Master's degree thesis

LOG950 Logistics

The impact of slow steaming practices on cost and emission from shipping

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Preface

This thesis is the requirement of the Master of Science in Logistics at Molde University College. I finished the thesis under the guidance of my supervisor Associated Professor Harald Martin Hjelle.

Firstly I would like to express my gratitude to my supervisor for his professional, helpful, patient guidance and encouragement during my thesis writing. With the help of my supervisor, I got inspirations and learned many knowledge in writing the thesis.

Then I would like to thank Molde University College for providing an excellent and outstanding studying and living environment during my two year study program.

At last I must thank my parents and my grandmother, with their selfless supporting I can finish my study successfully.

Abstract

Slow steaming is a highly cost motivated behaviour by intentionally reducing the ship speed mainly for saving bunker fuel consumption. Meanwhile it brings an extra benefit of emission reduction. This thesis aims to discuss two questions, find fleet total cost minimized optimal point of slow steaming on a liner service and measure the market and environment sustainability by using a concept of boundary point. In the thesis, section 1 introduces the definition and history of slow steaming. Section 2 and 3 are literature review and methodology. Section 4, author draws the Pareto curve to analyze the distribution and layout of merchant fleet transportation work, fuel consumption and emission in different detailed ship types. Section 5 writes about advantages and disadvantages of slow steaming and each advantage is formed by phenomenon, influencing factors and slow steaming improving three parts. Section 6, the first part, labeled as 6.1.1, is to answer the first question to find the fleet total cost optimal point by calculating fleet total cost on a liner service, the second part, labeled as 6.1.2 is to answer the second question to describe the market sustainability from ship cost view by calculating and comparing with boundary point. It can be understood that the whole content of section 6.1 is surrounding a core sentence, that is whether the fuel cost saving from slow steaming on the case liner service can compensate for extra cost from hiring extra more ships, longer roundtrip time and when. Section 6.2 is the emission amount analysis of the liner service which uses the same method in section 6.1. Section 7 and 8 are conclusion and reference.

Key words: Slow Steaming, Pareto Analysis, COSCO, Cost, Emission.

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1. Introduction

1.1 Slow steaming

Slow steaming is a ship operating behaviour that intentionally make the ship sail at a speed which is slower than its design speed.

It was first being used as a shipping operating strategy to reduce bunker fuel consumption during the first oil crisis in 1973 (Zanne, 2013) when the crude oil price soared from $3 per barrel to $13 per barrel caused by the Yom Kippur War. This created significant negative impact on the shipping industry at that time which motivated slow steaming behaviour emerging to save bunker fuel. Then 34 years later, during the financial crisis of 2007 and 2008, the bunker fuel IFO380 price arose from $350 per metric ton (tonne) in July, 2007 to $700 per metric ton (tonne) in July, 2008. Slow steaming was then adopted again to reduce the fuel consumption. In February, 2011 Maersk ordered 10 Triple E class 18340TEU containerships from Daewoo Shipbuilding & Marine Engineering (DSME) whose first ship delivery time was in 2013, with a design speed of, which is already as low as 19 knots while Maersk continuously reserved 10 more Triple E class ships in four months late, June, 2011 (Maersk, 2014). It can be shown that slow steaming will still be an important issue in the future.

Ships steaming at a higher speed consume more bunker fuel and make more emission than those steaming at a lower speed (Psaraftis and Kontovas 2009). A 10% ship speed reduction will lead to a 27% engine power reduction (Faber, 2012) which directly influence the fuel consumption and 19% emission reduction (Kloch, 2013) from a whole fleet view even extra ships will be added into the fleet to maintain the same service frequency after the average speed is reduced. This kind of fuel saving and emission reduction will be discussed and calculated in this article below.

1.2 Research problem

1. What is the optimal point of slow steaming on MEX liner service from minimizing fleet total cost under single ship type and standard weekly service ?

2. What is the market and environment sustainability point of slow steaming on MEX liner service under single ship type and standard weekly service?

MEX here is short for Mid-East Express, it is a liner service of COSCO which will be used as the case service below in section 6.

2. Literature review

2.1 Slow steaming fuel consumption, time factor and cost review

Slow steaming is a ship operating strategy that makes the ship steam under design speed for the purpose of bunker fuel saving. Maloni, Paul and Gilgor (2013) classified the different degree of containership slow steaming according to the average operating speed. Sailing from maximum speed lager or equals to 24 knots was defined as full speed, from less than 24 knots to larger or equals to 21 knots was defined as slow steaming, from less than 21 knots to larger or equals to 18 knots was defined as extra slow steaming, from less than 18 knots to larger or equals to minimum speed was defined as super slow steaming (Maloni, Paul and Gilgor, 2013). Different sailing speed will lead to different hydrodynamic resistance. The main resistances for ships sailing at sea is the hydrodynamic resistance, which is closely related to speed. Hassan and White (2010) optimized the ship fuel efficiency from a ship designing view, who mainly concentrated on the hull design. They classified the hull design into under water hull and above water hull, then analyzed the aerodynamic resistances and hydrodynamic resistances with different ship speed. Hassan and White (2010) also used different ship speed and different hull design to find the resistances constitution change and fuel efficiency change. Slow steaming does impact on saving cost not only from the hydrodynamic resistances reduction but also from slower speed leading to fuel consumption reduction. Since slow steaming is a broad topic and the real situation of slow steaming practice is different from route to route, therefore focusing on a specific route to describe slow steaming is suitable. Notteboom and Vernimmen (2009) chose an Europe-Far East trade as the research object route to find the influence of high bunker fuel cost to the service design of liner shipping. Psaraftis (2011), Cariou (2011) both used the bunker fuel price as the independent variable in affecting the result of their cost models to show the soaring bunker fuel price the slow steaming practices. While Notteboom and Vernimmen (2009) developed a cost model describing the influence of soaring bunker fuel price on the operating cost in each container unit. Lee, Lee and Zhang (2013) constructed a model to describe the link between the time related factors in shipping and the delivery reliability. From the model, slow streaming helped to reduce the delivery delay rate and reduced the delivery variance. Notteboom (2006) wrote about the time factor in the liner shipping service, he mainly focused on the containership time unreliability phenomenon and analyzed the sources which led to them. A liner service connecting East Asia and Norther Europe was used as a research object and port congestion was ascribed to be the main unreliability reason.

2.2 Slow steaming emission review

Maloni, Paul and Gilgor (2013) also revealed that a 20% speed reduce could help to save 43% carbon dioxide emission from an Asia-North America route. Cariou (2011) discussed the sustainability of slow steaming on the emission reduction aspect. Emission reduction situation during 2008 to 2010 was analyzed first, Cariou (2011) constructed a model to calculate the fuel price impact on emission to measure whether slow steaming was sustainable. NTM (2008) presented the emission profile data in different fuel type in different speed. The emission profile data showed the different gas components in different kinds of fuel or in different ship types. Kevin Cullinane and Sharon Cullinane (2013) revealed the detailed ingredients of atmospheric emission gas and raise the technical solutions to improve the fuel efficiency including improve engine, install waste gas heat recovery system, hull design optimization and thrusters or rudders melioration. Devanney (2010) pointed out that the emission reduction in shipping industry could be included as the market based endeavors and non-market endeavors. He discussed the main economic methods which could be feasible for the shipping emission reduction, including add carbon based tax into the bunker fuel price and establishing emission trading system for the emission gases emitted from shipping. Wiesmann (2010) started from a globe shipping view to write about the several important considerations and consequences of slow steaming, which involved the incentives of slow steaming, commercial and environmental consequences resulted from slow steaming and challenges in slow steaming practice. Among which, Wiesmann (2010) expressed the concerns in the technical and engineer aspect of slow steaming from those early built ships with a high design speed around 27 knots and further gave out the engineering solution, technical improvement kits and facilities for them. Knotovas and Psaraftis (2011) discussed the lessons learned from slow steaming practice and write about the sustainability of slow steaming both based on the economy and environment sides.

2.2 Pareto analysis review

Pareto law was first found by an Italian economist named Vilfredo Federico Damaso Pareto who was born in 1848. He found that 20% citizens controlled 80% of the society properties from the observation in his country. Then Pareto principle was described that the vital minority elements decide the majority of the output (Lai and Cheng, 2009). Pareto principle was frequently used in analyzing the contribution of sales item to the total revenue. Pareto analysis can be applied in many fields apart from the revenue analysis. For example, Talib (2011) used Pareto analysis to analyze the critical success factors of total quality management in service industry. Ziarati (2006) used Pareto analysis in finding the main accidents causes in shipping.

Karuppusami and Gandhinathan (2006) deployed Pareto analysis in the total quality management (TQM) and it was found that few vital critical success factors determine the effect of total quality management. In this thesis, Pareto analysis will be used to analyze the relationship between transportation work, fuel consumption, emission and the ship numbers in different detailed merchant fleet.

2.3 Classifications in shipping related to slow steaming review

2.3.1 Classification of cost

The general cost can be classified into 5 main aspects of cost when running a ship. They are, respectively, operating cost, periodic maintenance cost, voyage cost, cargo-handling costs and capital cost (Stopford, 2009).

Operating cost. Operating cost is a basic cost which is necessary to be paid to operate a ship in a working status no matter it is in port or at sea. It can be seen as a kind of cost that relates to ship operating time. It includes manning cost, stores and consumables as lubricants, routine maintenance and repair, ship insurance and other administration cost like the registration cost (Alizadeh and Nomikos, 2011). Among all the four kind of charter-parties (contract), exclude the bareboat charter, the ship owner is responsible for paying the operating cost. As in the following MEX liner service, Costamare Shipping is the ship owner of these 9469TEU containerships.

Periodic maintenance cost. The insurance rate to a single ship is in some degree according to the results of classification agencies and relied on their judgment. Therefore in order to obtain a good rate of the insurance rate ships are always needed to keep periodic maintenance every period of time. Periodic maintenance cost entails the cost occurred during the dry docking time and the expense of regular or special surveys (Stopford, 2009). It can be concluded that periodic maintenance varies with ship age, dry docking days and varies with ship type. Older ship age and loner dry docking days always may bring higher periodic maintenance cost.

Voyage cost. This cost happens during the whole voyage from departure port to destination port while bunker fuel cost can be seen as the biggest weight of the voyage cost. Other typical cost within voyage cost includes port and canal charges, light and tug charges, pilotage charges (Stopford, 2009). Voyage cost is an unavoidable cost only if the ship is sailing. But it can be influenced by adopting different voyage speed strategies which is the theoretical basement of slow steaming. Adjusting speed and less port calls are the most ordinary strategies can be seen in practice in order to cut voyage cost. Slow steaming is therefore by utilizing the cubic rule to realize cutting voyage cost by reducing the speed (Stopford, 2009).

Cargo handling cost. It is mainly composed of cargo loading cost, discharging cost and cargo claims cost three parts (Stopford, 2009). The major part of cargo loading and discharging cost is the fees of utilizing the terminal based cranes and other facilities, the cost of renting these terminal based cranes is charged by the time, therefore modern specialized ships with ship based cargo handling kit or ship based cranes may directly reduce the cargo handling cost and significantly increase the cargo handling efficiency (Stopford, 2009).

2.3.2 Classification of charter contract

Chartering contract can be divided into 4 types, voyage charter, time charter, COA, and bare boat charter.

Voyage charter.Voyage charter is a kind of contract that the ship owner provides the whole ship or certain number of cabins to the charterer and the ship owner is responsible for hiring crew and organizing the transportation in a certain route. All the operating cost, voyage cost and periodic maintenance cost are paid by the ship owner (Stopford, 2009) except cargo handling cost. The charterer is charged by weight based freight rate.

Voyage charter can be further divided into single voyage charter, roundtrip voyage charter and consecutive voyage charter (Stopford, 2009). Single voyage charter is the the ship is chartered for only single trip and the charter party is finished after cargo is delivered to the destination. Round trip voyage charter is after discharging cargoes at the destination port, immediately load new cargoes for the back haul and the charter party is ended after discharging these new cargoes to the destination port of the back haul. Consecutive voyage charter is the charter party is finished after at least 2 times of single or roundtrip voyage in same route. It can be seen as a multi-times single or round trip voyage (Stopford, 2009).

It can be concluded that the characteristic of voyage charter is the ship owner taking both operation and market risk, ship owner pays all the cost except cargo handling cost, charterer is charged by the weight of cargoes in a certain route and voyage charter detail is greatly determined by the charter party. Voyage charter is common in bulk and tanker freight market.

Time charter. Time charter means the ship owner provides the ship to charterer and the ship owner is only responsible for hiring captain, crew whilst the charter are responsible for organizing the transportation in a period of time (Stopford,2009). All the operating cost and periodic maintenance cost are paid by the ship owner while the voyage cost and cargo handling cost are all paid by the charter (Stopford,2009). Charterer pays a the freight rate to ship owner calculated from time. On the MEX liner service the 9469 TEU containership is COSCO time chartered from Costamare Shipping with a 12 years contract from 2006 to December, 2017 with a price of $36,400 per day per ship.

It can be concluded that time chart means the ship owner only undertakes the operation risk while the market risk is undertaken by the charterer. Time charter is common in the freight liner service market of containership.

Contract of affreightment. Contract of affreightment (COA) is a kind of special voyage charter. It can be seen as a cluster of voyage charter contracts in a period of time which is consulted between ship owner and charterer. The freight rate is pre-consulted and calculated according to the weight. Ship owner pays operating cost, periodic maintenance, voyage cost (Stopford, 2009). COA is commonly seen in coal iron ore these mineral cargo freight market. Compared with traditional voyage charter, COA helps the ship owner to schedule the ship more efficiently and it is good for ship owner to arrange the back haul in advance aim to increase the ship utilization (Stopford, 2009).

Bare boat charter. Bare boat charter means although the ship owner owns the ship, the charterer is in charge of all the operational affairs, detailed transportation and cargo handling activities according to charter party (contract). The charterer undertakes both operation and market risks so it can always be seen as a financial investment of ship owner (Stopford, 2009).

2.3.3 Classification of vessel

World's merchant ships (fleet) can be classified into 4 main types, bulk cargo ship, general cargo ship, specialized cargo ship and non-cargo ship.

Bulk cargo fleet. Among bulk cargo ships, wet bulk and dry bulk ships can be further divided. Below is the wet bulk cargo fleet classification.

Table 2.1 Wet bulk ship classification

Bulk cargo(wet) ship classification	
DWT	**Class**
[320,000 , 500,000)	Ultra Large Crude Carries (ULCC)
[160,000 , 320,000)	Very Large Crude Carries (VLCC)
[120,000 , 160,000)	Suezmax
[80,000 , 120,000)	Aframax
[60,000 , 80,000)	Panamax
[10,000 , 60,000)	Handy

Source: Own illustration based on Stopford (2009).

Dry bulk ships, can be divided into 4 categories.

Table 2.2 Dry bulk ship classification

Bulk cargo(dry) ship classification	
DWT	**Class**
⩾100,000	Capesize
[60,000 , 100,000)	Panamax
[40,000 , 60,000)	Handymax
[10,000 , 40,000)	Handy

Source: Own illustration based on Stopford (2009).

These dry bulk ships are designed for carrying minerals and agriculture, forest related products. For example iron ore, coal in minerals, and wheat, corns in agriculture.

General cargo fleet. General cargo fleet can be further classified into container fleet, Roll-on and roll off (Ro-Ro) fleet, and Multi-purpose (MPP) fleet (Stopford, 2009). Containerships can be classified both in deadweight tonnage or TEU carrying capacity. Below is the classification of containership from TEU carrying capacity view.

