternatives as the optimum operational strategy for shipping lines with considering current main strategic goals of shipping line. Thus, shipping lines can select their suitable operational strategy by considering their resources, market share and their mid-term and long-term policies flexibly.

However, this study has some limitation also to explain the impact of slow steaming in liner shipping. Firstly, even though the dynamic simulation model designed in this study used mostly real market data, it held some assumptions for the simulation mechanism. Hence, it is necessary to simulate the impact of slow steaming using real data of shipping lines for more precise analysis.

Secondly, this thesis focused on the operation sector in terms of operating system, costs and environmental performance on liner shipping. Thus, there is a need to expand the research scope to relevant sectors such as terminal operation, Supply Chain Management (SCM) and customers' needs and behavior.

Thirdly, the simulation model did not consider directly the financial costs and some detailed technical factors in terms of the vessel design, parts and structure of the vessel. Therefore, it is needed to improve and/or expand this model considering more diverse variables and conditions, especially, in terms of the financial and technical conditions to improve the results.

8.4. Future Plan

This thesis provided various significant results in terms of the slow steaming effects in the liner shipping industry however some limitations were remained also. Nevertheless, this thesis, especially a Dynamic Slow Steaming Evaluation Model (DSSEM), has strong possibilities to expand the research scope from economic and business perspectives. For example, it is expected that a DSSEM can expand its research scope to the terminal operation, financial and investment strategies, supply chain management (SCM) and customers' needs and behavior.

Moreover, it can be expected that a DSSEM would be utilized by shipping line as one of the measurements or analysis tools to simulate the level of environmental performance with Energy Efficiency Operational Indicator (EEOI), operating cost, service quality and optimization of fleet mix and size at various conditions, i.e. the changes of voyage speed, vessel size and voyage distance. Thus, further studies on the development of an analysis tools for shipping lines using a DSSEM are needed also. At the very least, it is to be hoped that this thesis will contribute further to the research as a platform in shipping and its related industries.

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Appendix

Appendix 1: The changes of service pattern at each voyage speed (8,000 TEU)

	Average vessel size (TEU)	Voyage time at sea (days)	Voyage time in port (days)	Total voyage time (days)	Frequency (number)	Number of vessel (number)
25.0	8,000	36.0	18.1	54.1	6.7	7.7
24.9	8,000	36.1	18.1	54.2	6.7	7.7
24.8	8,000	36.3	18.1	54.4	6.7	7.7
24.7	8,000	36.4	18.1	54.5	6.7	7.8
24.6	8,000	36.6	18.1	54.7	6.7	7.8
24.5	8,000	36.7	18.1	54.8	6.7	7.8
24.4	8,000	36.9	18.1	55.0	6.6	7.8
24.3	8,000	37.0	18.1	55.1	6.6	7.9
24.2	8,000	37.2	18.1	55.3	6.6	7.9
24.1	8,000	37.3	18.1	55.4	6.6	7.9
24.0	8,000	37.5	18.1	55.6	6.6	7.9
23.9	8,000	37.7	18.1	55.7	6.5	7.9
23.8	8,000	37.8	18.1	55.9	6.5	8.0
23.7	8,000	38.0	18.1	56.1	6.5	8.0
23.6	8,000	38.1	18.1	56.2	6.5	8.0
23.5	8,000	38.3	18.1	56.4	6.5	8.0
23.4	8,000	38.5	18.1	56.5	6.5	8.1
23.3	8,000	38.6	18.1	56.7	6.4	8.1
23.2	8,000	38.8	18.1	56.9	6.4	8.1
23.1	8,000	39.0	18.1	57.0	6.4	8.1
23.0	8,000	39.1	18.1	57.2	6.4	8.2
22.9	8,000	39.3	18.1	57.4	6.4	8.2
22.8	8,000	39.5	18.1	57.6	6.3	8.2
22.7	8,000	39.6	18.1	57.7	6.3	8.2
22.6	8,000	39.8	18.1	57.9	6.3	8.2
22.5	8,000	40.0	18.1	58.1	6.3	8.3
22.4	8,000	40.2	18.1	58.3	6.3	8.3
22.3	8,000	40.4	18.1	58.4	6.2	8.3
22.2	8,000	40.5	18.1	58.6	6.2	8.4
22.1	8,000	40.7	18.1	58.8	6.2	8.4
22.0	8,000	40.9	18.1	59.0	6.2	8.4
21.9	8,000	41.1	18.1	59.2	6.2	8.4
21.8	8,000	41.3	18.1	59.4	6.1	8.5
21.7	8,000	41.5	18.1	59.6	6.1	8.5
21.6	8,000	41.7	18.1	59.7	6.1	8.5
21.5	8,000	41.9	18.1	59.9	6.1	8.5
21.4	8,000	42.1	18.1	60.1	6.1	8.6
21.3	8,000	42.2	18.1	60.3	6.0	8.6
21.2	8,000	42.4	18.1	60.5	6.0	8.6
21.1	8,000	42.6	18.1	60.7	6.0	8.7
21.0	8,000	42.9	18.1	60.9	6.0	8.7
20.9	8,000	43.1	18.1	61.1	6.0	8.7
20.8	8,000	43.3	18.1	61.4	5.9	8.7
20.7	8,000	43.5	18.1	61.6	5.9	8.8
20.6	8,000	43.7	18.1	61.8	5.9	8.8
20.5	8,000	43.9	18.1	62.0	5.9	8.8
20.4	8,000	44.1	18.1	62.2	5.9	8.9

20.3	8,000	44.3	18.1	62.4	5.8	8.9
20.2	8,000	44.5	18.1	62.6	5.8	8.9
20.1	8,000	44.8	18.1	62.9	5.8	9.0
20.0	8,000	45.0	18.1	63.1	5.8	9.0
19.9	8,000	45.2	18.1	63.3	5.8	9.0
19.8	8,000	45.4	18.1	63.5	5.7	9.1
19.7	8,000	45.7	18.1	63.8	5.7	9.1
19.6	8,000	45.9	18.1	64.0	5.7	9.1
19.5	8,000	46.1	18.1	64.2	5.7	9.2
19.4	8,000	46.4	18.1	64.5	5.7	9.2
19.3	8,000	46.6	18.1	64.7	5.6	9.2
19.2	8,000	46.9	18.1	65.0	5.6	9.3
19.1	8,000	47.1	18.1	65.2	5.6	9.3
19.0	8,000	47.4	18.1	65.4	5.6	9.3
18.9	8,000	47.6	18.1	65.7	5.6	9.4
18.8	8,000	47.9	18.1	66.0	5.5	9.4
18.7	8,000	48.1	18.1	66.2	5.5	9.4
18.6	8,000	48.4	18.1	66.5	5.5	9.5
18.5	8,000	48.6	18.1	66.7	5.5	9.5
18.4	8,000	48.9	18.1	67.0	5.4	9.5
18.3	8,000	49.2	18.1	67.3	5.4	9.6
18.2	8,000	49.4	18.1	67.5	5.4	9.6
18.1	8,000	49.7	18.1	67.8	5.4	9.7
18.0	8,000	50.0	18.1	68.1	5.4	9.7
17.9	8,000	50.3	18.1	68.4	5.3	9.7
17.8	8,000	50.6	18.1	68.6	5.3	9.8
17.7	8,000	50.8	18.1	68.9	5.3	9.8
17.6	8,000	51.1	18.1	69.2	5.3	9.9
17.5	8,000	51.4	18.1	69.5	5.3	9.9
17.4	8,000	51.7	18.1	69.8	5.2	9.9
17.3	8,000	52.0	18.1	70.1	5.2	10.0
17.2	8,000	52.3	18.1	70.4	5.2	10.0
17.1	8,000	52.6	18.1	70.7	5.2	10.1
17.0	8,000	52.9	18.1	71.0	5.1	10.1
16.9	8,000	53.2	18.1	71.3	5.1	10.2
16.8	8,000	53.6	18.1	71.7	5.1	10.2
16.7	8,000	53.9	18.1	72.0	5.1	10.3
16.6	8,000	54.2	18.1	72.3	5.0	10.3
16.5	8,000	54.5	18.1	72.6	5.0	10.3
16.4	8,000	54.9	18.1	73.0	5.0	10.4
16.3	8,000	55.2	18.1	73.3	5.0	10.4
16.2	8,000	55.5	18.1	73.6	5.0	10.5
16.1	8,000	55.9	18.1	74.0	4.9	10.5
16.0	8,000	56.2	18.1	74.3	4.9	10.6
15.9	8,000	56.6	18.1	74.7	4.9	10.6
15.8	8,000	57.0	18.1	75.0	4.9	10.7
15.7	8,000	57.3	18.1	75.4	4.8	10.7
15.6	8,000	57.7	18.1	75.8	4.8	10.8
15.5	8,000	58.1	18.1	76.1	4.8	10.8
15.4	8,000	58.4	18.1	76.5	4.8	10.9
15.3	8,000	58.8	18.1	76.9	4.7	11.0
15.2	8,000	59.2	18.1	77.3	4.7	11.0
15.1	8,000	59.6	18.1	77.7	4.7	11.1
15.0	8,000	60.0	18.1	78.1	4.7	11.1
14.9	8,000	60.4	18.1	78.5	4.7	11.2
14.8	8,000	60.8	18.1	78.9	4.6	11.2
14.7	8,000	61.2	18.1	79.3	4.6	11.3
14.6	8,000	61.6	18.1	79.7	4.6	11.4
14.5	8,000	62.1	18.1	80.1	4.6	11.4
14.4	8,000	62.5	18.1	80.6	4.5	11.5

