8-23-2015

Optimization of containership speed based on operation and environment regulations

Changjiang Yu

WORLD MARITIME UNIVERSITY

Dalian, China

OPTIMIZATION OF CONTAINERSHIP SPEED BASED ON OPERATION AND ENVIRONMENT REGULATIONS

By

Yu Changjiang

The People's Republic of China

A research paper submitted to the World Maritime University in partial
Fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

(MARITIME SAFETY AND ENVIRONMENTAL MANAGEMENT)

2015

DECLARATION

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

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

Signature: Yu Changjiang

Date: 9th June 2015

Supervised by: Cheng Dong
Professor
Dalian Maritime University

Assessor:

Co-assessor

ACKNOWLEDGEMENTS

As an important part of my life, I cherish the time sharing knowledge and happiness with my dear teachers and classmates. Without the generous help from dedicated professors and kind-hearted persons, the research work can never be accomplished. Hence, I would like to express my gratitude to those who have helped me during the learning time.

First of all, I gratefully acknowledge the help from my supervisor professor Cheng Dong. I sincerely appreciate his guidance and encouragement throughout the whole process of research. His professional advices and continuous support also helped me select the right direction during my thesis writing. Also, I would like to thank other professors in the course of Maritime Safety and Environmental Management who impart knowledge to us without reservation.

Secondly, special thanks should be given to Shandong MSA and its branch RiZhao MSA for providing me with such good opportunity to study for the master's degree of science.

Last but not least, I would like to extend my sincere gratitude to my family, especially my beloved wife who has been assisting and caring about me all of my life.

Title: Optimization of Containership Speed Based on Operation and Environment Regulations

Degree: MSc

ABSTRACT

This paper is to clarify the optimal speed of containership in various geographical areas aiming to minimize the consumption of oil fuel as well as protection marine environment under the new MARPOL ANNEX VI requirements.

Also considering the Green House Gas emission contributed by the shipping sector, this paper discusses slow steaming approaches aiming to reduce GHG by operation approach. However, extreme slow steaming may increase economic burden as it pays high price for time cost. For addressing this issue, this paper develops mathematic models for determining optimization speed of a single ship as well as its performance in fleet scenario. Additionally, examples and test data will be given to demonstrate the solutions in practice.

Firstly, a brief introduction of the paper and literature review will be presented in the Chapter 1 and Chapter 2. Chapter 3 is to solve the boundary problem like fuel price estimation and inventory cost related to this topic. Due to the fact that fuel cost has a close relationship with cost by different speed and fuel quality in various geography locations, the regression functions are also discussed in this chapter for highlighting the effect of two elements.

Chapter 4 is to discuss the mathematic model used for analyzing the problem. The difference from other researches is that this paper uses authentic data to verify the mathematic model. Further, Tans- Pacific and Asia- Europe routes are selected to test the model and evaluation results are given as for comparison of a prevailing approach.

Proposals and trends for the new phenomenon in the container shipping industry are discussed in Chapter 5, and the limitations of this research are also given in this Chapter. In the final part of this paper, a brief conclusion is made.

Interestingly, although the new innovations of maritime technology are stepping into the arenas which are always driven by the competition in shipping sector like LNG fuel, the international conventions are giving and will still give more pressure to ship operators regarding the marine environmental protection.

Key words: containership; slow steaming; environment; MARPOL; ECA

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AIS	Automatic Identification System
CIF	Cost, Insurance and Freight
CKYHE	The Container company alliance of COSCON, KLINE, YANGMING, HanJin and Evergreen-line
CPS	CHINA – US SOUTH WEST COAST EXPRESS SERVICE
COSCON	COSCO Container Lines, Co., Ltd.
ECA	Emission Control Area
EEOI	Energy Efficiency Operational Index
EGR	Exhausted Gas Recirculation
FAL	French Asia Line
GHG	Green House Gas
IAME	International Association of Maritime Economists
MEPC	Maritime Environment Protection Committee
PPM	Part Per Million
SFOC	Specific Fuel Oil Consumption
UNCLOS	United Nations Convention on the Law of the Sea1982

CHAPTER 1

Introduction

1.1 Study purpose

As one of mainly purposes for engaging in the shipping industry is to pursue profit, the better use of precious fuel should be concerned in the prevailing technology background. The voyage profit, which means single voyage revenue minus single voyage cost and tax, has a direct relationship to the whole interest. For making the maximum profit, one method is focusing on the increasing revenue, while another way is by controlling the cost. This paper centers on the second method by finding the optimization speed during a single containership voyage as well as the whole fleet interest in a liner company.

For a given voyage under certain fixed freight rate and status, one of variables is the speed of a ship, which can also be controlled by operation. The different speed will bring different profit in a fixed scenario for container shipping industry. High speed may save time by which it may bring extra revenue while it may also cause a sharp decrease of the profit due to the excessive fuel consumption. By contrast, slow steaming may save fuel consumption, but the customers may complain the schedule of liner particular for high value cargoes. Further, as per the MARPOL ANNEX VI requirement, the emissions from ships should also be controlled in various geography areas. That is why many operators consider the scientific management approach regarding the fuel consumption and its influence to marine environment.

The purpose of the study is to provide suggestions and mathematics models for the shippers, charters or owners on selecting containership's speed based on the analysis case.

1.2 Container shipping background

The containership as an efficient transport tool has developed significantly from Feeder to Post PANAMAX in the past thirty years (Ashar, 1999, pp.57–61.). According to the Equasis statistics, the number of 6000+ TEU containership in 2014 has grown three times larger than that in 2005 (See Fig -1). The total quantity of container ship maintained in around 3500(UNCTAD, 2015, p.43) in the past ten years, while the average ship size increased sharply from 2004 to 2014(See Fig-2). However, by reviewing the container freight in the past five years (2000-2014), the container freight rate is not booming as the trend of containerships' development. By contrast, the average of freight rate in 2014 is significantly below that of 2012 (UNCTAD, 2015a, pp.44-46). Take the market in Trans-Pacific for example, the figure had dropped by 3.7-11.11% (11.11% is the maximum figure appeared in the Shanghai to the US West Coast) compared to that of 2013(Clarkson, 2014a).

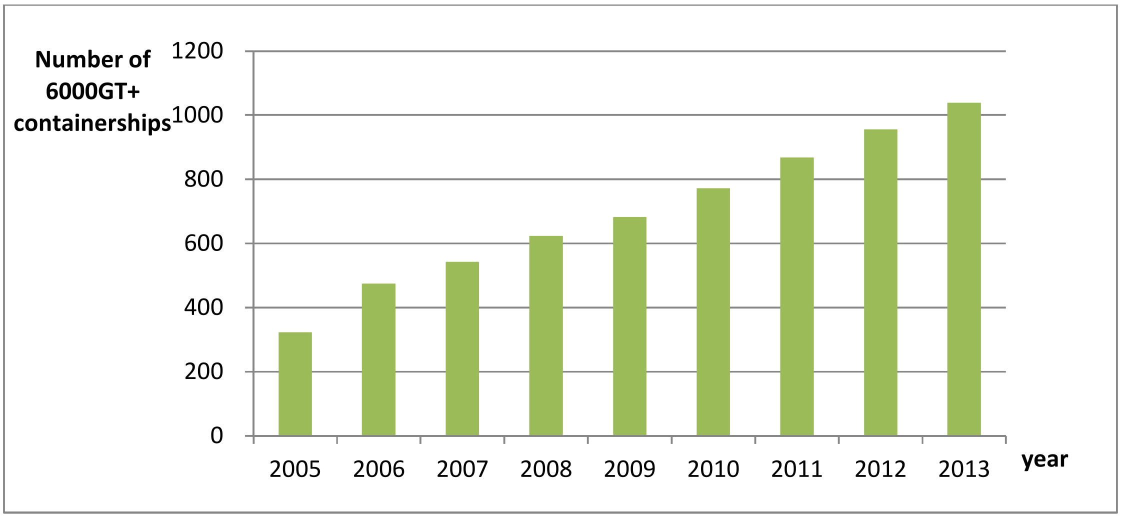
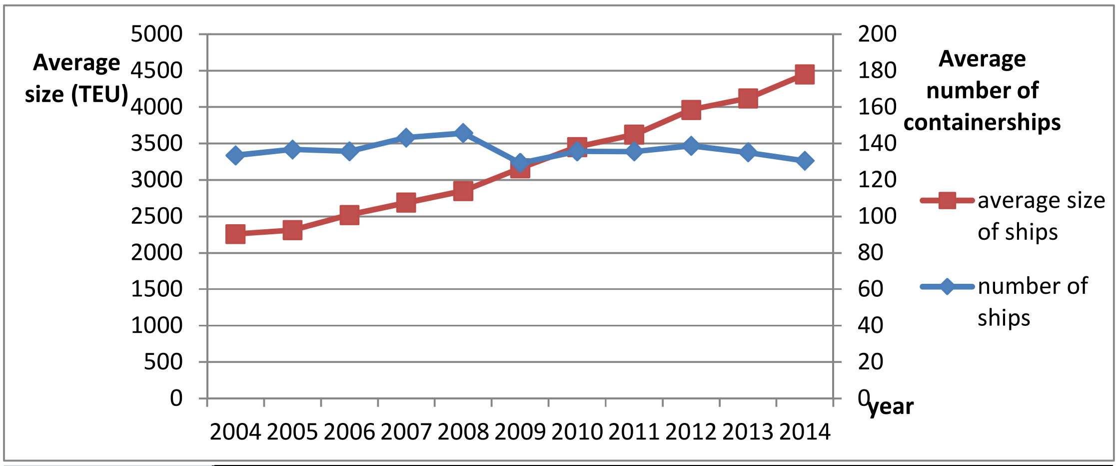


Figure 1 - 6000+GT containership develop trend from 2005 to 2013

Source: The Author (Note: The data are based on *The World Merchant Fleet 2013* achieved by Equasis)



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
number of ships	134	136.7	135.7	143.2	145.7	129.3	135.7	135.6	138.8	135	130.5
average size of ships	2259	2312	2520	2689	2848	3161	3452	3622	3962	4121	4449

Figure 2 - Global number of containerships and average size of ship by TEU

Source: UNCTAD. (2015). Review of Maritime Transport 2014. United Nations Conference on trade and development secretariat, New York and Geneva: Author.

For seeking the maximum profit by decreasing the operation cost, the capacity of containership by TEUs has increased significantly (Clarkson, 2014b), which also trigger the market competition increasingly fierce. For example, the Maersk announced that the Triple E series containerships with maximum capacity of 18,000 TEUs would be serviced to the market in 2013, but no less than two years, a vessel with 19,100 TEUs named CSCL GLOBE under the flag of China Shipping Company stepped into oceans in early 2015. Moreover, another four ships of similar sizes are under construction (Liu, 2015). The Maersk Line did not keep silence and they planned to build six vessels of the same level. By far, the maximum capacity of the future containership is still in doubt.

1.3 Bunkering effects

Bunkering industry has a great connection with maritime shipping, which provides the fuel oil to the vessel (Notteboom & Vernimmen, 2009.p.325). For marine fuel sectors, three types of fuel oil are mainly concerned to the operation of engine and ship's emission. *MGO, shorts for marine gas oil,* which is lighter fraction and better quality compared to diesel oil, is sometime used for auxiliary engine to generate electricity power (Lim, 1998, p.363). *Marine diesel oil,* also named *MGO* with low sulphur of less than 0.65% is usually used for better maneuvering of main engine during inbound of berth. *Internet Fuel Oil* can be divided by IFO 180 and IFO 380 for maritime transport purpose, but the IFO180 is more expensive than IFO380 with low percentage of sulphur.

The international crude oil fluctuates in recent years due to various uncertain and unpredictable factors. Accordingly, the marine fuel oil also changes fiercely. For example, the price of IFO 380 in Singapore is about $330 per ton, but this figure has reached to $700 per ton in history (Ship&Bunker, 2015). The COSCO Dalian Company has stated that the cost of fuel accounts for 80-90% of the overall various cost according to its own report (Wang, 2013, p.9).

1.4 Main Contents and Methodology

Cost structure of a single given voyage will be analyzed first aiming to clarify the fixed cost and variable cost components. Then the relationship between speed, main engine power and fuel consumption will be discussed in the following step.

From the perspective of main engine management, with the help of index EEOI, the better solution for addressing the control of emission and seeking high efficiency of fuel consumption will be found.

By analyzing the collection data, the software MS Excel will be used for comparative analyze in factual scenario, and further simulation analysis will be carried out for verifying the math model. The final conclusion is based on the following four aspects:

1) The actual problems of container shipping industry as well as the environment issues;
2) The development trends of containership construction in future;
3) The necessity of specialized environment protection resolution based on the requirement of MARPOL convention after 2015 and the operation cost related to it;
4) Discussion on the feasibility of mathematical model by using real data from shipping companies.

CHAPTER 2

Literature Review

Before discussing the optimization of containership speed, the fixed speed has been assumed in the famous RS/MS mathematics model (Rana and Vickson, 1991). But the possible misconception is the index of speed which is treated as a fixed value in transport. In that model, two steps were defined. Firstly, it provided the optimization model; secondly a text of such algorithm would be conducted. Similarly, the third research for emission in shipping sector achieved by IMO also considered the speed as a fixed value, but it provided a comprehensive perspective for the contribution of emission in such area (IMO, 2014a).

In this research paper, much attention should be paid to the data test which will be explained in the real situation as the following aspects are concerned:

i. The function of fuel consumption related to the speed;
ii. The forecast scenarios under different fuel oil prices;
iii. Market and mixed chartering requirements for high speed or economic speed;
iv. Inventory cost, slot cost, etc.,

From the very beginning, the relationship between speed and fuel will be discussed.

2.1 The resistance and effective power functions

Fig-3 shows a simple force suffered by a floating ship. Horizontally, the resistance and propulsion depends on the final instantaneous velocity. As early as in the year 1956, the direct proportion between cubic of velocity and fuel consumption had been discovered (Manning, 1956).

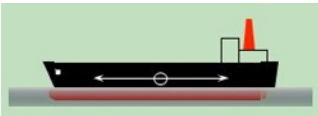
THRUST  RESISTANCE

Figure 3 - The horizontal force of a floating ship
Source: The author.

Total resistance R_t has roughly directed proportional relationship to the square of ship velocity V_s as is shown in the following formula:

$$R_t = C \cdot V_s^2 \qquad (1)$$

Here, C means coefficient.

The efficient power, which has a rough relationship with Vs, as is shown in the following formula:

$$P_E = R_t V_s = 1/2\ C_t\ \rho\ S * V_s^3 \qquad (2)$$

(ρ : density [kg/m^3] ,S : wetted surface [m^2], V_s : ship speed [m/s], C_t : frictional coefficient)

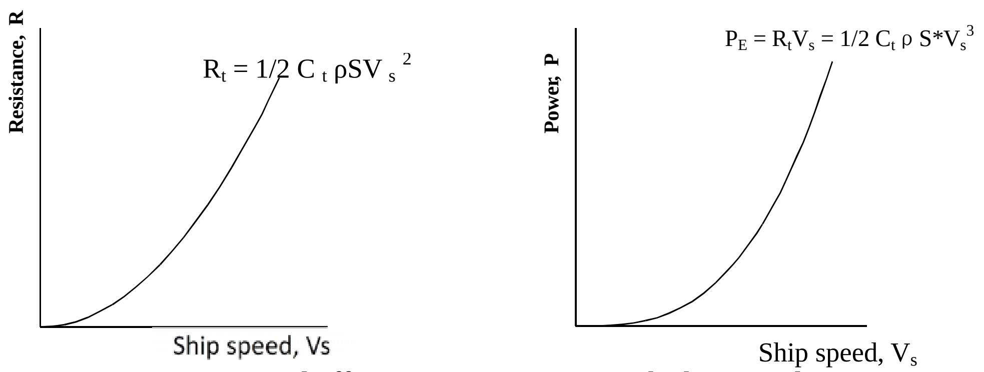


Figure 4 - Resistance and effective power curves with ship speeds
Source: NAKAZAWA. (2014). Impact of the maritime innovation and technology (unpublished handout). World Maritime University.

Many researches have verified the general relationship between the fuel consumption and speed, which can be concluded as: *Fuel consumption* $\propto P_E \propto V_s^3$. But this situation does not consider whether a large containership is powered by shore electricity device and when its speed is near zero, in most cases, it is only good for estimation of fuel consumption (Buxton, 1985, pp.47-53). Some scholars propose a quadratic function to estimate the consumption of fuel (Christiansen et al, 2007, pp. 189-184).

By adding another coefficient in the direct proportion function to the cubic velocity, the function fuel consumption with velocity: $Fc = K_1 \times V_s + K_2$ means that the bigger size vessel consume fuel faster than those smaller one (Yao, et al, 2011).

For seeking the minimum value of the triplicate integral method, a mathematical model absent inventory cost and weather condition have been established in an average assumption (Andersson, et al, 2015, pp. 233–240).

2.2 The operation perspective

A routing model had been assumed by the operation method used in real practice (Fagerholt et al, 2015, pp.53-57). In this model it highlights the path thorough ECA used for optimization speed for saving cost. This study is focusing on the math problem but the environmental effect is neglected. In contrast, Angelos provided the cost calculation but without any optimization speed problem (Angelos, 2004). For better solutions of this complex issue, some researches focus on how to determine the vessel speed dynamically as well as refueling issues under uncertain bunker prices scenarios (Sheng et al, 2013).

