8-4-2007

Shipping economic analysis of enlargement for containership to Maersk AE10

Xiaodi Chen

WORLD MARITIME UNIVERSITY
Shanghai, China

SHIPPING ECONOMIC ANALYSIS OF ENLARGENEMT FOR CONTAINERSHIP TO MAERSK AE10

By

Chen Xiaodi
China

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

MASTER OF SCIENCE

THE FINAL DISSERTATION

2007

DECLARATION

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

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

(Signature): ....

(Date): ....

Supervised by
Associate Professor Xu Dazhen
Shanghai Maritime University

Assessor
Professor Pierre Cariou
World Maritime University

Co-Assessor
Professor Shi Xin
Shanghai Maritime University

ACKNOWLEGEMENT

At the very beginning, I am very grateful having this opportunity to express my sincere thanks to WMU and SMU, who have given me the chance to write here.

On the base of almost six months' effort, this dissertation has finally come to the end. During this whole period of time, I have been profoundly impressed by my supervisor, Associate Professor Xu Dazhen, who has poured great effort, attention, patience, and passion.

I also want to express my gratitude to my colleagues and friends for their support and encouragement all these days, especially to Susan and Tim, for being there when I need them. Without them, I couldn't have finished it.

Thank you all.

ABSTRACT

Title of Research paper**: Shipping Economic Analysis of Enlargement for Containership to Maersk AE10**

Degree**:** **MSc**

In the recent years, along with the rapid development of global economy and international trade as well as the advancement of ship building technology, the size of containership tends to be larger and larger. Nearly all the shipping companies are competing with the rivals in bring ultra large containerships into services. Large ships of 9,000+ TEU has and will continue to be brought into Asia-Europe and Transpacific services, and ultra large ships of 12,500+ TEU are also expected to be brought into service in the very near future. In these famous shipping companies, Maersk can be definitely regarded as the giant in this field, who has already owned ultra large containerships above 8000TEU.Therefore, it is a typical shipping line operating large containerships in trans-Pacific lines, which is very significant for the research in enlargement for containership.

The thesis has tried to conduct a two-objective model by individually minimizing shipping costs and inventory costs for decision-making on the optimal ship size and sailings frequency and analyzing the shipping economies of ultra large ships, which will be of great assistance in Maersk AE10 (Asia-Europe)'s operation control.

After having studied the current situation of enlargement for containership, including its development trend, main characteristics, the influence to the port, its influential factors and restrictions, the author brings shipping and inventory cost functions formulated for a multi-port calling route and give them separate analysis. Besides, the author derives a relationship equation for exploring trade-off between shipping costs

and inventory costs for using different sizes of ships
Based on this, all feasible solutions for the two-objective model are determined, and the optimal ship size and sailings frequency can also be obtained, simultaneously. And then, a case study regarding Maersk AE10 service is made to analyze shipping economies for ultra large ships. Ship and port costs related to the transpacific container service are collected to construct cost functions and make the optimal ship size decision based on the formulated model. Moreover, the minimum route flows that realize scale economies for using ultra large ships on different routes are estimated. And the effects of key parameters on the decisions of using ultra large ships are further analyzed.

For the reasons that the author has limited working experience in Maersk Line, and lack of many up-to-date data, this thesis must have a lot to improve, but the purpose of author is to explore a new methodology to economic analysis the enlargement for containership with what he has learned in the past two years.

Keywords: Enlargement, Containership, Maersk AE10, Shipping Cost, Inventory Cost

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

AE10	Asia-Europe Route NO.10
FEFC	Far East Freight Conference
GT	Gross Tonnage
JIT	Just in Time
MSF	Minimum Sailing Frequency
MSC	Minimum Shipping Cost
MIC	Maximum Inventory Cost
TEU	Twenty Equivalent Unit
TTL	Total

CHAPTER 1 Introduction

1.1 Research Background

In the recent years, along with the rapid development of global economy and international trade as well as the advancement of ship building technology, the size of containership tends to be larger and larger. The development strides of containership size being large are great, especially after 1990. The largest ship in the world is 4,400 TEU in 1991, 6,000 TEU in 1996, and 7,500 TEU in 2003. The 8,000 TEU ship of OOCL (Orient Overseas Container Line) rewrites the record in 2004. Moreover, large ships of 9,000+ TEU has and will continue to be brought into Asia-Europe and Transpacific services, like Maersk Emma; and ultra large ships of 12,500+ TEU are also expected to deliver in the very near future.

There are some main characteristics of this large scale trend, such as the increasing average slots, the rising percentage of large containership, the fierce competition in new orders and the main emphasis focusing on three main lines: Asia-Europe, Pacific Ocean and Europe-America.