14.3	8,000	62.9	18.1	81.0	4.5	11.5
14.2	8,000	63.4	18.1	81.5	4.5	11.6
14.1	8,000	63.8	18.1	81.9	4.5	11.7
14.0	8,000	64.3	18.1	82.4	4.4	11.7
13.9	8,000	64.7	18.1	82.8	4.4	11.8
13.8	8,000	65.2	18.1	83.3	4.4	11.9
13.7	8,000	65.7	18.1	83.8	4.4	11.9
13.6	8,000	66.2	18.1	84.3	4.3	12.0
13.5	8,000	66.7	18.1	84.7	4.3	12.1
13.4	8,000	67.2	18.1	85.2	4.3	12.1
13.3	8,000	67.7	18.1	85.7	4.3	12.2
13.2	8,000	68.2	18.1	86.3	4.2	12.3
13.1	8,000	68.7	18.1	86.8	4.2	12.4
13.0	8,000	69.2	18.1	87.3	4.2	12.4
12.9	8,000	69.8	18.1	87.8	4.2	12.5
12.8	8,000	70.3	18.1	88.4	4.1	12.6
12.7	8,000	70.9	18.1	88.9	4.1	12.7
12.6	8,000	71.4	18.1	89.5	4.1	12.8
12.5	8,000	72.0	18.1	90.1	4.1	12.8
12.4	8,000	72.6	18.1	90.7	4.0	12.9
12.3	8,000	73.2	18.1	91.2	4.0	13.0
12.2	8,000	73.8	18.1	91.8	4.0	13.1
12.1	8,000	74.4	18.1	92.5	3.9	13.2
12.0	8,000	75.0	18.1	93.1	3.9	13.3
11.9	8,000	75.6	18.1	93.7	3.9	13.4
11.8	8,000	76.3	18.1	94.3	3.9	13.4
11.7	8,000	76.9	18.1	95.0	3.8	13.5
11.6	8,000	77.6	18.1	95.7	3.8	13.6
11.5	8,000	78.3	18.1	96.3	3.8	13.7
11.4	8,000	78.9	18.1	97.0	3.8	13.8
11.3	8,000	79.6	18.1	97.7	3.7	13.9
11.2	8,000	80.3	18.1	98.4	3.7	14.0
11.1	8,000	81.1	18.1	99.2	3.7	14.1
11.0	8,000	81.8	18.1	99.9	3.7	14.2
10.9	8,000	82.6	18.1	100.6	3.6	14.3
10.8	8,000	83.3	18.1	101.4	3.6	14.4
10.7	8,000	84.1	18.1	102.2	3.6	14.6
10.6	8,000	84.9	18.1	103.0	3.5	14.7
10.5	8,000	85.7	18.1	103.8	3.5	14.8
10.4	8,000	86.5	18.1	104.6	3.5	14.9
10.3	8,000	87.4	18.1	105.5	3.5	15.0
10.2	8,000	88.2	18.1	106.3	3.4	15.1
10.1	8,000	89.1	18.1	107.2	3.4	15.3
10.0	8,000	90.0	18.1	108.1	3.4	15.4

Appendix 2: The changes of the operating cost, the amount of GHG emissions and the service quality at each voyage speed (8,000 TEU)

	Average vessel size (TEU)	Designed operating cost (MUS$)	net operating cost (MUS$)	Sum of Positive effects (MUS$)	Sum of Negative effect (MUS$)	Net Slow Steaming Effect (MUS$)	GHG (M Ton)	Productivity (%)
25.0	8,000	879.3	879.3	-	-	-	2.9	100.0
24.9	8,000	879.3	875.1	5.9	1.7	4.2	2.9	99.7
24.8	8,000	879.3	871.0	11.7	3.4	8.3	2.8	99.5
24.7	8,000	879.3	866.9	17.5	5.1	12.4	2.8	99.2
24.6	8,000	879.3	862.9	23.2	6.8	16.4	2.7	98.9
24.5	8,000	879.3	858.9	28.9	8.5	20.4	2.7	98.7
24.4	8,000	879.3	854.9	34.6	10.3	24.3	2.6	98.4
24.3	8,000	879.3	851.1	40.3	12.1	28.2	2.6	98.1
24.2	8,000	879.3	847.2	45.9	13.8	32.0	2.5	97.8
24.1	8,000	879.3	843.5	51.4	15.6	35.8	2.4	97.6
24.0	8,000	879.3	839.7	57.0	17.4	39.5	2.4	97.3
23.9	8,000	879.3	836.1	62.5	19.3	43.2	2.3	97.0
23.8	8,000	879.3	832.4	67.9	21.1	46.8	2.3	96.8
23.7	8,000	879.3	828.9	73.4	23.0	50.4	2.3	96.5
23.6	8,000	879.3	825.3	78.8	24.8	53.9	2.2	96.2
23.5	8,000	879.3	821.9	84.1	26.7	57.4	2.2	95.9
23.4	8,000	879.3	818.4	89.4	28.6	60.8	2.1	95.6
23.3	8,000	879.3	815.1	94.7	30.5	64.2	2.1	95.4
23.2	8,000	879.3	811.8	100.0	32.5	67.5	2.0	95.1
23.1	8,000	879.3	808.5	105.2	34.4	70.8	2.0	94.8
23.0	8,000	879.3	805.3	110.4	36.4	74.0	1.9	94.5
22.9	8,000	879.3	802.1	115.6	38.4	77.2	1.9	94.2
22.8	8,000	879.3	799.0	120.7	40.4	80.3	1.9	94.0
22.7	8,000	879.3	795.9	125.8	42.4	83.4	1.8	93.7
22.6	8,000	879.3	792.9	130.8	44.4	86.4	1.8	93.4
22.5	8,000	879.3	789.9	135.9	46.5	89.4	1.7	93.1
22.4	8,000	879.3	787.0	140.9	48.6	92.3	1.7	92.8
22.3	8,000	879.3	784.1	145.8	50.7	95.1	1.7	92.5
22.2	8,000	879.3	781.3	150.7	52.8	98.0	1.6	92.3
22.1	8,000	879.3	778.6	155.6	54.9	100.7	1.6	92.0
22.0	8,000	879.3	775.9	160.5	57.1	103.4	1.6	91.7
21.9	8,000	879.3	773.2	165.3	59.2	106.1	1.5	91.4
21.8	8,000	879.3	770.6	170.1	61.4	108.7	1.5	91.1
21.7	8,000	879.3	768.0	174.9	63.6	111.3	1.5	90.8
21.6	8,000	879.3	765.5	179.6	65.9	113.8	1.4	90.5
21.5	8,000	879.3	763.1	184.3	68.1	116.2	1.4	90.2
21.4	8,000	879.3	760.7	189.0	70.4	118.6	1.4	89.9
21.3	8,000	879.3	758.3	193.7	72.7	121.0	1.3	89.6
21.2	8,000	879.3	756.0	198.3	75.0	123.3	1.3	89.3
21.1	8,000	879.3	753.8	202.9	77.4	125.5	1.3	89.0
21.0	8,000	879.3	751.6	207.4	79.7	127.7	1.2	88.7
20.9	8,000	879.3	749.4	212.0	82.1	129.8	1.2	88.5
20.8	8,000	879.3	747.3	216.5	84.5	131.9	1.2	88.2
20.7	8,000	879.3	745.3	220.9	86.9	134.0	1.2	87.9
20.6	8,000	879.3	743.3	225.4	89.4	136.0	1.1	87.6
20.5	8,000	879.3	741.4	229.8	91.9	137.9	1.1	87.3
20.4	8,000	879.3	739.5	234.1	94.4	139.8	1.1	87.0
20.3	8,000	879.3	737.7	238.5	96.9	141.6	1.0	86.6
20.2	8,000	879.3	735.9	242.8	99.5	143.4	1.0	86.3
20.1	8,000	879.3	734.2	247.1	102.0	145.1	1.0	86.0

20.0	8,000	879.3	732.5	251.4	104.6	146.7	1.0	85.7
19.9	8,000	879.3	730.9	255.6	107.3	148.3	0.9	85.4
19.8	8,000	879.3	729.4	259.8	109.9	149.9	0.9	85.1
19.7	8,000	879.3	727.9	264.0	112.6	151.4	0.9	84.8
19.6	8,000	879.3	726.5	268.1	115.3	152.8	0.9	84.5
19.5	8,000	879.3	725.1	272.3	118.1	154.2	0.9	84.2
19.4	8,000	879.3	723.7	276.4	120.8	155.5	0.8	83.9
19.3	8,000	879.3	722.5	280.4	123.6	156.8	0.8	83.6
19.2	8,000	879.3	721.3	284.5	126.4	158.0	0.8	83.3
19.1	8,000	879.3	720.1	288.5	129.3	159.2	0.8	82.9
19.0	8,000	879.3	719.0	292.5	132.2	160.3	0.8	82.6
18.9	8,000	879.3	717.9	296.4	135.1	161.3	0.7	82.3
18.8	8,000	879.3	717.0	300.3	138.0	162.3	0.7	82.0
18.7	8,000	879.3	716.0	304.3	141.0	163.2	0.7	81.7
18.6	8,000	879.3	715.2	308.1	144.0	164.1	0.7	81.4
18.5	8,000	879.3	714.4	312.0	147.1	164.9	0.7	81.0
18.4	8,000	879.3	713.6	315.8	150.1	165.7	0.6	80.7
18.3	8,000	879.3	712.9	319.6	153.2	166.4	0.6	80.4
18.2	8,000	879.3	712.3	323.4	156.4	167.0	0.6	80.1
18.1	8,000	879.3	711.7	327.1	159.6	167.6	0.6	79.8
18.0	8,000	879.3	711.2	330.8	162.8	168.1	0.6	79.4
17.9	8,000	879.3	710.8	334.5	166.0	168.5	0.6	79.1
17.8	8,000	879.3	710.4	338.2	169.3	168.9	0.6	78.8
17.7	8,000	879.3	710.0	341.8	172.6	169.2	0.5	78.5
17.6	8,000	879.3	709.8	345.5	176.0	169.5	0.5	78.1
17.5	8,000	879.3	709.6	349.1	179.4	169.7	0.5	77.8
17.4	8,000	879.3	709.5	352.6	182.8	169.8	0.5	77.5
17.3	8,000	879.3	709.4	356.2	186.3	169.9	0.5	77.1
17.2	8,000	879.3	709.4	359.7	189.8	169.9	0.5	76.8
17.1	8,000	879.3	709.5	363.2	193.4	169.8	0.5	76.5
17.0	8,000	879.3	709.6	366.6	197.0	169.7	0.4	76.1
16.9	8,000	879.3	709.8	370.1	200.6	169.5	0.4	75.8
16.8	8,000	879.3	710.1	373.5	204.3	169.2	0.4	75.5
16.7	8,000	879.3	710.4	376.9	208.0	168.9	0.4	75.1
16.6	8,000	879.3	710.8	380.3	211.8	168.5	0.4	74.8
16.5	8,000	879.3	711.3	383.6	215.6	168.0	0.4	74.5
16.4	8,000	879.3	711.8	386.9	219.5	167.5	0.4	74.1
16.3	8,000	879.3	712.4	390.2	223.4	166.8	0.4	73.8
16.2	8,000	879.3	713.1	393.5	227.4	166.1	0.4	73.4
16.1	8,000	879.3	713.9	396.7	231.4	165.4	0.3	73.1
16.0	8,000	879.3	714.7	400.0	235.4	164.5	0.3	72.8
15.9	8,000	879.3	715.7	403.2	239.5	163.6	0.3	72.4
15.8	8,000	879.3	716.6	406.3	243.7	162.6	0.3	72.1
15.7	8,000	879.3	717.7	409.5	247.9	161.6	0.3	71.7
15.6	8,000	879.3	718.8	412.6	252.2	160.4	0.3	71.4
15.5	8,000	879.3	720.1	415.7	256.5	159.2	0.3	71.0
15.4	8,000	879.3	721.4	418.8	260.9	157.9	0.3	70.7
15.3	8,000	879.3	722.7	421.9	265.4	156.5	0.3	70.3
15.2	8,000	879.3	724.2	424.9	269.8	155.1	0.3	70.0
15.1	8,000	879.3	725.8	427.9	274.4	153.5	0.3	69.6
15.0	8,000	879.3	727.4	430.9	279.0	151.9	0.2	69.3
14.9	8,000	879.3	729.1	433.9	283.7	150.2	0.2	68.9
14.8	8,000	879.3	730.9	436.8	288.5	148.4	0.2	68.6
14.7	8,000	879.3	732.8	439.8	293.3	146.5	0.2	68.2
14.6	8,000	879.3	734.8	442.7	298.1	144.5	0.2	67.8
14.5	8,000	879.3	736.8	445.5	303.1	142.5	0.2	67.5
14.4	8,000	879.3	739.0	448.4	308.1	140.3	0.2	67.1
14.3	8,000	879.3	741.2	451.2	313.2	138.0	0.2	66.8
14.2	8,000	879.3	743.6	454.0	318.3	135.7	0.2	66.4
14.1	8,000	879.3	746.0	456.8	323.6	133.3	0.2	66.0