Table 2.3 Containership classification

General cargo(container) ship classification	
TEU	Class
⩾130,000	New-Panamax
[8,000 , 130,000)	Mega-Post-Panamx
[4,000 , 8,000)	Post-Panamax
[3,000 , 4,000)	Panamax
[2,000 , 3,000)	Sub-Panamax
[1,000 , 2,000)	Handy
[500 , 1,000)	Feedermax
[100 , 500)	Feeder

Source: Own illustration based on Maritime-connector (2014) and Notteboom (2006)

The pace of containership maximization trend is becoming more obvious after the year of 2011. Take the example of ship delivery amount of 2012, the number of 8000+ TEU ship delivery is more than 80 which is accounting for approximately more than 50% of total ship delivery number in 2012. Another evidence of containership maximization is that Maersk ordered 20 triple E class containerships from Daewoo Shipbuilding & Marine Engineering (DSME) in 2011 which can carry 18,340 TEUs (Jorgensen, 2012).

Specialized cargo fleet. The specialized cargo fleet contains reefer, chemical tanker, Liquefied Petroleum Gas (LPG) and Liquefied Natural Gas (LNG) carriers (Stopford, 2009). These highly specialized ships are always equipped with freezing systems and providing extreme low temperature environment. LNG is also being regarded as the high value-added in the shipbuilding market.

Non cargo fleet. The common non cargo fleet can be seen in ordinary life among which are ferries and cruises provide traveling and transportation service for passengers or vehicles (Stopford, 2009). And ship types to offer port dredging or offshore engineer services.

3. Methodology

3.1 Case study as research method

Yin (2009) pointed out the essence of case study research is an empirical inquire. Case study can be used as an efficient method or measurement to research the phenomenon intensively when the borderline between phenomenon and background is not obvious (Yin, 2009). Yin (1994) also pointed out exploratory case study was an extensively used case study research method. This thesis explores the optimal point of slow steaming from the fleet total cost minimum view on MEX liner service and also explores when it is sustainable through calculating the boundary point. Boundary point explores whether the current ship number and speed strategy is sustainable and when it should be adjusted under the circumstances of ship cost fluctuates in different market situation.

3.2 Research design

Research design is a logic process that links the data to the research questions and to the finally conclusion (Yin, 2009). And case study can be divided into multi-case study and single case study (Yin, 2003). In this thesis, single case study will be used.

The single case study is surrounded by the two research question with the implementation methods below.

1) Find the optimal point of slow steaming on MEX liner service under standard weekly service. Ship number in the fleet (fleet size) will be used as the independent variable, and fleet total cost per roundtrip is the dependent variable. The independent variable will vary in integer to describe the change of total fleet cost per roundtrip. By calculating and comparing the fleet total cost in different ship numbers and speed to fine the optimal point at the lowest fleet total cost.

2) Find the sustainability (market and environment) point of slow steaming on MEX liner service under standard weekly service. Then a boundary point concept will be

raised below. In measuring market sustainability, the boundary point is maximum allowed ship cost per day per ship. If the actual ship cost is lower than boundary point then, it is market sustainable. In measuring environment sustainability, the boundary point is the maximum allowed CO_2e emission from shipbuilding section per ship. The advantage of using boundary point to illustrate the market sustainability is that it can tell the operator when it is sustainable at current fleet size and speed by comparing the actual ship cost with the boundary point. Same to the environment sustainable boundary point.

Slow steaming is realized by ascending ship numbers. The service frequency of MEX liner service is set to be standard weekly service. Therefore more ship on the route per roundtrip will lead to the per ship average speed reduction.

3.2.1 Quality of research design

Quality of research design includes four main parts. Construct validity, internal validity, external validity and reliability constitute the quality of research design.

Construct validity

Construct validity means constructing the right procedures for the research questions Yin (1994). Three case study strategies can be used for promoting the construct validity they are more data source, evidence chain and pivotal information review.

Internal and external validity

Internal and external validity means the "establishing a causal relationship to distinguish the real and misleading relationships" Yin (1994). External validity means the adaptability of the conclusions found in the case study used in the real life Yin (2003). A case study based on real life has more external validity than a theoretical based case study.

Reliability

Reliability means the duplicability or the replication of the case study research. Reduce the mistakes and errors are the main purposes of case study reliability. And there are two strategies to raise the reliability, they are case study protocol and case study database (Yin, 2003).

3.2 Data collection

Yin (1994) pointed out that the data collection sauce was mainly including "documentation, archival records, interviews, direct observations, particular observation and physical artifacts" (Yin, 1994) these 6 aspects. The data used in this thesis can be concluded from COSCO data sauce, mainly for the data in calculation related to the MEX liner service, shipping related website sauce, mainly for other data in calculation, literatures, mainly for the explain advantages and disadvantages of slow steaming and others. Source of some pivotal data used in calculation is described in the following. Port distance data is from Searates, bunker fuel price is from the ShipandBunker, case ship cost data is from Costamare 2014 report, case ship technical detail data is from Container-info and the merchant fleet Pareto analysis data is used the data sheet from Psaraftis (2009), the data sheet can be seen in the Appendix 4.

4. Merchant fleet transportation work, fuel consumption and emission Pareto analysis

Pareto analysis is a good tool to distinguish the importance and contribution degree of few vital elements or factors in determining the final output. In this part, author draws the Pareto curve to analyze the distribution layout and characteristics of world's merchant fleet in aspects of transportation work, fuel consumption and emission respectively. The ship type will be further sorted into detailed ship type according to the TEU carrying capacity for containership fleet and deadweight tonnage for other ship types. This Pareto curve can help to reveal different detailed ship type's contribution to the transportation work, fuel consumption and emission. Data used is from the data sheet from Psaraftis (2009) which can be seen in Appendix 4.

4.1 Merchant fleet transportation work Pareto analysis

The Pareto curve of world's merchant fleet can be drawn in four steps which are based on the raw data attached in Appendix 4 and integrated calculation can be seen from Appendix 1 to Appendix 3. The tonne-km refers to the cargo transported. Below are the brief steps.

Step1. Get two main aspects of data, one is the average transportation work (tonne-km) for every detailed ship type per year. The other is the number of ships in this detail ship type.

Step2. Calculate the transportation work per detailed ship fleet and calculate its percentage in the whole.

Step3. Sort the transportation work per detailed ship fleet in a descending order.

Step4. Calculate the cumulative percentage of the total transportation work per detailed ship fleet and draw the Pareto curve with Excel.

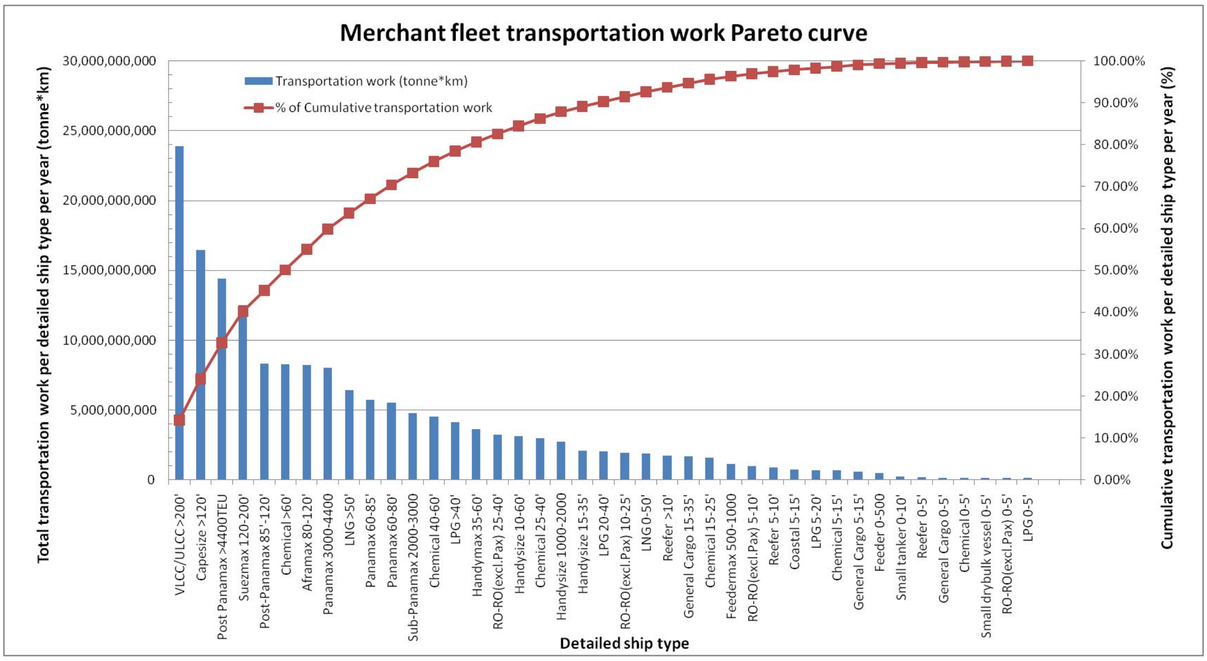


Figure 4.1 Merchant fleet transportation work Pareto curve

The blue bar in the figure above means the transportation work per detailed ship type fleet per year, for example, the first blue bar on the left in the figure above means the total transportation work of 516 ships of VLCC/ULCC >200,000dwt is 23,879,106,183 tonne-km per year. Beside is the same. The red curve means the cumulative percentage of transportation work. The detail percentage distribution can be seen in the figure below.

Rank	Ship type	Detail ship type ('000 dwt)	Ship number in size group	% of total ship numbers	% of cumulative ship numbers	Transportation work (tonne*km)	Cumulative transp. work	% of Cumulative transp. work
1	Crude Oil	VLCC/ULCC >200'	516	1.41%	1.41%	23879106183	23879106183	14.27%
2	Dry Bulk	Capesize >120'	722	1.98%	3.39%	16464276593	40343382776	24.11%
3	Container	Post Panamax >4400TEU	712	1.95%	5.34%	14404444807	54747827583	32.72%
4	Crude Oil	Suezmax 120-200'	332	0.91%	6.25%	12495006794	67242834377	40.19%
5	Dry Bulk	Post-Panamax 85'-120'	98	0.27%	6.51%	8345885855	75588720232	45.18%
6	Chemical	Chemical >60'	238	0.65%	7.17%	8291118437	83879838669	50.14%
7	Crude Oil	Aframax 80-120'	648	1.77%	8.94%	8207170707	92087009376	55.04%
8	Container	Panamax 3000-4400	568	1.55%	10.49%	8030486625	100117496001	59.84%
9	LNG	LNG >50'	221	0.60%	11.10%	6408488501	106525984502	63.67%
10	Dry Bulk	Panamax 60-85'	1383	3.79%	14.88%	5738689444	112264673946	67.10%
11	Crude Oil	Panamax 60-80'	177	0.48%	15.37%	5545193472	117809867418	70.42%
12	Container	Sub-Panamax 2000-3000	689	1.89%	17.25%	4761738206	122571605624	73.27%
13	Chemical	Chemical 40-60'	705	1.93%	19.18%	4513046136	127084651760	75.96%
14	LPG	LPG >40'	135	0.37%	19.55%	4147643575	131232295335	78.44%

Figure 4.2 Merchant fleet transportation work Pareto analysis

It can be seen from the figure above that the transportation work of top 14 detailed ship type fleets takes up as high as 78.44% of the total transportation work with only

19.55% of total ship numbers in the whole merchant fleet, which is perfectly obeying the “80/20 rule”. Especially the top 5 detailed ship fleet with a 6.51% number of total ships to finish the 45.18% total transportation work. It can be shown the importance of large-scale ships in affecting the world’s shipping freight market.

26	Chemical	Chemical 15-25'	430	1.18%	40.06%	1607649695	160032906257	95.66%
27	Container	Feedermax 500-1000	757	2.07%	42.13%	1137846685	161170752942	96.34%
28	RO-RO	RO-RO(excl.Pax) 5-10'	674	1.84%	43.98%	979619744	162150372686	96.92%
29	Reefer	Reefer 5-10'	358	0.98%	44.96%	906791981	163057164667	97.47%
30	Dry Bulk	Coastal 5-15'	236	0.65%	45.60%	710876741	163768041408	97.89%
31	LPG	LPG 5-20'	235	0.64%	46.25%	678646370	164446687778	98.30%
32	Chemical	Chemical 5-15'	1407	3.85%	50.10%	660522652	165107210430	98.69%
33	General Cargo	General Cargo 5-15'	3014	8.25%	58.34%	605853976	165713064406	99.05%
34	Container	Feeder 0-500	363	0.99%	59.34%	469332852	166182397258	99.33%
35	Crude Oil	Small tanker 0-10'	115	0.31%	59.65%	216120361	166398517619	99.46%
36	Reefer	Reefer 0-5'	508	1.39%	61.04%	203228700	166601746319	99.58%
37	General Cargo	General Cargo 0-5'	9009	24.66%	85.70%	145225951	166746972270	99.67%
38	Chemical	Chemical 0-5'	3125	8.55%	94.25%	142654101	166889626371	99.76%
39	Dry Bulk	Small drybulk vessel 0-5	517	1.41%	95.67%	139158763	167028785134	99.84%
40	RO-RO	RO-RO(excl.Pax) 0-5'	932	2.55%	98.22%	138768467	167167553601	99.92%
41	LPG	LPG 0-5'	651	1.78%	100.00%	130496886	167298050487	100.00%

Figure 4.3 Merchant fleet transportation work Pareto analysis

However, the bottom 59.96% (59.96%=1-40.06%) of total ship number in the world merchant fleet is only occupying 4.34% (59.96%=1-95.66%) of the total transportation work, the bottom 15% of total ship number in the world merchant fleet is only holding 0.33% of the total transportation work.

Therefore, it can be concluded that from the transportation work view, it is so concentrated that 78.44% merchant fleet transportation work is centralized on the top 19.55% large-scale ships. It also shows the trend of large-scale vessel that affect the market structure from transportation work view.

4.2 Merchant fleet fuel consumption Pareto analysis

Almost the same as the transportation work calculation way, the merchant fleet fuel consumption Pareto curve also can be drawn.

After doing almost the same 4 steps, the Pareto curve can be obtained below and detailed calculation process can be seen in the Appendix 2.

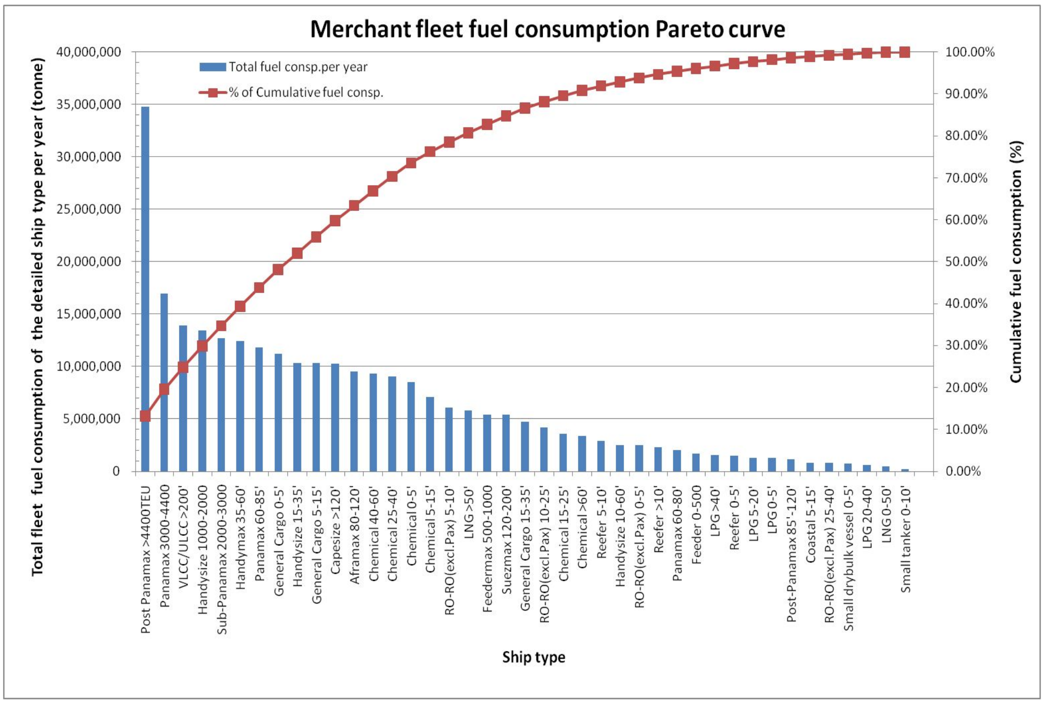


Figure 4.4 Merchant fleet fuel consumption Pareto curve

The blue bar represents the total fuel consumption per detailed ship type fleet. The red curve represents the cumulative percentage of the total fuel consumption per detail ship type. For example, the first bar on the left means the total fuel consumption of 712 ships of Post-Panamax >4400TEU containerships is 34,813,952 tonnes.