Most people hold the opinion that the steps in the large scale trend is irresistible, which can be indicated by the following reasons: the need for economize the transportation cost, the growing up of global transaction, the containerization of cargoes, the catalysis from multi-national companies, the new step of liner shipping companies' alliance, the development of shipbuilding technology and ship capacity.

However, the tendency for containerships also has unavoidable negative restrictions, such as unsatisfied port conditions, lacking of powerful cargo flow, competition from small and medium sized containership and the current situation that international trade less depends on shipping.

From the view of economy, whether those large ships will provide services as well as expectation depend not only shipbuilding technology and port accommodation constraints are overcome but also those large ships must be more economic than existing ships used on current major routes. Although ultra large ships have the advantage of scale economies, that is, the average container cost decreases as ship size increases, it works only if cargo flow is large enough and sailings frequency is adequate for shippers. That is why, in reality, shipping companies always alliance with each other or provide their services using hub-and-spoke networks to realize scale economies. Besides, key factors such as shipping distance, port efficiency, and the number of ports of call also influence the extent of scale economies. Therefore, this study takes those factors into account and constructs a model to analyze the shipping economies of ultra large ships and determine the minimum flows that realize scale economies.

1.2 Research Purpose and Methodology

Previous studies on ship size or ultra large ships were focused largely on economies of ship size. These studies indicate that economies of ship size occur at sea, while diseconomies of ship size are suffered in port, and that the choice of optimal ship size involves a balancing of the cost per ton at sea and the cost per ton in port Besides, Cullinane and Khanna indicated that the diseconomies of ship size in port are not apparent and the optimal ship size tends to be large as a result of improving port productivity. Moreover, McLellan provided detail discussions about the effects of larger ships on ports. Lim discussed that ships being large would impact all shipping industry. And Robinson forecasted the shipping service position of ultra large ships based on the trend of shipping development.

Differing from previous studies, the study considers that ocean carriers not only aims at lowering their shipping costs but also enhancing their services, thereby attracting more shippers. The study aims to construct a two-objective model by individually minimizing shipping costs and inventory costs for decision-making on the optimal ship size and sailings frequency and analyzing the shipping economies of ultra large ships.

The inventory costs resulted from the shipping process along the shipping route and ports usually are the main considerations of shippers. Inventory cost is commonly regarded as a major factor affecting shipping service decision in logistics literature. These studies usually determined the optimal shipping frequency by minimizing total shipping and inventory costs. Chaug-Ing constructed the model minimizing shipping costs and minimizing inventory costs as two separate objectives, which will be further studied and adapted in the thesis.

In the analysis chapters, shipping and inventory cost functions are formulated for a multi-port calling route. Shipping costs include ocean carriers' capital and operating cost, fuel cost, and port charge on serving the route, while inventory costs include costs due to freight waiting to be shipped in a loading port and on a ship along the shipping route. The third part derives a relationship equation for exploring trade-off between shipping costs and inventory costs for using different sizes of ships. Based on this, all feasible solutions for the two-objective model are determined, and the optimal ship size and sailings frequency can also be obtained, simultaneously. And then, a practical studies regarding a Asia to Europe, like Maersk AE10 container service is made to analyze shipping economies for ultra large ships. Ship and port costs related to the transpacific container service are collected to construct cost functions and make the optimal ship size decision based on the formulated model. Moreover, the minimum route flows that realize scale economies for using ultra large ships on different routes are estimated. And the effects of key parameters on the decisions of using ultra large ships are further analyzed.

1.3 The Logical Link and Skeleton of Thesis

The whole thesis is divided into six chapters, which are closely inter-related.

Chapter1 gives a brief introduction of the research background, study purpose and research methodology as well as the logical link of each chapter.