14.0	8,000	879.3	748.6	459.6	328.9	130.7	0.2	65.7
13.9	8,000	879.3	751.2	462.3	334.2	128.1	0.2	65.3
13.8	8,000	879.3	753.9	465.0	339.7	125.4	0.2	64.9
13.7	8,000	879.3	756.8	467.7	345.2	122.5	0.2	64.6
13.6	8,000	879.3	759.7	470.4	350.8	119.6	0.2	64.2
13.5	8,000	879.3	762.7	473.1	356.5	116.5	0.2	63.8
13.4	8,000	879.3	765.9	475.7	362.3	113.4	0.1	63.4
13.3	8,000	879.3	769.1	478.3	368.2	110.1	0.1	63.1
13.2	8,000	879.3	772.5	480.9	374.2	106.8	0.1	62.7
13.1	8,000	879.3	776.0	483.5	380.2	103.3	0.1	62.3
13.0	8,000	879.3	779.6	486.0	386.3	99.7	0.1	61.9
12.9	8,000	879.3	783.3	488.6	392.6	96.0	0.1	61.6
12.8	8,000	879.3	787.1	491.1	398.9	92.1	0.1	61.2
12.7	8,000	879.3	791.1	493.5	405.4	88.2	0.1	60.8
12.6	8,000	879.3	795.2	496.0	411.9	84.1	0.1	60.4
12.5	8,000	879.3	799.4	498.4	418.5	79.9	0.1	60.0
12.4	8,000	879.3	803.7	500.9	425.3	75.6	0.1	59.7
12.3	8,000	879.3	808.2	503.3	432.2	71.1	0.1	59.3
12.2	8,000	879.3	812.8	505.6	439.1	66.5	0.1	58.9
12.1	8,000	879.3	817.5	508.0	446.2	61.8	0.1	58.5
12.0	8,000	879.3	822.4	510.3	453.4	56.9	0.1	58.1
11.9	8,000	879.3	827.4	512.6	460.7	51.9	0.1	57.7
11.8	8,000	879.3	832.5	514.9	468.2	46.7	0.1	57.3
11.7	8,000	879.3	837.9	517.2	475.8	41.4	0.1	56.9
11.6	8,000	879.3	843.3	519.5	483.5	36.0	0.1	56.5
11.5	8,000	879.3	848.9	521.7	491.3	30.4	0.1	56.1
11.4	8,000	879.3	854.7	523.9	499.3	24.6	0.1	55.7
11.3	8,000	879.3	860.6	526.1	507.4	18.6	0.1	55.3
11.2	8,000	879.3	866.7	528.3	515.7	12.5	0.1	54.9
11.1	8,000	879.3	873.0	530.4	524.1	6.3	0.1	54.5
11.0	8,000	879.3	879.4	532.5	532.7	-0.2	0.1	54.1
10.9	8,000	879.3	886.1	534.6	541.4	-6.8	0.1	53.7
10.8	8,000	879.3	892.9	536.7	550.3	-13.6	0.1	53.3
10.7	8,000	879.3	899.8	538.8	559.4	-20.6	0.1	52.9
10.6	8,000	879.3	907.0	540.8	568.6	-27.7	0.1	52.5
10.5	8,000	879.3	914.4	542.9	578.0	-35.1	0.1	52.1
10.4	8,000	879.3	922.0	544.9	587.6	-42.7	0.1	51.7
10.3	8,000	879.3	929.8	546.9	597.3	-50.5	0.1	51.3
10.2	8,000	879.3	937.8	548.8	607.3	-58.5	0.0	50.9
10.1	8,000	879.3	946.0	550.8	617.5	-66.7	0.0	50.5
10.0	8,000	879.3	954.4	552.7	627.8	-75.1	0.0	50.0

Appendix 3: The changes of the operating cost, the amount of GHG emissions and the service quality at each voyage speed (10,000 TEU)

	Average vessel size (TEU)	net operating cost (MUS$)	Designed operating cost (MUS$)	Sum of Positive effects (MUS$)	Sum of Negative effect (MUS$)	Net Slow Steaming Effect (MUS$)	GHG (M Ton)	Productivity (%)
25.0	10,000	1,012.4	1,012.4	-	-	-	3.4	80.0
24.9	10,000	1,007.6	1,012.4	6.8	2.0	4.8	3.3	79.8
24.8	10,000	1,002.8	1,012.4	13.6	3.9	9.6	3.3	79.6
24.7	10,000	998.1	1,012.4	20.3	5.9	14.3	3.2	79.4
24.6	10,000	993.4	1,012.4	26.9	7.9	19.0	3.1	79.1
24.5	10,000	988.8	1,012.4	33.6	10.0	23.6	3.1	78.9
24.4	10,000	984.3	1,012.4	40.1	12.0	28.2	3.0	78.7
24.3	10,000	979.8	1,012.4	46.7	14.1	32.6	3.0	78.5
24.2	10,000	975.4	1,012.4	53.2	16.1	37.1	2.9	78.3
24.1	10,000	971.0	1,012.4	59.7	18.2	41.4	2.8	78.1
24.0	10,000	966.7	1,012.4	66.1	20.3	45.7	2.8	77.8
23.9	10,000	962.5	1,012.4	72.4	22.5	50.0	2.7	77.6
23.8	10,000	958.3	1,012.4	78.8	24.6	54.2	2.7	77.4
23.7	10,000	954.1	1,012.4	85.1	26.8	58.3	2.6	77.2
23.6	10,000	950.1	1,012.4	91.3	28.9	62.4	2.6	77.0
23.5	10,000	946.0	1,012.4	97.5	31.1	66.4	2.5	76.7
23.4	10,000	942.1	1,012.4	103.7	33.4	70.4	2.5	76.5
23.3	10,000	938.2	1,012.4	109.9	35.6	74.3	2.4	76.3
23.2	10,000	934.3	1,012.4	116.0	37.9	78.1	2.3	76.1
23.1	10,000	930.6	1,012.4	122.0	40.1	81.9	2.3	75.8
23.0	10,000	926.8	1,012.4	128.0	42.4	85.6	2.2	75.6
22.9	10,000	923.2	1,012.4	134.0	44.7	89.3	2.2	75.4
22.8	10,000	919.6	1,012.4	140.0	47.1	92.9	2.2	75.2
22.7	10,000	916.0	1,012.4	145.9	49.4	96.4	2.1	74.9
22.6	10,000	912.5	1,012.4	151.7	51.8	99.9	2.1	74.7
22.5	10,000	909.1	1,012.4	157.5	54.2	103.3	2.0	74.5
22.4	10,000	905.7	1,012.4	163.3	56.6	106.7	2.0	74.3
22.3	10,000	902.4	1,012.4	169.1	59.1	110.0	1.9	74.0
22.2	10,000	899.2	1,012.4	174.8	61.5	113.3	1.9	73.8
22.1	10,000	896.0	1,012.4	180.5	64.0	116.5	1.8	73.6
22.0	10,000	892.9	1,012.4	186.1	66.5	119.6	1.8	73.3
21.9	10,000	889.8	1,012.4	191.7	69.1	122.7	1.8	73.1
21.8	10,000	886.8	1,012.4	197.3	71.6	125.7	1.7	72.9
21.7	10,000	883.8	1,012.4	202.8	74.2	128.6	1.7	72.6
21.6	10,000	880.9	1,012.4	208.3	76.8	131.5	1.6	72.4
21.5	10,000	878.1	1,012.4	213.8	79.4	134.4	1.6	72.2
21.4	10,000	875.3	1,012.4	219.2	82.1	137.1	1.6	71.9
21.3	10,000	872.6	1,012.4	224.6	84.7	139.8	1.5	71.7
21.2	10,000	870.0	1,012.4	229.9	87.5	142.5	1.5	71.5
21.1	10,000	867.4	1,012.4	235.3	90.2	145.1	1.5	71.2
21.0	10,000	864.8	1,012.4	240.5	92.9	147.6	1.4	71.0
20.9	10,000	862.4	1,012.4	245.8	95.7	150.1	1.4	70.8
20.8	10,000	860.0	1,012.4	251.0	98.5	152.5	1.4	70.5
20.7	10,000	857.6	1,012.4	256.2	101.3	154.8	1.3	70.3
20.6	10,000	855.3	1,012.4	261.3	104.2	157.1	1.3	70.0