In fact, the speed of ship is deeply affected by the main engine and maintenance.

2.3 Study from the perspective of marine environment protection

Engine with EGR and other equipment like *hybrid turbocharger* can filter the content of NOx, and a new model of engine is set up using a power turbine can lead to 3-4% SFOC and NOx reductions (Larsen et al, 2015, p.555).

For slow steaming approach, operation of slow steaming will bring good profit as well as the benefit for environment (Lindstad et al, 2013, pp. 5-8). However, some people argued that the operation of slow steaming would cause less revenue and reduce the demand of additional ships in the market (UNCTAD, 2012). This conflicting argument encourages a new study on how to find an optimization speed for decreasing emission as well as operation cost (Chang & Wang, 2014, pp. 110-115).

From the policy's perspective, as per MARPOL ANNEX Reg.14, the sulphur content limitation of fuel oil should be no more than 0.1% inside the ECA after January 2015, which shrinks the selection of fossil fuel.

2.4 Other elements

In practice, the weather condition seriously affects the speed in many situations, so the whole simulate process should be based on average weather condition as many literatures do. If a coefficient is added on such mathematics model, the coefficient should be set up in a general situation that wave, wind, tidy and current are considered in an average level.

As for maintenance, the hull and main engine condition should not be ignored. Because the rough surface will increase the oil consumption significantly, while smooth surface helps reduction of resistance, hence, an average hull condition is considered in the next calculation.

Fuel price is also a potential element. If the oil price drops to a relatively low level, the operators will pursue time rather than other elements.

Inventory cost is also another uncontrollable element for assessing the optimal speed. It is worth to mentioning that cargo inventory costs may lead liner operators to change their mind particularly when high valued goods are involved. For example, the price of one unit freight of high valued goods like medical instruments ($95,000/ton, for instance) were five time higher than that of low valued goods like furniture in 2004 (CBO, 2006). Just assuming the delay only cost of trans- cargo in a relatively low level, for a 10,000+ containership, the money should be calculated in millions, so this result may lead to less benefit by slow steaming(Fagerholt, 2004, 259–268.). As an important element, the trans-cargo inventory will be discussed in the mathematics model as a special consideration.

CHAPTER 3

Other Issues Regarding Operations

3.1 The various economic pressure brought by speed

Technically, the speed of containership can be categorized into normal speed, slow steaming and extremely slow steaming (Maloni et al, 2013, p.3). Although the world's oil price is in a reasonable level due to the good news by the technology development for exploration of shale oil, no one knows how it will fluctuate in the future market. According to the Ship & Bunker data, the price of IFO180 was $319 per ton in the February of 2015; however, this figure had jumped to over $700 per ton in history. For better analyzing the pressure brought by the oil price, different levels of oil price are defined. High level of price means that the fuel oil price is more than $700/ ton; intermediate level of price means in the period between $500/ton and $700/ton; accordingly, low level of price means less than $500/ ton. Hence, three scenarios will be assumed as a coefficient *X* (*X_1= the real time price/ 700 in high price level, X_2= the real time price/ 600 in intermediate price level, X_3= the real time price/ 500 in low price level)* in the following discussion. The first scenario will be defined as high oil price level in which it gives a value $*700X_1/ton*, accordingly, *\$500X_2/ton* for intermediate price level and *\$300X_3/ton* for low price level.

For containerships of different capacity, the fuel consumption has a complex nonlinear relationship based on statistics (See Figure 5).

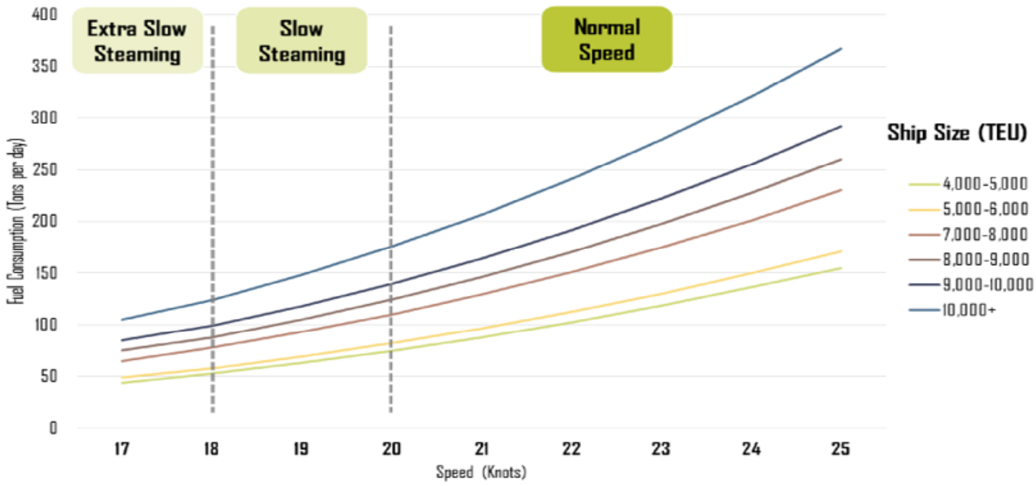


Figure- 5: Statistics on containership fuel consumption with different speed

Source: Notteboom, T. & Carriou, P. (2009). IAME Conference, Copenhagen.

3.1.1 An example of large containership

Take the 10,000+ TEU containership as an example, the cost of fuel in different speed can be summarized in the following table.

Table 1- Daily fuel cost in different fuel oil price by speed for 10,000+TEU containerships

Daily fuel cost(unit:$) / Speed	Low price level	Intermediate price level	High price level	Coefficient: X(X_1= real time price / 700, X_2= real time price / 600, X_3 = real time price / 500)
25Kn	108000	180000	252000	
22 Kn	75000	125000	175000	
19 Kn	45000	75000	105000	
17 Kn	30000	50000	70000	

Source: The author.

Obviously, the difference on costs between the speed at 25Kn and 17Kn will reach to \$18,200X_1 *(X_1=real time price / 700)* per day. In general, the nonlinear relationship with speed can be expressed by the following regression function:

$$y = 4666.7x^3 - 24500x^2 - 36167x + 308000, R^2 = 1 \quad (3)$$

Here, y means the daily fuel cost, x means the speed of containership. The general cost trend with ship of different speeds in different fuel oil prices can be drawn as is shown in the following figure.

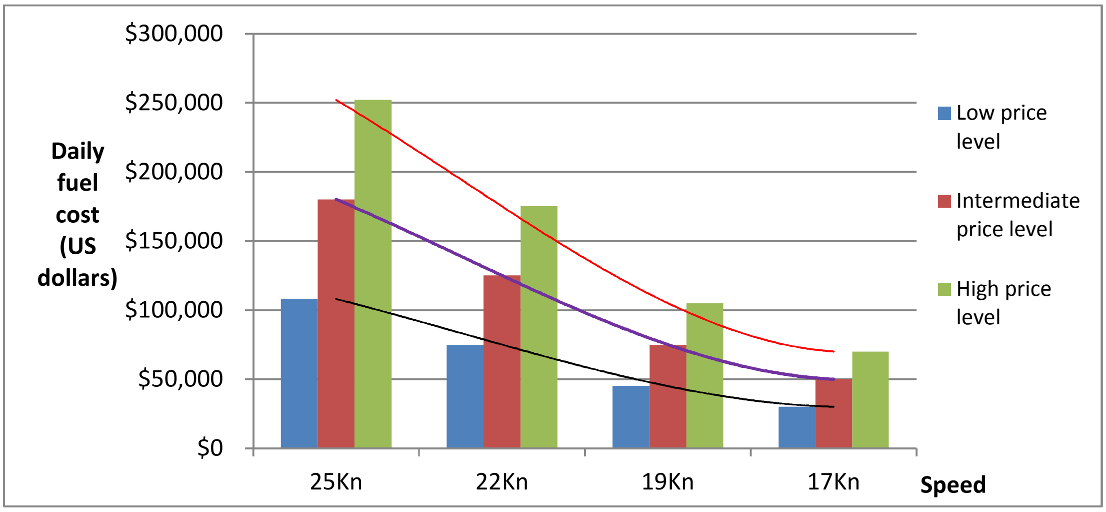


Figure 6 - Daily fuel cost in different fuel oil prices by speed for 10,000+TEU containerships
Source: The author.

3.1.2 The analysis for 4,000-5,000 TEU containership

Accordingly, the similar figure can be drawn the same calculation way as is mentioned above.

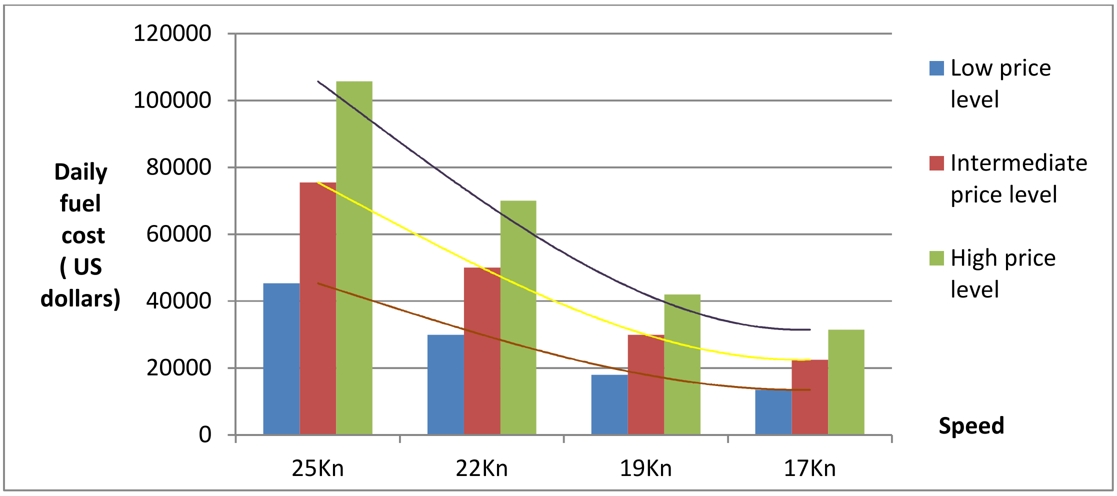


Figure 7- Daily fuel cost in different oil price by speed for 40,000-50,000TEU containerships
Source: The author.

Any daily difference can be calculated with the following formula:

$$Y=1633.3x^3 - 5950x^2 - 29283x + 139300, \quad (4)$$

Specially, x means the differential speed, while Y means the daily fuel cost which has not been modified by the coefficient X (X_1, X_2, X_3 for different fuel oil price scenario).

3.2 The influence to engine efficiency

3.2.1 An environment index

EEOI concerning the efficiency of ships in operations is adopted by IMO as an engine efficiency index by which the emission of carbon dioxide can be measured per ton – kilometer. It is calculated with the following equation:

$$EEOI = \frac{\sum_j FC_j * C_{Fj}}{m_{cargo} * D} \quad (5)$$

In this equation, the *j* is the fuel type; FC_j is the mass of consumption fuel in a certain voyage, while C_{Fj} is a convert factor from the quality of fuel to that of carbon dioxide (IMO, 2009).

Different types of fuel will affect the value of EEOI deeply due to the various values of C_{Fj} and carbon content (Acomi & Acomi, 2014, p.533). Basically, a smaller overall index value means higher engine efficiency.

3.2.2 The relation between EEOI and speed

Totem Plus Company has developed software to calculate the value of EEOI. One observation of the calculation result shows that the index decreases when the speed of a vessel decreases simultaneously. According to the result, the difference in a same voyage may be about 18-20% in different load condition or sailing speed (Acomi & Acomi, 2013).when the speed reduce by 10kn, the overall index will change to smaller, which means the performance of EEOI is improved by such change (Table 2). Hence, optimization speed can improve the EEOI by high fuel efficiency utilization ratio.

Voyage Leg	Consumers	Days	Speed 14 kt	Days	Reduced Speed 13 kt	Days	Reduced Speed 12 kt	Days	Reduced Speed 11 kt	Days	Reduced Speed 10 kt
Anchor	DG Iddle	3.0	7.5	3.0	7.5	3.0	7.5		7.5	3.0	7.5
	AB Iddle		6.0		6.0		6.0	3.0	6.0		6.0
Maneuver	ME Maneuver	0.2	3.6	0.2	3.6	0.2	3.6		3.6	0.2	3.6
	DG Maneuver		0.8		0.8		0.8	0.2	0.8		0.8
Loading	DG Iddle	3.0	7.5	3.0	7.5	3.0	7.5		7.5	3.0	7.5
	AB Iddle		6.0		6.0		6.0	3.0	6.0		6.0
Maneuver	ME Maneuver	0.2	3.6	0.2	3.6	0.2	3.6		3.6	0.2	3.6
	DG Maneuver		0.8		0.8		0.8	0.2	0.8		0.8
Loaded Voyage	ME at sea	18.8	637.5	20.2	605.8	21.9	568.8	23.9	536.9	26.3	525.0
	DG at sea	18.8	46.9	20.2	50.5	21.9	76.6	23.9	83.5	26.3	91.9
	AB at sea	18.8	0.0	20.2	0.0	21.9	6.6	23.9	16.7	26.3	26.3
Anchor	DG Iddle	10.0	25.0	8.6	21.4	6.9	17.2	4.9	12.2	2.5	6.3
	Boiler Iddle	10.0	20.0	8.6	17.1	6.9	13.8	4.9	9.8	2.5	5.0
Maneuver	ME Maneuver	0.4	7.2	0.4	7.2	0.4	7.2	0.4	7.2	0.4	7.2
	DG Maneuver		1.6		1.6		1.6		1.6		1.6
Discharge	DG Discharge	3.0	16.8	3.0	16.8	3.0	16.8	3.0	16.8	3.0	16.8
	AB Iddle		6.0		6.0		6.0		6.0		6.0
Maneuver	ME Maneuver	0.4	7.2	0.4	7.2	0.4	7.2	0.4	7.2	0.4	7.2
	DG Maneuver		1.6		1.6		1.6		1.6		1.6
Anchor	DG Iddle	5.0	12.5	5.0	12.5	5.0	12.5	5.0	12.5	5.0	12.5
	AB Iddle		10.0		10.0		10.0		10.0		10.0
Ballast Voyage	ME at sea	2.8	79.8	3.0	75.6	3.2	70.7	3.5	66.6	3.2	54.6
	DG at sea	2.8	6.9	3.0	7.4	3.2	11.2	3.5	12.3	3.2	11.2
	AB at sea	2.8	0.0	3.0	0.0	3.2	1.0	3.5	2.5	3.2	3.2
Fuel consumption		[T]	914.8		876.5		864.4		839.1		822.1
CO2/1000000		[T]	2849		2730		2692		2613		2560
Cargo		[T]	30000		30000		30000		30000		30000
Distance Loaded		[Nm]	6300		6300		6300		6300		6300
Distance Ballast		[Nm]	925		925		925		925		925
EEOI			15.07		14.44		14.24		13.83		13.55

Table 2 - An example of EEOI Calculation

Source: N.Acomia,& O.C. Acomib.(2014). The 9th International Conference on Traffic & Transportation Studies, Shaoxing, Zhejiang Province, China.

3.3 Restriction under MARPOL convention Annex VI

For controlling the emission from ships, two general areas are divided by IMO, named SOx-ECA and NOx and SOx-ECA area respectively (See figure 8).

Figure 8: Emission control area map
Source: TOCPRO(2015), *MARPOL 73/78 Practical Guide*
London: Author

For controlling the emission of suphur, the IMO establishes a global standard that the content of sulphur in the fuel should be less than 3.50% from 2012, but after January1st, 2015, only the content of sulphur being less than0.1% can be used in ECAs, however, the following steps will still continue to reduce to 0.50% from 2020 (this step may be prolonged to 2025). Further, the marine diesel engines installed on ships should apply to the NO_X control approach which was passed through in the 66th IMO MEPC, aiming to reduce NO_X to less than 2KG/Kwh, which is nearly one eighth of the figure in 2000 (Cullinane & Bergqvist, 2014, pp.1-5). Normally, the fuel grade has directly been ralated with the quantity of Suphur (see Tab - 3). Consequently, the oil price usually rises with the fuel grade.

Table 3- Sulphur content in different fuel grades

Fuel Grade	IFO380 & IFO180	LS180	MDO	ULSFO180	LSMGO
Sulphur Content	3.50%	1. 0%	1.5%	0.10%	0.10%

Source: Ship & bunker, www.shipandbunker.com

The two mainly liner routes, namely Tans-Pacific and Fast East – Europe will be affected dramatically by IMO new marine environment protection policy due to the ECAs could not pass by.

3.3.1 The period from 2015 to 2020

As is mentioned above, after January 2015, when a ship enter the North American ECA, 1000 ppm sulphur content fuel oil should be used which is only one tenth of the fuel oil that had been used before 2015. Although the limits in other pacific area can stay at 35,000 PPM level, this change will increase the cost of fuel significantly (Cullinane&

Bergqvist, 2014, p.3).