Rank	Ship type	Detail Ship type ('000 dwt)	Ship number in size group	% of total ship numbers	% of cumulative ship numbers	Total avg. fuel/ (ship*year)	Total fuel consp. per year	Cumulative fuel consp.	% of Cumulative fuel consp.
1	Container	Post Panamax >4400TEU	712	1.95%	1.95%	48896.00	34813952.00	34813952.00	13.15%
2	Container	Panamax 3000-4400	568	1.55%	3.50%	29811.20	16932761.60	51746713.60	19.55%
3	Crude Oil	VLCC/ULCC >200'	516	1.41%	4.92%	27008.00	13936128.00	65682841.60	24.81%
4	Container	Handysize 1000-2000	1143	3.13%	8.04%	11760.00	13441680.00	79124521.60	29.89%
5	Container	Sub-Panamax 2000-3000	689	1.89%	9.93%	18400.00	12677600.00	91802121.60	34.68%

Figure 4.5 Merchant fleet fuel consumption Pareto analysis

Being limited to the top 5 detailed ship types, it can be seen that the centralization trend of top 5 detailed ship type, for 9.93% ships accounts for the 34.68% of world's merchant fleet fuel consumption. Among these 5 top fuel consumption ship types, 4 in

5 are containerships and the Post-Panamax >4400TEU containership is even accounting for as high as 13.15% of world merchant fleet fuel consumption with a fleet number of only 1.95% of world merchant fleet ship numbers.

So it can be concluded that Post-Panamax >4400TEU containerships consumes the most fuel from a total view among all kinds of detailed fleet.

4.3 Merchant fleet emission Pareto analysis

Almost use the same method as calculating the transportation work.

After doing the same 4 steps, the Pareto curve can be obtained below. Differentiated form the transportation work and fuel consumption data, the total emission data is calculated by the product of transportation work and the emission factor which is tonne-km based (the emission is measured by CO_2 according to the data). While the transportation work and fuel consumption data is directly shown in the raw data. The calculation can be seen in Appendix 3.

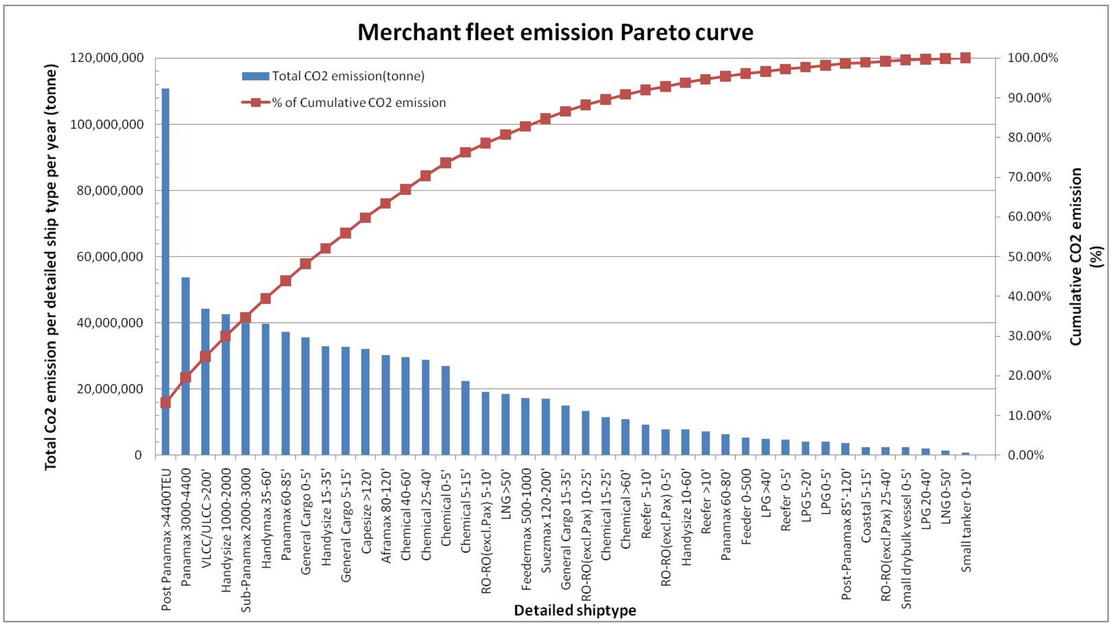


Figure 4.6 Merchant fleet emission Pareto curve

Rank	ship type	Detail ship type ('000 dwt)	ship number in size group	% of total ship numbers	% of cumulative ship numbers	Total transportation volumn	gr CO2/(tonne-km)	Total CO2 emission(tonne)	Cumulative fuel consp.	% of Cumulative CO2 emission
1	Container	Post Panamax >4400TEU	712	1.95%	1.95%	14404444807	10.80	110764418.79	110764418.79	13.19%
2	Container	Panamax 3000-4400	568	1.55%	3.50%	8030486625	11.80	53823533.56	164587952.34	19.60%
3	Crude Oil	VLCC/ULCC >200'	516	1.41%	4.92%	23879106183	3.60	44357827.65	208945779.99	24.89%
4	Container	Handysize 1000-2000	1143	3.13%	8.04%	2726036069	13.70	42687271.41	251633051.40	29.97%
5	Container	Sub-Panamax 2000-3000	689	1.89%	9.93%	4761738206	12.20	40026219.01	291659270.41	34.74%

Figure 4.7 Merchant fleet emission Pareto analysis

The figure above illustrates the emission situation in the merchant fleet, although the emission data is tonne-km based calculated, the layout of the final result is quite the same to the layout of the merchant fleet fuel consumption curve. Among the top 5 emission detailed ship types, containerships still take up 4 positions of them. Therefore containership fleet not only has the biggest influence on fuel consumption reduction, but also has the biggest impact on emission.

It can be concluded from all the analysis above that Post-Panamax>4400TEU detailed fleet takes up the biggest proportion of both fuel and emission reduction from a total view and studying on the Post-Panamax>4400TEU fuel and emission reduction is meaningful.

5. Advantages and disadvantages of slow steaming

This part contains slow steaming advantages and disadvantages. Advantages can be summarized in fuel saving, time reliability improving and emission reducing. Disadvantages mainly from the marine engineers, who regards slow steaming in a high design speed may be hazard to the engine and power system components.

5.1 Advantages of slow steaming

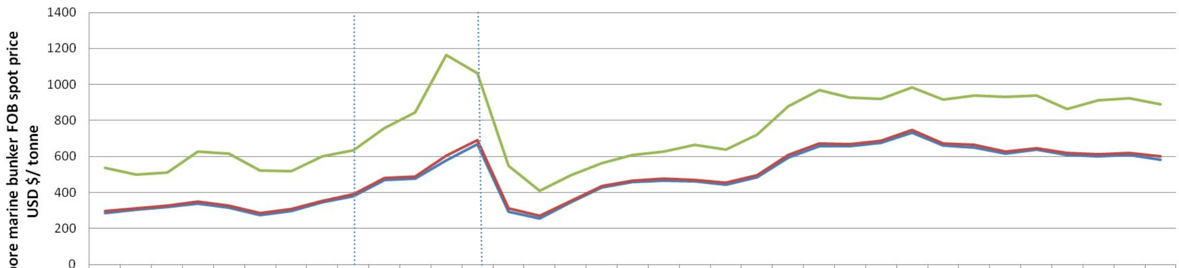
Each of the slow steaming advantages will be illustrated from three parts including phenomenon, influencing factors and slow steaming improvement.

5.1.1 Save fuel

Phenomenon

From the statistics of World shipping Council WSC (2008), the bunker fuel cost is already accounting for approximately 50% to 60% in the total ship (broad) operating cost. So how to save fuel is an important topic for carriers and ship owners .

The majority motivation of carriers to implement slow steaming is to reduce the marine bunker fuel consumption, therefore slow steaming can be regarded as a highly cost driven behavior. The Brent crude oil price had raised from average price $28.23 per barrel in 2000 to average price $93.67 per barrel in 2008 and up to $104.79 per barrel on April 3rd of 2014. At the same time the Singapore marine bunker FOB spot price of IFO380 had increased from $303 per tonne in 2005Q4 to as high as $582.5 per tonne in April 3rd of 2014.



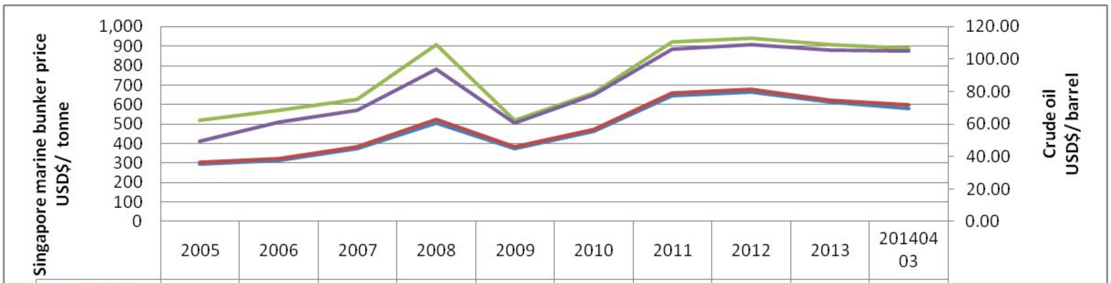
	2005Q3	2005Q4	2006Q1	2006Q2	2006Q3	2006Q4	2007Q1	2007Q2	2007Q3	2007Q4	2008Q1	2008Q2	2008Q3	2008Q4	2009Q1
IFO380	285	303	318	339	316	275	296	344	380	470	476	578	669	295	257
IFO180	298	314	328	349	327	285	307	355	390	482	488	605	691	314	270
MDO	536	498	510	626	617	523	520	601	636	759	845	1164	1064	550	410

	2009Q2	2009Q3	2009Q4	2010Q1	2010Q2	2010Q3	2010Q4	2011Q1	2011Q2	2011Q3	2011Q4	2012Q1	2012Q2	2012Q3	2012Q4	2013Q1	2013Q2	2013Q3	2013Q4	20140403
IFO380	347	428	459	468	461	442	486	595	657	658	675	734	661	650	617	638	608	601	609	583
IFO180	355	435	467	477	471	453	497	607	671	668	688	746	673	663	629	646	621	611	619	600
MDO	494	563	608	628	664	638	719	878	968	926	921	983	917	938	930	939	863	914	922	891

Figure 5.1 Singapore marine bunker spot price from 2005Q3 to 2014

Source: Own illustration based on data from New Zealand Ministry of Transport (2014).

Form a wider yearly range average view of crude oil and bunker fuel price starting from 2005 to April 3rd ,2014.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	20140403
IFO380	294.00	311.73	372.33	504.40	372.60	464.08	646.18	665.45	613.70	582.5
IFO180	305.85	322.03	383.48	524.50	381.48	474.43	658.28	677.65	623.88	599.5
MDO	517.15	569.03	628.85	905.60	518.90	662.08	923.30	941.83	909.55	890.5
Crude oil	49.32	61.45	68.36	93.67	60.88	78.11	106.39	108.97	105.50	104.79

Figure 5.2 Singapore marine bunker and Brent crude oil price from 2005 to 2014

Source: Own illustration based on data from New Zealand Ministry of Transport (2014).

As we can see from figure below, the IFO380 price is highly related to crude oil price with a Pearson correlation of 0.980, the correlation between the IFO180, MDO and crude oil is 0.983 and 0.978 respectively. So it can be seen that a tight price correlation existing between crude oil and bunker fuel, crude oil fluctuation will impact on the cost of shipping greatly and directly.

Correlations

		Crude oil	IFO380	IFO180	MDO
Crude oil	Pearson Correlation	1	.980**	.983**	.978**
	Sig. (2-tailed)		.000	.000	.000
	N	10	10	10	10

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 5.3 Pearson Correlation between crude oil and 3 types of bunker fuel

Influencing factors

As it is known that the fuel consumed by containerships can be divided into following ways, one way is the fuel consumed by main engine to motivate the containership to keep forward motion, another way is the fuel consumed by auxiliary engine to motivate for example generator, water pumps and cranes for containerships to load and discharge containers when in port, lubricating oil consumed for engines will not be considered here.

As for the fuel consumed by the main engine, it is influenced by many factors in the following.

Hydrodynamic resistance and hull design. Keeping a forward motion to overcome hydrodynamic resistance at sea is a major fuel consumption source for a containership in sailing. Hydrodynamic resistance can be classified into 3 types, wave resistance, eddy resistance and viscous resistance. Wave resistance can be further divided into wave making and wave breaking resistance, viscous resistance also can be divided into frictional resistance and pressure resistance. These hydrodynamic resistances can be influenced by speed and ship design factors as hull design.

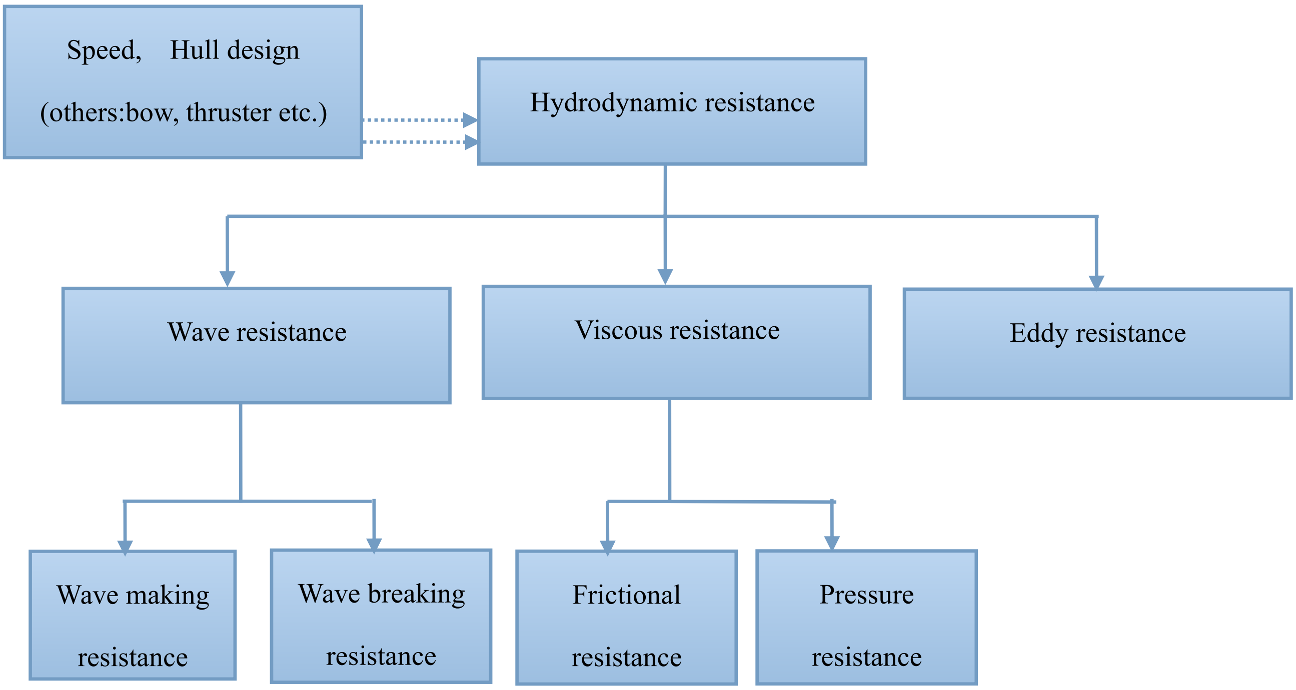


Figure 5.4 Hydrodynamic resistance classification

In certain practice, wave making resistance and frictional resistance are always taken into calculation mainly when measuring the hydrodynamic resistance at sea roughly of a containership. As a case research focused on the hydrodynamic resistance of a containership shows the hydrodynamic resistance variation in different speed can be seen below.