20.5	10,000	853.1	1,012.4	266.4	107.1	159.3	1.3	69.8
20.4	10,000	850.9	1,012.4	271.5	110.0	161.5	1.2	69.6
20.3	10,000	848.8	1,012.4	276.6	113.0	163.6	1.2	69.3
20.2	10,000	846.8	1,012.4	281.6	115.9	165.6	1.2	69.1
20.1	10,000	844.8	1,012.4	286.5	118.9	167.6	1.2	68.8
20.0	10,000	842.9	1,012.4	291.5	122.0	169.5	1.1	68.6
19.9	10,000	841.1	1,012.4	296.4	125.0	171.4	1.1	68.3
19.8	10,000	839.3	1,012.4	301.3	128.1	173.1	1.1	68.1
19.7	10,000	837.6	1,012.4	306.1	131.3	174.9	1.0	67.9
19.6	10,000	835.9	1,012.4	310.9	134.4	176.5	1.0	67.6
19.5	10,000	834.3	1,012.4	315.7	137.6	178.1	1.0	67.4
19.4	10,000	832.8	1,012.4	320.5	140.8	179.6	1.0	67.1
19.3	10,000	831.4	1,012.4	325.2	144.1	181.1	0.9	66.9
19.2	10,000	830.0	1,012.4	329.9	147.4	182.5	0.9	66.6
19.1	10,000	828.6	1,012.4	334.5	150.7	183.8	0.9	66.4
19.0	10,000	827.4	1,012.4	339.1	154.1	185.1	0.9	66.1
18.9	10,000	826.2	1,012.4	343.7	157.5	186.3	0.9	65.9
18.8	10,000	825.1	1,012.4	348.3	160.9	187.4	0.8	65.6
18.7	10,000	824.0	1,012.4	352.8	164.4	188.4	0.8	65.3
18.6	10,000	823.0	1,012.4	357.3	167.9	189.4	0.8	65.1
18.5	10,000	822.1	1,012.4	361.8	171.4	190.4	0.8	64.8
18.4	10,000	821.2	1,012.4	366.2	175.0	191.2	0.7	64.6
18.3	10,000	820.4	1,012.4	370.6	178.6	192.0	0.7	64.3
18.2	10,000	819.7	1,012.4	375.0	182.3	192.7	0.7	64.1
18.1	10,000	819.1	1,012.4	379.3	186.0	193.3	0.7	63.8
18.0	10,000	818.5	1,012.4	383.6	189.7	193.9	0.7	63.6
17.9	10,000	818.0	1,012.4	387.9	193.5	194.4	0.7	63.3
17.8	10,000	817.6	1,012.4	392.2	197.3	194.8	0.6	63.0
17.7	10,000	817.2	1,012.4	396.4	201.2	195.2	0.6	62.8
17.6	10,000	817.0	1,012.4	400.6	205.1	195.5	0.6	62.5
17.5	10,000	816.8	1,012.4	404.8	209.1	195.7	0.6	62.2
17.4	10,000	816.6	1,012.4	408.9	213.1	195.8	0.6	62.0
17.3	10,000	816.6	1,012.4	413.0	217.1	195.9	0.6	61.7
17.2	10,000	816.6	1,012.4	417.1	221.2	195.8	0.5	61.5
17.1	10,000	816.7	1,012.4	421.1	225.4	195.7	0.5	61.2
17.0	10,000	816.9	1,012.4	425.2	229.6	195.6	0.5	60.9
16.9	10,000	817.1	1,012.4	429.2	233.8	195.3	0.5	60.7
16.8	10,000	817.5	1,012.4	433.1	238.1	195.0	0.5	60.4
16.7	10,000	817.9	1,012.4	437.1	242.5	194.6	0.5	60.1
16.6	10,000	818.4	1,012.4	441.0	246.9	194.1	0.5	59.8
16.5	10,000	818.9	1,012.4	444.8	251.3	193.5	0.4	59.6
16.4	10,000	819.6	1,012.4	448.7	255.8	192.9	0.4	59.3
16.3	10,000	820.3	1,012.4	452.5	260.4	192.1	0.4	59.0
16.2	10,000	821.2	1,012.4	456.3	265.0	191.3	0.4	58.8
16.1	10,000	822.1	1,012.4	460.1	269.7	190.4	0.4	58.5
16.0	10,000	823.1	1,012.4	463.8	274.4	189.4	0.4	58.2
15.9	10,000	824.1	1,012.4	467.5	279.2	188.3	0.4	57.9
15.8	10,000	825.3	1,012.4	471.2	284.1	187.1	0.4	57.7
15.7	10,000	826.6	1,012.4	474.9	289.0	185.9	0.3	57.4
15.6	10,000	827.9	1,012.4	478.5	294.0	184.5	0.3	57.1
15.5	10,000	829.4	1,012.4	482.1	299.0	183.1	0.3	56.8
15.4	10,000	830.9	1,012.4	485.7	304.1	181.5	0.3	56.5
15.3	10,000	832.5	1,012.4	489.2	309.3	179.9	0.3	56.3
15.2	10,000	834.3	1,012.4	492.7	314.6	178.2	0.3	56.0

15.1	10,000	836.1	1,012.4	496.2	319.9	176.4	0.3	55.7
15.0	10,000	838.0	1,012.4	499.7	325.3	174.4	0.3	55.4
14.9	10,000	840.0	1,012.4	503.1	330.7	172.4	0.3	55.1
14.8	10,000	842.1	1,012.4	506.6	336.2	170.3	0.3	54.8
14.7	10,000	844.3	1,012.4	509.9	341.8	168.1	0.3	54.6
14.6	10,000	846.7	1,012.4	513.3	347.5	165.8	0.2	54.3
14.5	10,000	849.1	1,012.4	516.6	353.3	163.4	0.2	54.0
14.4	10,000	851.6	1,012.4	520.0	359.1	160.8	0.2	53.7
14.3	10,000	854.3	1,012.4	523.2	365.1	158.2	0.2	53.4
14.2	10,000	857.0	1,012.4	526.5	371.1	155.4	0.2	53.1
14.1	10,000	859.9	1,012.4	529.7	377.2	152.6	0.2	52.8
14.0	10,000	862.8	1,012.4	532.9	383.3	149.6	0.2	52.5
13.9	10,000	865.9	1,012.4	536.1	389.6	146.5	0.2	52.2
13.8	10,000	869.1	1,012.4	539.3	396.0	143.3	0.2	51.9
13.7	10,000	872.5	1,012.4	542.4	402.4	140.0	0.2	51.6
13.6	10,000	875.9	1,012.4	545.5	409.0	136.5	0.2	51.4
13.5	10,000	879.5	1,012.4	548.6	415.6	133.0	0.2	51.1
13.4	10,000	883.1	1,012.4	551.6	422.3	129.3	0.2	50.8
13.3	10,000	887.0	1,012.4	554.7	429.2	125.5	0.2	50.5
13.2	10,000	890.9	1,012.4	557.7	436.1	121.5	0.2	50.2
13.1	10,000	895.0	1,012.4	560.7	443.2	117.5	0.2	49.9
13.0	10,000	899.2	1,012.4	563.6	450.4	113.3	0.1	49.6
12.9	10,000	903.5	1,012.4	566.5	457.6	108.9	0.1	49.3
12.8	10,000	908.0	1,012.4	569.4	465.0	104.4	0.1	48.9
12.7	10,000	912.6	1,012.4	572.3	472.5	99.8	0.1	48.6
12.6	10,000	917.4	1,012.4	575.2	480.1	95.0	0.1	48.3
12.5	10,000	922.3	1,012.4	578.0	487.9	90.1	0.1	48.0
12.4	10,000	927.4	1,012.4	580.8	495.7	85.1	0.1	47.7
12.3	10,000	932.6	1,012.4	583.6	503.7	79.8	0.1	47.4
12.2	10,000	938.0	1,012.4	586.3	511.9	74.5	0.1	47.1
12.1	10,000	943.5	1,012.4	589.1	520.1	68.9	0.1	46.8
12.0	10,000	949.2	1,012.4	591.8	528.5	63.2	0.1	46.5
11.9	10,000	955.1	1,012.4	594.5	537.1	57.4	0.1	46.2
11.8	10,000	961.1	1,012.4	597.1	545.8	51.4	0.1	45.9
11.7	10,000	967.3	1,012.4	599.8	554.6	45.2	0.1	45.5
11.6	10,000	973.7	1,012.4	602.4	563.6	38.8	0.1	45.2
11.5	10,000	980.2	1,012.4	605.0	572.7	32.2	0.1	44.9
11.4	10,000	987.0	1,012.4	607.5	582.0	25.5	0.1	44.6
11.3	10,000	993.9	1,012.4	610.1	591.5	18.6	0.1	44.3
11.2	10,000	1,001.0	1,012.4	612.6	601.1	11.4	0.1	44.0
11.1	10,000	1,008.3	1,012.4	615.1	610.9	4.1	0.1	43.6
11.0	10,000	1,015.9	1,012.4	617.5	620.9	-3.4	0.1	43.3
10.9	10,000	1,023.6	1,012.4	620.0	631.1	-11.1	0.1	43.0
10.8	10,000	1,031.5	1,012.4	622.4	641.5	-19.1	0.1	42.7
10.7	10,000	1,039.7	1,012.4	624.8	652.0	-27.2	0.1	42.3
10.6	10,000	1,048.1	1,012.4	627.2	662.8	-35.6	0.1	42.0
10.5	10,000	1,056.7	1,012.4	629.5	673.7	-44.2	0.1	41.7
10.4	10,000	1,065.5	1,012.4	631.8	684.9	-53.1	0.1	41.4
10.3	10,000	1,074.6	1,012.4	634.1	696.3	-62.2	0.1	41.0
10.2	10,000	1,083.9	1,012.4	636.4	707.9	-71.5	0.1	40.7
10.1	10,000	1,093.5	1,012.4	638.7	719.7	-81.1	0.1	40.4
10.0	10,000	1,103.4	1,012.4	640.9	731.8	-90.9	0.1	40.0