3.3.2 Deep influence after 2020

There will be more challenges to ship operators after the year 2020, because at that time the suphur content may decrease to 1000PPM, which means IFO380 may not be used as general ship fuel oil, a new standard marine fuel oil with less than 0.5% sulphur content will replace IFO380 all over the world. Unfortunately, this will bring astonishing extra cost for ship operators in the near future (Veenstra & Ludema, 2006, pp.159-171). But for marine environment, it is completely good news.

CHAPTER 4

The Mathematic Model for Optimal Speed

4.1 The major premise of this problem

The general cost of a container fleet includes the operation cost, capital cost, inventory cost, fuel cost and port charges (Fagerholt, 2004, p.36). The inventory cost, capital cost and fuel cost has a close relationship to the speed, this chapter is aiming to decrease fuel cost by the adequate operation approach for ship operators except the inventory cost which will be discussed in the following chapter. The average weather condition is the first premise for this problem, and fuel price is also to be defined according to the prevailing price in the market. Assuming the operators will abide by the convention for the restriction in the ECA, the main mathematics parameters can be expressed (See Table 4):

Table 4-The parameters used in the mathematic model

parameters	Descriptions
p^E	MGO inside of ECA
f^E	Fuel consumption per day when ship proceeding in ECA with alternative speed v

t^E	Time of ship navigate in ECA with alternative speed *v* by day
p^G	Fuel oil price in Non-ECA
f^G	Fuel consumption for global navigation in Non-ECA
t^G	Time of ship navigate out ECA

Source: The author

The main purpose is to seek the minimum value in the following formula:

$$Min \{\sum\sum\sum[\, p^E f^E t^E + (1 + \frac{T_i^P}{24}) p^G f^G t^G]\} \quad (6)$$

4.1.1 The bunker consumption function

As is mentioned above, the bunker consumption has direct proportional relationship with the cubic velocity, but this function had been rectified by two coefficients based on the data acquired from the shipping liner company (Yao, et al, 2011).

$$f_c = \begin{cases} if\ ship\ size < 8{,}000TEU, f_c = K_1V^3 + K_2 \\ if\ ship\ size \geq 8{,}000TEU, f_c = 0.087V^{K^3} \end{cases} \quad (7)$$

This function will be used by inputting the different coefficients in various velocity (See Tab -5).

Table 5- K_1,K_2 coefficients are listed by various containership capacity

Size(TEU)	K_1	K_2
1000-	0.004476	6.17
1000-2000	0.004595	16.42
2001-3000	0.004501	29.28
3001-4000	0.006754	37.32
4001-5000	0.006732	55.84
5001-6000	0.007297	71.4
6001-8000	0.006705	87.71

Source: Zhishuang Yao et al (2011). *A study on bunker fuel management for the shipping liner services*. Computers & Operations Research.

However, the limitation of this statistic does not provide more details if the size of containership is over 8,110 TEU. For calculation of the ship over 8,000TEU, here a new specified coefficient K_3 is given (See Table - 6).

Table 6 -The coefficient K_3

Size (TEU)	*Value of K_3*
8,000-9,000	3.21
9,000-10,000	3.24
10,000+	3.30

Source: The Author.1

4.1.2 The value of total trip time

The container liner company always put several sister-ships on the same line in order to fulfill their schedule, so the service frequency in mostly situation is fixed (Ting &Tzeng, 2003, p.381). The routing is not like tramp shipping, actually it is a loop routing or cycle. Once a schedule has been published to the public, the ship operator will push the service

1 Note: Please refer to Appendix I for the details of calculation.

at least for one week unless a new turn of market assessment begin.

So the total trip time: $T = \sum_{i=0}^{p} T_i + \frac{D}{24 * V_s}$ (8)

Here, $\sum_{i=0}^{p} T_i$ means the total port time, V_{max} is the maximum sea speed, V_s is a discrete value which is subjected to $V_S \in V_{max}$.

4.2 Mathematics model

The model is based on the assumption that the very operation day contributes to the same amount of cost which includes the capital cost of a company in one service cycle.

4.2.1 The model in non-ECA areas

Table 7 - The notations of the mathematics model

notations	Descriptions
p^E	MGO inside of ECA
f^E	Fuel consumption per day when ship proceeding in ECA with alternative speed *v*
t^E	Time of ship navigate in ECA with alternative speed *v* by day
D^E	Distance navigated in the ECA
D^C	Distance for preparing berth in Non - ECA
p^G	Fuel oil price in Non-ECA
p^m	MDO price, MDO may be used before berth for better maneuver
f^G	Fuel consumption for global navigation in Non-ECA
t^G	Time of ship navigate out ECA
D^G	Distance navigated out of ECA
T	Overall trip time by days
$\mathbf{T_i^P}$	Overall time in port by days
T_e	Time for navigating in the ECA by days

T_g	Time for navigating outside of ECA by days
V_s	The discrete speed of vessels
V_e	The average ship's speed in the ECA
V_g	The average ship's speed outside of ECA, a normal speed in the global waters
V_{max}	The maximum speed of a certain containership
$f_c(V)$	Fuel cost function with the variable value speed

Source: The Author

Maximize: $p_{max}(v) = \begin{cases} R - C_F - \dfrac{p^G *(K_1+K_2V_g^3)*\frac{D^G}{V_g*24}+C_f^c}{\sum_{i=0}^{p} T_i + \frac{D^G}{24*V_g}} & \text{(If container capacity is less than 8,000TEU)} \\ R - C_F - \dfrac{p^G *\left(0.087V_g{}^{K^3}\right)*\frac{D^G}{V_g*24}+C_f^c}{\sum_{i=0}^{p} T_i + \frac{D^G}{24*V_g}} & \text{(If container capacity is more than 8,000TEU)} \end{cases}$

(9)

Subject to: $V_s,\ V_e, V_g < V_{max}$;

$$V_e * T_e + V_g * T_g = D;$$

$$D_e + D_g = D;$$

$$T_e + T_g = T;$$

$$C_f^c = \begin{cases} p^m * \left(K_1 + K_2V_g^3\right) * \frac{D^C}{V_g*24} & \text{(If container capacity is less than 8,000TEU)} \\ p^m * \left(0.087V_g{}^{K^3}\right) * \frac{D^C}{V_g*24} & \text{(If containers capacity is more than 8,000TEU)} \end{cases}$$

Here p_{max} means the maximum profit function with the variable value V_s, while R means the revenue of a voyage or a cycle; C_F means the average fixed cost including the capital cost, manning cost and maintenance cost, port changes, tug fee, etc., C_f^c means the correction of MGO cost for better maneuvering in non – ECA when preparing for the berth operation.

4.2.1 The model for a ship passing through ECA

Similarly, for seeking the maximum profit, the equation can be expressed as:

$$p_{max}(v) = \begin{cases} R - C_F - \dfrac{p^G*(K_1+K_2V_g^3)*\frac{D^G}{V_g*24} + p^E*(K_1+K_2V_S^3)*\frac{D^E}{V_e*24} + C_f^c}{\sum_{i=0}^{p} T_i + \frac{D^E}{24*V_e} + \frac{D^G}{V_g*24}} & \text{(If container capacity is less than 8,000TEU)} \\ R - C_F - \dfrac{p^G*\left(0.087{V_g}^{K^3}\right)*\frac{D^G}{V_g*24} + p^E*\left(0.087{V_e}^{K^3}\right)*\frac{D^E}{V_e*24} + C_f^c}{\sum_{i=0}^{p} T_i + \frac{D^E}{24*V_e} + \frac{D^G}{V_g*24}} & \text{(If containers capacity is more than 8,000TEU)} \end{cases}$$

(10)

Particularly, the general fuel cost function combined with ECA route is:

$$f_c(V_e, V_g) = \begin{cases} \dfrac{p^G*(K_1+K_2V_g^3)*\frac{D^G}{V_g*24} + p^E*(K_1+K_2V_e^3)*\frac{D^E}{V_e*24} + C_f^c}{\sum_{i=0}^{p} T_i + \frac{D^E}{24*V_e} + \frac{D^G}{V_g*24}} & \text{(If container capacity is less than 8,000TEU)} \\ \dfrac{p^G*\left(0.087{V_g}^{K^3}\right)*\frac{D^G}{V_g*24} + p^E*\left(0.087{V_e}^{K^3}\right)*\frac{D^E}{V_e*24} + C_f^c}{\sum_{i=0}^{p} T_i + \frac{D^E}{24*V_e} + \frac{D^G}{V_g*24}} & \text{(If container capacity is more than 8,000TEU)} \end{cases}$$

(11)

4.3 Value of simulation

4.3.1 Fuel price

The fuel price always changes in various supply ports. Considering the mainly routing and the probability of ECA passing through in the word, the average price in the

Rotterdam and Houston are used for analysis. The fuel price may fluctuate frequently in the market, and the relationship between ship routing and speed is similar in the model.

According the *Ship & Bunker* price in April 2015, the average price of IFO180 in Rotterdam and Houston is $405/ton and the average MGO in the same place is $ 590/ ton for the analysis of standard scenario. But after 2020, the more strict regulation requires high quality of marine fuel oil which generates less sulphur dioxide. Normally, it is hard to forecast the future price; therefore, assuming the price in three scenarios namely high price, intermediate price and low price may be reasonable for forecasting the future scenarios (See Table 8).

Table 8 - Oil price index used in the mathematics model

	ECA	MDO may be used before berth in Non -ECA	Non - ECA	Remark
Standard Scenario	590	500[2]	405	IFO still can be used in non-EGA.MGO shall only be used in ECA, the real price can be rectified by coefficient *a* and *b* referred to real time price.
Forecasting Scenarios(before 2020)	590**a*,	500* *a*	405 *a*	
Forecasting Scenarios(after 2020)	590* *b*	500*b*[3]	500*b*[4]	

Source: The Author.

4.3.2 The calculation approach for short distance

The short distance route is obtained from the Google Earth, a virtual global tool for

2 It is a given value estimated by the prevailing price level.
3 It is a given value estimated by the prevailing price level.
4 It is a given value estimated by the prevailing price level.

providing the geography information. The cases are retrieved from the real service on the web site of COSON which illustrates the main business conducted in the global scope.

4.4 Cases text

The following two examples contain two different mathematic models discussed above.

4.4.1 Tans - Pacific service: CPS Route

The CPS service is one of most important Tans – Pacific route which is linked with the logistics between Eastern China and the Southwest Coast of U.S (COSON, 2015). The loop begins from the port Qingdao, Shanghai, and Ningbo to Los Angles in California State, and then returns to port Qingdao, China through the transport of Oakland (see Figure 9).

Figure 9 – Ports of call under CPS Route
Source: COSOCN. (2015). http://www.coscon.com/schedule/schedulecn.jsp

In this loop, the main ECAs are located in the US jurisdiction waters (See Figure 9) where are inescapable areas for ships to pass through. The shortest path for passing through this area is 230 nautical miles, but the reasonable deviation in practice should be considered. Therefore, the data 250 nautical miles is adopted in the following analysis.

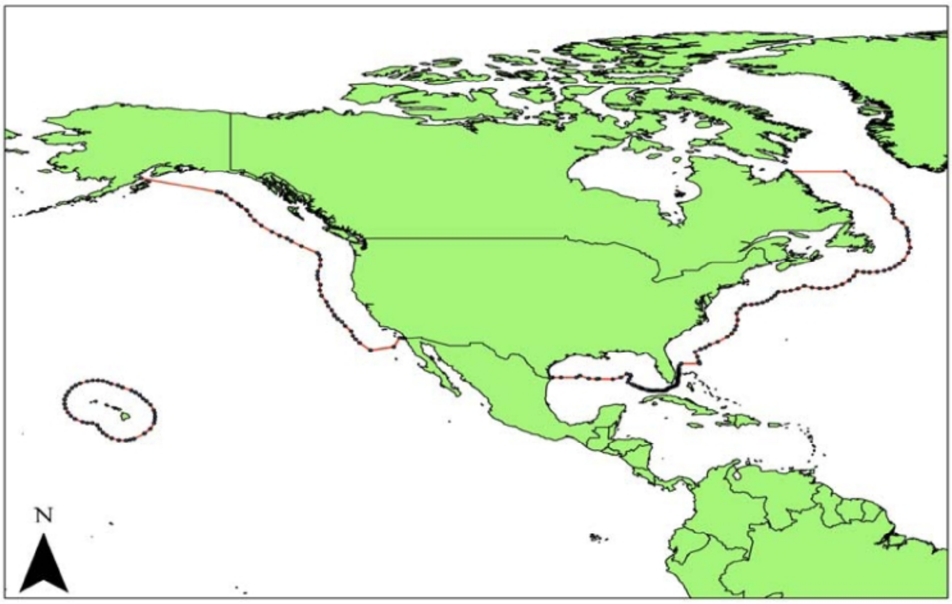


Figure 9 - Geographical Distribution of ECA in CPS route
Source: IMO. (2010). MEPC.1/Circular.723, London, UK.

The loop of CPS service is from the Qingdao, China to Los Angles, California, in the middle way of which Shanghai and Ningbo will be berthed as a transshipment port. The legs in different ports categorized by ECA and Non – ECA scenarios are listed (See Table 9). Additionally, the containership always change MDO when she approaches to the berth, so 10 nautical miles is assumed for her change from IFO to MDO before she arrives at to the berth. This distance will be treated the same way as she proceeds in the ECA because the same fuel oil (MGO) is used for better maneuver.

Table 9 - Distance of route legs

Legs	*Distance (unit: nautical miles)*			
	ECA	Distance for use MGO when prepare for berth	Non - ECA	Total
Qingdao – Shanghai	0	20	379	399
Shanghai – Ningbo	0	20	150	170

Ningbo – Los Angles	250	10	5,936	6,166 *
Los Angles – Oakland	369	0	0	369
Oakland - QingDao	300	10	5,098	5,408
The cycle				12,512

Source: The author, note: "*" means the data is retrieved from http://www.sea-distances.org/

Due to the fact that eight of ten containerships engaging on the CPS service are over 8000TEU capacity (See Table 10), the coefficient K_3 shall be used. With regarding to the other two vessels, the coefficient K_1, K_2 can be referred to calculation result at the beginning of this Chapter where K_1 equals 0.006705 and K_2 equals 87.71.

Table 10 - CPS service Schedule

Vessel	*Voyage*	*Port*	*ATA/ETA*	*ATD/ETD*	*Distance*	*cycle time (days)*	*Size (TEU)*
EVER URSULA	0635E	Ningbo/ Los Angeles	2015-2-16 21:20	2015-3-26 4:15	6166	37.288	5652
EVER LOGIC	0637E	Qingdao/ Los Angeles	2015-3-5 2:40	2015-4-2 4:07	6735	28.060	8452
EVER LUCID	0638E	Qingdao/ Oakland	2015-3-11 16:40	2015-4-10 3:43	7104	29.460	8508
EVER LEARNED	0642E	Qingdao/ Oakland	2015-4-8 20:30	2015-5-1 4:00	7104	22.312	9200
EVER LIBERAL	0643E	Qingdao/ Oakland	2015-4-15 15:30	2015-5-10 8:00	7104	24.687	8452
EVER CONQUEST	No data						8073
ITAL CONTESSA							8073
EVER LUCKY							8452
EVER LASTING							8452

EVER UNITY	5652

Source: www. COSCON.com & www. evergreen-marine.com

a) Standard Scenario – fuel oil price in the current level

The vessel EVER URSULA and vessel EVER LOGIC will be taken as an example since this route involves two types of containerships.

i. M/V EVER URSULA

Table 11- The service data of M/V EVER URSULA

Port	*ATA*	*ATD*	*port time (days)*	*at sea (days)*	*Distances(nmiles)*		
					ECA	*Distance for use MDO when prepare for berth*	*Non - ECA*
Ningbo	2015-2-16 21:20	2015-2-17 14:00	0.694		0	10	0
Shanghai	2015-2-22 3:00	2015-2-22 14:00	0.458	4.542	0	20	140
Qingdao	2015-2-24 7:40	2015-2-24 14:40	0.292	1.736	0	20	379
Los Angeles	2015-3-23 6:00	2015-3-26 4:15	2.927	26.639	250	10	5706
Port time: 4.372 days, At sea time: 32.917days. Average speed: 9.24 kn, v_e=9.32 kn, v_g= 9.21 kn							

Source: The Author (Note: Data of ATA&ATD are based on the Evergreen-marine International Service).

Evergreen Company set up the line schedule in CPS service based on 21.667 days from Qingdao to Los Angles. Since the vessel is less than 6000TEU, the following equation shall be applied (see calculation details in the Appendix II):

$$f(V_e,V_g)=\frac{p^G*(K_1+K_2V_g^3)*\frac{D^G}{V_g*24}+p^E*(K_1+K_2V_e^3)*\frac{D^E}{V_e*24}+C_f^C}{\sum_{i=0}^{p}T_i+\frac{D^E}{24*V_e}+\frac{D^G}{V_g*24}+\frac{D^M}{V_g*24}}\quad (K_1=0.006705, K_2=87.71)$$

$$=\frac{405*(87.71+0.006705V_g^3)*\frac{6225}{V_g*24}+590*(87.71+0.006705V_e^3)*\frac{250}{V_e*24}+500*(87.71+0.006705V_g^3)*\frac{70}{V_g*24}}{4.372+\frac{250}{24*V_e}+\frac{6225}{V_e*24}+\frac{70}{V_g*24}}$$

Subject to: $V_e, V_g < V_{max}$;

$$\sum_{i=0}^{p}T_i+\frac{D^E}{24*V_e}+\frac{D^G}{V_g*24}+\frac{D^M}{V_g*24}=T \qquad (12)$$

$f(v_e)$ Function curve of M/V EVER URSULA can be drawn combined with the Vg Function curve based on the calculation result of Appendix II (Figure 10).