Table 5.1 Hydrodynamic resistance variation with speed

Hydrodynamic resistance variation with speed		
Speed(knot)	% of wave making res.in total	% of fritional res. in total
23	30%	70%
13	2.50%	97.50%

Source: Own illustration based on Hassan and White (2010).

Therefore lower speed can reduce wave making resistance significantly.

Engine load. Engine load is a percentage, it means the percentage of the working engine's power accounting for the theoretical maximum continuous rate power. So 70% of theoretical maximum continuous rate power is generated at 70% engine load.

Slow steaming improvement

Slow steaming realizes fuel saving in two ways. One way is that lower speed will lead to lower wave making resistance. The other way is that lower speed reduces the engine power significantly, following a cubic relationship according to propeller law, which will reduce the fuel consumption effectively.

For hydrodynamic resistance, when the speed of the ship is reduced, the wave making resistance decrease significantly following a square relationship (Moraes, 2004).

For the engine power, according to propeller law, $P = c * n^3$, P = engine power for propulsion, n = propeller speed, c = constant (MAN, 2010) propeller speed reduce 10% means engine power will reduce 27.1%. Although propeller speed does not directly equals to ship speed, ship speed still can be viewed as directly influenced by propeller speed, therefore engine power varies following the cubic relationship with ship speed.

The engine type of the case ship is MAN B&W K98MC7-TII two-stroke engine. The optimal engine state appears at 80% and when the speed reduces from 24.4 knots to 19.4 knots, the engine load reduces from 80% to 40%. Therefore the engine fuel consumption is reduced significantly. In literatures the relationship of fuel consumption reduction and speed reduction is directly described as $F = F_0 * \left(\frac{V}{V_0}\right)^3$, F_0 means fuel consumption at the speed of V_0 (Psaraftis and Kontovas, 2009; *et al.*). This formula is used in a considerable quantity of literatures in describing the relationship between speed and fuel consumption, it will also be used in the calculation below.

5.1.2 Improve time unreliability problem of arriving ports

Phenomenon

Delivery time reliability is vital for shippers and freight forwarders. As for shippers who ship for finished products, poor delivery time reliability may delay their plan of putting products on the shelf (Lee, Lee, and Zhang, 2013), therefore selling schedule may be interrupted. "As for shippers who ship for raw materials, poor delivery time reliability may delay the supply of raw material therefore production schedule may be interfered" (Lee, Lee, and Zhang, 2013). The poor delivery time reliability is common in different specific trade routes according to the data below.

Table 5.2 Delay rate in different routes

Delay rate in different routes				
Route			**On time**	**Delay**
Departure	Final destination	Abbreviation		
Asia	Europe &Mediterranean	A/ E	44%	56%
Asia	Africa	A/ Af.	43%	57%
Asia	South America(east coast)	A/ ESA	46%	54%
Europe &Mediterranean	Australia and New Zealand	E/ Aus	31%	69%
Europe &Mediterranean	South America (east coast)	E/ ESA	62%	38%
Europe &Mediterranean	South America (west coast)	E/ ESA	24%	76%
North American	Africa	NA/ Af.	50%	50%
North American	Australia	NA/ Aus	56%	44%
North American	Indian	NA/ Ind.	76%	24%

Source: Notteboom (2008)

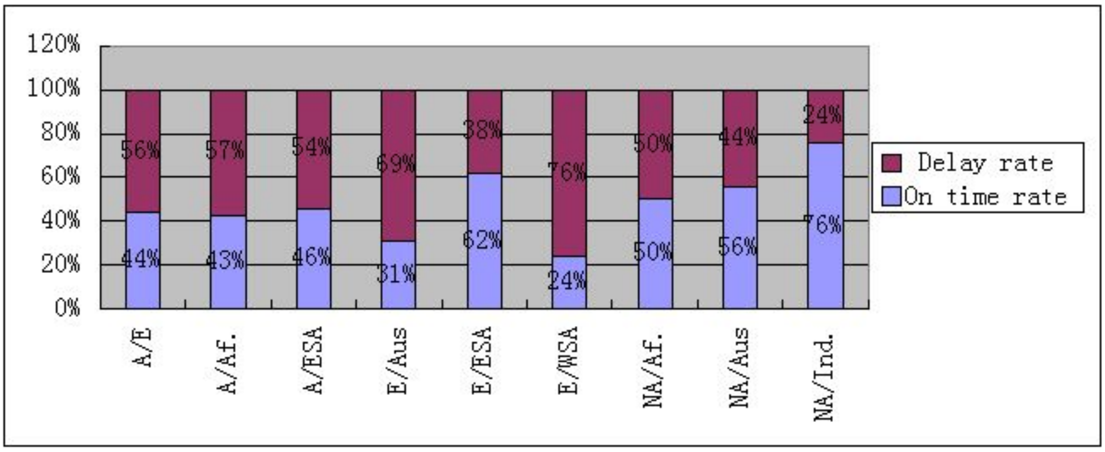


Figure 5.5 Delay rate in different routes

Source: Own illustration based on data sheet (Notteboom, 2008)

From the figure above it is quite obvious that the poor delivery time reliability problem is existing commonly in the international shipping. Specifically, among all the trade routes above, only the route of North American to Australia, route of Europe to South American east coast and the route of North America to Indian can keep the delay rate below 50%, the delay rates of the rest routes are all above 50%, the route of Europe to Australia and the route of Europe to South American west coast are even higher, their delay rate are as high as 69% and 70% respectively.

Influencing factors

Differentiated from road, pipe and air transportation, international shipping transportation is more complex and more easily influenced by external factors like sea condition, weather and others. Therefore the delivery time reliability of international shipping could not be as accurate as other transportation method except Maersk. Maersk occupied the most reliable carrier 12 times in 13 quarters up to February 2013 (Jorgensen, 2012). Nautical condition is only one of the reasons which lead to the time unreliability but is not the most important one. Actually the majority aspect of delivery time unreliability is caused by port operation, port productivity and other port related factors.

Table 5.3 Time unreliability reasons and sources

Unreliability source (extra waiting time)	Percentage %	Cumulative percentage %	Group	%
Port congestion before arrival and departure	65.50%	65.50%	In port factors delay	86.10%
Port low productivity	20.60%	86.10%		
Port channel access for tidal windows	2.80%	88.90%	Port channel access factors delay	7.50%
Port channel access for pilotage and	4.70%	93.60%		
Weather and machine	5.30%	98.90%	Weather and machine	5.30%
Suez miss	0.90%	99.80%	Other factors	1.10%

Source: Own calculation based on survey data (Notteboom, 2006)

These seven factors result in the delivery time unreliability can be ascribed into four main groups. 1) Port and terminal congestion. 2) Port channel related 3) Weather and mechanical. 4) Others.

Port and terminal congestion, also can be regarded as queuing, and port low productivity form the first unreliability source accounting for 86.1% among all the unreliability sources. The second unreliability source is port channel access related factors such as the waiting time for tidal window or pilotages, which is occupying 7.5%, weather, mechanical problem and other external factors takes up for 5.3% and 1.1% respectively. So the conclusion can be obtained that the majority reason and source of delivery time unreliability happened in the section of before arrival and departure is insufficient port productivity and port congestion.

Slow steaming improvement

This delivery time unreliability problem can be improved in some degree by implementing slow steaming. Slow steaming means longer sailing time and lower average speed, therefore if delay has already happened during last period of the voyage, containership can increase its speed in the rest of the voyage to “save” the time back which is delayed, then arriving at the next port on time still can be realized (Lee, Lee, and Zhang, 2013). In contrast, if containership is already sailing at a rather high speed, quite a little speed increase space will be left when delay has already happened in previous voyage period. In general, slow steaming can make the sailing schedule more flexible by leaving more speed potential space, so the integral delivery time reliability for the whole voyage can be improved.

5.1.3 Reduce emission

Phenomenon

Emission from shipping is huge in the amount of greenhouse gases is as high as 840 million tonnes accounting for 3% of global overall greenhouse emission amount (IMO, 2009). Among the emission from shipping, emission caused by fuel burning and consumption is the biggest share. Fuel consumption of a ship has a cubic relationship with its speed, and CO_2e emission has a positive relationship with fuel consumption, therefore slow steaming can contribute to reducing CO_2e emission directly.

There are two main calculation methods to estimate the CO_2e emission from shipping. One of the method is estimating the amount of CO_2e from shipping according to the sales data of bunker fuel, this kind of method is called “top down ” method, also can be described as the fuel selling based method or energy based method (Psaraftis and Kontovas, 2009). The other way is estimating the amount of CO_2e from shipping according to the routines and distances of ships in different type and different size. This kind of method is called "Bottom up" method, also can be described as the activity based method (Psaraftis and Kontovas, 2009).

Influencing factors

CO_2 equivalent is a number that measures the climate warming effect (potential) in a time span (100 years) coursed by a mix of gases, contains but not be limited to CO_2 (Cullinane, 2013). Obviously, what the emission gases from a containership burning residual oil and diesel oil is not possible to be only one kind of gas. It is a mixture of gases.

Main Engine (ME) emissions at sea, unit: [kg/tonne fuel]

Engine type	Fuel type	CO2 Fossil [kg/tonne]	NOx (as NO2) [kg/tonne]	HC/VOC (Total) [kg/tonne]	CH4 [kg/tonne]	PM [kg/tonne]	CO [kg/tonne]	SOx (as SO2) [kg/tonne]	Specific Fuel Consumption [g/kWh]
SSD	**RO**	3179	93	3,1	0,031	4,10	2,6	54	195
MSD	**RO**	3179	66	2,3	0,019	3,76	5,1	54	213
HSD	**MGO**	3177	59	1,0	0,02*	1,48	5,4*	10	203
HSD	**RO**	3179	60	0,94	0,019	3,76	5,1	54	213
ST	**RO**	3179	7	0,33	0,007	2,62	0,66	54	305
Reference *=data for MDO		Whall et al. (2002)	Whall et al. (2002)	Whall et al. (2002)	SMED (2004)	Whall et al. (2002)	SMED (2004)	Whall et al. (2002)	Whall et al. (2002)

SSD – Slow Speed Diesel, MSD – Medium Speed Diesel, HSD – High Speed Diesel, ST – Steam Turbine
RO – Residual Oil, MDO – Marine Diesel Oil and MGO – Marine Gas Oil.

Figure 5.6 Emission factor in different fuel and engine type

Source: NTM (2008)

As can be seen from the figure above, the ingredient of emission gases is different according from fuel to fuel, from CO_2 emission view, residual oil and marine gas oil are almost the same, however, in other gases view, marine gas oil is obviously much cleaner than the residual oil. Still from the figure above, analyzed from the engine emission data of the same fuel type in different speed (SSD, MSD, HSD) it can be found that slow speed diesel engine type will lead to more CO_2e emission because of the adequate fuel burning. Every ship has its design speed, within the design speed range the fuel can be burned adequately.

There are 4 main types of bunker fuel in the bunkerworld website whose price is updated every day. They are IFO380, IFO180, MDO and MGO.

IFO (Intermediate Fuel Oil) is a mix of gasoil (contains less gasoil than MDO) and heavy fuel oil. The number behind means the maximum viscosity at a temperature of 50℃. IFO380 means the maximum viscosity of the fuel is 380cst (centistokes) at 50℃, IFO180 means the maximum viscosity of the fuel is 180cst (centistokes) at 50℃, IFO380 is cheaper and more viscous than IFO180.

MDO (Marine Diesel Oil) is mostly based on heavy gasoil, the viscosity of MDO is always up to 12cst (centistokes) at 50℃, much lower than IFO, otherwise MDO is cleaner and more expensive.

So it can be concluded that IFO is more viscous, cheaper than MDO and MDO is cleaner, more expensive and has higher quality than IFO. In containership freight market, a containership is often equipped with two types of engines, they are main engine and auxiliary engine. IFO is used for the main engine at sea to motivate the ship keep forward moving. MDO is always used in port for ship based generators and cranes. The authority of ports in U.S. and Europe order ships to use MDO in port because using IFO in port may lead to heavy air pollution in the port area and may also jeopardize the activity of loading and discharging containers. Therefore containership fuel consumption needs considering at least two kinds of bunker fuel and the price of IFO380 in Shanghai port on April 2nd 2014 is $620.50 per tonne while the price of MDO in Shanghai port on April 2nd 2014 is as high as $1057.50 per tonne, almost doubled. That is why in the fuel consumption cost calculation in the case will be made up of two fuel types.

Slow steaming improvement

Slow steaming realizes emission reduction by reducing the fuel consumption in a large scale. Although slow steaming will lead to the fuel inadequate burning, however, this is limited to the ships built in a high design speed, in the new generation containership design, the design speed has been reduced in the shipbuilding section and other fuel efficiency improvement kits like heat recovery system, propeller modification and pulse lubricating system (Wiesmann, 2010) have been added which will provide better technical conditions for slow steaming. Through implementing slow steaming Maersk saved approximately 2.1 million tonnes of CO_2e emission in 2012 which has already in advance fulfilled the emission reduction task up to 2020 (Maersk, 2014).

5.2 Disadvantages of slow steaming

The dissenting voice against slow steaming is partly coming from marine engineer groups. Because the layout of main engine and power system are designed according to a range around the design speed. For example, the design speed of Post-Panamax containerships delivered in early built vessel is rather fast around 25 knots which is faster than the Maersk Triple E containerships which the first one was delivered in 2013 with a design speed of 19 knots. In these circumstances, the power system can work in a optimized state. So if a containership with a rather high design speed steams in a deliberate low speed for a long time (slow steaming), damages will be made to the main engine as well as power system components. These damages will increase the periodic maintenance cost and further shorten the service lifespan of the containership.

6. A case study on the MEX liner service of COSCO and findings.

6.1 Cost analysis of slow steaming on MEX liner service of COSCO

China Ocean Shipping Company (COSCO) is China's largest international marine transportation, ship building and mending company which is established in the year of 1961. Now its total merchant fleet scale is more than 700 ships (including ships chartered from other ship owners) providing shipping transportation service involving general cargo (container), bulk, crude oil, reefer transportation service and other specialized maritime transportation services. It also provides subordinate shipping related service (COSCO, 2014).

COSCO Container Lines Company Limited, which is short for COSCON, is a subsidiary company of COSCO centralizing and specialized in the container transportation, containership liner service operating.

Figure 6.1 Route of MEX liner service

Mid-East Express Service (MEX) liner service is a weekly service connecting Shanghai Singapore in East Asia and Dammam in Mid East with covering a total distance of 12089.98 nautical miles. It acts as an important role of containership freight service in the international trade between these two regions.

There are 11 port calls alongside the whole roundtrip in the service (including double calls), they are port of Shanghai (SHA, China), port of Ningbo (NGB, China), port of Hong Kong (HKG, China), port of Shekou (SHK, China), port of Singapore (SIN, Singapore), port of Jebel Ali (JEA, UAE), port of (Dammam, Saudi Arabia) and port of Kelang (PKG, Malaysia). The detail situation can be seen from the figure below.

Table 6.1 Port calls of MEX

Front-haul voyage	Back-haul voyage
port of Shanghai (SHA, China)	port of Kelang (PKG, Malaysia)
port of Ningbo (NGB, China)	port of Singapore (SIN, Singapore)
port of Hong Kong (HKG, China)	port of Hong Kong (HKG, China)
port of Shekou (SHK, China)	port of Shanghai (SHA, China)
port of Singapore (SIN, Singapore)	
port of Jebel Ali (JEA, UAE)	
port of (Dammam, Saudi Arabia)	

Source: MEX schedule of COSCO.