Appendix 4: The changes of the operating cost, the amount of GHG emissions and the service quality at each voyage speed (12,000 TEU)

	Average vessel size (TEU)	net operating cost (MUS$)	Designed operating cost (MUS$)	Sum of Positive effects (MUS$)	Sum of Negative effect (MUS$)	Net Slow Steaming Effect (MUS$)	GHG (M Ton)	Productivity (%)
25.0	12,000	1,220.6	1,220.6	-	-	-	4.2	66.7
24.9	12,000	1,214.4	1,220.6	8.4	2.2	6.2	4.1	66.5
24.8	12,000	1,208.3	1,220.6	16.8	4.5	12.3	4.0	66.3
24.7	12,000	1,202.3	1,220.6	25.0	6.8	18.3	4.0	66.1
24.6	12,000	1,196.4	1,220.6	33.3	9.1	24.2	3.9	66.0
24.5	12,000	1,190.5	1,220.6	41.5	11.4	30.1	3.8	65.8
24.4	12,000	1,184.7	1,220.6	49.6	13.7	35.9	3.7	65.6
24.3	12,000	1,178.9	1,220.6	57.7	16.1	41.7	3.7	65.4
24.2	12,000	1,173.3	1,220.6	65.7	18.4	47.3	3.6	65.2
24.1	12,000	1,167.7	1,220.6	73.7	20.8	52.9	3.5	65.0
24.0	12,000	1,162.2	1,220.6	81.7	23.2	58.4	3.4	64.9
23.9	12,000	1,156.7	1,220.6	89.5	25.6	63.9	3.4	64.7
23.8	12,000	1,151.3	1,220.6	97.4	28.1	69.3	3.3	64.5
23.7	12,000	1,146.0	1,220.6	105.2	30.6	74.6	3.2	64.3
23.6	12,000	1,140.8	1,220.6	112.9	33.1	79.8	3.2	64.1
23.5	12,000	1,135.6	1,220.6	120.6	35.6	85.0	3.1	63.9
23.4	12,000	1,130.5	1,220.6	128.2	38.1	90.1	3.0	63.8
23.3	12,000	1,125.5	1,220.6	135.8	40.7	95.1	3.0	63.6
23.2	12,000	1,120.5	1,220.6	143.3	43.2	100.1	2.9	63.4
23.1	12,000	1,115.6	1,220.6	150.8	45.8	105.0	2.8	63.2
23.0	12,000	1,110.8	1,220.6	158.2	48.5	109.8	2.8	63.0
22.9	12,000	1,106.1	1,220.6	165.6	51.1	114.5	2.7	62.8
22.8	12,000	1,101.4	1,220.6	173.0	53.8	119.2	2.7	62.6
22.7	12,000	1,096.8	1,220.6	180.3	56.5	123.8	2.6	62.5
22.6	12,000	1,092.2	1,220.6	187.5	59.2	128.3	2.6	62.3
22.5	12,000	1,087.8	1,220.6	194.7	61.9	132.8	2.5	62.1
22.4	12,000	1,083.4	1,220.6	201.9	64.7	137.2	2.4	61.9
22.3	12,000	1,079.1	1,220.6	209.0	67.5	141.5	2.4	61.7
22.2	12,000	1,074.8	1,220.6	216.0	70.3	145.8	2.3	61.5
22.1	12,000	1,070.7	1,220.6	223.1	73.1	149.9	2.3	61.3
22.0	12,000	1,066.5	1,220.6	230.0	76.0	154.0	2.2	61.1
21.9	12,000	1,062.5	1,220.6	237.0	78.9	158.1	2.2	60.9
21.8	12,000	1,058.5	1,220.6	243.8	81.8	162.0	2.1	60.7
21.7	12,000	1,054.7	1,220.6	250.7	84.7	165.9	2.1	60.5
21.6	12,000	1,050.8	1,220.6	257.5	87.7	169.8	2.0	60.3
21.5	12,000	1,047.1	1,220.6	264.2	90.7	173.5	2.0	60.1
21.4	12,000	1,043.4	1,220.6	270.9	93.7	177.2	1.9	60.0
21.3	12,000	1,039.8	1,220.6	277.6	96.8	180.8	1.9	59.8
21.2	12,000	1,036.3	1,220.6	284.2	99.9	184.3	1.9	59.6
21.1	12,000	1,032.8	1,220.6	290.8	103.0	187.8	1.8	59.4
21.0	12,000	1,029.4	1,220.6	297.3	106.1	191.2	1.8	59.2
20.9	12,000	1,026.1	1,220.6	303.8	109.3	194.5	1.7	59.0
20.8	12,000	1,022.9	1,220.6	310.2	112.5	197.7	1.7	58.8
20.7	12,000	1,019.7	1,220.6	316.6	115.8	200.9	1.7	58.6
20.6	12,000	1,016.6	1,220.6	323.0	119.0	204.0	1.6	58.4
20.5	12,000	1,013.6	1,220.6	329.3	122.3	207.0	1.6	58.2
20.4	12,000	1,010.7	1,220.6	335.6	125.6	209.9	1.5	58.0
20.3	12,000	1,007.8	1,220.6	341.8	129.0	212.8	1.5	57.8
20.2	12,000	1,005.0	1,220.6	348.0	132.4	215.6	1.5	57.6
20.1	12,000	1,002.3	1,220.6	354.2	135.8	218.3	1.4	57.4
20.0	12,000	999.6	1,220.6	360.3	139.3	221.0	1.4	57.2

19.9	12,000	997.1	1,220.6	366.3	142.8	223.5	1.4	57.0
19.8	12,000	994.6	1,220.6	372.4	146.3	226.0	1.3	56.7
19.7	12,000	992.2	1,220.6	378.3	149.9	228.4	1.3	56.5
19.6	12,000	989.8	1,220.6	384.3	153.5	230.8	1.3	56.3
19.5	12,000	987.5	1,220.6	390.2	157.2	233.0	1.2	56.1
19.4	12,000	985.4	1,220.6	396.1	160.8	235.2	1.2	55.9
19.3	12,000	983.3	1,220.6	401.9	164.6	237.3	1.2	55.7
19.2	12,000	981.2	1,220.6	407.7	168.3	239.4	1.1	55.5
19.1	12,000	979.3	1,220.6	413.4	172.1	241.3	1.1	55.3
19.0	12,000	977.4	1,220.6	419.2	176.0	243.2	1.1	55.1
18.9	12,000	975.6	1,220.6	424.8	179.8	245.0	1.1	54.9
18.8	12,000	973.9	1,220.6	430.5	183.8	246.7	1.0	54.7
18.7	12,000	972.3	1,220.6	436.1	187.7	248.3	1.0	54.5
18.6	12,000	970.7	1,220.6	441.6	191.7	249.9	1.0	54.2
18.5	12,000	969.2	1,220.6	447.1	195.8	251.4	1.0	54.0
18.4	12,000	967.8	1,220.6	452.6	199.9	252.7	0.9	53.8
18.3	12,000	966.5	1,220.6	458.1	204.0	254.1	0.9	53.6
18.2	12,000	965.3	1,220.6	463.5	208.2	255.3	0.9	53.4
18.1	12,000	964.2	1,220.6	468.8	212.4	256.4	0.9	53.2
18.0	12,000	963.1	1,220.6	474.2	216.7	257.5	0.8	53.0
17.9	12,000	962.1	1,220.6	479.5	221.0	258.4	0.8	52.7
17.8	12,000	961.3	1,220.6	484.7	225.4	259.3	0.8	52.5
17.7	12,000	960.5	1,220.6	489.9	229.8	260.1	0.8	52.3
17.6	12,000	959.7	1,220.6	495.1	234.3	260.8	0.7	52.1
17.5	12,000	959.1	1,220.6	500.3	238.8	261.5	0.7	51.9
17.4	12,000	958.6	1,220.6	505.4	243.4	262.0	0.7	51.7
17.3	12,000	958.1	1,220.6	510.5	248.0	262.5	0.7	51.4
17.2	12,000	957.8	1,220.6	515.5	252.7	262.8	0.7	51.2
17.1	12,000	957.5	1,220.6	520.5	257.4	263.1	0.6	51.0
17.0	12,000	957.3	1,220.6	525.5	262.2	263.3	0.6	50.8
16.9	12,000	957.2	1,220.6	530.4	267.1	263.3	0.6	50.5
16.8	12,000	957.3	1,220.6	535.3	272.0	263.3	0.6	50.3
16.7	12,000	957.4	1,220.6	540.2	276.9	263.2	0.6	50.1
16.6	12,000	957.6	1,220.6	545.0	282.0	263.0	0.6	49.9
16.5	12,000	957.8	1,220.6	549.8	287.1	262.7	0.5	49.6
16.4	12,000	958.2	1,220.6	554.6	292.2	262.4	0.5	49.4
16.3	12,000	958.7	1,220.6	559.3	297.4	261.9	0.5	49.2
16.2	12,000	959.3	1,220.6	564.0	302.7	261.3	0.5	49.0
16.1	12,000	960.0	1,220.6	568.6	308.0	260.6	0.5	48.7
16.0	12,000	960.8	1,220.6	573.2	313.4	259.8	0.5	48.5
15.9	12,000	961.7	1,220.6	577.8	318.9	258.9	0.5	48.3
15.8	12,000	962.7	1,220.6	582.4	324.5	257.9	0.4	48.0
15.7	12,000	963.8	1,220.6	586.9	330.1	256.8	0.4	47.8
15.6	12,000	965.0	1,220.6	591.4	335.8	255.6	0.4	47.6
15.5	12,000	966.3	1,220.6	595.8	341.5	254.3	0.4	47.4
15.4	12,000	967.7	1,220.6	600.3	347.4	252.9	0.4	47.1
15.3	12,000	969.2	1,220.6	604.6	353.3	251.4	0.4	46.9
15.2	12,000	970.9	1,220.6	609.0	359.3	249.7	0.4	46.6
15.1	12,000	972.6	1,220.6	613.3	365.3	248.0	0.4	46.4
15.0	12,000	974.5	1,220.6	617.6	371.5	246.1	0.3	46.2
14.9	12,000	976.4	1,220.6	621.9	377.7	244.1	0.3	45.9
14.8	12,000	978.5	1,220.6	626.1	384.0	242.1	0.3	45.7
14.7	12,000	980.8	1,220.6	630.3	390.4	239.8	0.3	45.5
14.6	12,000	983.1	1,220.6	634.4	396.9	237.5	0.3	45.2
14.5	12,000	985.5	1,220.6	638.5	403.5	235.0	0.3	45.0
14.4	12,000	988.1	1,220.6	642.6	410.2	232.5	0.3	44.7
14.3	12,000	990.8	1,220.6	646.7	416.9	229.8	0.3	44.5
14.2	12,000	993.7	1,220.6	650.7	423.8	226.9	0.3	44.3
14.1	12,000	996.6	1,220.6	654.7	430.8	224.0	0.3	44.0
14.0	12,000	999.7	1,220.6	658.7	437.8	220.9	0.3	43.8