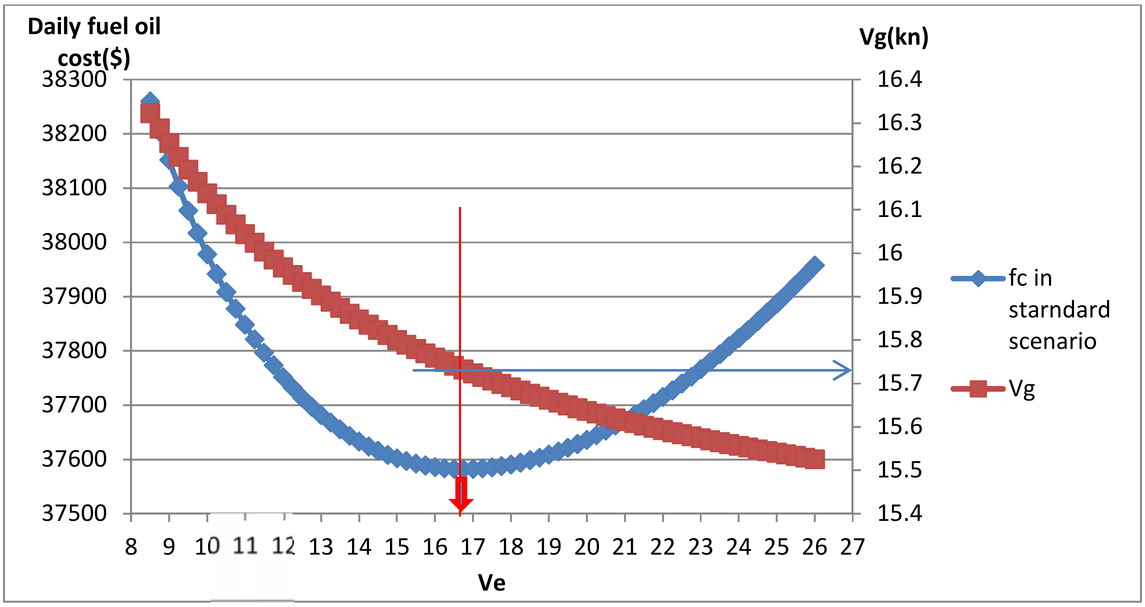


Figure 10 - The $f(v_e)$ function curve of M/V EVER URSULA

Source: The Author.

The lowest point of $f(v_e)$ function curve in standard scenario implies minimum fuel cost where the optimize speed of the M/V EVER URSULA in ECA is 16.75 kn and the speed out of ECA is 15.73 kn. Both of them are relatively higher than the real speed.

That means if the company does not improve the prevailing speed it may not catch up with the schedule as it promises on the Internet.

ii. M/V EVER LOGIC

The capacity of M/V EVER LOGIC is more than 8,000TEU; hence, the formula *(13)* shall be applied for estimating the fuel consumption rate. Accordingly, the coefficient K_3 equals 3.21.

$$f(v_g, v_e) = \frac{p^G * \left(0.087 {V_g}^{K^3}\right) * \frac{D^G}{V_g * 24} + p^E * \left(0.087 {V_e}^{K^3}\right) * \frac{D^E}{V_e * 24} + C_f^c}{\sum_{i=0}^{p} T_i + \frac{D^E}{24 * V_e} + \frac{D^G}{V_g * 24} + \frac{D^M}{V_g * 24}}$$

$$= \frac{405 * \left(0.087 {V_g}^{3.21}\right) * \frac{6225}{V_g * 24} + 590 * \left(0.087 {V_e}^{3.21}\right) * \frac{250}{V_e * 24} + 500 * \left(0.087 {V_g}^{3.21}\right) * \frac{70}{V_g * 24}}{\sum_{i=0}^{p} T_i + \frac{6225}{24 * V_e} + \frac{250}{V_g * 24} + \frac{70}{V_g * 24}}$$

Subject to: $V_e, V_g < V_{max}$;

$$\sum_{i=0}^{p} T_i + \frac{D^E}{24 * V_e} + \frac{D^G}{V_g * 24} + \frac{D^M}{V_g * 24} = T \quad (13)$$

After calculation, the optimization speed in ECA is 14 konts and the average speed out of ECA is 15.85 knots (See Figure 11).

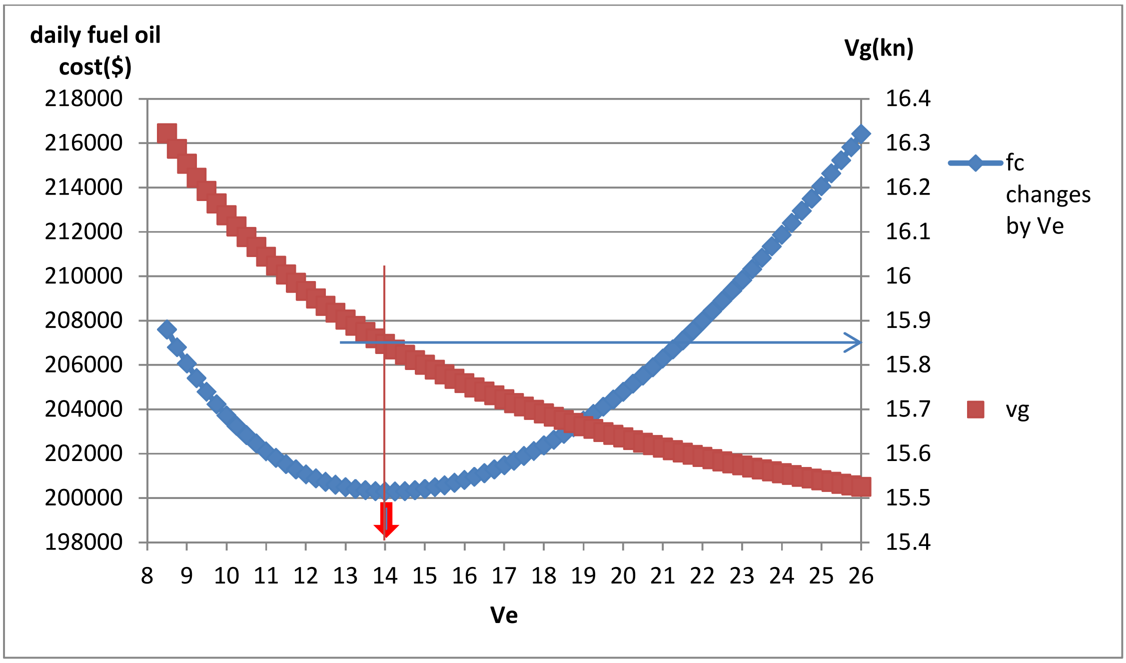


Figure 11 - The calculation result of M/V EVER LOGIC

Source: The Author.

b) The virtual scenario in different oil prices for the CPS service

In addition to the standard scenario with the estimated price applied in the math model, three possible virtual scenarios are analyzed. As is expected, the overall cost will increase accordingly (See Figure 12 and Figure 13). The difference between the two trends is that, for M/V EVER URSULA, the effect brought by optimal speed in ECA is becoming less and less with the speed increase because the weight of ECA legs are relative smaller particular when the oil price rises up. The operator will have more space for selecting adequate speed out of ECAs.

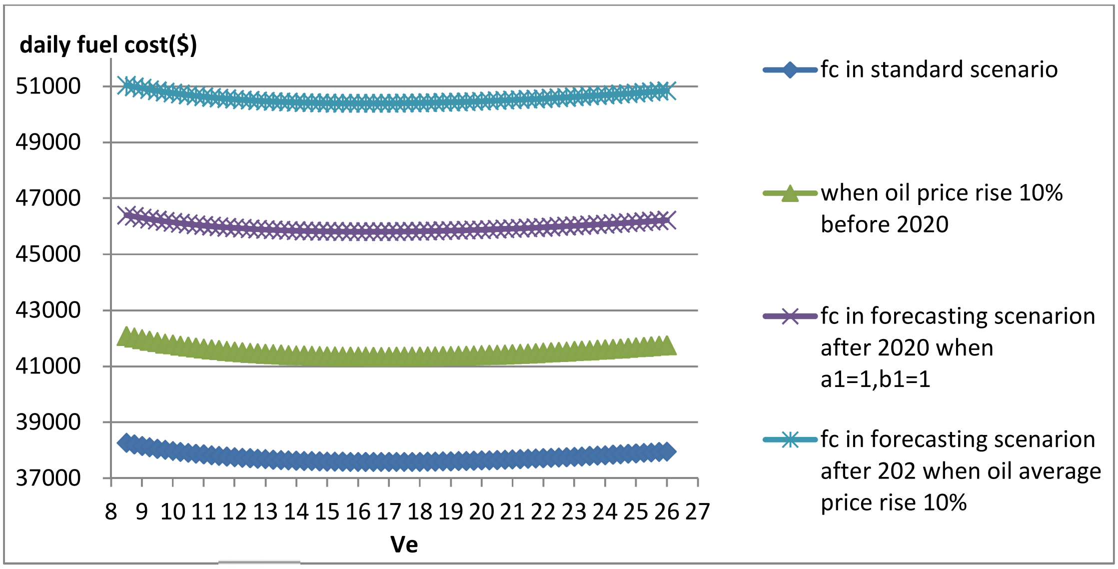


Figure 12- The $f(v_e)$ function curve changes by different virtual scenario of M/V EVER URSULA

Source: The Author.

By contrast, for large ships more than 8,000 TEUs, if the oil price rises up, the influence caused by ECAs will still be relatively strong with optimal point moving forward as is shown in the graph. Ship operators may pay more attention in this scenario and it may be operated through a whole year.

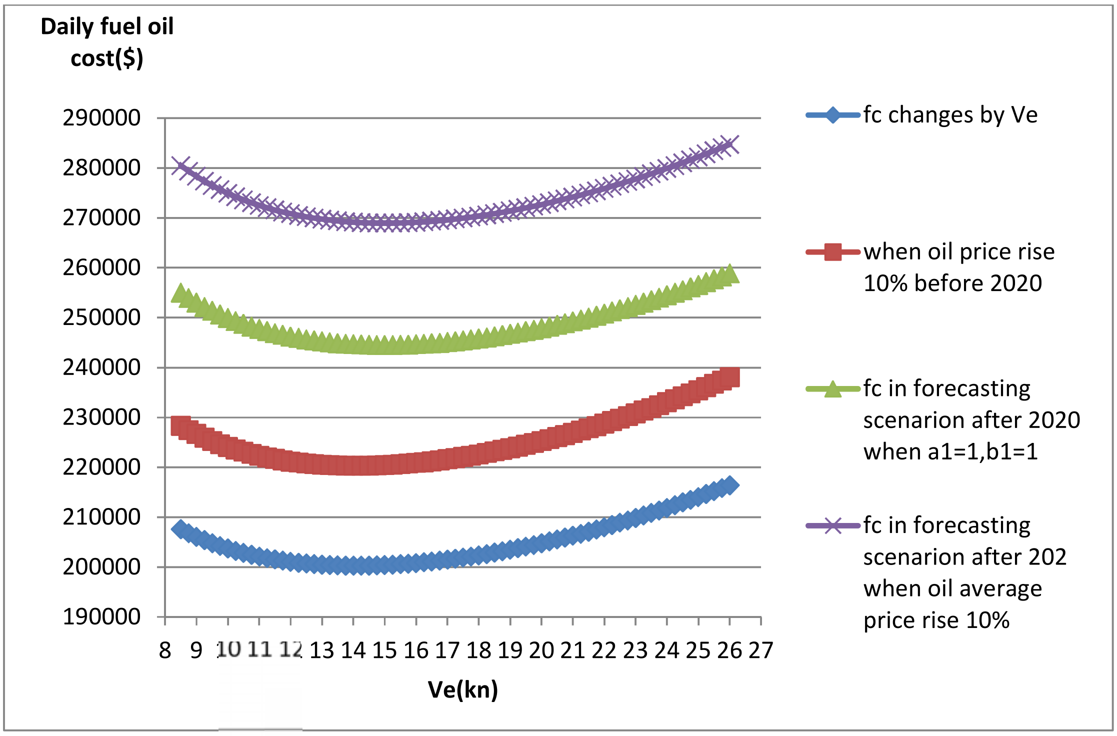


Figure 13- The $f(v_e)$ function curve changes by different virtual scenario of M/V EVER LOGIC

Source: The Author.

c) Summary of CPS service

Basically, the loop of this route is 57 days. The number of ships deployed in this route should meet the current requirement based on the schedule published to the customers (Karlaftis et al, 2009.p.210). According to the company public plan, the ports in this route will be called at least once per week, 8 vessels should be deployed on this route, but in factual practice, 10 vessels are servicing on this line (See Table 12).

Table 12 - Calculation result of the CPS Service

	Deployment	*Speed in ECA*	*Speed out of ECA*	*Cost($)*	*Difference for single vessel ($/day)*	*Difference for fleet($/day)*
Optimal Resolution 1	Two 6000TEU vessels	16.75	15.73	37581*2	increase $4127/day	Save $ 416882
	Six 8000+TEUvessels	14	15.85	200288*6	save$12/day	
Optimal Resolution 2	Eight 8000+ TEU vessels	14	15.85	200288*8	save$12/day	Increase $87686/day
Current	Two 6000TEU vessels	9.24	9.21	33454*2	-	1669228
	Eight 8000+ TEU vessels	14.26	13.21	200290*8	-	

Source: The Author.

For determining the optimal speed, the introduction of ECAs is one of the elements due to the extra fuel consumption cost by compliance with the environment policy (Doudnikoff &Lacoste, 2014, pp. 19-29). The optimal number of vessels servicing on the same route is another important concern. In the given CPS real practice, there are two optimal solutions to eight vessels engaging in service.

i. Assuming the two containerships less than 8,000GT and six 8,000+GT containership service in this route as the original deployment

This scenario is based on the fact that overall transportation demands do not change obviously, so the revenue keeps in a relative steady level. The purpose of this method is to control the overall cost and be competitive ability in the market simultaneously. By calculation, the daily cost will be saved $416,882 per day for the whole fleet.

ii. Assuming eight 8,000+ TEU containerships engaging in service

This solution is from the perspective of revenue increase by using mega vessels with 8,000+ capacity TEUs. Although the overall cost will increase by substituting the smaller vessel, the transport efficiency and revenue will increase as more cargo will be loaded on vessels. Hence, this solution may be adopted when the freight rises up or the anticipated profit becomes better in operation.

4.4.2 Asia – Europe service: FAL_1 Route

Asia – Europe is very significant particularly when China proposes *"the Silk Road Economic Belt"* strategy (Xi, 2013, para.12). As a link between the Far East and Europe, many famous P3 or CKYHE member companies like MARSK, CMA CGM, and COSCON are paying more attention to Asia – Europe business. Beside the cooperation, they compete for acquiring the maximum profit in the big cake.

There are 13 ports involving shipment service on the FAN_1 route (See Figure14).

Figure 14 -The FAL_1 Service diagram

Source: COSCON. (2015b). FAL_1 Service (http://www.coscon.com/)
Shanghai: Author.

The five European ports, namely Southampton, Hamburg, Rotterdam, and Le harve where are all located in the North Sea ECAs restrict the emission of NO_X and SO_X from ships (See Table 13). Consequently, the quality of fuel oils loaded should meet with much stricter requirement under MARPOL ANNEX VI.

Table 13 - The distances by legs on FAL_1 Route

Legs	*Distance (unit: nautical miles)*			
	ECA	Distance for use MGO when prepare for berth	Non - ECA	Total
Ningbo – Shanghai	0	20	150	170
Shanghai – Xiamen	0	20	565	585
Xiamen – Hong Kong	0	20	267	287
Hong Kong – Chiwan	0	35	0	35
Chiwan – Yantian	0	20	110	90
Yantian – Kelang	0	20	1,650	1,670
Kelang – Southampton (through Suez canal)	330	20	7,521	7,871*
Southampton- Hamburg	505	-	0	505*
Hamburg – Rotterdam	305	-	0	305*
Rotterdam –Zeebrugge	87	-	0	87*
Zeebrugge – Le harve	181	-	0	181*
Le harve –Ningbo (through Suez canal)	210	-	10,090	10,300
The cycle				22,086

Source: The Author, "*" means the data is based on http://www.sea-distances.org/

a) Standard Scenario – fuel oil price in the current level

Nine over 80,000TEU CMA CGM containerships are deployed on the FAL_1 line, five of which are sister ships with the capacity of 13,830 TEU (see Table 14).