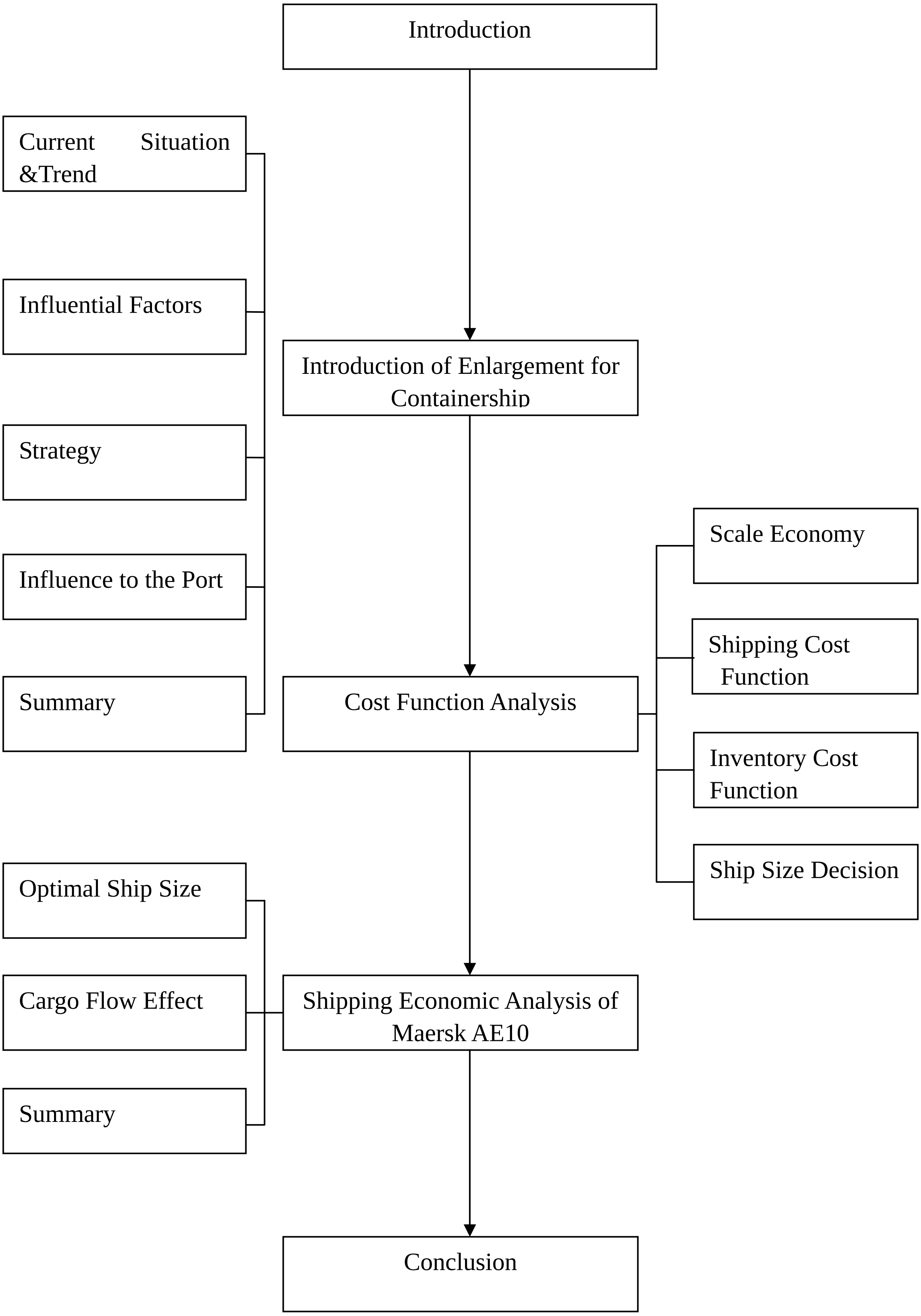
Chapter2 is literature review, which the author intends to bring up his appreciation to those experts who are well-known in the research on enlargement for containership and briefly introduce their accomplishment to assist the thesis.

Chapter3 detailed introduces the concept of enlargement of containership in every aspects, including development procedure, current situation for large-scale containership in Maersk AE10, the influential factors of enlargement for containerships, the strategy applied for such enlargement, and the effects brought to ports.

The author in chapter 4 would like to set up the two-optimal subjective model for shipping cost function and inventory cost function respectively. After introducing the scale economy, the writer analysizes the shipping cost function and inventory cost function individually and finally obtains the final ship size decision.

Chapter5 takes Maersk AE10 for example to analysize the current situation of Asia to Europe route and the optimal ship size regarding the cargo flow. And last, the author makes conclusion of the above analysis and summarizes that the scale economy of enlargement for containership can only be realized when the cargo flow is big enough and the conditions of ports of call are adequate for ultra large containerships.

Chapter 6 makes a final conclusion of the thesis and brings up some new questions for the future research. Introduction


Introduction
Current Situation &Trend
Influential Factors
Strategy
Influence to the Port
Summary
Introduction of Enlargement for Containership
Cost Function Analysis
Scale Economy
Shipping Cost Function
Inventory Cost Function
Ship Size Decision
Optimal Ship Size
Cargo Flow Effect
Summary
Shipping Economic Analysis of Maersk AE10
Conclusion

CHAPTER 2 Literature Review

Quite a number of scholars and researchers have done a considerable amount of work on studying the large scale trend for large containerships, and I conclude their respective accomplishment one by one in the following:

There has been considerable speculation regarding how big containerships may become in future. In his analysis of ships up to 15,000 TEU capacity, McLellan in his article *Bigger vessels: How big is too big?* cautioned against continued upsizing suggesting that the size of the biggest ships would be likely to plateau due to physical restrictions in ports. Yet the number of new deep-water offshore hubs that have been developed over recent years means larger vessels can now be accommodated.