13.9	12,000	1,003.0	1,220.6	662.6	445.0	217.6	0.2	43.5
13.8	12,000	1,006.3	1,220.6	666.5	452.2	214.3	0.2	43.3
13.7	12,000	1,009.8	1,220.6	670.4	459.6	210.8	0.2	43.0
13.6	12,000	1,013.5	1,220.6	674.2	467.1	207.1	0.2	42.8
13.5	12,000	1,017.2	1,220.6	678.0	474.7	203.4	0.2	42.5
13.4	12,000	1,021.2	1,220.6	681.8	482.4	199.4	0.2	42.3
13.3	12,000	1,025.2	1,220.6	685.5	490.2	195.4	0.2	42.0
13.2	12,000	1,029.5	1,220.6	689.3	498.1	191.1	0.2	41.8
13.1	12,000	1,033.8	1,220.6	692.9	506.2	186.8	0.2	41.5
13.0	12,000	1,038.4	1,220.6	696.6	514.4	182.2	0.2	41.3
12.9	12,000	1,043.0	1,220.6	700.2	522.7	177.5	0.2	41.0
12.8	12,000	1,047.9	1,220.6	703.8	531.1	172.7	0.2	40.8
12.7	12,000	1,052.9	1,220.6	707.4	539.7	167.7	0.2	40.5
12.6	12,000	1,058.1	1,220.6	710.9	548.4	162.5	0.2	40.3
12.5	12,000	1,063.4	1,220.6	714.4	557.2	157.2	0.2	40.0
12.4	12,000	1,069.0	1,220.6	717.8	566.2	151.6	0.1	39.8
12.3	12,000	1,074.7	1,220.6	721.3	575.3	145.9	0.1	39.5
12.2	12,000	1,080.5	1,220.6	724.7	584.6	140.1	0.1	39.3
12.1	12,000	1,086.6	1,220.6	728.1	594.1	134.0	0.1	39.0
12.0	12,000	1,092.8	1,220.6	731.4	603.7	127.8	0.1	38.7
11.9	12,000	1,099.3	1,220.6	734.7	613.4	121.3	0.1	38.5
11.8	12,000	1,105.9	1,220.6	738.0	623.3	114.7	0.1	38.2
11.7	12,000	1,112.7	1,220.6	741.3	633.4	107.8	0.1	38.0
11.6	12,000	1,119.8	1,220.6	744.5	643.7	100.8	0.1	37.7
11.5	12,000	1,127.0	1,220.6	747.7	654.1	93.6	0.1	37.4
11.4	12,000	1,134.5	1,220.6	750.9	664.7	86.1	0.1	37.2
11.3	12,000	1,142.2	1,220.6	754.0	675.6	78.4	0.1	36.9
11.2	12,000	1,150.1	1,220.6	757.1	686.6	70.5	0.1	36.6
11.1	12,000	1,158.2	1,220.6	760.2	697.8	62.4	0.1	36.4
11.0	12,000	1,166.5	1,220.6	763.2	709.2	54.0	0.1	36.1
10.9	12,000	1,175.1	1,220.6	766.3	720.8	45.4	0.1	35.8
10.8	12,000	1,184.0	1,220.6	769.2	732.6	36.6	0.1	35.6
10.7	12,000	1,193.1	1,220.6	772.2	744.7	27.5	0.1	35.3
10.6	12,000	1,202.4	1,220.6	775.1	757.0	18.2	0.1	35.0
10.5	12,000	1,212.0	1,220.6	778.0	769.5	8.6	0.1	34.7
10.4	12,000	1,221.9	1,220.6	780.9	782.2	-1.3	0.1	34.5
10.3	12,000	1,232.1	1,220.6	783.8	795.3	-11.5	0.1	34.2
10.2	12,000	1,242.5	1,220.6	786.6	808.5	-21.9	0.1	33.9
10.1	12,000	1,253.3	1,220.6	789.4	822.0	-32.7	0.1	33.6
10.0	12,000	1,264.3	1,220.6	792.1	835.8	-43.7	0.1	33.4

Appendix 5: The changes of the operating cost, the amount of GHG emissions and the service quality at each voyage speed (14,000 TEU)

	Average vessel size (TEU)	net operating cost (MUS$)	Designed operating cost (MUS$)	Sum of Positive effects (MUS$)	Sum of Negative effect (MUS$)	Net Slow Steaming Effect (MUS$)	GHG (M Ton)	Productivity (%)
25.0	14,000	1,435.3	1,435.3	-	-	-	5.0	57.1
24.9	14,000	1,427.7	1,435.3	10.1	2.5	7.6	4.9	57.0
24.8	14,000	1,420.2	1,435.3	20.1	5.1	15.0	4.8	56.8
24.7	14,000	1,412.9	1,435.3	30.0	7.6	22.4	4.8	56.7
24.6	14,000	1,405.6	1,435.3	39.9	10.2	29.7	4.7	56.5
24.5	14,000	1,398.4	1,435.3	49.7	12.8	36.9	4.6	56.4
24.4	14,000	1,391.2	1,435.3	59.4	15.4	44.0	4.5	56.2
24.3	14,000	1,384.2	1,435.3	69.1	18.0	51.1	4.4	56.1
24.2	14,000	1,377.2	1,435.3	78.8	20.7	58.0	4.3	55.9
24.1	14,000	1,370.3	1,435.3	88.3	23.4	64.9	4.2	55.8
24.0	14,000	1,363.5	1,435.3	97.8	26.1	71.7	4.1	55.6
23.9	14,000	1,356.8	1,435.3	107.3	28.8	78.4	4.0	55.4
23.8	14,000	1,350.2	1,435.3	116.6	31.6	85.1	4.0	55.3
23.7	14,000	1,343.7	1,435.3	126.0	34.4	91.6	3.9	55.1
23.6	14,000	1,337.2	1,435.3	135.2	37.2	98.1	3.8	55.0
23.5	14,000	1,330.8	1,435.3	144.4	40.0	104.4	3.7	54.8
23.4	14,000	1,324.5	1,435.3	153.6	42.8	110.7	3.6	54.7
23.3	14,000	1,318.3	1,435.3	162.7	45.7	116.9	3.6	54.5
23.2	14,000	1,312.2	1,435.3	171.7	48.6	123.1	3.5	54.3
23.1	14,000	1,306.1	1,435.3	180.7	51.5	129.1	3.4	54.2
23.0	14,000	1,300.2	1,435.3	189.6	54.5	135.1	3.3	54.0
22.9	14,000	1,294.3	1,435.3	198.4	57.5	141.0	3.3	53.9
22.8	14,000	1,288.5	1,435.3	207.2	60.5	146.8	3.2	53.7
22.7	14,000	1,282.8	1,435.3	216.0	63.5	152.5	3.1	53.5
22.6	14,000	1,277.2	1,435.3	224.6	66.5	158.1	3.1	53.4
22.5	14,000	1,271.6	1,435.3	233.3	69.6	163.7	3.0	53.2
22.4	14,000	1,266.1	1,435.3	241.8	72.7	169.1	2.9	53.0
22.3	14,000	1,260.8	1,435.3	250.4	75.9	174.5	2.9	52.9
22.2	14,000	1,255.5	1,435.3	258.8	79.0	179.8	2.8	52.7
22.1	14,000	1,250.3	1,435.3	267.2	82.2	185.0	2.7	52.6
22.0	14,000	1,245.1	1,435.3	275.6	85.4	190.1	2.7	52.4
21.9	14,000	1,240.1	1,435.3	283.9	88.7	195.2	2.6	52.2
21.8	14,000	1,235.1	1,435.3	292.1	92.0	200.1	2.6	52.1
21.7	14,000	1,230.2	1,435.3	300.3	95.3	205.0	2.5	51.9
21.6	14,000	1,225.4	1,435.3	308.4	98.6	209.8	2.4	51.7
21.5	14,000	1,220.7	1,435.3	316.5	102.0	214.5	2.4	51.6
21.4	14,000	1,216.1	1,435.3	324.6	105.4	219.2	2.3	51.4
21.3	14,000	1,211.6	1,435.3	332.5	108.8	223.7	2.3	51.2
21.2	14,000	1,207.1	1,435.3	340.5	112.3	228.2	2.2	51.1
21.1	14,000	1,202.7	1,435.3	348.3	115.8	232.5	2.2	50.9
21.0	14,000	1,198.4	1,435.3	356.2	119.3	236.8	2.1	50.7
20.9	14,000	1,194.2	1,435.3	363.9	122.9	241.0	2.1	50.5
20.8	14,000	1,190.1	1,435.3	371.6	126.5	245.1	2.0	50.4
20.7	14,000	1,186.1	1,435.3	379.3	130.2	249.2	2.0	50.2
20.6	14,000	1,182.2	1,435.3	386.9	133.8	253.1	1.9	50.0
20.5	14,000	1,178.3	1,435.3	394.5	137.5	257.0	1.9	49.9
20.4	14,000	1,174.5	1,435.3	402.0	141.3	260.7	1.8	49.7
20.3	14,000	1,170.8	1,435.3	409.5	145.1	264.4	1.8	49.5
20.2	14,000	1,167.2	1,435.3	416.9	148.9	268.0	1.8	49.3
20.1	14,000	1,163.7	1,435.3	424.3	152.7	271.5	1.7	49.2
20.0	14,000	1,160.3	1,435.3	431.6	156.6	275.0	1.7	49.0