Table 14 -The statistic of containerships of CMA CGM servicing on the FAL line

Vessel	*Voyage*	*Port*	*ETA*	*ATD*	*cycle time (days)*	*Size (TEU)*
CMA CGM AMERIGO VESPUCCI	FLB24W/ FLB45E	Ningbo	2015-4-23 21:00	2015-1-29 23:59	83.9	13,830
CMA CGM NEVADA	FLB26W/ FLB47E	Ningbo	2015-4-29 2:00	2015-2-5 14:00	82.5	12,552
CMA CGM JULES VERNE	FLB28W/ FLB49E	Ningbo	2015-5-6 0:00	2015-2-16 12:00	78.5	16,022
CMA CGM GEMINI	FLB30W/ FLB51E	Ningbo	2015-5-13 12:00	2015-2-19 22:00	82.6	11,388
CMA CGM CORTE REAL	FLB34W/ FLB53E	Ningbo	2015-5-20 2:00	2015-3-5 6:00	75.8	13,830
CMA CGM CHRISTOPHE COLOMB	FLB36W/ FLB55E	Ningbo	2015-5-21 2:00	2015-3-12 1:00	70	13,830
CMA CGM LAPEROUSE	FLB38W/ FLB57E	Ningbo	2015-6-10 0:00	2015-3-20 9:00	81.6	13,830
CMA CGM MARCO POLO	FLB40W/ FLB59E	Ningbo	2015-6-17 2:00	2015-3-26 14:00	82.5	16,022
CMA CGM MAGELLAN	FLB42W/ FLB63E	Ningbo	2015-7-8 0:00	2015-4-24 14:20	74.4	13,830

Source: COSCON Office & CMA CGM. (2015). *COSCON Office Materials*. Shanghai,China. (note:the data of ship size areretrieved from: http://www.cma-cgm.com, others are retrieved from COSCON Office located in Shanghai).

Obviously, all the vessels deployed on this route are over 8,000 TEUs, and the coefficient k_3 should be used for estimating the fuel consumption in standard scenario. Since five of nine ships are sister-ships with same the capacity(13,800 TEU), the 365.5 meters length of all with 51.20 meter beam vessel named *CMA CGM AMERIGO VESPUCCI* whose summer dead weight can reach to 156,887 tons will be taken as an example in the following analysis (CMA CGM, 2015) (See Table 15).

Table 15 -The actual service voyage FLB24W/ FLB45E of M/V *CMA CGM AMERIGO VESPUCCI* deployed on the Asia – Europe line

Port	*ATA*	*ATD*	*port time (days)*	*at sea (days)*	*distances(nmiles)*			*speed*
					ECA	*Distance for use MGO when prepare for berth*	*Non - ECA*	
Ningbo	2015-1-28 11:00	2015-1-29 23:59	1.541		0	10	0	14.14
Shanghai	2015-1-30 12:00	2015-1-31 10:00	0.917	0.501	0	20	140	14.15
Xiamen	2015-2-1 15:30	2015-2-2 7:50	0.681	1.229	0	20	565	19.83
Hong Kong	2015-2-3 12:05	2015-2-4 5:15	0.715	1.177	0	20	267	10.16
Chiwan	2015-2-4 7:30	2015-2-4 22:30	0.625	0.094	0	35	0	15.56
Yantian	2015-2-5 6:20	2015-2-5 22:35	0.677	0.326	0	20	90	14.04
Port kelang	2015-2-9 13:55	2015-2-10 11:10	0.885	3.639	0	20	1650	19.12
Southampton	2015-3-28:29	2015-3-3 11:50	1.140	19.888	330	20	7521	16.49
Hamburg	2015-3-5 7:38	2015-3-6 21:49	1.591	1.825	505	0	0	11.53

Rotterdam	2015-3-7 22:02	2015-3-9 7:27	1.392	1.009	305	0	0	12.59
Zeebrugge	2015-3-9 14:00	2015-3-10 4:35	0.608	0.273	87	0	0	13.28
Le Havre	2015-3-10 21:48	2015-3-11 21:11	0.974	0.717	181	0	0	10.51
Ningbo	2015-4-23 21:00			42.992	210	0	10300	10.19
Overall port time: 11.746 days, overall sea time: 73.671days. average speed: 12.62 kn; average speed in ECA V_e = 12.22kn; average speed out of ECA V_g =12.55kn								

Source: The Author.

Similarly, because all giant ships are over 8,000TEUs, the fuel consumption function coefficient should be referred to second part of the formula 11:

$$f(V_g,V_e) = \frac{p^G \left(0.087{V_g}^{K^3}\right) * \frac{D^G}{V_g * 24} + p^E * \left(0.087{V_e}^{K^3}\right) * \frac{D^E}{V_e * 24} + C_f^c}{\sum_{i=0}^{p} T_i + \frac{D^E}{24 * V_e} + \frac{D^G}{V_g * 24}}$$

Subject to: $V_s,\ V_e, V_g < V_{max}$;

$$\frac{D_e+D_c}{V_e} + \frac{D_g}{V_g} = T;$$

$$C_f^c = p^m \left(0.087{V_g}^{K^3}\right) * \frac{D^C}{V_g * 24}. \qquad (14)$$

Even some engines can be operated appropriately at the 10–25% load region (Guan et al, 2014, p.382), typically, for a containership, the persistent sea speed should not be less than 9 knots for better protection of main engine particularly for very large ship over 10,000 TEU. Therefore the range of speed value is calculated from the 9 knots to its maximum design speed and the detailed calculation result is listed on the Appendix II.

The low point of the two curves $f(c)$ with variable v_e distributed in the transversal direction shows the minimum value of cost in terms of speed in ECA on average (See Figure 15).

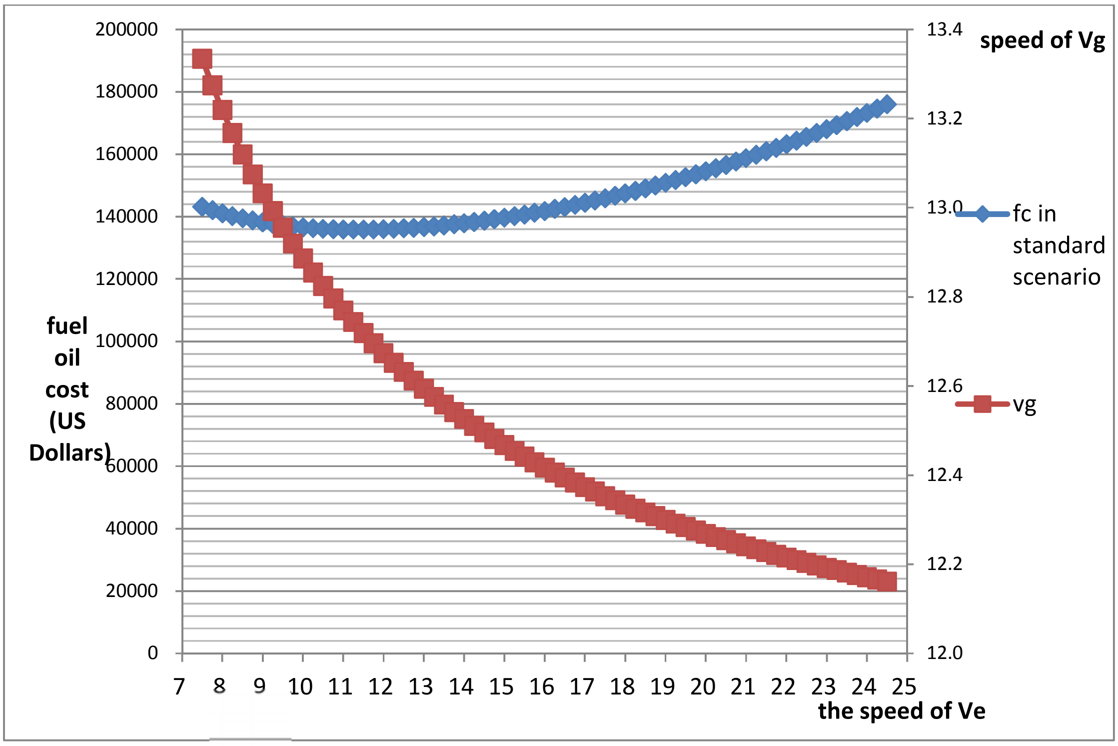


Figure 15 -The $f(c)$ function curve in standard scenario and V_g curve changes by V_e for FAL_1 Service

Source: The Author.

The optimization of speed in the standard scenario happened where the v_e equals 11.5 knot and v_g equals 12.7 knots considering opportunity cost by the correction of maneuver MDO consumption and the port time.

b) The virtual scenario in different oil prices for the FAL_1

Given the coefficient a_1 =1 in different price scenario, the $f(v_e)$curve has similar property that in the vicinity if 11.5 knots the overall fuel cost reaches to the lowest point (See Figure 16). The reason caused by this phenomenon is attributed by the different weight legs in the given route that the Non – ECA leg takes 92.75% (20,698 nmiles in Non – ECA legs).

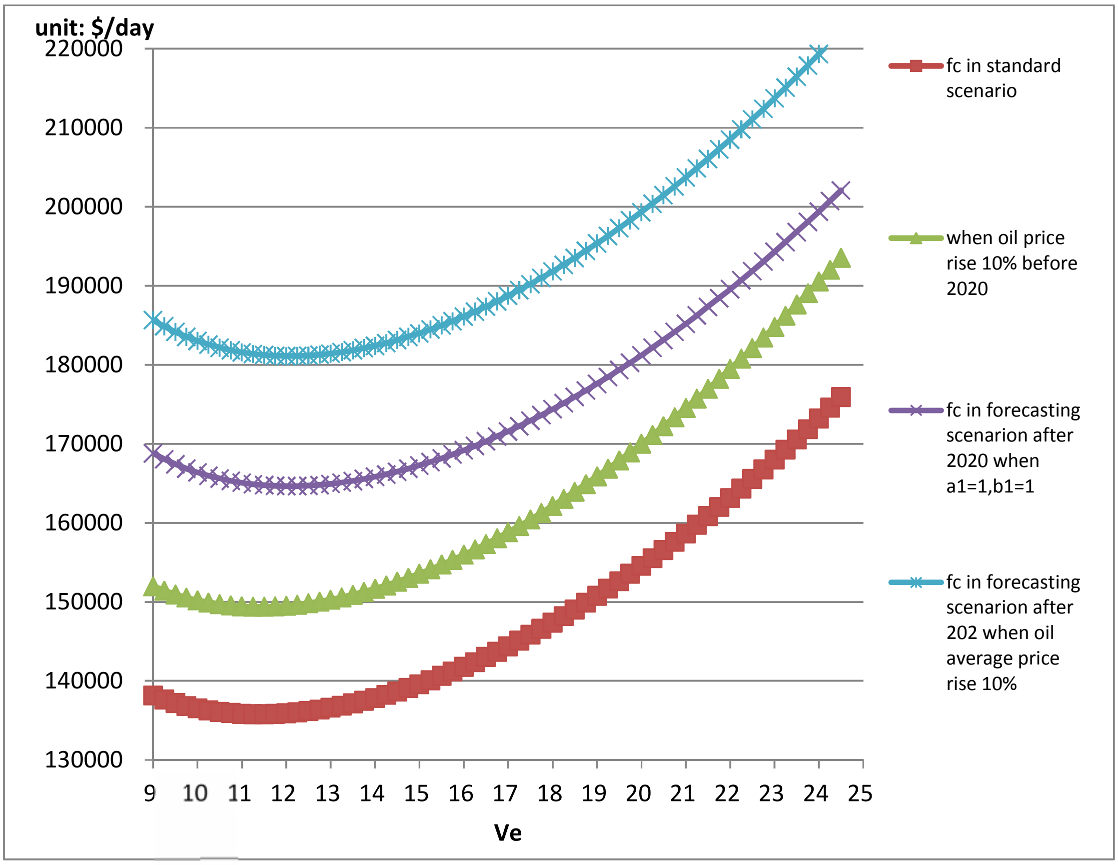


Figure 16 - $f(v_e)$ function curves in different oil price scenario for FAL_1 Service. Source: The Author.

c) The assessment of deployment in the FAL_1 service

The average cycle time of FAL_1 service is 79 days, according to the schedule of the CMA CGM. The frequency of a single port called by the fleet is one week one time which is under the considering of shipper's demand in the market. A certain threshold of a fixed liner service should not exceed a given frequency with certain numbers of ships deployed on the port of call (Notteebooma & Vernimmen, 2009, 325–337).

According to Notteebooma and Vernimmen 's theory:

$$\frac{n*7}{F} \geq T \qquad (15)$$

Where *n* means the number of containership deployed in the service line, *F* means the service frequency per week, *T* means the overall cycle time. So, the number of ship deployed is regulated by the $n \geq T*F/7$. Considering the factual practice, the service is set up on the one-week-one-time principle, so $n \geq 11$ *(where* $n \in INT$, $n \geq 79/7$*).*

Based on the discussion and calculation above, Table 16 shows the final result of FAL_1 Service.

Table 16 - Final result of FAL_1 Service

	Deployment	*Speed in ECA*	*Speed out of ECA*	*Cost($)*	*Difference for single vessel ($/day)*	*Difference for fleet($/day)*
Optimal	11	11.25	12.74	135,820	Save $248/day	Increase
Current	9	12.27	12.65	136,068		$ 269,408

Source: The Author.

d) Summary of the FAL_1 service

The performance of this route is roughly located in the optimal intervals where the cost difference is relatively small ($248/day), but the overall supply is insufficient which may be bound to the alliance cooperation treaty for avoiding vicious competition or be treated as a special marketing strategy to keep the freight rate in a satisfied level. In addition, the shrinking demand of container ships caused by global economic depression may force the operators to decrease deployment.

CHAPTER 5

Perspective from Different Points of View

5.1 The pressure of marine environmental protection

The third GHG research shows that the shipping sector accounts for about 3.1% of the annual global emission from 2007 to 2012 on average (IMO, 2014, p.16). In the shipping sector, container shipping has been the biggest sector of emission and may continue its growth in the next few decades (IMO, 2009b). 16 different scenarios are developed in 2050 by IMO, showing that the emission will increase from 50% to 250% (IMO, 2014, p.164); the environment pushes the shipping innovation by decreasing the fossil fuel or by conducting more strict emission regulations.

The calculation quantity on the carbon dioxide is based on the equation that every ton of heavy fuel oil will generate 3,021 grams of CO_2 and every ton of marine gas oil will generate 3,082 grams CO_2 (Psaraftis & Kontovas ,2013). Although the uncertain bunker prices causes a scenario tree structure for calculation (Sheng et al, 2015, p.76), assuming that 20 tons of MDO are consumed for electricity generators per day in 8,000+ TEUs containerships, it can get the mass of emission function with speed: M_E(V) = 3.021*0.087* V^{k^3}+3.01*20, which is very similar to the fuel consumption by moving the whole graph towards the vertical direction in coordinate system. It also happens in the vessel less than 8,000 TEUs, as the fuel consumption have certain relationships with the ship's speed. Hence, the reduction of carbon dioxide also has similar a non-leaner relationship as is mentioned above.

The potential emission reduction for an attainable ship speed in a specific route can be estimated. The optimization could be based on the requirement of environment rules and operation. It will not only bring the economic profit but also be beneficial to the air condition. From that point of view, the overall reduction of emission will also benefit from the optimal speed.

5.2 Performance of containerships by assessing the index $\frac{\mathbf{P}}{\mathbf{WV}}$

The speed of containership also affects the general transport efficiency which is expressed by the index $\frac{\mathrm{P}}{\mathrm{WV}}$ where P means the average engine power of the containership fleet and V means the averages speed in service. Assuming the minimum resistance effects on ship, the index has a nonlinear relationship with $\frac{V^2}{\nabla^{\frac{1}{3}}}$ (NAKAZAWA, 2014, p.74). From a global perspective, the trend of average $\frac{\mathbf{P}}{\mathbf{WV}}$ **[5]** value is becoming smaller, which implies the transport efficiency has become well. In another word, the fierce competition in the container shipping sector also becomes obvious (See Figure 17).

[5] The calculation result and parameters are listed on the Appendix VI.

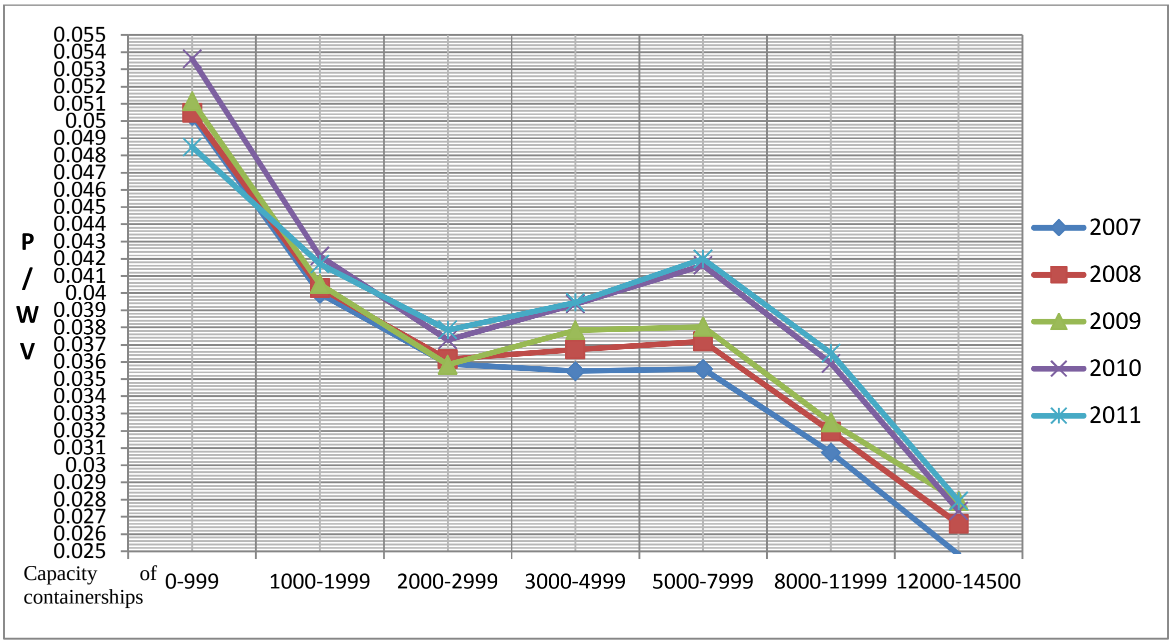


Figure 17 - Average of value P/WV for container ships in global scope
Source: The Author.