Investigation by O'Mahony's article *Opportunities for Container Ports: A Cargo Systems Report* also suggested that most of the port technical barriers to handling bigger ships such as crane size, the productivity of equipment and quay strength, etc could be overcome.

In a very detailed study named *Economies of Scale in Large Containerships,* Cullinane and Khanna. M modeled ship costs for the major east-west trades. Findings suggested that economies of scale are enjoyed for ship sizes of above 8,000 TEU on both the Europe-Far East and trans-Pacific trades, and for ship sizes of between 5,000–6,000 TEU on the shorter trans-Atlantic trade. The study also found that continued improvements in port productivity would serve to increase even further ship size optima for all routes.

Based on a survey of the top-30 liner operators, Baird concluded in *Container Vessels in the New Millennium: Implications for Seaports* that containerships with a loading capacity of somewhere between 10,000-15,000 TEU were expected to enter service before 2010. Such vessels, according to the survey, would be primarily designed to serve “offshore” transhipment mega-hubs, avoiding many traditional liner ports.

While recognizing the many constraints to handling larger ships, Wijnolst in *Ships, Larger and Larger: Containerships of 18,000 TEU – impacts on operators and ports* maintains that the ultimate ship size will be determined by the draught limitation of the Strait of Malacca. The draught limitation in question is 21 meters, from which Wijnolst deduced that a ship size of 18,000 TEU would become the maximum size. However, the motivation behind such analysis seemed to be more to do with strengthening the potential hub function of the port of Rotterdam, rather than the result of any informed economic evaluation. Indeed, taking the depth constraint of the Strait of Malacca as the main guide to future ship size might appear to some observers to be rather crude, especially from an economic perspective.

In Zhen Louxian’s article *Analysis on the Advantages and Disadvantages of Large Scale Trend for Containership*, he discussed the problems relating with large scale trend as water depth of port, wharf equipment, stack yard, hoisting machinery capacity and inland transportation distribution. Container transportation is capital-intensive and technology-intensive business with high risk and huge investment; any strategic mistake will cause the big loss of the company, therefore, the optimal size of container should take the whole transportation system into account.

Zhuhua’s paper *The Influence of Large International Containership on the World’s Container Port Development* pointed out that the development of container ports in China should adapt demands and the main emphasis is laid on the construction of pivotal container ports of international navigation centre, proper distribution and the formation of perfect arterial network.

Some previous study of Jansson and Shneerson in *Liner Shipping Economy* indicate that economies of ship size occur at sea, while diseconomies of ship size are suffered in port, and that the choice of optimal ship size involves a balancing of the cost per ton at sea and the cost per ton in port; besides, Cullinane and Khanna indicated that the diseconomies of ship size in port are not apparent and the optimal ship size tends to be large as a result of improving port productivity in their another famous research *Large Containerships and the Concentration of Load Centres*. Moreover, Lim.S.M discussed that ships being large would impact all shipping industry in *Economies of Scale in Containership*. And Robinson R forecasted the shipping service position of ultra large ships based on the trend of shipping development in *Asian hub/feeder net: the dynamics of restructuring*.

In terms of inventory costs, it is resulted from the shipping process along the shipping route and ports usually are the main considerations of shippers. Inventory cost is commonly regarded as a major factor affecting shipping service decision in logistics literature. Daganzo.C.F.'s *Logistics System Analysis* determined the optimal shipping frequency by minimizing total shipping and inventory costs. In maritime study, Jansson and Shneerson also proposed an economic model to analyze shipping service decision by minimizing total shipping and inventory costs. However, in reality, although container carriers consider inventory cost as a decision factor, the weight placed on inventory cost is usually not equal to that on shipping cost. Therefore, the model proposed in the thesis regards minimizing shipping costs and minimizing inventory costs as two separate objectives.

Last but not the least, in Chaug-Ing HSU's paper *Shipping Economic Analysis for ultra Large Containership*, he brought up both shipping cost function and inventory cost function by analysizing them individually, which may give the decision-makers more room for deicide the optimal ship size for individual shipping companies, which gives great assistance to my model structure.

Those scholars I mentioned above are only a part of people I shall express my gratitude to. Without their detailed and comprehensive researches in the related area, it would be next to impossible for this thesis to come out. What the paper tries to express and convey is largely based on the production of those respected professors. What I am trying to achieve is to systematically classify these useful information from all possible sources including books, magazines and articles from distinguished scholars so as to enable readers to have a better and more detailed view of this topic.

CHAPTER 3

Current Situation of Enlargement for Containership

3.1 The Current Situation and Trend for Large-Scale Containerships

In 1955, Malcom Mclean initiated the revolution of land-sea container, which greatly changed the traditional transportation. Moreover, since “Gateway City” was put into operation in 1957, the scale of containerships also undertook rapid development. The author holds the opinion that the tendency for ultra large containerships is irreversible as the growth of global economy and innovation in ship building.