19.9	14,000	1,157.0	1,435.3	438.9	160.6	278.3	1.6	48.8
19.8	14,000	1,153.7	1,435.3	446.1	164.5	281.5	1.6	48.6
19.7	14,000	1,150.6	1,435.3	453.3	168.6	284.7	1.6	48.5
19.6	14,000	1,147.5	1,435.3	460.4	172.6	287.8	1.5	48.3
19.5	14,000	1,144.5	1,435.3	467.5	176.7	290.7	1.5	48.1
19.4	14,000	1,141.6	1,435.3	474.5	180.9	293.6	1.4	47.9
19.3	14,000	1,138.8	1,435.3	481.5	185.0	296.4	1.4	47.8
19.2	14,000	1,136.1	1,435.3	488.4	189.3	299.1	1.4	47.6
19.1	14,000	1,133.5	1,435.3	495.3	193.5	301.8	1.3	47.4
19.0	14,000	1,131.0	1,435.3	502.1	197.9	304.3	1.3	47.2
18.9	14,000	1,128.5	1,435.3	508.9	202.2	306.7	1.3	47.0
18.8	14,000	1,126.2	1,435.3	515.7	206.6	309.1	1.2	46.9
18.7	14,000	1,123.9	1,435.3	522.4	211.1	311.3	1.2	46.7
18.6	14,000	1,121.8	1,435.3	529.1	215.6	313.5	1.2	46.5
18.5	14,000	1,119.7	1,435.3	535.7	220.1	315.5	1.1	46.3
18.4	14,000	1,117.8	1,435.3	542.2	224.7	317.5	1.1	46.1
18.3	14,000	1,115.9	1,435.3	548.8	229.4	319.4	1.1	45.9
18.2	14,000	1,114.1	1,435.3	555.2	234.1	321.1	1.1	45.8
18.1	14,000	1,112.4	1,435.3	561.7	238.9	322.8	1.0	45.6
18.0	14,000	1,110.9	1,435.3	568.1	243.7	324.4	1.0	45.4
17.9	14,000	1,109.4	1,435.3	574.4	248.5	325.9	1.0	45.2
17.8	14,000	1,108.0	1,435.3	580.7	253.4	327.3	0.9	45.0
17.7	14,000	1,106.7	1,435.3	587.0	258.4	328.5	0.9	44.8
17.6	14,000	1,105.5	1,435.3	593.2	263.4	329.7	0.9	44.6
17.5	14,000	1,104.5	1,435.3	599.3	268.5	330.8	0.9	44.5
17.4	14,000	1,103.5	1,435.3	605.5	273.7	331.8	0.8	44.3
17.3	14,000	1,102.6	1,435.3	611.5	278.9	332.7	0.8	44.1
17.2	14,000	1,101.8	1,435.3	617.6	284.1	333.4	0.8	43.9
17.1	14,000	1,101.2	1,435.3	623.6	289.5	334.1	0.8	43.7
17.0	14,000	1,100.6	1,435.3	629.5	294.8	334.7	0.8	43.5
16.9	14,000	1,100.1	1,435.3	635.4	300.3	335.1	0.7	43.3
16.8	14,000	1,099.8	1,435.3	641.3	305.8	335.5	0.7	43.1
16.7	14,000	1,099.5	1,435.3	647.1	311.4	335.7	0.7	42.9
16.6	14,000	1,099.4	1,435.3	652.9	317.1	335.9	0.7	42.7
16.5	14,000	1,099.4	1,435.3	658.7	322.8	335.9	0.7	42.6
16.4	14,000	1,099.5	1,435.3	664.4	328.6	335.8	0.6	42.4
16.3	14,000	1,099.7	1,435.3	670.0	334.4	335.6	0.6	42.2
16.2	14,000	1,100.0	1,435.3	675.6	340.4	335.3	0.6	42.0
16.1	14,000	1,100.4	1,435.3	681.2	346.4	334.9	0.6	41.8
16.0	14,000	1,101.0	1,435.3	686.7	352.4	334.3	0.6	41.6
15.9	14,000	1,101.6	1,435.3	692.2	358.6	333.6	0.6	41.4
15.8	14,000	1,102.4	1,435.3	697.7	364.8	332.9	0.5	41.2
15.7	14,000	1,103.3	1,435.3	703.1	371.1	332.0	0.5	41.0
15.6	14,000	1,104.3	1,435.3	708.5	377.5	330.9	0.5	40.8
15.5	14,000	1,105.5	1,435.3	713.8	384.0	329.8	0.5	40.6
15.4	14,000	1,106.7	1,435.3	719.1	390.6	328.5	0.5	40.4
15.3	14,000	1,108.1	1,435.3	724.4	397.2	327.1	0.5	40.2
15.2	14,000	1,109.6	1,435.3	729.6	404.0	325.6	0.4	40.0
15.1	14,000	1,111.3	1,435.3	734.8	410.8	324.0	0.4	39.8
15.0	14,000	1,113.1	1,435.3	739.9	417.7	322.2	0.4	39.6
14.9	14,000	1,115.0	1,435.3	745.0	424.7	320.3	0.4	39.4
14.8	14,000	1,117.0	1,435.3	750.0	431.8	318.2	0.4	39.2
14.7	14,000	1,119.2	1,435.3	755.1	439.0	316.0	0.4	39.0
14.6	14,000	1,121.5	1,435.3	760.0	446.3	313.7	0.4	38.8
14.5	14,000	1,124.0	1,435.3	765.0	453.7	311.3	0.4	38.6
14.4	14,000	1,126.6	1,435.3	769.9	461.2	308.7	0.3	38.4
14.3	14,000	1,129.3	1,435.3	774.7	468.8	305.9	0.3	38.1
14.2	14,000	1,132.2	1,435.3	779.6	476.5	303.0	0.3	37.9
14.1	14,000	1,135.3	1,435.3	784.3	484.4	300.0	0.3	37.7
14.0	14,000	1,138.5	1,435.3	789.1	492.3	296.8	0.3	37.5

13.9	14,000	1,141.8	1,435.3	793.8	500.3	293.5	0.3	37.3
13.8	14,000	1,145.3	1,435.3	798.5	508.5	290.0	0.3	37.1
13.7	14,000	1,148.9	1,435.3	803.1	516.8	286.3	0.3	36.9
13.6	14,000	1,152.8	1,435.3	807.7	525.2	282.5	0.3	36.7
13.5	14,000	1,156.7	1,435.3	812.3	533.7	278.5	0.3	36.5
13.4	14,000	1,160.9	1,435.3	816.8	542.4	274.4	0.3	36.3
13.3	14,000	1,165.2	1,435.3	821.3	551.2	270.1	0.2	36.0
13.2	14,000	1,169.6	1,435.3	825.7	560.1	265.6	0.2	35.8
13.1	14,000	1,174.3	1,435.3	830.1	569.2	261.0	0.2	35.6
13.0	14,000	1,179.1	1,435.3	834.5	578.4	256.1	0.2	35.4
12.9	14,000	1,184.1	1,435.3	838.8	587.7	251.1	0.2	35.2
12.8	14,000	1,189.3	1,435.3	843.1	597.2	246.0	0.2	35.0
12.7	14,000	1,194.7	1,435.3	847.4	606.8	240.6	0.2	34.7
12.6	14,000	1,200.2	1,435.3	851.6	616.6	235.0	0.2	34.5
12.5	14,000	1,206.0	1,435.3	855.8	626.6	229.3	0.2	34.3
12.4	14,000	1,211.9	1,435.3	860.0	636.7	223.3	0.2	34.1
12.3	14,000	1,218.1	1,435.3	864.1	646.9	217.2	0.2	33.9
12.2	14,000	1,224.5	1,435.3	868.2	657.4	210.8	0.2	33.6
12.1	14,000	1,231.0	1,435.3	872.2	668.0	204.2	0.2	33.4
12.0	14,000	1,237.8	1,435.3	876.2	678.8	197.5	0.2	33.2
11.9	14,000	1,244.8	1,435.3	880.2	689.7	190.5	0.2	33.0
11.8	14,000	1,252.0	1,435.3	884.1	700.9	183.2	0.1	32.8
11.7	14,000	1,259.5	1,435.3	888.0	712.2	175.8	0.1	32.5
11.6	14,000	1,267.1	1,435.3	891.9	723.8	168.1	0.1	32.3
11.5	14,000	1,275.1	1,435.3	895.7	735.5	160.2	0.1	32.1
11.4	14,000	1,283.2	1,435.3	899.5	747.5	152.1	0.1	31.9
11.3	14,000	1,291.6	1,435.3	903.3	759.6	143.7	0.1	31.6
11.2	14,000	1,300.3	1,435.3	907.0	772.0	135.0	0.1	31.4
11.1	14,000	1,309.2	1,435.3	910.7	784.6	126.1	0.1	31.2
11.0	14,000	1,318.3	1,435.3	914.3	797.4	116.9	0.1	30.9
10.9	14,000	1,327.8	1,435.3	918.0	810.5	107.5	0.1	30.7
10.8	14,000	1,337.5	1,435.3	921.5	823.8	97.7	0.1	30.5
10.7	14,000	1,347.5	1,435.3	925.1	837.4	87.7	0.1	30.2
10.6	14,000	1,357.8	1,435.3	928.6	851.2	77.4	0.1	30.0
10.5	14,000	1,368.4	1,435.3	932.1	865.2	66.8	0.1	29.8
10.4	14,000	1,379.3	1,435.3	935.5	879.6	55.9	0.1	29.5
10.3	14,000	1,390.5	1,435.3	938.9	894.2	44.7	0.1	29.3
10.2	14,000	1,402.1	1,435.3	942.3	909.1	33.2	0.1	29.1
10.1	14,000	1,413.9	1,435.3	945.7	924.3	21.3	0.1	28.8
10.0	14,000	1,426.1	1,435.3	949.0	939.8	9.1	0.1	28.6