For a given route, like the CPS and FAL_1 service mentioned above, the optimal speed may apparently decrease the transport efficiency, but considering the whole fleet, optimal speed effected the actual performance of power and load ability through which the transport efficiency increase accordingly. Relative emissions of GHG from containerships (kg/t km) have a deep connection with capacity utilization which is very sensitive to transport efficiency (Prpic-Orsic´& Faltinsen, 2012, p.9). Indeed, the value of $\frac{P}{WV}$ can be referred to as a kind of marine environmental protection index to some extent.

5.2 Time and circumstances for considering the inventory cost

The inventory cost is usually caused by human operation, compared to the limited actions conducted on capital cost, which can be decreasing as reasonable level as possible via adequate operations.

5.2.1 The inventory estimated by the average level

In 2014, the overall value of global container trade with a total number of 170 million TEUs reaches to 56,000 billion US Dollars (UNCTAD, 2015, p.69), which means one single container cargo is worth $32,941 on average (56,000 billion/170million TEUs). The international return rate is much higher than loan rate, for inventory cost, 20% is usually used for calculation (Bergh, 2010, pp.10-13).

Take 13,800 TEUs vessel CMA CGM AMERIGO VESPUCCI in FAL_1 line for example, assuming that 20% cost is caused by the trans-cargo inventory and the load rate is 80%, the number will be $249,088/day (20%*13,800 TEUs*$32,941/365days for a year). Even a charterer in a CIF trade mode would select a faster vessel for quicker delivery of cargoes.

5.2.2 Time to consider the trans- cargo inventory from a shipper perspective

The time for adjusting the speed of containership is depended on the freight rate in the international trade. Extra freight may be got from high value cargo then extra fuel cost can be considered in a given voyage. Still take the vessel CMA CGM AMERIGO VESPUCCI in FAL_1 line for example, Figure 18 shows the optimal speed in normal situation. A reference line drawn in the longitudinal direction mean the extra cost can be added for quicker a delivery of cargoes and the difference between optimal point cost and vertical value crossed with the reference line is the extra cost for getting more revenue by minimizing the cargo owners' inventory cost.

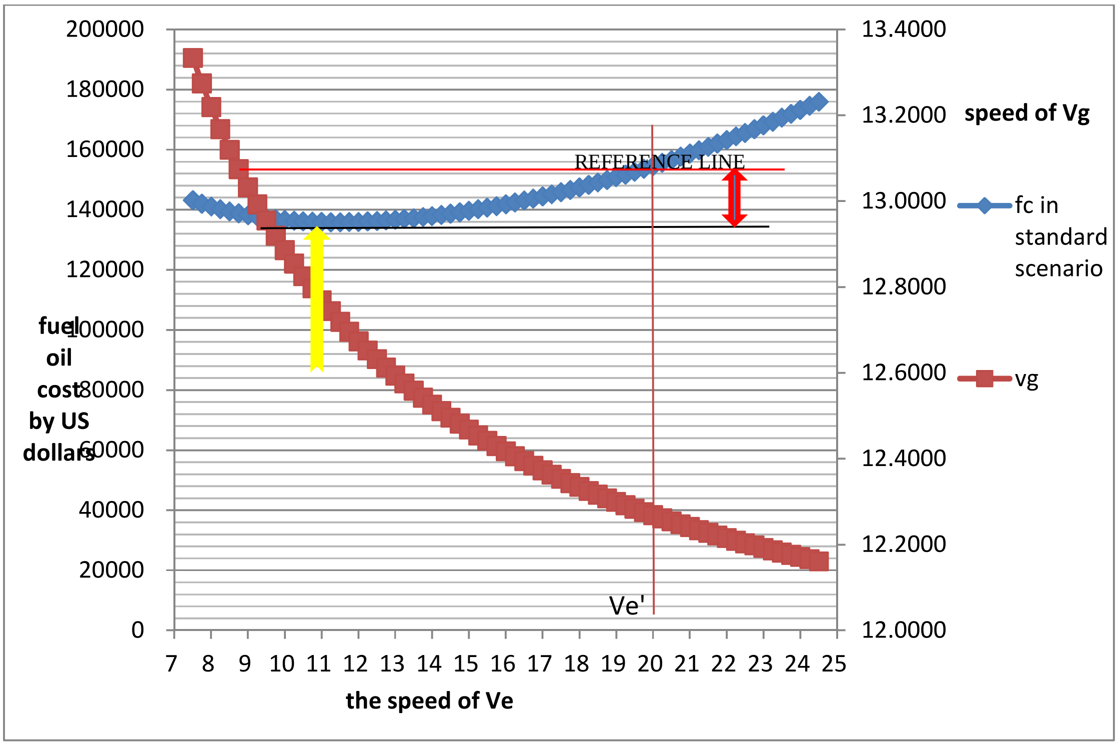


Figure 18 - The selected speed after considering the inventory cost
Source: The Author

By drawing a reference line, a new Ve, Vg can be obtained from the table. Sometimes it may get two groups of Ve and Vg, and the value adopted is determined by the geography position of cargo for delivery and ship's position.

5.3 Questionnaire accomplished by cargo agencies

For better assessment on the service level of company and cargo delivery, a questionnaire is designed by the author to find the critical issues involving the speed from the cargo agencies perspective.

5.3.1 Questionnaire table

Q1. What do you think of the general performance of global liner service?

Good □ Acceptable □ Poor□
Q2. What do you think of the ship speed in Trans – Pacific service?
Fast □ Normal □ Slow□ Extremely Slow□
Q3. What is the reasonable freight for Trans – Pacific service ($/FEU) by your knowledge?
900-1200□ 1200-1500□ 1500-1800□ 1800-2200□ Others□
Q4. What do you think of the ship speed of the Asia – Europe Service?
Fast □ Normal □ Slow□ Extremely Slow□
Q5.What is the reasonable freight for Asia –Europe service ($/TEU) by your knowledge?
900-1200□ 1200-1500□ 1500-1800□ 1800-2200□ Others□
Q6. Which are the first three options should be considered when your select liner service?
(Multiple – choice question)
Safety □ Reputation □ Cargo delivery □ Service speed □ Freight □
Port to call □
Q7. What is the most important factors for selecting business partner?
A company with fixed schedule □
A company which provides fast transport service but the schedule is always changed □

Table 17- Questionnaire for the liner service

Source: The Author.

5.3.2 Data analysis

58 cargo agencies give the feedback of the questionnaire by helping my friends who are working at Shanghai customs.

Q1 shows that the containership liner service still continue to improve their performance from the customer's point of view, interestingly, more than 70% of cargo agencies complain the service speed both on the Trans – Pacific and on the Asia – Europe service (See Figure 19).

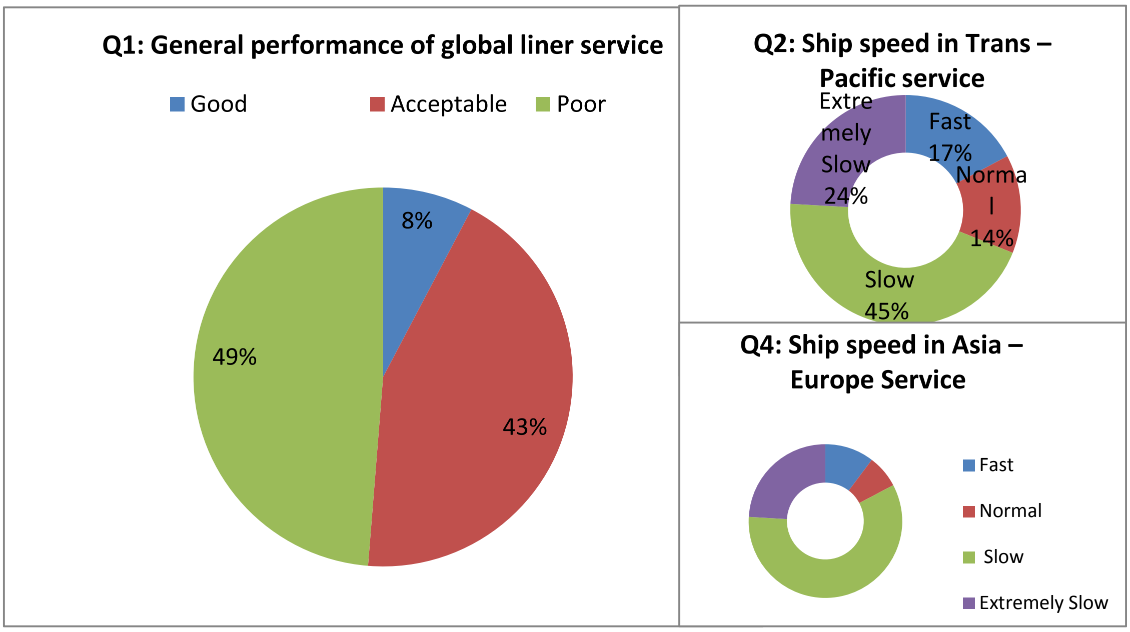


Figure 19- The answer analysis of liner performance

Source: The Author.

In terms of the freight, the result shows diversified selections. But less than 10 % of the customers think the freight is in a reasonably high level (Figure 20).

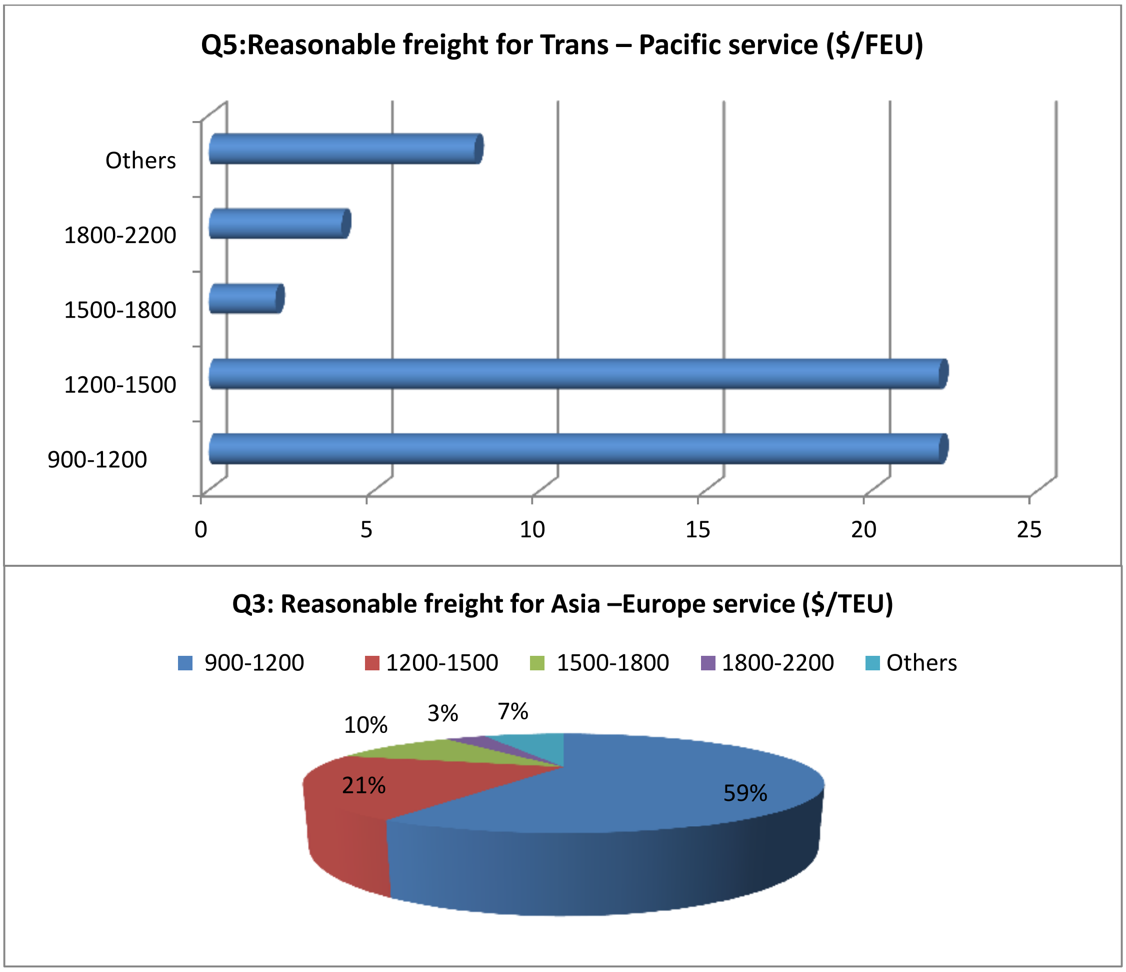


Figure 20 - The analysis of prevailing freight
Source: The Author.

Q6 & Q7 are the core part for analyzing how the decisions would be made when they face different business partners. Except the safety considering, freight and service speed are the mostly concerned for cargo agencies, which means that the optimal speed is significantly for improving the service level as well as to obtain more potential customers. Additionally, 90% of the clients believe that schedules much more important than fast transport service with unfixed schedules, which gives more pressure to the liner company to achieve their practice as they promised to the public. For a fixed route, optimal speed will not only brings maximum profit but also keep their reputation in the long run.

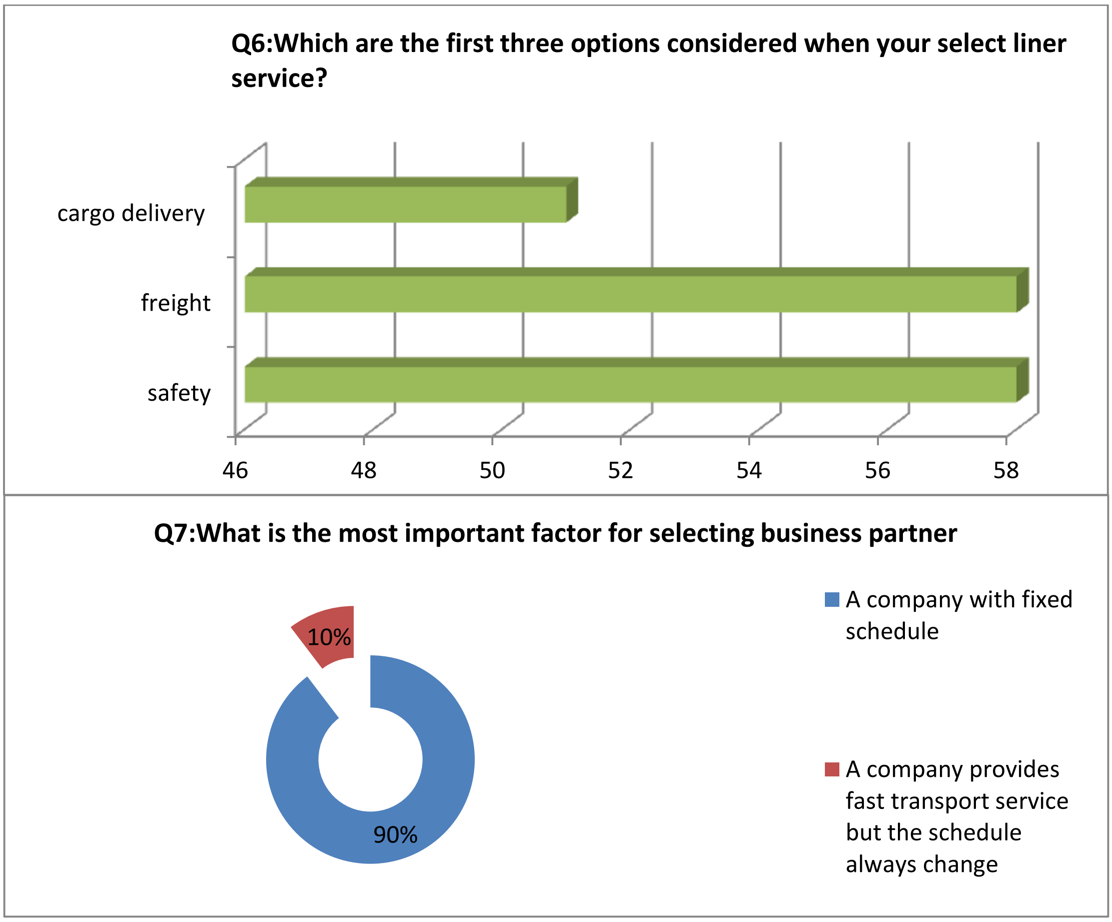


Figure 21- Statistic result of Q6 &Q7
Source: The Author.