Table 3-1 Enlargement Process of Containership

Type	TEU	Deadweight （DWT）	Length(m)	Breadth(m)	Draft(m)
1st	～1 000	10 000	about150	22	8～9
2nd	1 000～2 000	15 000～20 000	175～225	22～30	9.5～10.5
3rd	2 000～3 000	about30 000	240～275	about32	10.5～12.5
4th	3 000～4 000	40 000～50 000	275～295	about32	11.5～12.5
5th	4 000～8 000	50 000～75 000	280～300	32～39	11.5～13.5
6th	8 000～15 000	75 000～	about400	about69	14.0～14.5

Source: Shipping Intelligence 05/2004

Table 3-1 shows the enlargement process of containership from 1st generation to 6th generation, which generally concludes the development procedure of large containerships.

Table 3-2 Current Situation of World's Containerships (01/01/2007)

Size (TEU)	NO.	TEU (,000)
<500	444	138
500-999	730	531
1,000-1,499	589	696
1,500-1,999	465	790
2,000-2,499	299	684
2,500-2,999	334	909
3,000-3,999	307	1,047
4,000-4,999	339	1,487
5,000-5,999	227	1,236
6,000-6,999	107	694
7,000-7,999	46	338
8,000+	112	970
Total	3,999	9,519

Source: Drewry Shipping Insight 03/2007

In the early 1980s, there were few container vessels over 3000TEU; however, in the middle that period, the carriers above 3500TEU became the main force in international shipping field and some of them were over 4000TEU. Some giant shipping companies competed in building large containerships above 5000TEU, which were gradually put into operation and turn into main stream in shipping lines.

The development strides of containership size being large are great, especially after 1990. The largest ship in the world is 4,400 TEU in 1991, 6,000 TEU in 1996, and 7,500 TEU in2003. The 8,000 TEU ship of OOCL (Orient Overseas Container Line) currently rewrites the record, and the ship is the largest ship among existing ships used. Moreover, large ships of 9,000+ TEU have been brought into Asia-Europe and Transpacific services soon in the near future, and ultra large ships of 12,500+ TEU are also expected to deliver in five to ten years.

Table 3-3 Vessel Deliveries During 01/2007

Vessel name	Shipyard	TEU	DWT	Owner	Comments
Eleonora Maersk	Odense Steel	11,000	170,794	Maersk Line	AE7 service
MSC Roma	Samsung HI	9,200	109,600	MSC	Silk express
YM Ultimate	Hyundai HI	8,204	99,500	Yang Ming	AES1 service
MSC Xian	Hyundai Samho	8,204	108,900	MSC	Lion Express
OOCL Tokyo	Samsung HI	8,063	99,500	OOCL	GA-EU4 service
Bunga Seroja Dua	Daewoo	7,943	97,000	MISC	
Hyundai Colombo	Hyundai HI	6,800	85,250	HMM	AEX service
Palena	Hyundai HI	6,539	85,500	CSAV	AEM service
Puelche	Hyundai HI	6,539	85,500	CSAV	AEM service
Maersk Kowloon	Hanjin HI	6,500	81,000	Maersk Line	AE6 service
Maersk Kwangyang	Hanjin HI	6,500	81,000	Maersk Line	AE6 service

Source: Containerization International 03/2007

From the table 3-3, the ship building factories received 5 orders for container vessels over 8000TEU in January 2007. According to these orders, the containerships all over the world will get to 9 million TEU in the early 2007. Moreover, these ultra large containerships of 8000+TEU cover more than 35% of the world's overall capacity.

On one hand, the overwhelming development of international container transportation positively stimulates the aspiration of most shipping enterprises for ship building orders, which leads to the rapid increase in the number of large containerships in recent years. As the following table 3-4 illustrates:

Table 3-4 Enlargement for Containerships of the World

Time	2007		2008		2009		2010		Total		% of fleet
Range	NO.	TEU (000)	NO.	TEU (000)	NO.	TEU (000)	NO.	TEU (000)	NO.	TEU (000)	
<500	9	6	5	1，242					14	3,454	2.5
500-999	84	68,118	56	44,999	14	12,115	8	7,040	162	132,272	24.9
1,000-1,499	79	89,246	78	93,904	30	37,127	4	5,294	191	225,571	32.4
1,499-1,999	49	84,281	41	71,183	37	64,526	3	5,180	130	225,170	28.5
2,000-2,499	20	43,277	3	7,022					23	50,299	7.4
2,500-2,999	49	133,463	49	129,495	24	63,488			122	326,446	35.9
3,000-3,999	33	112,136	24	81,484	28	94,926	5	17,000	91	308,946	29.5
4,000-4,999	52	226,952	64	279,046	53	229,544	13	56,100	182	791,642	53.2
5,000-5,999	22	114,954	29	155,522	15	79,410	6	31,500	72	381,386	30.9
6,000-6,999	14	90,610	35	228,015	36	233,312	11	69,948	96	621,885	89.7
7,000-7,999	5	35,996							5	35,996	10.6
8,000+	47	417,857	45	403,910	56	523,764	12	117,386	160	1,462,917	150.8
Total	463	1,419,102	429	1,495,822	293	1,338,212	62	309,448	1,248	4,565,984	48.0

Source: Containerization International 03/2007

On the other hand, many port authorities invest a lot of money in renewing port facilities and equipment, establishing water-depth terminals, expanding channels and waterways, improving conditions in transportation distribution, which increase the port efficiency and thereby promote the large scale trend for containerships.