The distance between each port is collected and illustrated below and the a cumulative distance of the whole roundtrip is found to be 12089.98 nautical miles with 11 port calls including double calls.

Table 6.2 Roundtrip voyage distance of MEX

From	To	Distance (nautical miles)
port of Shanghai (SHA, China)	port of Ningbo (NGB, China)	126.47
port of Ningbo (NGB, China)	port of Hong Kong (HKG, China)	726.90
port of Hong Kong (HKG, China)	port of Shekou (SHK, China)	31.88
port of Shekou (SHK, China)	port of Singapore (SIN, Singapore)	1448.22
port of Singapore (SIN, Singapore)	port of Jebel Ali (JEA, UAE)	3470.43
port of Jebel Ali (JEA, UAE)	port of (Dammam, Saudi Arabia)	288.54
port of Dammam(, Saudi Arabia)	port of Kelang (PKG, Malaysia)	3533.69
port of Kelang (PKG, Malaysia)	port of Singapore (SIN, Singapore)	200.43
port of Singapore (SIN, Singapore)	port of Hongkong (HKG, China)	1460.02
port of Hongkong (HKG, China)	port of Shanghai (SHA, China)	803.40
Cumulative distance		12089.98

Source: Searates.com

The ship arrangement combination could be two types, single fleet (9469TEU containership) and mix fleet (9469TEU and 10020TEU containership). In this case calculation will be based on the single ship type fleet. The technical detail of the 9469 TEU containership can be seen below, COSCO Guangzhou taken for example, other same class containerships in the fleet are the same except the names according to the detail information from containership-info.com.

Table 6.3 COSCO Guangzhou technical detail

Item / Ship	COSCO Guangzhou
Owner	Costamare Shipping
Shipyard	Hyundai Heavy Industries. Ltd. Co, South Korea
IMO No.	9305570
Flag	Greece
Operator	COSCO
Completion year	Feb-06
Hull No.	1643
Engine design	B&W
Engine type	12K98MC
Power output(kw)	74,760
Max speed(kn)	25.4
Overall length(m)	350
Overall beam(m)	42.8
Maximum draught(m)	14.5
Maximum TEU capacity (TEU)	9,469
Deadweight(tonne)	107,277
Gross tonnage(tonne)	99,833

Source: Containership-info.com

Port time is an important and time consuming section in the whole voyage, it mainly involving the discharging and uploading containers and other activities. The time length of port time is mainly determined by the port efficiency and crane productivity. Therefore different port requires different port time, the departure and destination port always entail longer port time and the whole roundtrip port time is determined by the number of port calls and the port time of each port call.

Below is the specific port time of MEX liner service along the whole roundtrip, it can be found that total port time is 305 hours approximately to 12.71 days. No matter how many ships will be deployed and which speed strategy will be adopted, the port time will not be changed.

Table 6.4 Pot time of MEX

Port Name	ETA	ETD	Port time (hours)
port of Shanghai (SHA, China)	SUN 3:00	MON 12:00	33
port of Ningbo (NGB, China)	TUE 10:00	WED 6:00	20
port of Hong Kong (HKG, China)	FRI 0:00	FRI 18:00	18
port of Shekou (SHK, China)	FRI 22:00	SAT 16:00	18
port of Singapore (SIN, Singapore)	WED 1:00	THU 13:00	36
port of Jebel Ali (JEA, UAE)	SAT 0:00	SUN 12:00	36
port of Dammam(, Saudi Arabia)	MON 8:00	THU 12:00	76
port of Kelang (PKG, Malaysia)	TUE 21:00	WED 15:00	18
port of Singapore (SIN, Singapore)	THU 13:00	FRI 21:00	32
port of Hong Kong (HKG, China)	THU 4:00	THU 22:00	18
port of Shanghai (SHA, China)	SUN 3:00		
		Total	305 (12.71 days)

Source: Own illustration based on COSCO schedule.

6.1.1 Find the optimal point of slow steaming on the MEX

In order to calculate the impact of slow steaming on the fleet total cost in a more clear way, several assumptions need to be settled.

Assumption1. The total port time is fixed no matter which fleet size and ship speed will be adopted, according to the COSCO schedule the accumulative total port time is 12.71 days (305 hours).

Assumption2. The service frequency is assumed to be a standard weekly service. It means the time interval between the 2 ships arrive the same port is 7 days.

Assumption3. Extra adding ships are the same class 9469TEU containership.

Step 1 Calculate starting ship number. As it has been calculated above the total round trip distance is 12089.98 nm, then we let the containership sail at its maximum speed of 25.4 knots. So the total at sea time is $\frac{12089.98}{25.4*24} \approx 19.83$ days and the total port time is known as 12.71 days, so the total round trip time is 19.83+12.71= 32.54 days. As the time interval between the two ships is 7 days (standard weekly service) so $\frac{32.54}{7} \approx 4.65$ ships are needed to maintain this weekly service. The number of ships should be an integer so it is at least 5 ships are needed, therefore the starting ship number is 5.

Step 2 Calculate ship speed according to ship number. The logic between the number of ships and ship speed to maintain a standard weekly service can be illustrated below.

$$V = \frac{D}{N*7 - T_{port}} \div 24$$

V (knots) is the dependent variable means the average speed per ship in the round trip.

N (ship) is the independent variable means the number of ships needed to maintain a standard weekly service frequency in the roundtrip.

D (nautical mile) is a constant means the round trip distance, in this case it is

12089.98 nm.

T_{port} (day) is a constant means the accumulative total round trip port time in this line, in this case it is 12.71 days (305 hours).

As it has been calculated above, the starting number of ships is 5 ships. To realize slow steaming is by increasing the number of ships one by one until the minimum allowed speed, the theoretical minimum speed here is set to be 8.79 knots, the speed at 10 ships.

$$V = \frac{D}{N * 7 - T_{port}} \div 24$$

N(ship)	D(nm)	T_{port}(day)	V(knot)
5	12089.98	12.71	22.60
6	12089.98	12.71	17.20
7	12089.98	12.71	13.88
8	12089.98	12.71	11.64
9	12089.98	12.71	10.02
10	12089.98	12.71	8.79

Figure 6.2 Relationship between ship numbers and speed

Step 3 Calculate at sea fuel consumption in different ship speed. The single ship type fleet strategy (9469 TEU Mega-Post-Panamax containership) will be used in the following calculation, so the fuel consumption data and maximum speed data will be based on the 9469 TEU containership. This ship and its sister ships are owned by Castamare Shipping company, Greece and COSCO chartered them with a 12 years contract which will expire at December, 2017. (Costamare Shipping, 2014).

Main engine speed (rpm)	Actual speed (knot)	Actual distance (nm/day)	At sea fuel cons. (tonne/day)
92	25.40	609.10	257.70

Figure 6.3 Fuel consumption data of 9469TEU COSCO Guangzhou

Source: Ministry of Transport of the People's Republic of China (2014)

According to the formula of speed and fuel consumption below, the fuel consumption of 9469TEU COSCO Guangzhou in different speed can be obtained with deploying the Excel.

$$F_i = F_0 * \left(\frac{V_i}{V_0}\right)^3,$$

F_i (tonne/day) is fuel consumption per day at sea per ship at the speed of V_i (knot)

F_0 (tonne/day) is fuel consumption per day at sea per ship at the speed of V_0 (knot)

In this case of COSCO Guangzhou 9469 TEU containership, V_0 is 25.4 knots, F_0 is 257.7 tonnes per day at sea day at the speed of 25.4 knots.

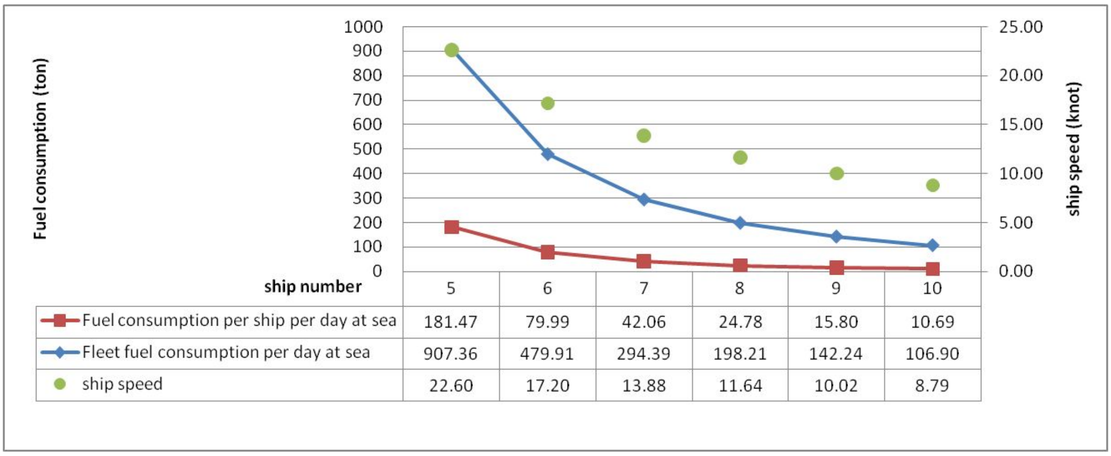
Then we calculate and obtain the results below.

$$F_i = F_0 * \left(\frac{V_i}{V_0}\right)^3 \qquad V_0=25.4 \quad F_0=257.7$$

N(ships)	D(nm)	T_{port}(days)	V_i(knots)	F_i(ton/day)	T_{sea}(days)	F_i*N(ton/day)
5	12089.98	12.71	22.60	181.47	22.29	907.36
6	12089.98	12.71	17.20	79.99	29.29	479.91
7	12089.98	12.71	13.88	42.06	36.29	294.39
8	12089.98	12.71	11.64	24.78	43.29	198.21
9	12089.98	12.71	10.02	15.80	50.29	142.23
10	12089.98	12.71	8.79	10.69	57.29	106.90

Figure 6.4 Ship number, speed and at sea fuel consumption

$F_i * N$ (tonne/day) means the fleet fuel consumption per day at sea. We calculate the fleet fuel consumption data per day at sea according to different speed which is caused by different ship numbers in the fleet.



ship number	5	6	7	8	9	10
Fuel consumption per ship per day at sea	181.47	79.99	42.06	24.78	15.80	10.69
Fleet fuel consumption per day at sea	907.36	479.91	294.39	198.21	142.24	106.90
ship speed	22.60	17.20	13.88	11.64	10.02	8.79

Figure 6.5 Ship number, speed and at sea fuel consumption

The figure above shows the trend that slow steaming does great impact on the fuel consumption per ship per day at sea. The red curve represents the fuel consumption per ship per day at sea, the blue curve represents the fleet fuel consumption per day ate sea. From 5 ships to 10 ships in the fleet, both of fuel consumption from per ship and whole fleet view keep decreasing. Drastic decrease of fleet fuel consumption happened from the ship number changes from 5 to 6 ships, after 6 ships the curve is much more gentle. The impact of cubic power of slower speed on fuel consumption is so significant that even when extra ships are added into the fleet, the fleet fuel consumption per day at sea still can be reduced.

Step 4 Calculate total fleet cost per roundtrip to find the optimal ship number and speed. Then a cost model can be constructed, the total fleet cost per roundtrip includes the fleet fuel cost at sea, fleet fuel cost in port and ship cost. The independent variable in the cost model is the number of ships in the whole fleet in a roundtrip. The logic is that the service frequency (standard weekly service) and roundtrip distance (12089.98nm) are fixed, so the ship number changing will cause the average ship speed changing (more ships less average speed), the average ship speed changing will influence the fuel consumption changing. Finally, fuel cost and ship cost changing will influence the total cost changing for the roundtrip. The construction of the cost model is partly inspired from Psaraftis (2011), Psaraftis (2009), Ronen (2011) and

Notteboom (2008) and it can be seen below.

$$
\begin{aligned}
TC_{fleet} &= \left(FC_{sea} + FC_{port} + C_s * T_{total}\right) * N \\
&= \left(P_{IFO380} * (T_{sea} * F_i) + P_{MDO} * (T_{port} * f_{port}) + C_s * T_{total}\right) * N \\
&= \left(P_{IFO380} * (T_{sea} * F_0 * (\frac{V_i}{V_0})^3) + P_{MDO} * (T_{port} * f_{port}) + C_s * T_{total}\right) * N
\end{aligned}
$$

TC_{fleet} (\$) means the total cost (the sum of total fuel cost and ship cost) of the whole fleet covering MEX, a 12089.98 nautical miles roundtrip form Shanghai to Dammam then back to Shanghai. Other costs like cargo handling cost will not be discussed here because it does not varies with ship speed.

FC_{sea} (\$) means the total fuel cost at sea per ship per roundtrip.

FC_{port} (\$) means the total fuel cost in port per ship per roundtrip.

C_s (\$/day) means the daily ship cost. It means the pre-negotiated cost or money charterer pays to the ship owner to use the containership per ship per day excluding fuel cost. Here we use the data of COSCO Guangzhou from Costamare Shipping (2014) of \$36400 per day per 9469TEU containership.

T_{total} (day) means the total roundtrip days per ship. $T_{total} = T_{total} + T_{port}$

P_{IFO380} (\$/tonne) means the price of bunker fuel IFO 380 per metric ton, we use \$620.50 per metric ton, the IFO380 price in port of Shanghai on April 2nd, 2014.

T_{sea} (day) means the total time at sea per ship per roundtrip.

F_i (tonne/day) means the daily fuel (IFO380) consumption per ship at sea. $F_i = F_0 * \left(\frac{V_i}{V_0}\right)^3$, MEX use the 9469 TEU mega-post-Panamax containership, maximum speed is 25.4 knots and the fuel consumption is 257.7 tonnes per day at sea at the speed of 25.4 knots, so $V_0 = 25.4$, $F_0 = 257.7$.

T_{port} (day) means the total time in port per ship per roundtrip. In the MEX, it is 12.708 days for 11 port calls per ship.

f_{port} (tonne/day) means the daily in port fuel (MDO) consumption per ship, we use 6 tonnes of MDO per day in port for a typical mega-post-Panamax containership.

P_{MDO} (\$/tonne) means the price of MDO per metric ton. We use \$1057.50 per metric ton, the MDO price in port of Shanghai on April 2th, 2014.