CHAPTER 6

Summary and Conclusions

6.1 Limitations of the study

This paper is focusing on the traditional fuel consumption in container shipping. Basically, there are three approaches to compliance with the new regulations except the fuel switching method. Since the sulphur emission and nitrogen oxides can be reduced by introduction of LNG fuel, this new trend may be widely applied in the future. But ship - owners should retrofit the vessels so that the main engine can use LNG as fuel, and the refueling should also be considered. Although the basic physical and mathematics principles are the same, the initial investment is very huge and the effect of LNG fuel to the shipping economic still need to be set up based on statistics and observations.

Another attention is technology innovation. For example, Scrubbers installed on a ship can also comply with the requirements, but the result should be modified by adding a coefficient in the model which is determined by the cost weight of the Scrubber including maintenance fees.

6.2 Conclusion

This paper develops a dynamic mathematics model for the solution of containership optimal speed based on two selected vessels in real world. The two parameters V_e, V_g involving the fuel consumption are discussed respectively. Solutions are given depending on the calculation of two vessels as well as the performance of fleets they belong to.

For single vessels:

Two challenges are affecting the shipping industry obviously. One of them is the fuel price, and sometimes it accounts for more than half of the total operational costs. Another challenge is the strict environment regulations. The new MARPOL Convention gives strict limits on emission, particular in ECAs. This paper proposes a mathematic model to be applied by ship operators by considering the sailing path in ECAs as well as the preparation for berth. For single vessels, the speeds are always determined by the quality of various fuels which has an obvious price differences.

From the policy perspective, even though the global emission reduction regulations were still unknown, IMO may increase the cost of emission not only focusing on the sulphur content of fuel oil. Therefore, the objective of optimal speed will not only reduce the direct cost brought by fuel consumption but also the indirect cost for protecting marine environment.

For liner shipping:

It is a special service by deploying certain type vessel on fixed frequency of calling ports on each voyage. The fuel cost should take the whole performance of the fleet as well as the freight it can gain into consideration.

This paper aims at finding the optimal speed in the given shipping route by minimizing the total fuel consumption as well as the emissions, in which the operation of oil change before berth is considered. A standard scenario is defined by analyzing the fuel cost in the current fuel oil price, and a simulation based on approximation methods containing random variables is used to address the fuel cost in the future.

For the two schedules, FAL_1 and CPS, this paper provides two different target functions by two variables V_e and V_g. Through the calculations, it shows two useful managerial insights:

(i) In the CPS service, the weight of ECA legs is relative small compared to the whole Trans-Pacific service journey. When the oil price rises up, the effect brought by the speed in ECAs become smaller, this means that the operators of container vessels should focus on the cost control out of ECA. In contrast, the FAL_1 line is very different in that the speed in ECA always affects the binding points of $f_c\,(V_e, V_g)$ curves. In another word, the ECA legs will influence the overall profit and emission significantly. Hence, the cost control is determined by the weight of ECA legs.

(ii) The slow steaming strategy is not always a cue for saving cost. For a single vessel, like M.V EVER URSULA in in its 0635E/ 0635W voyage, the delays caused by slow speed makes the whole loop longer than the schedule published on the internet initially, which may cause the loss of potential customers. What’s more, another vessel should substitute the role of M.V EVER URSULA that it could have played. Although a single vessel cost may decrease, the whole cost of fleet may increase simultaneously.

The major contributions of this paper can be summarized as follows:

Firstly, the relationship between different speeds of containership in various fuel price scenarios on fuel cost are found to help the operators consider the best solution during navigation particular for single vessels.

Secondly, the coefficient K_3 is calculated by statistic data for solving the 8,000+TEU containership fuel cost function with variable value speed. By substituting a simple cubic function, a non-linear relationship specified in different grade of containerships is set up from the capacity of 8,000TEU to 10,000TEU.

Thirdly, the mathematic model is set up for calculation in different service line. Two real liner examples are analyzed in detail, and an optimal result is given categorized by ECA and Non – ECA speed respectively. Compared to the company original operation, significant fuel savings are found via the calculation of deterministic data by the math model.

Finally, the emission problems involving speeds are discussed in the last part of this paper. The control of the emission will not only benefit to the overall marine environment but also improve the service level of containership companies. Although Market – Based Measures is delayed, as long as the emission continues, the pressure of environmental protection will never cease.

References

Acomi, N. & Acomi, O.C. (2013). *The influence of the voyage parameters over the Energy Efficiency Operational Index*, The 18th Conference of the Hong-Kong Society for Transportation Studies Hong Kong, CHINA, HKSTS.

Acomi, N. & Acomi, O. C. (2014). Improving the Voyage Energy Efficiency by Using EEOI. *Procedia - Social and Behavioral Sciences 138, 531 – 536*

Andersson, H., Fagerholt, K., Hobbesland, K., 2015. Integrated maritime fleet deployment and speed optimization: case study from RoRo shipping. *Computer Operator Resource. 55, 233–240.*

Ashar,A. (1999). The Fourth Revolution. *Containerization International.12, 57–61.*

Bergh, I. (2010). Optimum speed – from a shipper's perspective. *Container ship update, 2, 10-13.*

Buxton, I.L.(1985). Fuel costs and their relationship with capital and operating costs. *Maritime Policy and Management 12 (1), 47–54.*

CBO. (2006). The Economic Costs of Disruptions in Container Shipments. U.S. Congress, Congressional Budget Office, Washington, DC.

Chang, C. & Wang, C. (2014). Evaluating the effects of speed reduce for shipping costs and CO2 emission. *Transportation Research Part D 31 (2014), 110–115.*

Christiansen, M., Fagerholt, K., Nygreen, B. & Ronen, D. (2007).*Maritime transportation.* In: Barnhart, C. and Laporte, G. (eds). Handbooks in Operations Research and Management Science: Transportation. North-Holland: Amsterdam, 189–284

Clarkson. (2014a). *Container Intelligence Quarterly*. First quarter. Clarkson Research Services Ltd., London.

Clarkson. (2014b). Container Intelligence Monthly, vol. 15. Clarkson Research Services Ltd., London.

CMA CGM. (2015). CMA CGM LAPEROUSE. Retrieved 27th April, 2015, from http://www.cma-cgm.com/the-group/activities/shipping/vessel/9454412/cma-cgm-laperouse

Cullinane, K.&Bergqvist, R. (2014). Emission control areas and their impact on maritime transport. *Transportat. Res. Part D: Transp. Environ. 28, 1–5.*

Doudnikoff, M. & Lacoste, R. (2014). Effect of a speed reduction of containerships in response to higher energy costs in sulphur emission control areas. T*ransportat. Research. Part D: Transport. Environment. 27, 19 –29.*

EMERSON. (2010).Marine Fuel Measurement,Superior measurement for outstanding results. EMERSON: Author. Retrieved 25th April, 2015 from http://www2.emersonprocess.com/siteadmincenter/PM%20Micro%20Motion%20Documents/MFM-BRO-MC-001406.pdf

Fagerholt, K. (2004). A computer-based decision support system for vessel fleet scheduling – experience and future research. *Decision Support Systems. 37, 35–47.*

Fagerholt, K.(2004). Designing optimal routes in a liner shipping problem. *Maritime Policy and Management 31, 259–268.*

Fagerholt,K., Gausel, N.T., Rakke.J.G., & Psaraftis,H.N. (2015). Maritime routing and speed optimization with emission control areas, *Transportation Research Part C, 52,57–73*

Guan,C., Theotokatos.G, Zhou P., Chen,H. (2014). Computational investigation of a large containership propulsion engine operation at slow steaming conditions. *Applied Energy 130, 370–383.*

IMO. (2009a). Prevention of Air Pollution from Ships: Energy Efficiency Design Index, Marine Environment Protection Committee (MEPC), 59th Session, Agenda item 4.

IMO, (2009b) Guidelines for voluntary use of the ship energy efficiency operational indicator,EEOI, Marine Environment Protection Committee, MEPC.1/Circ.684

IMO. (2014). Third IMO GHG study. Doc. MEPC\67\INF-3. International Maritime

Organization (IMO), London, UK.

Larsen,U., Pierobon, L., Baldi, F., Haglind, F. & Ivarsson, A. (2015). Development of a model for the prediction of the fuel consumption and nitrogen oxides emission trade-off for large ships. *Energy 80 (2015), 545-555.*

Lim, S. M.(1998). Economies of scale in container shipping. *Maritime Policy and Management 25, 361–373.*

Lindstad, Haakon, Asbjørnslett, Bjørn Egil, Jullumstrø &Egil. (2013). Assessment of profit, cost and emissions by varying speed as a function of sea conditions and freight market. *Transport. Res. D: TRE 19 (1), 5–13.*

Liu, X.M.(2015). *Speech given at the ceremony conference of M/V CSCL GLOBE*. Retrieved April 29, 2015 from the World Web Site: http://www.fmprc.gov.cn/mfa_chn/zwbd_602255/t1227136.shtml

Karlaftis, M.G., Kepaptsoglou, K., Sambracos, E. (2009). Containership routing with time deadlines and simultaneous deliveries and pick-ups. *Transportation Research 45E, 210–221.*

Manning,G. C. (1956). *The theory and technique of ship design*. Cambridge, Massachusetts: MIT Press.

NAKAZAWA. T.(2014). *Impact of the maritime innovation and technology (unpublished handout).* World Maritime University.

Notteblooma, T. E., & Vernimmen, B. (2009). The effect of high fuel costs on liner service configuration in container shipping. *Journal of Transport Geography*, *17*, 325–337.

Prpic-Orsic´,J.& Faltinsen, O.M.(2012). Estimation of ship speed loss and associated CO2 emissions in a seaway. *Ocean Engineering 44, 1–10.*

Psaraftis, H.N.& Christos,K. A.(2013). Speed models for energy-efficient maritime transportation: a taxonomy and survey. *Transportation Research Part C, 26, 331-351.*

Rana, K.&Vickson, R.G. (1991). Routing container ships using Lagrangean relaxation and decomposition. *Transportation Science. 25 (3), 201–214.*

Sheng, X., Lee. L.H., Chew, E.P., (2013). Dynamic determination of vessel speed and selection of bunkering ports for liner shipping under stochastic environment. *OR Spectrum, 1–26.*

Sheng, X., Lee. L.H., Chew, E.P., (2015). (s,S)policy model for liner shipping refueling and sailing speed optimization problem. *Transportation Research Part E 76 ,76–92.*

Ship&Bunker. (2015). World Bunker Prices. Retrieved from World Web Site on April 14, 2015 From http://shipandbunker.com/prices#_IFO380

Ting, S.C., Tzeng, G.H. (2003). Ship scheduling and cost analysis for route planning in liner shipping. *Maritime Economics & Logistics 5, 378–392.*

UNCTAD. (2012).Review of Maritime Transport 2012, Report by the UNCTAD secretariat, New York and Geneva

UNCTAD. (2015). Review of Maritime Transport 2014. United nations Conference on trade and development secretariat, New York and Geneva.

Veenstra, A.& Ludema, M.W.(2006). The relationship between design and economic performance of ships. *Maritime Policy & Management 33 (2), 159–171.*

Wang, W. (2013). Saving Energy by Using Adequate Draft. *China Shipping(originated in Chinese),13(12),9.*

Xi, J.P.(2013). President Xi Jinping gave a speech at the Congress of the Republic of Indonesia (Originating from Chinese). Retrieved from World Web Site on May 5th, 2015 from http://www.chinanews.com/gn/2013/10-03/5344133.shtml

Yao, Z. S., Ng, S. H., & Lee, L. H. (2011). A study on bunker fuel management for the shipping liner services. *Computers & Operations Research, 39, 1160–1172.*

Bibliography

Andersson,H., Fagerholt, K., Hobbesland, K. (2015). Integratedmaritime fleet deploymentandspeedoptimization: Case studyfromRoRoshipping. *Computers &OperationsResearch. 55,233–240*

Ghiţă, S. & Ardelean, I. (2010). Dynamics of marine bacterioplankton density in filtered (0.45 µm) microcosms supplemented with gasoline. *The 3th International Conference on Environmental and Geological Science and Engineering EG 2010, (93 - 98). ISBN: 978-960-474-221-9*

Kojima,K. and Ryan,L. (2010). TRANSPORT ENERGY EFFICIENCY. Paris: International Energy Agency Press.

IMO, (2012) .*Guidance for the development of a ship energy efficiency management plan*, *SEEMP* .MEPC 59/24/Add.1, ANNEX 19

Ma, S. (2002). Economics of maritime safety and environment regulations. In C. T. Grammenos (Ed.), The handbook of Maritime Economics and Business. (pp. 399-425). London: Informa Professional (a trading division of Informa UK Ltd).

SAJ. (2014). Shipbuilding Statistics. Tokyo: the shipbuilder's association of Japan press. April 28, 2015 retrieved from:
http://www.sajn.or.jp/pdf/Shipbuilding_Statistics_Mar2015.pdf

Appendices

Appendix I: The calculation of coefficient K_3

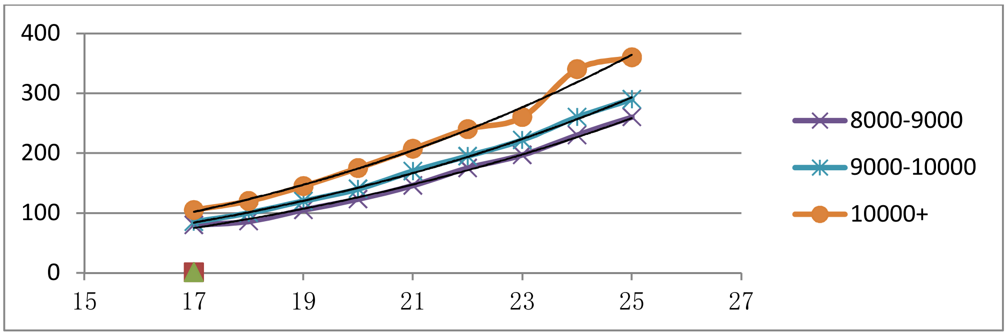
Due to the limitation of YAO's theory and insufficient statistic data if containership is more than 8110TEU, the fowling statistic will be based on professor Notteboom &Carriou's research which was presented in the IAME conference in 2009 (See Figure 22).

Table 18 – Daily fuel consumption by different grade of ships

	Daily fuel consumption ton/day		
SPEED(kn)	8000-9000 TEU ship	9000-10000 TEU ship	10000+ TEU ship
17	80	85	105
18	86	100	120
19	105	120	145
20	123	140	175
21	146	170	207
22	175	195	240
23	197	222	260
24	230	260	340
25	260	290	360

Source: The Author.

Figure 23- The relationship between speed and fuel consumption for 8000TEU+ containership



Source: The Author. (Note: the data are based on Notteboom &Carriou's research)

By calculating the regression function of different grade ship daily consumption of different sizes, the trend line of the statistic data can be categorized (See Table 19).

Table 19- Trend line of fuel oil consumption by different size of containerships over 8000 TEU

Ship size (TEU)	*Trend line*
8,000 – 9,000	$y = 0.0084x^{3.2107}$
9,000 – 10,000	$y = 0.0087x^{3.2387}$
10,000+	$y = 0.0087x^{3.3047}$

Source: The Author.

Then, the value of K_3 can be get as 3.21, 3.24, and 3.30 respectively for different grade ships.