Regarding the Maersk AE10, which is an important route of Asia to Europe, it mainly calls shanghai, Hong Kong, Tangjung Pelepas, Le Harve, Antwerp and Hamburger. Now the containerships are used in the route are Nedlloyd Hudson, Maersk Dallas, Nedlloyd Tasman and Nedlloyd Barentsz. Except Maersk Dallas is 5043TEU, the other three ships are 5468 TEU. Besides, the cargo flow between East Asia and Europe has been developing rapidly these years, and therefore the author believes that the enlargement for containership is typical in the research. The detailed analysis will be brought up in chapter 5.

3.2 The Influential Factors of Enlargement for Containership

The international container transportation is becoming more and more mature after the rapid development for half a century. Some relative organization made data analysis towards the merchant marines in Panama Canal, which indicated that containerships will stand the position as the first one in quantity in 2040. According to these researches, the container transportation will maintain the powerful promotion. Therefore, the trend for large scale container vessels is the inevitable and consequential outcome.

3.2.1 The Increasing Cargo Flow of Global Economy

Due to the rapid growth of international transaction, it is the economic increase globally in the next 3 or 5 years rather than the ship building technologies to decide whether the large scale container vessels can be adapted and promoted. This is to say, the rapid increase of cargo flow stands the most important role in deciding the enlargement for containerships.

After 2003, with the revivification of America's economy and the recovery economic development of Europe as well as the powerful progress made by china, Korea, India and other Asian countries, the global economy is looking forward to another increasing period. Between 2006 to 2010, there will be three 10000 TEU to 12500TEU container vessels delivered, which will promote more shipping companies ordering more ultra large ships for maintaining their own market shares. Besides, the more prosperous cargo flow can pull the rapid development of shipping market. For example, with the step of increasing cargo flow in Asia-Europe route, the ship size definitely tends to be larger. From the statistics of Far East Freight Conference (FEFC), there would be a 15% increase in box volumes on Asia-Europe services, especially westbound. Based on delivery schedules, the FEFC forecasted that 53 vessels of 6,500teu and larger will enter service on Asia-Europe trade routes this year, compared with 47 in 2006. They also believed that it is inevitable that some boxes would be left on-dock during busy periods, while overall utilization is expected to average 95% in 2007. Therefore, we can forecast that the current ship size could not satisfy the demand in the near future, which will need some amendment in the practice.

Therefore, the blooming shipping market will definitely provide business opportunities for ship building industry, and thereby continue the enlargement for containerships.

3.2.2 Economize the Transportation Costs

It is an effective way to realize the economies of scale and decrease the cost per unit slot by equipping large quantity of slots and advanced container carriers. Though the total capital cost will increase with the quantity of slots, the cost every unit is obviously descended. On the condition of fully loaded, the operation cost per slot is of

1000TEU, 2900TEU, 4500TEU, and 6000TEU is shown in table 5. Another example is that the unit cost of 8000TEU ship is 5%-10% less than that of 5000TEU vessel. The advantage of that is quite attractive for those shipping companies engaging in main lines operation.

Table 3-5 Operation Cost per Slot for Different Ship Size

TEU	1000	2900	4500	6000
Operation cost/slot($)	3.25	1.52	1.13	0.92

In order to pursuing more shipping profits, the problem of economize the transportation cost is an emergency for shipping corporations. After comprehensive consideration to the salary of crew, ship maintenance, insurance, inventory, management, bunker and port charges, Britain Drury Shipping Consultants made rough calculations that the operation cost of one container is 2315 dollars for a 4000TEUcontainership operating in Pacific Ocean line while 1449 dollars for 12000TEUship. That is to say, the cost for 125000TEU containership can be 20% less than that of 4000TEU ship per container. In accordance with Germany Dynamar consultant's research paper about the shipping economy in Malacca containerships, the operation cost of 18000 standard containers- ship can be reduced 30% compared with that of 4000 containers-ship and it can reserves 40 dollars per container.