N (ships) is the independent variable means how many ships will be deployed in the fleet per roundtrip.

$$TC_{fleet} = \left(P_{IFO380} * (T_{sea} * F_i) + P_{MDO} * (T_{port} * f_{port}) + C_s * T_{total}\right) * N$$

$$F_i = F_0 * \left(\frac{V_i}{V_0}\right)^3 \quad V_0 = 25.4 \quad F_0 = 257.7$$

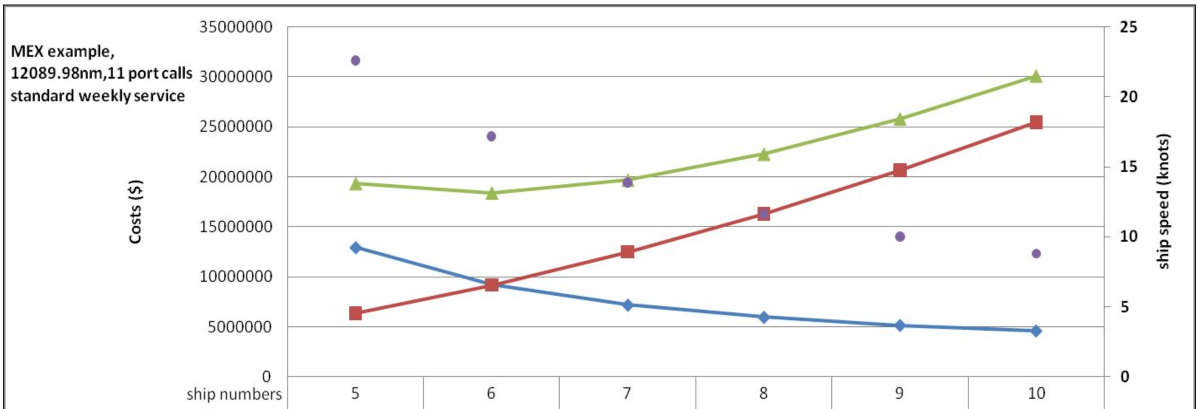
N	D	T_{port}	V_i	F_i	T_{sea}	T_{total}	f_{port}	P_{IFO380}*	P_{MDO}**	C_s	$(FC_{sea}+FC_{port})*N$	$C_s*T_{total}*N$	TC_{fleet}
5	12089.98	12.71	22.60	181.47	22.29	35.00	6.00	620.50	1057.50	36400	12953920.93	6370000.00	19323920.93
6	12089.98	12.71	17.20	79.99	29.29	42.00	6.00	620.50	1057.50	36400	9206500.39	9172800.00	18379300.39
7	12089.98	12.71	13.88	42.06	36.29	49.00	6.00	620.50	1057.50	36400	7193827.17	12485200.00	19679027.17
8	12089.98	12.71	11.64	24.78	43.29	56.00	6.00	620.50	1057.50	36400	5969483.70	16307200.00	22276683.70
9	12089.98	12.71	10.02	15.80	50.29	63.00	6.00	620.50	1057.50	36400	5164257.26	20638800.00	25803057.26
10	12089.98	12.71	8.79	10.69	57.29	70.00	6.00	620.50	1057.50	36400	4606554.60	25480000.00	30086554.60

* IFO 380 price was 02/April/2014 IFO 380 bunker price of Shanghai port from *shipandbunker.com*

** MDO price was 02/April/2014 MDO bunker price of Shanghai port from *shipandbunker.com*

Figure 6.6 Fleet total cost analysis

From the calculation above, the optimal fleet size for the MEX liner service is 6 containerships and it leads to the optimal speed of 17.20 knots, while the total fleet cost will be minimized at \$18,379,300.39.



ship numbers	5	6	7	8	9	10
Fleet fuel cost per roundtrip	12953920.93	9206500.39	7193827.17	5969483.7	5164257.26	4606554.6
Fleet ship cost per roundtrip	6370000.00	9172800.00	12485200.00	16307200.00	20638800.00	25480000.00
Fleet total cost per roundtrip	19323920.93	18379300.39	19679027.17	22276683.70	25803057.26	30086554.60
ship speed	22.60	17.20	13.88	11.64	10.02	8.79

Figure 6.7 Fleet fuel cost, ship cost and total cost

It can be seen from the chart above, from a whole fleet whole roundtrip view, with the number of ships in the fleet increases, the average ship speed keeps reducing. When the number of ships in the fleet increases from 5 ships to 10 ships, slow steaming is realized by the average ship speed reducing from 22.60 knots to 8.79 knots. The fleet fuel cost keeps decreasing from $12,953,920.93 to $4,606,554.6 while the fleet ship cost arises from $6,370,000 to $ 25,480,000 for hiring more ships. The fleet total cost reduces from 5 ships to 6 ships to achieve its optimal point of $18,379,300.39 at the fleet size of 6 with the speed of 17.20 knots. After 6 ships, the fleet total cost keeps ascending because the fuel cost saving from slow steaming can not compensate for the extra ship cost from hiring extra more ships. So slow steaming does not mean the slower the better if existing service frequency wants to be maintained, and there is an optimal point existing in every line, in this case it is 6 ships.

6.1.2 Market sustainability of slow steaming by calculating boundary point from ship cost view

In the cost model above, there are two assumptions, 1) the ship cost is fixed, 2) standard weekly service (one ship arrives per port per week). But in real containership freight market, the ship cost is fluctuating according to market situation. So, we assume the ship cost would be $5,000 per day of the Mega-Post- Panamax containership representing the containership freight market is in an extreme recession. $125,000 per day per ship representing market is in an extreme prosperity. Then we allow the service frequency can be larger than 1, it means at least or more than 1 ships will be arrived per week per port (The purpose to do so is to let the total fleet cost can be shown in full speed range, from maximum 25.4 knot to minimum speed). The bunker fuel price is fixed still using the IFO380 of $620.50/ton, MDO of $1057.50 which is the bunker price of Shanghai port on April 2nd, 2014. Then the fleet total cost per roundtrip according to the ship numbers and ship speed can be calculated below.

				C_s($/day) Ship cost for 9500TEU Mega-Post-Panamax containership													
N	V_i	T_{total}	Ser.Freq(ships/week*port)	5000	8000	15000	25000	35000	45000	55000	65000	75000	85000	95000	10500	115000	125000
4	32.942	28.00	1	22219339	22555339	23339339	24459339	25579339	26699339	27819339	28939339	30059339	31179339	32299339	33419339	34539339	35659339
5	25.400	32.54	1.08	17073159	17561269	18700191	20327224	21954256	23581288	25208320	26835352	28462385	30089417	31716449	33343481	34970514	36597546
5	24.130	33.58	1.04	15553248	16057015	17232471	18911695	20590918	22270141	23949365	25628588	27307812	28987035	30666258	32345482	34024705	35703928
5	22.920	34.69	1.01	14181586	14701885	15915915	17650244	19384574	21118903	22853232	24587561	26321891	28056220	29790549	31524878	33259208	34993537
5	22.598	35.00	1	13828921	14353921	15578921	17328921	19078921	20828921	22578921	24328921	26078921	27828921	29578921	31328921	33078921	34828921
6	17.197	42.00	1	10466500	11222500	12986500	15506500	18026500	20546500	23066500	25586500	28106500	30626500	33146500	35666500	38186500	40706500
7	13.880	49.00	1	8908827	9937827	12338827	15768827	19198827	22628827	26058827	29488827	32918827	36348827	39778827	43208827	46638827	50068827
8	11.636	56.00	1	8209484	9553484	12689484	17169484	21649484	26129484	30609484	35089484	39569484	44049484	48529484	53009484	57489484	61969484
9	10.016	63.00	1	7999257	9700257	13669257	19339257	25009257	30679257	36349257	42019257	47689257	53359257	59029257	64699257	70369257	76039257
10	8.793	70.00	1	8106555	10206555	15106555	22106555	29106555	36106555	43106555	50106555	57106555	64106555	71106555	78106555	85106555	92106555

Figure 6.8 Trend of different ship cost and ship number influence total fleet cost

It can be seen from the figure above that when ship cost is $5,000 per day, fleet total cost per roundtrip can be minimized at the optimal fleet size of 9 ships and the speed of 10.02 knots. With the ship cost ascending, the optimal fleet size decreasing, because the saving cost from consuming less fuel can not compensate or make up for hiring more ships at higher ship cost, so the incentive of slow steaming is weaker and incentive of increasing ship speed to hire less ship is stronger.

In market recession time, the container freight demand reduce, so it will cause large numbers of idle containerships, then large numbers of idle ships will lead to the ship hiring cost reduce (e.g $5,000 per day per ship), which encourages slow steaming. Because the fuel cost saving from slower speed can make up for hiring extra ships.

In market prosperity time, the container freight demand increase, idle containerships become less, or even containerships will be in a shortage, this kind of shortage will directly result in the ship hiring cost increase (e.g.$ 125,000 per day per ship), which suppress slow steaming and encourage the ship to increase the speed to hiring less ships.

Calculate boundary point from ship cost view

As can be seen from the figure above that whether slow steaming is market sustainable or not, ship cost is an important factor, lower ship cost provides more possibility of slow steaming and higher ships cost suppresses slow steaming. Therefore a "market sustainability boundary point"(boundary point) concept can be raised here to show whether slow steaming is market sustainable in a certain fleet size with a certain ship cost. The market boundary point is maximum allowed ship cost in the current fleet size, if the real ship cost per ship is lower than the market boundary point, then slow steaming is market sustainable in current fleet size, if the real ship cost is higher than the market boundary point then slow steaming is not market sustainable.

This boundary point can be calculated below.

$$\left|FC^{N+1}{}_{fleet} - FC^{N}{}_{fleet}\right| \geq C_s * T^{N+1}{}_{total} * (N+1) - C_s * T^{N}{}_{total} * N,$$

$FC^{N}{}_{fleet}$ ($) means fleet total fuel consumption cost per roundtrip at the fleet size of N ships

$\left|FC^{N+1}{}_{fleet} - FC^{N}{}_{fleet}\right|$ ($) means the fleet total fuel consumption cost saving per roundtrip from fleet size N to N+1(N$\geq$5).

C_s (ton) means the ship cost per day per ship.

$T^{N}{}_{total}$ (day) means the total roundtrip time per ship at the fleet size of N.

N (ship) is the independent variable means the number of ships in the fleet.

$C_s * T^{N+1}{}_{total} * (N+1) - C_s * T^{N}{}_{total} * N$ means the fleet total ship cost increasing per roundtrip from fleet size N reduce to N+1 (N≥5).

The formula can be simply illustrated as "Fleet fuel consumption cost saving after adding one more ship"≥ "Fleet ship cost increasing after adding one more ship".

Then we calculate with Excel.

N	FC_{fleet}	$\lvert FC^{N}{}_{fleet} - FC^{N-1}{}_{fleet} \rvert$	T_{total}	$T^{N}{}_{total} * N$	$T_{total}{}^{N} * N - T^{N-1}{}_{total} * (N-1)$	Boundary point (Maximum C_s)
4	21659339.01	-	28.00	112.00	-	
5	12953920.93	8705418.08	35.00	175.00	63.00	138181.24
6	9206500.39	3747420.54	42.00	252.00	77.00	48667.80
7	7193827.17	2012673.22	49.00	343.00	91.00	22117.29
8	5969483.70	1224343.47	56.00	448.00	105.00	11660.41
9	5164257.26	805226.43	63.00	567.00	119.00	6766.61
10	4606554.60	557702.67	70.00	700.00	133.00	4193.25

Figure 6.9 Boundary point of market sustainability from ship cost view

				C_s($/day) Diffirent Ship cost per day per ship for 9469TEU Mega-Post-Panamax containership					
N	V_i	T_{total}	Ser.Freq(ships/week*po	5000	8000	15000	25000	35000	45000
4	32.942	28.00	1	22219339	22555339	23339339	24459339	25579339	26699339
5	25.400	32.54	1.08	17073159	17561269	18700191	20327224	21954256	23581288
5	24.130	33.58	1.04	15553248	16057015	17232471	18911695	20590918	22270141
5	22.920	34.69	1.01	14181586	14701885	15915915	17650244	19384574	21118903
5	22.598	35.00	1	13828921	14353921	15578921	17328921	19078921	20828921
6	17.197	42.00	1	10466500	11222500	12986500	15506500	18026500	20546500
7	13.880	49.00	1	8908827	9937827	12338827	15768827	19198827	22628827
8	11.636	56.00	1	8209484	9553484	12689484	17169484	21649484	26129484
9	10.016	63.00	1	7999257	9700257	13669257	19339257	25009257	30679257
10	8.793	70.00	1	8106555	10206555	15106555	22106555	29106555	36106555

N	55000	65000	75000	85000	95000	10500	115000	125000
4	27819339	28939339	30059339	31179339	32299339	33419339	34539339	35659339
5	25208320	26835352	28462385	30089417	31716449	33343481	34970514	36597546
5	23949365	25628588	27307812	28987035	30666258	32345482	34024705	35703928
5	22853232	24587561	26321891	28056220	29790549	31524878	33259208	34993537
5	22578921	24328921	26078921	27828921	29578921	31328921	33078921	34828921
6	23066500	25586500	28106500	30626500	33146500	35666500	38186500	40706500
7	26058827	29488827	32918827	36348827	39778827	43208827	46638827	50068827
8	30609484	35089484	39569484	44049484	48529484	53009484	57489484	61969484
9	36349257	42019257	47689257	53359257	59029257	64699257	70369257	76039257
10	43106555	50106555	57106555	64106555	71106555	78106555	85106555	92106555

Ship cost boundary point 4193.25($/day) betw.10 & 9 ships

Ship cost boundary point 6766.61($/day) betw.9 & 8 ships

Ship cost boundary point 11660.41($/day) betw.8 & 7 ships

Ship cost boundary point 22117.29($/day) betw.7 & 6 ships

Ship cost boundary point 48667.80($/day) betw.6 & 5 ships

Ship cost boundary point 138181.24($/day) betw.5 & (4) ships

Figure 6.10 Market sustainability boundary point in different ship numbers

The figure above shows why slow steaming is popular and common in market recession time clearly, the ship cost per day per ship is cheap in market recession time, therefore hiring more ships for slow steaming can reduce the fleet total cost dramatically, while in booming market, any one more ship only increases the total cost drastically. For example, if the fleet size is 6 and the ship cost per ship per day is \$80,000, then it is not market sustainable, for \$80,000> \$48,667.80. If the ship cost per ship per day is \$37,000, then fleet size of 6 is market sustainable, for \$37,000<\$48,667.80.

The market sustainability can be concluded whether saving cost of fuel consumption reduction from slow steaming can compensate for the extra ship cost from slow steaming, and boundary point can explain when it is sustainable.

In this MEX case, slow steaming is market sustainable at the optimal point of 6 ships at the speed of 17.20 knots, because the market sustainability boundary point is \$48,667.80 (under current fuel price) per day per ship of 6 ship fleet size while the real ship cost is \$36,400 per ship per day (Costamare Shipping, 2014) for 9469TEU Mega-Post-Panamax COSCO Guangzhou and its same class ships.

6.2 Emission analysis of slow steaming on MEX liner service of COSCO

6.2.1 CO_2e emission analysis on the MEX.

As described in 5.1.3, two methods are used to measure emission from shipping activities, they are “Top down” and “Bottom up” (Psaraftis and Kontovas, 2009). “Top down” method is fuel consumed based measurement, that is evaluating the emission amount by calculating the fuel volume consumed, also can be seen as “per tonne bunker fuel based”. And “Bottom up” method is distance or activities based measurement that is the emission per tonne-kilometer of a ship is a constant, then measure the emission amount by multiplying the activities distances and payload, also can be seen as “per tonne-km based” (Psaraftis and Kontovas, 2009). Since the impact of slow steaming to emission is realized by different ship speed and different fleet size, the distance in the case is fixed as actual distance of 12089.98nm, so “Top down” method is more suitable in this case to use in measuring the emission amount rather than the “Bottom up” method.

$$TE_{fleet} = c_{sea} * (F_i * T_{sea} * N) + c_{port} * (f_{port} * T_{port} * N)$$

TE_{fleet} (tonne) means the fleet total CO_2e emission per roundtrip

c_{sea} means the CO_2e emission factor(also can be call as emission profile) for the fuel used at sea, the data is set to be 3.33 (tonne CO_2e/ tonne of fuel) calculated from NTM (2008).

F_i (tonne/day) means fuel consumption per ship per day at sea.

T_{sea} (day) means the sea time per round trip

c_{port} means the CO_2e emission factor (emission profile) for the fuel used in port, data is to be 3.25 (tonne CO_2e/ tonnes of MDO) calculated from NTM (2008).

f_{port} (tonne/day) means fuel consumption per ship per day in port

T_{port} (day) means in port time per round trip

N (ship) means the number of ships in the fleet per roundtrip

N	D	T_{port}	V_i	F_i	T_{sea}	T_{total}	f_{port}	F_i*N*T_{sea}	$f_{port}*N*T_{port}$	c_{sea}	c_{port}	TE_{fleet}	E_{ship}
5	12089.98	12.71	22.60	181.47	22.29	35.00	6.00	20226.85	381.24	3.33	3.25	68574.59	13714.92
6	12089.98	12.71	17.20	79.99	29.29	42.00	6.00	14057.55	457.49	3.33	3.25	48284.86	8047.48
7	12089.98	12.71	13.88	42.06	36.29	49.00	6.00	10683.97	533.74	3.33	3.25	37302.10	5328.87
8	12089.98	12.71	11.64	24.78	43.29	56.00	6.00	8580.86	609.98	3.33	3.25	30548.75	3818.59
9	12089.98	12.71	10.02	15.80	50.29	63.00	6.00	7153.21	686.23	3.33	3.25	26043.98	2893.78
10	12089.98	12.71	8.79	10.69	57.29	70.00	6.00	6124.47	762.48	3.33	3.25	22867.17	2286.72

Figure 6.11 Emission in different ship numbers

From the view of not considering the CO_2e from shipbuilding section, the calculation result shows that the slower the ship is, the less CO_2e is generated even extra more ships are adopted. And the single ship CO_2e emission per roundtrip is also continuously decreasing.