Appendix 6: Questionnaire for Survey

Questionnaire on the Effects of Slow Steaming on the Liner Shipping Industry

During the last three decades, shipping lines have been focusing on the improvement of operational efficiency to strengthen their competitiveness and maximize their profits. However, in recent times, an obvious strategy in the liner shipping industry that has come to the fore is slow steaming. Shipping lines have decelerated the voyage speed to 18-20 knots on major routes, and some shipping lines announced that they have a plan to reduce it to below 18 knots. This is because slow steaming is helpful in reducing the operating cost and the amount of GHG emissions in the condition of high fuel prices and low freight rates. However, it also creates negative effects such as the opportunity cost, additional fixed costs and an in-transit inventory cost on a loop. Hence, net operating cost on a loop is changing dynamically due to the changes of voyage speed based on various slow steaming effects.

The aim of this survey is to investigate the current strategic goal of shipping lines. According to the definition of Bergantino & Veenstra (2002), shipping lines build and/or improve their operational strategy based on their own strategic goals. Moreover, they defined that shipping lines have eight main strategic goals. The aim of this study is to build the optimum operational strategy with considering the impact of slow steaming and current main strategic goals of shipping line. To achieve the aim, a dynamic simulation model was established, and the answers of this questionnaire will be utilized the main variable in this model.

This questionnaire consists of 40 questions, any information we receive from you will not be used other than for the purpose of research. Moreover, it will not be disclosed to third parties. I appreciate your answering the questionnaire, and we promise to try to make useful results and thesis. We are waiting for your excellent opinions.

Main strategic goals of shipping line

Strategic Goals (Factor)		Factor Name
1	The expansion of the transport capacity	CAPA
2	The expansion of the services network	NET
3	The improvement of the cost efficiency by reducing costs	COST
4	The increase of market share	MS
5	The improvement of the service quality	SQ
6	The improvement of environmental performance	GHG
7	The diversification of the business (horizontal/vertical Integration)	HVI
8	The improvement of the operational productivity	OPRO

TO RETURN THE QUESTIONNAIRE

Please return this questionnaire to below contact point (E-mail) until 30th September, 2011.

World Maritime University
PO BOX 500, S-201 24, Malmo, Sweden
Phone: +46 (0)40 35 63 00 / Fax: +46 (0) 40 12 84 42
E-mail: P1101@WMU.SE

May 2, 2011

Jong Kyun Woo, PhD Candidate

Part 1: Basic Information

Name		Survey date	. . 2011

Q1. Where is your residence? Please write the answer. ( )

1	North America	2	South America	3	Europe
2	Middle East	5	Asia	6	Oceania
7	Africa	8	the others		

Q2. Which institute are you working for? ( )

1	Government/ Institute	2	Port Authority	3	Shipping Company
4	Terminal Operator	5	Logistics / Transportation Company		
6	Manufacturer	7	University or Research Institute	8	the others

Q3. What level of the organization best describes your position? ( )

1	Elected Official	2	Director	3	Senior Manager
4	Middle-level Manager	5	Supervisor	6	Scholar, Researcher
7	Consultant	8	the others		

Q4. What Functions do you deal with on a regular basis? ( )

1	Strategic Planning	2	Tactical Issue	3	Operation Issue
4	Research	5	The other		

Part 2: Basic Information

Please rate the following strategic goals based on importance to shipping line.

Question Number	Strategic Goal	Not at all Important	←				→	Extremely Important
Q5	CAPA	○	○	○	○	○	○	○
Q6	NET	○	○	○	○	○	○	○
Q7	COST	○	○	○	○	○	○	○
Q8	MS	○	○	○	○	○	○	○
Q9	SQ	○	○	○	○	○	○	○
Q10	GHG	○	○	○	○	○	○	○
Q11	HVI	○	○	○	○	○	○	○
Q12	OPRO	○	○	○	○	○	○	○

Factor Name	Strategic Goals (Factor)
CAPA	The expansion of the transport capacity
NET	The expansion of the services network
COST	The improvement of the cost efficiency by reducing costs
MS	The increase of market share
SQ	The improvement of the service quality
GHG	The improvement of environmental performance
HVI	The diversification of the business (horizontal/vertical Integration)
OPRO	The improvement of the operational productivity

Part 3: Comparative Importance

Example

First Step: Please choice **<u>which factor is more important between two factors</u>**.
Second Step: If you choose **'No.2'**, please choice **how more important it is Rather than 'No.1'.** And please **write your answer in each Black Box.**

First Step	Which one is more important?	
1	2	Answer
Spider Man	***Super Man***	**2**

Second Step			How more important it is rather than the other?					
			Answer			**8**		
1	2	3	4	5	6	7	*8*	9
Equal Important ←			Strong Important		→	Absolute Important		

Question

Q13. CAPA and NET		
First Step	Which one is more important?	
1	2	Answer
The expansion of the transport capacity	The expansion of the services network	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important ←			Strong Important		→	Absolute Important		

Q14. CAPA and COST		
First Step	Which one is more important?	
1	2	Answer
The expansion of the transport capacity	The improvement of the cost efficiency	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q15. CAPA and MS		
First Step	Which one is more important?	
1	2	Answer
The expansion of the transport capacity	The increase of market share	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q16. CAPA and SQ		
First Step	Which one is more important?	
1	2	Answer
The expansion of the transport capacity	The improvement of the service quality	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q17. CAPA and GHG		
First Step	Which one is more important?	
1	2	Answer
The expansion of the transport capacity	The improvement of environmental performance	

Second Step	How more important it is rather than the other?							
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q18. CAPA and HVI		
First Step	Which one is more important?	
1	2	Answer
The expansion of the transport capacity	The diversification of the business	

Second Step	How more important it is rather than the other?							
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q19. CAPA and OPRO		
First Step	Which one is more important?	
1	2	Answer
The expansion of the transport capacity	The improvement of the operational productivity	

Second Step	How more important it is rather than the other?							
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q20. NET and COST		
First Step	Which one is more important?	
1	2	Answer
The expansion of the services network	The improvement of the cost efficiency	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q21. NET and MS		
First Step	Which one is more important?	
1	2	Answer
The expansion of the services network	The increase of market share	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q22. NET and SQ		
First Step	Which one is more important?	
1	2	Answer
The expansion of the services network	The improvement of the service quality	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q23. NET and GHG		
First Step	Which one is more important?	
1	2	Answer
The expansion of the services network	The improvement of environmental performance	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q24. NET and HVI		
First Step	Which one is more important?	
1	2	Answer
The expansion of the services network	The diversification of the business	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q25. NET and OPRO		
First Step	Which one is more important?	
1	2	Answer
The expansion of the services network	The improvement of the operational productivity	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q26. COST and MS		
First Step	Which one is more important?	
1	2	Answer
The improvement of the cost efficiency	The increase of market share	

Second Step	How more important it is rather than the other?							
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q27. COST and SQ		
First Step	Which one is more important?	
1	2	Answer
The improvement of the cost efficiency	The improvement of the service quality	

Second Step	How more important it is rather than the other?							
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q28. COST and GHG		
First Step	Which one is more important?	
1	2	Answer
The improvement of the cost efficiency	The improvement of environmental performance	

Second Step	How more important it is rather than the other?							
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q29. COST and HVI		
First Step	Which one is more important?	
1	2	Answer
The improvement of the cost efficiency	The diversification of the business	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q30. COST and OPRO		
First Step	Which one is more important?	
1	2	Answer
The improvement of the cost efficiency	The improvement of the operational productivity	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q31. MS and SQ		
First Step	Which one is more important?	
1	2	Answer
The increase of market share	The improvement of the service quality	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q32. MS and GHG		
First Step	Which one is more important?	
1	2	Answer
The increase of market share	The improvement of environmental performance	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q33. MS and HVI		
First Step	Which one is more important?	
1	2	Answer
The increase of market share	The diversification of the business	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q34. MS and OPRO		
First Step	Which one is more important?	
1	2	Answer
The increase of market share	The improvement of the operational productivity	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q35. SQ and GHG		
First Step	Which one is more important?	
1	2	Answer
The improvement of the service quality	The improvement of environmental performance	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q36. SQ and HVI		
First Step	Which one is more important?	
1	2	Answer
The improvement of the service quality	The diversification of the business	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q37. SQ and OPRO		
First Step	Which one is more important?	
1	2	Answer
The improvement of the service quality	The improvement of the operational productivity	

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		it	Strong Important		→	Absolute Important		

Q38. GHG and HVI								
First Step			Which one is more important?					
1			2			Answer		
The improvement of environmental performance			The diversification of the business					

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q39. GHG and OPRO								
First Step			Which one is more important?					
1			2			Answer		
The improvement of environmental performance			The improvement of the operational productivity					

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Q40. HVI and OPRO								
First Step			Which one is more important?					
1			2			Answer		
The diversification of the business			The improvement of the operational productivity					

Second Step			How more important it is rather than the other?					
			Answer					
1	2	3	4	5	6	7	8	9
Equal Important		←	Strong Important		→	Absolute Important		

Thank you so much!