Though the calculation methods and results are different in each consultant companies, the conclusion can be drown that on the condition of sufficient quantity of cargo flow, the shipping company should use larger containerships in the middle and long lines. If we make comparison between 12000 containers-ship and 4000 containers-ship, the operation cost can be economized ten of dollars, even hundreds of dollars each voyage. This is one important driving force for enlargement in containerships.

3.2.3 The Containerization of Cargoes

In recent years, the percentage of containerization of bulk in international main lines is relatively high. 1.5 ton to 2 ton bulk carriers have been knocked out of market while full container vessels are quickly increased. Though the room for development of market share on containerships is limited as well as that the lighter, thinner and smaller trend for commodities will decrease the elastic index of quantity, the increasing rate of trade amount will be higher that of economy and the quantity of cargoes suitable for containers will not drop in the future.

On the other hand, different types of containers are developing rapidly. For example, the refrigerator containers substitute the position of refrigerator ships; the tank containers for liquid chemical are increasing in market share; some traditional cargoes such as grain, wood are transported by containers and specialized containers for cars have been introduced. Such factors will stimulate the rapid increase in containers transportation quantity and the promotion of enlargement for container vessels.

3.2.4 The Accelerating Function of Multi-national Companies

In modern world, the capital and producing activities are breaking through the national boundaries with the economic globalization. There are about 40000 multi-national companies and 250000 branches all over the world. 40% product and services transactions are carried out inside the multinational companies, 35% proceed in different multinational corporations. That is to say, 75% transactions have close relations with import and export trade and multinational enterprises. In the future, the multinational companies will dominate the world trade, especially in containerized cargo trade. Because of the large intercontinental transportation quantity, multinational companies become the main employer for container shipping business, which are also the target customers for first class shipping companies. Therefore, it is an essential strategy for shipping enterprises to establish good relationship with multinational companies.

In the fierce competition of international market, multinational corporations and their carriers have urgent requirement for JIT (just in time) transportation to reduce the reservation of raw material and semi-product and to increase the distribution speed. Consequently, mobility and quick transit times are two main factors in ship building, which result in the accelerating steps of enlargement for containerships.

3.2.5 The New Phase of Shipping Liner Alliance

In the previous period, people had many suspects towards the enlargement of ship, such as the decrease of voyage, sailing frequency and the number of ports of call. However, shipping alliances are trying to reduce the negative aspects of such trend to the lowest level. In recent years, the re-association of alliance in trans-Pacific lines fully prove that due to the reasonability of service, time allocation at each port becomes more effective and the time in port is decreased.

Each company in the alliance can set up cost-effective plan for liner service, which could decrease the number of ship and increase the storage percentage which could make full use of the resource and offer conditions for enlargement of ship.

The tide wave for shipping liner alliance at the end of 20^{th} century will continue for development. There are two categories of alliance: one is unity not referring capital, such as combination in starting sea route, leasing container slot and using terminals. The other is the unity based on capital, like merger and coalition. Though the former alliance is more popular, these two kinds of unity can illustrate the reasonability of larger vessels carrying more cargoes. Due to the usage of mutual advantages, shipping companies are able to overcome their own weakness as relative poor ability in attracting cargoes, which also accelerate the steps of enlargement of containerships.

3.2.6 The Development of Ship Building Techniques and Ship Capability

Along with the reforming of ship building techniques and the ship capability, the experts holding positive opinions towards the enlargement point out that the new generation ultra large(125000 slots) container can only equipped with one gas engine of 110000-135000 horsepower (80000-100000 kilowatt). That is to say, such ultra large container vessel only needs one main engine and one screw.

Recently, German MAN&W Gas Engine Company has produced the diesel engine for ship with 96300 horsepower (70000 kilowatts), which can drive 150000 ton containership with 15 knot in speed. They believe that with the advancement of such techniques, the speed of the vessel can be increased to 25-26 knot. Besides, Ishikawajima-Harima Heavy Industries has designed a 25-knot 10,000 TEU vessel using existing marine engines with a small and larger propeller on a single shaft. The ship would have a length of 346.6m, beam of 49.6m, and draught of 13.5m. Fuel consumption is put at around 240 tones per day. Other yards, including HDW and Samsung, have similar sized vessels on the drawing board.

3.3 The Strategy Applied for Enlargement of Containership

Since the enlargement trend for containership is irreversible, most of powerful ocean carriers take measures as compete in building ultra large containerships over 8000 TEU.

Since the first container vessel was put into operation in 1957, the tendency for ultra large ships has been maintained for 50 years. Therefore, the draft and width of ships increases relatively which are illustrated in the following table.