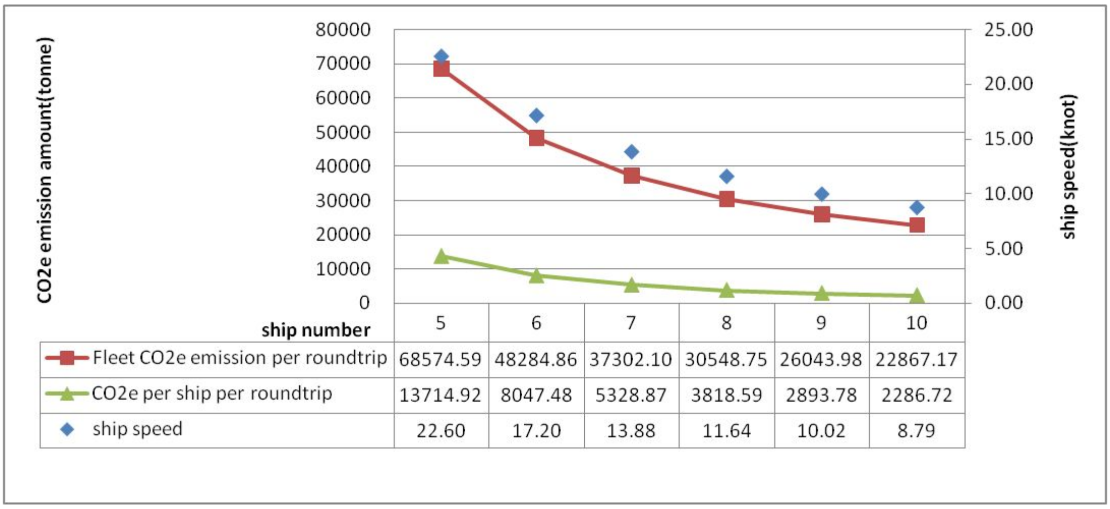


Figure 6.12 Fleet emission analysis

6.2.2 Environment sustainability of slow steaming from calculating boundary point from shipbuilding emission view

The CO_2e emission from shipbuilding per ship whole life is set to be E_{sb} tonne, so the CO_2e emission from shipbuilding per ship per day is $\frac{E_{sb}}{25*365}$ tonnes (of 25 years ship life).

Then we begin to calculate the emission boundary point.

$$\left|TE^{N+1}{}_{fleet} - TE^{N}{}_{fleet}\right| \geq \frac{E_{sb}}{25*365} * T^{N+1}{}_{total} * (N+1) - \frac{E_{sb}}{25*365} * T^{N}{}_{total} * N,$$

$TE^{N}{}_{fleet}$ (tonne) means fleet total fuel emission per roundtrip at the fleet size of N ships

$TE^{N+1}{}_{fleet} - TE^{N}{}_{fleet}$ (tonne) means the fleet total fuel emission saving per roundtrip from fleet size N to N+1(N$\geq$5)

E_{sb} (tonne) means the CO_2e emission from the shipbuilding section. $\frac{E_{sb}}{25*365}$ means the CO_2e emission from the shipbuilding per day with 25 years (Stopford, 2009) of operating lifetime.

$T^{N}{}_{total}$ (day) means the total roundtrip time per ship at the fleet size of N.

N (ship) is the independent variable means the number of ships in the fleet.

$\frac{E_{sb}}{25*365} * T^{N+1}{}_{total} * (N+1) - \frac{E_{sb}}{25*365} * T^{N}{}_{total} * N$ means the fleet total ship building emission consumption per roundtrip from fleet size N to N+1 (N≥5).

The model can be simply illustrated as "Fleet fuel emission saving amount after adding one more ship"≥ "Fleet shipbuilding emission increasing mount after adding one more ship". Then we calculate with Excel.

N	D	T_{port}	V_i	F_i	T_{sea}	T_{total}	f_{port}	F_i*N*T_{sea}	f_{port}*N*T_{port}	C_{sea}	C_{port}	TE_{fleet}	E_{ship}
5	12089.98	12.71	22.60	181.47	22.29	35.00	6.00	20226.85	381.24	3.33	3.25	68574.59	13714.92
6	12089.98	12.71	17.20	79.99	29.29	42.00	6.00	14057.55	457.49	3.33	3.25	48284.86	8047.48
7	12089.98	12.71	13.88	42.06	36.29	49.00	6.00	10683.97	533.74	3.33	3.25	37302.10	5328.87
8	12089.98	12.71	11.64	24.78	43.29	56.00	6.00	8580.86	609.98	3.33	3.25	30548.75	3818.59
9	12089.98	12.71	10.02	15.80	50.29	63.00	6.00	7153.21	686.23	3.33	3.25	26043.98	2893.78
10	12089.98	12.71	8.79	10.69	57.29	70.00	6.00	6124.47	762.48	3.33	3.25	22867.17	2286.72

Figure 6.13 Emission in different ship numbers

N	TE_{fleet}	$\lvert TE^{N}{}_{fleet} - TE^{N-1}{}_{fleet} \rvert$	T_{total}	$T^{N}{}_{total} * N$	$T_{total}{}^{N} * N - T^{N-1}{}_{total} * (N-1)$	Maximum E_{sb}
5	68574.59	-	35.00	175.00	-	>2404464.64
6	48284.86	20289.73	42.00	252.00	77.00	2404464.64
7	37302.10	10982.76	49.00	343.00	91.00	1101293.31
8	30548.75	6753.35	56.00	448.00	105.00	586898.22
9	26043.98	4504.77	63.00	567.00	119.00	345429.15
10	22867.17	3176.80	70.00	700.00	133.00	217957.32

Figure 6.14 Environment sustainability boundary point form shipbuilding view

N (ship)	Boundary point E_{sb} (Maximum allowed) per ship (tonnes of CO_2e)
5	>2,404,464. 64
6	2,404,464. 64
7	1,101,293.31
8	586,898.22
9	345,429.15
10	217,957.15

Figure 6.15 Environment sustainability boundary point from shipbuilding view

Fleet size is the independent variable, so the number of ships is set first then use the maximum allowed E_{sb} to test the actual shipbuilding emission data.

It means if 5 fleet size needs to be used, the maximum emission from shipbuilding section could be allowed larger than 2,404,464.64 tonnes of CO_2e, if the fleet size of 6 wants to be adopted, the maximum emission from shipbuilding section could be allow at 2,404,464.64 tonnes of CO_2e. Same to the rest parts. The more ships deployed, the stricter maximum allowed emission from shipbuilding section will be.

Therefore, this “environment sustainability boundary point” can be understood in a way which is similar to the market sustainability boundary point. This environment sustainability boundary point means the maximum allowed emission amount per ship from shipbuilding section at a certain fleet size. If the actual shipbuilding emission per ship in the fleet exceeds the boundary point, it means slow steaming is not environment sustainable at current fleet size. If the actual shipbuilding emission per ship in the fleet is below the boundary point, then it means slow steaming is environment sustainable at this fleet size. For example, if the fleet size is 6 and the actual shipbuilding emission data is 1,400,000 tonnes of CO_2e per ship, then fleet size of 6 is feasible and environment sustainable, (1,400,000<2,404,464.64). If the fleet size is 6 and the actual shipbuilding emission data is 7,500,000 tonnes of CO_2e per ship, then it is not environment sustainable and needs to cut and minus one ship in the fleet (7,500,000>2,404,464.64), because the emission reduction from slow steaming can not compensate for the shipbuilding emission for using one extra ship, therefore it is not environment sustainable at the fleet size of 6 when the shipbuilding emission is 7,500,000 tonnes of CO_2e per ship.

7. Conclusion

From the Pareto analysis in section3 it can be concluded that the world’s merchant fleet total transportation work is centralized on a few large-scale ship type fleet, for top 19.55% ship numbers occupies 78.44% transportation work. And the Post-Panamax >4400, from a total view, occupies the biggest proportion of both fuel consumption and emission amount according to the Pareto analysis result.

Then the two research questions can be answered based on the analysis of Section 6. The first question can be answered that in the MEX liner service analysis, from minimizing fleet total cost view, the optimal point is 6 ships with average speed of 17.20 knots. Under the condition of standard weekly service frequency and current IFO380 and MDO price.

The second question can be answered that the market sustainability boundary point of 6 ships is $48,667.80 per ship per day while the real ship cost is $36,400 per ship per day. So the 6 ship fleet size strategy will be continuously market sustainable with real ship cost below the boundary point. Other fleet size market boundary points also can be seen in figure in Section 6.1.2. The environment sustainability boundary point from shipbuilding section of 6 ships is 2,404,464.64 tonnes of CO_2e, and the 6 ships strategy will be continuously environment sustainable with the real shipbuilding emission below the boundary point.

Generally, it can be concluded that, slow steaming is a highly cost motivated behaviour, therefore the implementation of slow steaming of how many ships will be deployed in a fleet and which speed strategy will be adopted is according to how to get the optimal fleet total cost per roundtrip. Meanwhile the optimal point and market sustainability is different form route to route, however there is one point can be assured that there must be an optimal point and market sustainability boundary point in each route and it is able to be calculated respectively.

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Appendix

Appendix 1 Merchant fleet transportation work Pareto analysis

Rank	Ship type	Detail ship type ('000 dwt)	Ship number	% of total ship numbers	% of cumulative ship numbers	Transportation work (tonne*km)	Cumulative transp. work	% of Cumulative transp.work
1	Crude Oil	VLCC/ULCC >200'	516	1.41%	1.41%	23879106183	23879106183	14.27%
2	Dry Bulk	Capesize >120'	722	1.98%	3.39%	16464276593	40343382776	24.11%
3	Container	Post Panamax >4400TEU	712	1.95%	5.34%	14404444807	54747827583	32.72%
4	Crude Oil	Suezmax 120-200'	332	0.91%	6.25%	12495006794	67242834377	40.19%
5	Dry Bulk	Post-Panamax 85'-120'	98	0.27%	6.51%	8345885855	75588720232	45.18%
6	Chemical	Chemical >60'	238	0.65%	7.17%	8291118437	83879838669	50.14%
7	Crude Oil	Aframax 80-120'	648	1.77%	8.94%	8207170707	92087009376	55.04%
8	Container	Panamax 3000-4400	568	1.55%	10.49%	8030486625	100117496001	59.84%
9	LNG	LNG >50'	221	0.60%	11.10%	6408488501	106525984502	63.67%
10	Dry Bulk	Panamax 60-85'	1383	3.79%	14.88%	5738689444	112264673946	67.10%

11	Crude Oil	Panamax 60-80'	177	0.48%	15.37%	5545193472	117809867418	70.42%
12	Container	Sub-Panamax 2000-3000	689	1.89%	17.25%	4761738206	122571605624	73.27%
13	Chemical	Chemical 40-60'	705	1.93%	19.18%	4513046136	127084651760	75.96%
14	LPG	LPG >40'	135	0.37%	19.55%	4147643575	131232295335	78.44%
15	Dry Bulk	Handymax 35-60'	1732	4.74%	24.29%	3647781825	134880077160	80.62%
16	RO-RO	RO-RO(excl.Pax) 25-40'	51	0.14%	24.43%	3246941650	138127018810	82.56%
17	Crude Oil	Handysize 10-60'	240	0.66%	25.09%	3128483055	141255501865	84.43%
18	Chemical	Chemical 25-40'	643	1.76%	26.85%	3004401819	144259903684	86.23%
19	Container	Handysize 1000-2000	1143	3.13%	29.98%	2726036069	146985939753	87.86%
20	Dry Bulk	Handysize 15-35'	1774	4.86%	34.83%	2084935872	149070875625	89.10%
21	LPG	LPG 20-40'	68	0.19%	35.02%	2056555856	151127431481	90.33%
22	RO-RO	RO-RO(excl.Pax) 10-25'	342	0.94%	35.95%	1956459426	153083890907	91.50%
23	LNG	LNG 0-50'	29	0.08%	36.03%	1902263069	154986153976	92.64%
24	Reefer	Reefer >10'	225	0.62%	36.65%	1747605300	156733759276	93.69%
25	General Cargo	General Cargo 15-35'	816	2.23%	38.88%	1691497286	158425256562	94.70%
26	Chemical	Chemical 15-25'	430	1.18%	40.06%	1607649695	160032906257	95.66%

27	Container	Feedermax 500-1000	757	2.07%	42.13%	1137846685	161170752942	96.34%
28	RO-RO	RO-RO(excl.Pax) 5-10'	674	1.84%	43.98%	979619744	162150372686	96.92%
29	Reefer	Reefer 5-10'	358	0.98%	44.96%	906791981	163057164667	97.47%
30	Dry Bulk	Coastal 5-15'	236	0.65%	45.60%	710876741	163768041408	97.89%
31	LPG	LPG 5-20'	235	0.64%	46.25%	678646370	164446687778	98.30%
32	Chemical	Chemical 5-15'	1407	3.85%	50.10%	660522652	165107210430	98.69%
33	General Cargo	General Cargo 5-15'	3014	8.25%	58.34%	605853976	165713064406	99.05%
34	Container	Feeder 0-500	363	0.99%	59.34%	469332852	166182397258	99.33%
35	Crude Oil	Small tanker 0-10'	115	0.31%	59.65%	216120361	166398517619	99.46%
36	Reefer	Reefer 0-5'	508	1.39%	61.04%	203228700	166601746319	99.58%
37	General Cargo	General Cargo 0-5'	9009	24.66%	85.70%	145225951	166746972270	99.67%
38	Chemical	Chemical 0-5'	3125	8.55%	94.25%	142654101	166889626371	99.76%
39	Dry Bulk	Small drybulk vessel 0-5'	517	1.41%	95.67%	139158763	167028785134	99.84%
40	RO-RO	RO-RO(excl.Pax) 0-5'	932	2.55%	98.22%	138768467	167167553601	99.92%
41	LPG	LPG 0-5'	651	1.78%	100.00%	130496886	167298050487	100.00%

Appendix 2 Merchant fleet fuel consumption Pareto analysis

Rank	Ship type	Detail Ship type ('000 dwt)	Ship number	% of total ship numbers	% of cumulative ship numbers	Total fuel consp.per year(tonne)	Cumulative fuel consp.	% of Cumulative fuel consp.
1	Container	Post Panamax >4400TEU	712	1.95%	1.95%	34813952.00	34813952.00	13.15%
2	Container	Panamax 3000-4400	568	1.55%	3.50%	16932761.60	51746713.60	19.55%
3	Crude Oil	VLCC/ULCC >200'	516	1.41%	4.92%	13936128.00	65682841.60	24.81%
4	Container	Handysize 1000-2000	1143	3.13%	8.04%	13441680.00	79124521.60	29.89%
5	Container	Sub-Panamax 2000-3000	689	1.89%	9.93%	12677600.00	91802121.60	34.68%
6	Dry Bulk	Handymax 35-60'	1732	4.74%	14.67%	12459315.20	104261436.80	39.38%
7	Dry Bulk	Panamax 60-85'	1383	3.79%	18.45%	11820777.60	116082214.40	43.85%
8	General Cargo	General Cargo 0-5'	9009	24.66%	43.11%	11207196.00	127289410.40	48.08%
9	Dry Bulk	Handysize 15-35'	1774	4.86%	47.97%	10360160.00	137649570.40	51.99%
10	General Cargo	General Cargo 5-15'	3014	8.25%	56.22%	10337417.20	147986987.60	55.90%