Appendix II: Calculation Details for CPS Service

1. Table 20 - The result of M.V EVER URSULA by MS Excel

V_e (kn)	$V_g(kn)$	f_c in standard scenario(US Dollars)	when oil price rise 10% before 2020(US Dollars)	f_c in forecasting scenario after 2020 when a1=1, b1=1(US Dollars)	fc in forecasting scenario after 2020 when oil average price rise 10%(US Dollars)
8.5	16.32	38259.5	42085.4	46402.1	51042.3
8.75	16.29	38203.5	42023.8	46350.5	50985.6
9	16.25	38151.5	41966.6	46302.9	50933.1
9.25	16.22	38103.2	41913.5	46258.7	50884.6
9.5	16.19	38058.3	41864.2	46217.8	50839.6
9.75	16.16	38016.6	41818.3	46179.8	50797.8
10	16.14	37977.9	41775.6	46144.7	50759.1
10.25	16.11	37941.8	41736.0	46112.1	50723.3
10.5	16.09	37908.3	41699.1	46081.9	50690.1
10.75	16.07	37877.1	41664.8	46053.9	50659.3
11	16.04	37848.1	41633.0	46028.0	50630.8
11.25	16.02	37821.2	41603.4	46004.1	50604.5
11.5	16.00	37796.3	41575.9	45982.0	50580.2
11.75	15.99	37773.2	41550.5	45961.6	50557.8
12	15.97	37751.8	41527.0	45942.9	50537.2
12.25	15.95	37732.0	41505.2	45925.7	50518.3
12.5	15.93	37713.8	41485.2	45909.9	50500.9
12.75	15.92	37697.1	41466.8	45895.6	50485.1
13	15.90	37681.7	41449.9	45882.5	50470.8
13.25	15.89	37667.7	41434.5	45870.7	50457.8
13.5	15.87	37654.9	41420.4	45860.1	50446.1
13.75	15.86	37643.3	41407.7	45850.6	50435.6
14	15.85	37632.9	41396.2	45842.1	50426.4
14.25	15.84	37623.6	41385.9	45834.8	50418.2
14.5	15.82	37615.3	41376.8	45828.4	50411.2
14.75	15.81	37608.0	41368.8	45822.9	50405.2

15	15.80	37601.7	41361.9	45818.4	50400.2
15.25	15.79	37596.4	41356.0	45814.8	50396.2
15.5	15.78	37591.9	41351.1	45812.0	50393.2
15.75	15.77	37588.3	41347.1	45810.0	50391.0
16	15.76	37585.5	41344.1	45808.8	50389.7
16.25	15.75	37583.6	41341.9	45808.3	50389.2
16.5	15.74	37582.4	41340.6	45808.6	50389.5
16.75	15.73	37581.9	41340.1	45809.7	50390.6
17	15.72	37582.2	41340.5	45811.4	50392.5
17.25	15.71	37583.2	41341.6	45813.7	50395.1
17.5	15.71	37584.9	41343.4	45816.8	50398.4
17.75	15.70	37587.3	41346.0	45820.4	50402.5
18	15.69	37590.3	41349.3	45824.7	50407.2
18.25	15.68	37593.9	41353.3	45829.6	50412.5
18.5	15.68	37598.2	41358.0	45835.0	50418.6
18.75	15.67	37603.1	41363.4	45841.1	50425.2
19	15.66	37608.5	41369.3	45847.7	50432.4
19.25	15.66	37614.5	41376.0	45854.8	50440.3
19.5	15.65	37621.1	41383.2	45862.5	50448.7
19.75	15.64	37628.2	41391.0	45870.6	50457.7
20	15.64	37635.9	41399.4	45879.3	50467.3
20.25	15.63	37644.0	41408.4	45888.5	50477.4
20.5	15.62	37652.7	41418.0	45898.2	50488.0
20.75	15.62	37661.9	41428.1	45908.4	50499.2
21	15.61	37671.6	41438.7	45919.0	50510.9
21.25	15.61	37681.8	41449.9	45930.1	50523.1
21.5	15.60	37692.4	41461.6	45941.6	50535.8
21.75	15.60	37703.5	41473.8	45953.6	50549.0
22	15.59	37715.1	41486.6	45966.1	50562.7
22.25	15.59	37727.1	41499.8	45978.9	50576.8
22.5	15.58	37739.5	41513.5	45992.2	50591.4
22.75	15.58	37752.4	41527.7	46005.9	50606.5
23	15.57	37765.7	41542.3	46020.0	50622.0
23.25	15.57	37779.5	41557.4	46034.6	50638.0
23.5	15.56	37793.6	41573.0	46049.5	50654.4
23.75	15.56	37808.2	41589.0	46064.8	50671.3
24	15.56	37823.2	41605.5	46080.5	50688.6
24.25	15.55	37838.6	41622.4	46096.6	50706.3
24.5	15.55	37854.3	41639.8	46113.1	50724.4
24.75	15.54	37870.5	41657.6	46130.0	50743.0

25	15.54	37887.1	41675.8	46147.2	50761.9
25.25	15.54	37904.0	41694.4	46164.8	50781.3
25.5	15.53	37921.3	41713.4	46182.8	50801.0
25.75	15.53	37939.0	41732.9	46201.1	50821.2
26	15.53	37957.0	41752.7	46219.8	50841.8

Source: The author.

2. Table 21- The result of fuel consumption in M.V EVER LOGIC in different scenarios by MS Excel

V_e (kn)	$V_g(kn)$	f_c in standard scenario(US Dollars)	when oil price rise 10% before 2020(US Dollars)	f_c in forecasting scenario after 2020 when a1=1, b1=1(US Dollars)	fc in forecasting scenario after 2020 when oil average price rise 10%(US Dollars)
8.5	16.32	207599	228358.9	254981.7	280479.9
8.75	16.29	206801.1	227481.2	253956.4	279352.1
9	16.25	206070.6	226677.6	253012.6	278313.9
9.25	16.22	205402	225942.2	252143.6	277358.0
9.5	16.19	204790.6	225269.6	251343.4	276477.7
9.75	16.16	204232	224655.2	250606.8	275667.4
10	16.14	203722.5	224094.8	249929.0	274921.9
10.25	16.11	203258.8	223584.7	249306.1	274236.7
10.5	16.09	202837.7	223121.5	248734.1	273607.5
10.75	16.07	202456.7	222702.3	248209.8	273030.8
11	16.04	202113.1	222324.4	247730.2	272503.2
11.25	16.02	201804.9	221985.4	247292.5	272021.8
11.5	16.00	201530.1	221683.1	246894.3	271583.7
11.75	15.99	201286.8	221415.5	246533.3	271186.7
12	15.97	201073.4	221180.8	246207.6	270828.4
12.25	15.95	200888.5	220977.3	245915.2	270506.8
12.5	15.93	200730.6	220803.6	245654.6	270220.1
12.75	15.92	200598.4	220658.3	245424.1	269966.5
13	15.90	200491	220540.1	245222.4	269744.6
13.25	15.89	200407.2	220447.9	245048.1	269552.9

13.5	15.87	200346.1	220380.7	244900.0	269390.0
13.75	15.86	200306.7	220337.4	244777.2	269254.9
14	15.85	200288.3	220317.1	244678.5	269146.4
14.25	15.84	200290.1	220319.2	244603.1	269063.4
14.5	15.82	200311.5	220342.6	244550.0	269005.0
14.75	15.81	200351.7	220386.9	244518.5	268970.3
15	15.80	200410.2	220451.3	244507.8	268958.6
15.25	15.79	200486.5	220535.1	244517.3	268969.1
15.5	15.78	200580	220638	244546.3	269001.0
15.75	15.77	200690.2	220759.2	244594.3	269053.7
16	15.76	200816.7	220898.4	244660.6	269126.6
16.25	15.75	200959.1	221055	244744.7	269219.2
16.5	15.74	201117	221228.7	244846.2	269330.9
16.75	15.73	201290	221419.1	244964.7	269461.1
17	15.72	201477.9	221625.7	245099.6	269609.6
17.25	15.71	201680.2	221848.3	245250.7	269775.8
17.5	15.71	201896.8	222086.4	245417.5	269959.2
17.75	15.70	202127.2	222339.9	245599.7	270159.7
18	15.69	202371.3	222608.5	245797.0	270376.7
18.25	15.68	202628.9	222891.7	246009.0	270609.9
18.5	15.68	202899.6	223189.5	246235.6	270859.1
18.75	15.67	203183.3	223501.6	246476.3	271123.9
19	15.66	203479.7	223827.7	246731.0	271404.1
19.25	15.66	203788.8	224167.7	246999.5	271699.4
19.5	15.65	204110.2	224521.3	247281.4	272009.5
19.75	15.64	204443.9	224888.3	247576.6	272334.3
20	15.64	204789.7	225268.7	247885.0	272673.5
20.25	15.63	205147.4	225662.2	248206.2	273026.8
20.5	15.62	205516.9	226068.6	248540.1	273394.1
20.75	15.62	205898.1	226487.9	248886.6	273775.3
21	15.61	206290.8	226919.8	249245.5	274170.1
21.25	15.61	206694.9	227364.3	249616.7	274578.3
21.5	15.60	207110.3	227821.3	249999.9	274999.9
21.75	15.60	207536.9	228290.5	250395.1	275434.6
22	15.59	207974.6	228772	250802.2	275882.4
22.25	15.59	208423.3	229265.6	251221.0	276343.1
22.5	15.58	208882.9	229771.2	251651.4	276816.5
22.75	15.58	209353.3	230288.6	252093.2	277302.6
23	15.57	209834.5	230818	252546.5	277801.2
23.25	15.57	210326.4	231359	253011.1	278312.2
23.5	15.56	210828.8	231911.7	253486.9	278835.6
23.75	15.56	211341.8	232476	253973.8	279371.2

24	15.56	211865.3	233051.8	254471.7	279918.9
24.25	15.55	212399.1	233639.1	254980.6	280478.7
24.5	15.55	212943.4	234237.7	255500.4	281050.4
24.75	15.54	213497.9	234847.7	256031.0	281634.1
25	15.54	214062.6	235468.9	256572.3	282229.5
25.25	15.54	214637.6	236101.3	257124.3	282836.7
25.5	15.53	215222.7	236744.9	257686.9	283455.6
25.75	15.53	215817.9	237399.7	258260.0	284086.1
26	15.53	216423.1	238065.4	258843.7	284728.1

Source: The Author.

Appendix III: Calculation Details for FAL_1 Service

Table 22- The result of f(v) under the variable of V_e, V_g in a selected vessel of FAL_1 service by MS Excel

V_g*(kn)*	V_e*(kn)*	*fc in standard scenario(US Dollars)*	*when oil price rise 10% before 2020(US Dollars)*	*fc in forecasting scenario after 2020 when a1=1,b1=1 (US Dollars)*	*fc in forecasting scenario after 202 when oil average price rise 10%(US Dollars)*
13.3340	7.5000	143134.8	157448.3	175413.0	192954.3
13.2745	7.7500	142039.4	156243.3	173987.2	191385.9
13.2192	8.0000	141065.7	155172.3	172708.2	189979.0
13.1677	8.2500	140202.2	154222.4	171561.6	188717.8
13.1195	8.5000	139438.9	153382.8	170535.2	187588.8
13.0745	8.7500	138767.2	152643.9	169618.3	186580.2
13.0322	9.0000	138179.5	151997.4	168801.7	185681.8
12.9924	9.2500	137669.4	151436.3	168077.2	184884.9
12.9550	9.5000	137231.2	150954.3	167437.8	184181.6
12.9197	9.7500	136859.8	150545.8	166877.4	183565.1
12.8863	10.0000	136550.9	150206.0	166390.5	183029.5
12.8547	10.2500	136300.5	149930.5	165972.1	182569.3
12.8248	10.5000	136105.2	149715.7	165618.1	182179.9
12.7964	10.7500	135961.9	149558.0	165324.6	181857.1
12.7694	11.0000	135867.8	149454.5	165088.2	181597.0
12.7437	11.2500	135820.4	149402.5	164905.8	181396.4
12.7192	11.5000	135817.6	149399.4	164774.6	181252.1
12.6958	11.7500	135857.4	149443.1	164692.2	181161.4
12.6735	12.0000	135937.9	149531.7	164656.4	181122.0
12.6522	12.2500	136057.5	149663.3	164665.0	181131.5
12.6318	12.5000	136214.8	149836.3	164716.4	181188.0
12.6123	12.7500	136408.4	150049.3	164808.7	181289.6
12.5936	13.0000	136637.2	150300.9	164940.6	181434.6
12.5756	13.2500	136900.0	150590.0	165110.5	181621.6
12.5583	13.5000	137195.8	150915.3	165317.4	181849.1
12.5418	13.7500	137523.6	151276.0	165559.9	182115.9
12.5258	14.0000	137882.8	151671.1	165837.2	182420.9
12.5105	14.2500	138272.4	152099.7	166148.1	182762.9
12.4957	14.5000	138691.9	152561.1	166491.8	183141.0
12.4814	14.7500	139140.5	153054.5	166867.5	183554.3
12.4677	15.0000	139617.6	153579.4	167274.5	184001.9

12.4544	15.2500	140122.8	154135.1	167712.0	184483.2
12.4416	15.5000	140655.5	154721.0	168179.5	184997.4
12.4292	15.7500	141215.2	155336.7	168676.3	185543.9
12.4172	16.0000	141801.6	155981.8	169201.9	186122.1
12.4057	16.2500	142414.2	156655.7	169755.8	186731.4
12.3945	16.5000	143052.8	157358.0	170337.5	187371.3
12.3836	16.7500	143716.8	158088.5	170946.7	188041.3
12.3731	17.0000	144406.2	158846.8	171582.8	188741.1
12.3629	17.2500	145120.4	159632.5	172245.7	189470.2
12.3530	17.5000	145859.4	160445.4	172934.8	190228.3
12.3434	17.7500	146622.9	161285.2	173649.9	191014.9
12.3434	17.7500	147410.6	162151.7	174390.8	191829.8
12.3341	18.0000	148222.4	163044.6	175157.0	192672.7
12.3251	18.2500	149058.0	163963.8	175948.5	193543.3
12.3163	18.5000	149917.2	164909.0	176764.9	194441.4
12.3077	18.7500	150800.0	165880.0	177606.0	195366.6
12.2994	19.0000	151706.2	166876.8	178471.7	196318.9
12.2914	19.2500	152635.5	167899.1	179361.7	197297.9
12.2835	19.5000	153588.0	168946.8	180275.9	198303.5
12.2758	19.7500	154563.5	170019.8	181214.1	199335.5
12.2684	20.0000	155561.8	171118.0	182176.2	200393.8
12.2611	20.2500	156582.9	172241.2	183162.0	201478.2
12.2541	20.5000	157626.7	173389.4	184171.4	202588.6
12.2472	20.7500	158693.1	174562.4	185204.3	203724.8
12.2404	21.0000	159782.0	175760.2	186260.6	204886.7
12.2339	21.2500	160893.4	176982.8	187340.1	206074.2
12.2275	21.5000	162027.2	178229.9	188442.9	207287.1
12.2212	21.7500	163183.3	179501.7	189568.7	208525.5
12.2151	22.0000	164361.7	180797.9	190717.5	209789.3
12.2092	22.2500	165562.4	182118.6	191889.3	211078.2
12.2034	22.5000	166785.2	183463.7	193083.9	212392.3
12.1977	22.7500	168030.2	184833.2	194301.4	213731.6
12.1921	23.0000	169297.3	186227.1	195541.6	215095.8
12.1867	23.2500	170586.6	187645.2	196804.6	216485.0
12.1814	23.5000	171897.9	189087.7	198090.2	217899.2
12.1762	23.7500	173231.2	190554.3	199398.4	219338.2
12.1711	24.0000	174586.6	192045.2	200729.2	220802.1
12.1661	24.2500	175964.0	193560.4	202082.5	222290.8
12.1613	24.5000	143134.8	157448.3	175413.0	192954.3

Source: The author.

Appendix IV: Data Resource of the value P/WV

Table 23 - The average global performance of P/WV from 2007 to 2011

year	capacity (TEU)	Numbers of vessel detectable by AIS	Average deadweight	Average installed power	Average designspeed (knots)	Average sea time	Average sea speed (knots)	Average P/WV
2007	0-999	1015	8976	6004	16.7	178	13.3	0.050293
	1000-1999	1142	21644	13153	20	180	15.2	0.03998
	2000-2999	684	36869	22228	21.9	178	16.8	0.035886
	3000-4999	720	56198	37068	24.7	257	18.6	0.035462
	5000-7999	432	79567	58342	26.3	248	20.6	0.035594
	8000-11999	135	116415	76214	28.2	249	21.3	0.030736
	12000-14500	7	245802	125669	38.4	249	20.6	0.024818
	14500-+	0	0	0	0	0	0	–
2008	0-999	1082	9284	6187	17	178	13.2	0.050486
	1000-1999	1253	21824	13367	20.3	179	15.2	0.040295
	2000-2999	733	37556	22678	22.3	178	16.7	0.036158
	3000-4999	779	56036	37246	24.7	253	18.1	0.036723
	5000-7999	472	80503	58986	26.5	246	19.7	0.037194
	8000-11999	172	117315	76127	28.4	250	20.3	0.031966
	12000-14500	8	163136	83302	25.7	249	19.2	0.026595
	14500-+	0	0	0	0	0	0	–
2009	0-999	1081	9059	6117	16.9	183	13.2	0.051155
	1000-1999	1282	21440	13120	20.1	185	15.1	0.040526
	2000-2999	752	37550	22613	22.4	217	16.8	0.035846
	3000-4999	874	56648	37734	25	238	17.6	0.037847
	5000-7999	514	79317	57944	26	266	19.2	0.038049
	8000-11999	204	114387	73942	27.3	283	19.9	0.032483
	12000-14500	13	187649	91187	29.2	299	17.4	0.027928
	14500-+	0	0	0	0			–
2010	0-999	1023	9080	6182	17.1	191	12.7	0.053609
	1000-1999	1264	21520	13156	20.2	201	14.5	0.042161
	2000-2999	725	37478	22640	22.4	214	16.2	0.037289
	3000-4999	922	58072	39328	25.8	230	17.2	0.039374
	5000-7999	564	81168	59115	26.6	228	17.5	0.041617
	8000-11999	241	119058	76538	28.3	238	17.9	0.035914
	12000-14500	36	283558	131829	43.7	241	17	0.027348
	14500-+	0	0	0	0	0	0	–
2011	0-999	945	9676	5912	16.2	197	12.6	0.048492
	1000-1999	1172	20723	12443	19.3	206	14.4	0.041697
	2000-2999	666	35764	21668	21.6	222	16	0.037866
	3000-4999	864	53951	35980	23.8	241	16.9	0.039462
	5000-7999	545	76981	55592	25.2	246	17.2	0.041986
	8000-11999	236	108236	68779	25.4	250	17.4	0.03652
	12000-14500	47	164333	77563	27.1	240	16.9	0.027928

Source: IMO(2014). *Third IMO GHG study.*
London: Author.
(Note: The value P/WV is calculated by the Author.)