11	Dry Bulk	Capesize >120’	722	1.98%	58.19%	10295142.40	158282130.00	59.79%
12	Crude Oil	Aframax 80-120’	648	1.77%	59.96%	9497088.00	167779218.00	63.37%
13	Chemical	Chemical 40-60’	705	1.93%	61.89%	9352530.00	177131748.00	66.91%
14	Chemical	Chemical 25-40’	643	1.76%	63.65%	9060513.00	186192261.00	70.33%
15	Chemical	Chemical 0-5’	3125	8.55%	72.21%	8528437.50	194720698.50	73.55%
16	Chemical	Chemical 5-15’	1407	3.85%	76.06%	7080727.50	201801426.00	76.23%
17	RO-RO	RO-RO(excl.Pax) 5-10’	674	1.84%	77.90%	6066337.00	207867763.00	78.52%
18	LNG	LNG >50’	221	0.60%	78.51%	5814289.00	213682052.00	80.71%
19	Container	Feedermax 500-1000	757	2.07%	80.58%	5438288.00	219120340.00	82.77%
20	Crude Oil	Suezmax 120-200’	332	0.91%	81.49%	5375744.00	224496084.00	84.80%
21	General Cargo	General Cargo 15-35’	816	2.23%	83.72%	4756300.80	229252384.80	86.59%
22	RO-RO	RO-RO(excl.Pax) 10-25’	342	0.94%	84.66%	4205505.60	233457890.40	88.18%
23	Chemical	Chemical 15-25’	430	1.18%	85.83%	3604260.00	237062150.40	89.54%
24	Chemical	Chemical >60’	238	0.65%	86.49%	3408636.00	240470786.40	90.83%
25	Reefer	Reefer 5-10’	358	0.98%	87.47%	2917986.40	243388772.80	91.93%
26	Crude Oil	Handysize 10-60’	240	0.66%	88.12%	2472960.00	245861732.80	92.87%

27	RO-RO	RO-RO(excl.Pax) 0-5’	932	2.55%	90.67%	2467749.60	248329482.40	93.80%
28	Reefer	Reefer >10’	225	0.62%	91.29%	2300400.00	250629882.40	94.67%
29	Crude Oil	Panamax 60-80’	177	0.48%	91.77%	2016384.00	252646266.40	95.43%
30	Container	Feeder 0-500	363	0.99%	92.77%	1695936.00	254342202.40	96.07%
31	LPG	LPG >40’	135	0.37%	93.14%	1548288.00	255890490.40	96.66%
32	Reefer	Reefer 0-5’	508	1.39%	94.53%	1500428.80	257390919.20	97.22%
33	LPG	LPG 5-20’	235	0.64%	95.17%	1267120.00	258658039.20	97.70%
34	LPG	LPG 0-5’	651	1.78%	96.95%	1260336.00	259918375.20	98.18%
35	Dry Bulk	Post-Panamax 85’-120’	98	0.27%	97.22%	1145894.40	261064269.60	98.61%
36	Dry Bulk	Coastal 5-15’	236	0.65%	97.87%	792204.80	261856474.40	98.91%
37	RO-RO	RO-RO(excl.Pax) 25-40’	51	0.14%	98.00%	783921.00	262640395.40	99.21%
38	Dry Bulk	Small drybulk vessel 0-5’	517	1.41%	99.42%	769296.00	263409691.40	99.50%
39	LPG	LPG 20-40’	68	0.19%	99.61%	626252.80	264035944.20	99.73%
40	LNG	LNG 0-50’	29	0.08%	99.69%	477238.50	264513182.70	99.91%
41	Crude Oil	Small tanker 0-10’	115	0.31%	100.00%	228160.00	264741342.70	100.00%

Appendix 3 Merchant fleet emission Pareto analysis

Rank	ship type	Detail ship type ('000 dwt)	ship number	% of total ship numbers	% of cumulative ship numbers	Total CO2 emission(tonne)	Cumulative fuel consp.	% of Cumulative CO2 emission
1	Container	Post Panamax >4400TEU	712	1.95%	1.95%	110764418.79	110764418.79	13.19%
2	Container	Panamax 3000-4400	568	1.55%	3.50%	53823533.56	164587952.34	19.60%
3	Crude Oil	VLCC/ULCC >200'	516	1.41%	4.92%	44357827.65	208945779.99	24.89%
4	Container	Handysize 1000-2000	1143	3.13%	8.04%	42687271.41	251633051.40	29.97%
5	Container	Sub-Panamax 2000-3000	689	1.89%	9.93%	40026219.01	291659270.41	34.74%
6	Dry Bulk	Handymax 35-60'	1732	4.74%	14.67%	39803136.16	331462406.57	39.48%
7	Dry Bulk	Panamax 60-85'	1383	3.79%	18.45%	37302055.25	368764461.83	43.92%
8	General Cargo	General Cargo 0-5'	9009	24.66%	43.11%	35586864.12	404351325.94	48.16%
9	Dry Bulk	Handysize 15-35'	1774	4.86%	47.97%	32918218.51	437269544.45	52.08%
10	General Cargo	General Cargo 5-15'	3014	8.25%	56.22%	32686185.52	469955729.97	55.97%

11	Dry Bulk	Capesize >120’	722	1.98%	58.19%	32095460.79	502051190.76	59.80%
12	Crude Oil	Aframax 80-120’	648	1.77%	59.96%	30314005.72	532365196.48	63.41%
13	Chemical	Chemical 40-60’	705	1.93%	61.89%	29589786.99	561954983.47	66.93%
14	Chemical	Chemical 25-40’	643	1.76%	63.65%	28784272.51	590739255.98	70.36%
15	Chemical	Chemical 0-5’	3125	8.55%	72.21%	27015120.38	617754376.36	73.58%
16	Chemical	Chemical 5-15’	1407	3.85%	76.06%	22490399.99	640244776.35	76.26%
17	RO-RO	RO-RO(excl.Pax) 5-10’	674	1.84%	77.90%	19213673.89	659458450.23	78.54%
18	LNG	LNG >50’	221	0.60%	78.51%	18411587.46	677870037.70	80.74%
19	Container	Feedermax 500-1000	757	2.07%	80.58%	17226998.81	695097036.51	82.79%
20	Crude Oil	Suezmax 120-200’	332	0.91%	81.49%	17008203.25	712105239.75	84.81%
21	General Cargo	General Cargo 15-35’	816	2.23%	83.72%	15044853.46	727150093.21	86.61%
22	RO-RO	RO-RO(excl.Pax) 10-25’	342	0.94%	84.66%	13315271.56	740465364.78	88.19%
23	Chemical	Chemical 15-25’	430	1.18%	85.83%	11406274.59	751871639.36	89.55%
24	Chemical	Chemical >60’	238	0.65%	86.49%	10853074.03	762724713.40	90.84%
25	Reefer	Reefer 5-10’	358	0.98%	87.47%	9251998.58	771976711.98	91.95%
26	RO-RO	RO-RO(excl.Pax) 0-5’	932	2.55%	90.02%	7824598.78	779801310.76	92.88%

27	Crude Oil	Handysize 10-60’	240	0.66%	90.67%	7808693.71	787610004.46	93.81%
28	Reefer	Reefer >10’	225	0.62%	91.29%	7274407.06	794884411.53	94.67%
29	Crude Oil	Panamax 60-80’	177	0.48%	91.77%	6379745.09	801264156.61	95.43%
30	Container	Feeder 0-500	363	0.99%	92.77%	5383623.28	806647779.89	96.07%
31	LPG	LPG >40’	135	0.37%	93.14%	4927400.57	811575180.46	96.66%
32	Reefer	Reefer 0-5’	508	1.39%	94.53%	4759372.28	816334552.74	97.23%
33	LPG	LPG 5-20’	235	0.64%	95.17%	4018943.80	820353496.54	97.71%
34	LPG	LPG 0-5’	651	1.78%	96.95%	3992813.22	824346309.76	98.18%
35	Dry Bulk	Post-Panamax 85’-120’	98	0.27%	97.22%	3598745.98	827945055.74	98.61%
36	Dry Bulk	Coastal 5-15’	236	0.65%	97.87%	2516503.66	830461559.41	98.91%
37	RO-RO	RO-RO(excl.Pax) 25-40’	51	0.14%	98.00%	2483910.36	832945469.77	99.21%
38	Dry Bulk	Small drybulk vessel 0-5’	517	1.41%	99.42%	2438938.23	835384408.00	99.50%
39	LPG	LPG 20-40’	68	0.19%	99.61%	1985810.33	837370218.33	99.73%
40	LNG	LNG 0-50’	29	0.08%	99.69%	1511538.23	838881756.57	99.91%
41	Crude Oil	Small tanker 0-10’	115	0.31%	100.00%	723246.79	839605003.36	100.00%

Appendix 4 Merchant fleet Pareto analysis raw data

		Average Ship										per size bracket		
Typical Vessel types and sizes per vessel segment	Number of vessels in size group	Payload	Speed	Sea days %	Port days %	cargo capacity utilization at sea	Total CO_2, yr (tonnes)	**Total bunkers, YR**	Total tonne-kms, yr	gr CO_2 PER TONNE-KM		total CO_2 per size bracket (million)	% of total	Total billion MT-km per size bracket
Small Vessels 0-5'	517	1,937	12	70	30	60%	4,717	1,488.00	139,158,763	33.9		2.44	1.60	72
Coastal 5-15'	236	9,895	12	70	30	60%	10,641	3,356.80	710,876,741	15.0		2.51	1.70	168
Handysize 15'-35'	1774	24,876	14	70	30	60%	18,513	5,840.00	2,084,935,872	8.9		32.84	21.70	3,699
Handymax 35'-60'	1732	43,522	14	70	30	60%	22,804	7,193.60	3,647,781,825	6.3		39.50	26.20	6,318
Panamax 60'-85'	1383	68,469	14	70	30	60%	27,095	8,547.20	5,738,689,444	4.7		37.47	24.80	7,937
Post-Panamax 85'-120'	98	87,129	14	80	20	60%	37,066	11,692.80	8,345,885,855	4.4		3.63	2.40	818
Capesize >120'	722	160,425	15	80	20	60%	45,202	14,259.20	16,464,276,593	2.7		32.64	21.60	11,887
Total Dry Bulk	**6462**						166,037		37,131,605,092	4.5		151.03		30,898
Feeder (0-500)	363	5,169	13	70	30	70%	14,810	4,672.00	469,332,853	31.6		5.38	2.00	170
Feedermax (500-1000)	757	9,873	16.5	70	30	70%	22,773	7,184.00	1,137,846,685	20.0		17.24	6.40	861
Handysize (1000-2000)	1,143	19,515	20	70	30	70%	37,279	11,760.00	2,726,036,069	13.7		42.61	15.80	3,116
Sub-Panamax (2000-3000)	689	34,088	20	70	30	70%	58,328	18,400.00	4,761,738,206	12.2		40.19	14.90	3,281
Panamax (3000-4400)	568	47,907	21	70	30	70%	94,502	29,811.20	8,030,486,625	11.8		53.68	19.90	4,561
Post Panamax(>4400 TEU)	712	75,190	24	70	30	70%	155,000	48,896.00	14,404,444,807	10.8		110.36	41.00	10,256
Total Container	**4,232**						382,693		31,529,885,245	12.1		269.45		22,246
Small tanker (0-10)	115	3,159	12	80	20	50%	6,289	1,984.00	216,120,361	29.1		0.72	0.70	25
Handysize (10-60)	240	37,841	14.5	80	20	50%	32,664	10,304.00	3,128,483,055	10.4		7.84	7.40	751
Panamax (60-80)	177	64,838	15	80	20	50%	36,113	11,392.00	5,545,193,472	6.5		6.39	6.00	981
Aframax (80-120)	648	97,921	14.7	80	20	50%	46,460	14,656.00	8,207,170,707	5.7		30.11	28.30	5,318
Suezmax (120-200)	332	146,099	15	80	20	50%	51,329	16,192.00	12,495,006,794	4.1		17.04	16.00	4,148
VLCC/ULCC (>200)	516	279,208	15	80	20	50%	85,615	27,008.00	23,879,106,183	3.6		44.18	41.60	12,322
Total Crude oil	**2,028**						258,469		53,471,080,573	5		106.00		23,545
LNG (0-50)	**29**	23,588	17	80	20	50%	52,167	16,456.50	1,902,263,069	27.4		1.51	7.60	55
LNG (>50)	**221**	71,099	19	80	20	50%	83,400	26,309.00	6,408,488,501	13.0		18.43	92.40	1,416
Total LNG	**250**						135,567		8,310,751,570	16.3		19.94		1,471
LPG (0-5)	**651**	2,012	13	80	20	50%	6,137	1,936.00	130,496,886	47.0		4.00	26.80	85
LPG (5-20)	**235**	9,069	15	80	20	50%	17,093	5,392.00	678,646,370	25.2		4.02	26.90	159
LPG 20-40	**68**	25,764	16	80	20	50%	29,194	9,209.60	2,056,555,856	14.2		1.99	13.30	140
LPG (>40)	**135**	48,904	17	80	20	50%	36,356	11,468.80	4,147,643,575	8.8		4.91	32.90	560
Total LPG	**1,089**						88,780		7,013,342,687	12.7		14.91		944
Reefer (0-5)	**508**	2,060	13	80	20	60%	9,363	2,953.60	203,228,700	46.1		4.76	22.30	103
Reefer (5-10)	**358**	6,827	17.5	80	20	60%	25,838	8,150.80	906,791,981	28.5		9.25	43.40	325
Reefer (>10)	**225**	11,512	20	80	20	60%	32,410	10,224.00	1,747,605,300	18.5		7.29	34.20	393
Total Reefer	**1,091**						67,611		2,857,625,981	23.7		21.30		821
Product, chemical 0-5'	3125	2,009	11.5	70	30	60%	8,651	2,729.10	142,654,101	60.6		27.04	20.80	446
Product, chemical 5'-15'	1407	8,230	13	70	30	60%	15,953	5,032.50	660,522,652	24.2		22.45	17.30	929
Product, chemical 15'-25'	430	18,083	14.4	70	30	60%	26,571	8,382.00	1,607,649,695	16.5		11.43	8.80	691
Product, chemical 25'-40'	643	32,443	15	70	30	60%	44,668	14,091.00	3,004,401,819	14.9		28.72	22.10	1,932
Product, chemical 40'-60	705	43,512	14.7	70	30	60%	42,053	13,266.00	4,513,046,136	9.3		29.65	22.80	3,182
Product, chemical >60	238	78,339	15	70	30	60%	45,401	14,322.00	8,291,118,437	5.5		10.81	8.30	1,973
Total Chemical	**6,548**						183,298		18,219,392,840	10.1		130.08		9,153
RO-RO (excl. Pax) 0-5000	932	1,729	13	70	30	60%	8,394	2,647.80	138,768,467	60.5		7.82	18.20	129
RO-RO (excl. Pax) 5-15	674	9,334	17	70	30	60%	28,532	9,000.50	979,619,744	29.1		19.23	44.90	660
RO-RO (excl. Pax) 15-25	342	17,605	18	70	30	60%	38,981	12,296.80	1,956,459,426	19.9		13.33	31.10	669
RO-RO (excl. Pax) 25-40	51	27,680	19	70	30	60%	48,726	15,371.00	3,246,941,650	15.0		2.49	5.80	166
Total RO-RO	**1,999**		15.4				124,632		6,321,789,286.69	19.7		42.87		1,624
General Cargo (0-5)	9,009	2,138	11	70	30	60%	3,943	1,244.00	145,225,951	27.2		35.53	42.60	1,308
General Cargo (5-15)	3,014	7,549	13	70	30	60%	10,872	3,429.80	605,853,976	17.9		32.77	39.30	1,826
General Cargo (15-35)	816	19,570	14	70	30	60%	18,477	5,828.80	1,691,497,286	10.9		15.08	18.10	1,380
Total General Cargo	**12,839**						33,293		2,442,577,212	13.6		83.37		4,515
GRAND TOTAL	**36,538**							**Total CO_2 (million tonnes per year)=**				**838.95**		
							Bunker Consumption (million tonnes per year)=					**264.65**		