Table 3-6 The Changes in Containerships Type

	1	2	3	4	5	6	7	8	9
Type	Standardized	Large, high efficiency	Economized	Large	Post-panamax	Large		Ultra large	Super large
Time	Late 1960s	1970s	1970s-1980s	Late 1980s	Early 1990s	Late 1990s	1997 — 2002	Early 21 century	
Name	Feeder	Handy	Panamax	Panamax	Post-panamax	Post-Panamax +		Post-Panamax ++	
Slot (TEU)	700—1 500	1 800—2 300	2 000—2 500	2 500—4 400	4 300—5 400	6 000—6 670	7 000—8 700	11 000	12 500
Scale (TEU)	752	1 887	2 464	4 626	4 340	6 418	7 060	11 699	12 500
Length (M)	200	280	258.5	294	275.2	318.2	347	362	383
Width (M)	26	32.2	32.2	32.3	39.4	42.8	42.8	48	57.1
Depth (M)	15.5	19.6	24.1	21.4	23.6	24.1	24.1	29.8	29
Draft (M)	10.5	11.5	13.2	13.5	12.5	14	14.5	17	14.7
TTL Tonnage	16 240	37 799	52 615	53 800	61 900	81 488	91 560	140 000	150 000
Tire NO.									
Inside	6	7—9	8	8	8	9	9	11	9
Deck	2	2—3	3	5	4	6	6	7	7
Bay NO.									
Inside	7	9	10	11	12	14	14	17	18
Deck	9	12	13	13	16	17	17	19	22

Speed (knot)	22.6	26	19.5	24.5	24.2	25	26.4	25	25
Horsepower (MW)	27 800	69 600	34 840	49 640	59 960	74 640	74 555	76 800	64 000*2
Propeller	1	1	1	1	1	1	1	1	2
Company	NYK	K-Line	Safmarine	Hapaglloyld	APL	Maersk	Maersk		
Completion time	1968	1973	1979	1991	1988	1996	1997		

Source: Port 01/2005

3.3.1 The Change of Average Slot on Vessel

From 1986 to 2000, the slot of containerships increased about 100% and in 2002, the average slot got to 2473TEU.

Table 3-7 The Containerships of the World in 1969 and 2006

Year	1969	2006
NO. of ships	109	3705
Slot	70,000TEU	6,920,000TEU
Average Slot	642.2TEU/ship	3037.9TEU/ship

Source: Containerization International 07/2006

3.3.2 The Increasing Percentage of Large Containerships

The main ship types in shipping now is between1000-4000TEU, besides the number and slot cover 56% and 62.7% respectively. However, the vessels above 4000TEU gain favorable opportunity for growth, which rose from 2.87% in 1995 to 18.87% in

2000. From table 3-8, we can safely conclude that the percentage is expected to 41.3% in 2007.

Table 3-8 The Percentage of Large Containerships in the World Fleets

Type	Large containerships (>4000TEU)）			Medium and small containerships (1000-4000TEU)		Total	
Year	NO.	,000TEU	Percentage (%)	NO.	,000TEU	NO.	,000TEU
1975							355.0
1980				649	617.7	649	617.7
1985				981	1 057.6	981	1 057.6
1990	5	21.7	1.3	1 284	1 616.8	1 290	1 638.8
1995	15	65.9	2.6	1 717	2 426.7	1 733	2 492.9
2000	105	568.0	12.9	2 498	3 821.8	2 604	4 390.0
2005	399	2 250.0	31.6	3 000	4 870.0	3 399	7 120.0
2006	503	2 854.0	36.2	3 090	5 020.0	3 593	7 874.0
2007	611	3 600.0	41.3	3 185	5 120.0	3 796	8 720.0

Source: Containerization International 04/2003-05/2004

3.3.3 The Continuing Breakthrough of the Slots of Largest Containerships

Since the first specialized container vessel was burn in 1960s, the international containerships have been developing five or six revolution and the capacity is beyond 5000TEU. In 1996, Regina Maersk was put into business and the containerships realized the transition from 5000TEU to 7000TEU. Furthermore, Maersk is planning to expand its new order ships to 10000TEU, which indicates that the steps for large scale container carriers are irresistible.

3.3.4 The Large Containerships are Focusing on the Global Three Main Lines

In accordance with the data, most of large containerships are put into Asia-Europe, Pacific Ocean and Europe-America lines. Some experts hold the opinion that the vessels of 3000TEU are imperative to be substituted by ships of 5000TEU or 6000TEU, which will stand the dominate role in the next few years.

Although most shipping companies are competing in increasing their capacity of containerships to obtain more market ration, it depends whether the large containerships are really economic than the existing ones, like Maersk Line's ups and downs in 2006. Most of the Group's main business areas experienced a positive development in 2006. This particularly applied to Maersk Tankers, Maersk Contractors, Maersk Supply Service and Maersk Oil. However, this was overshadowed by a very negative development within the Group's container activities which made a substantial loss. The container activities' loss was primarily a result of decreasing rates and increased bunker costs as well as the fact that the amount of transported containers did not match expectations. The latter primarily due to difficulties in implementing major IT-systems simultaneously with the integration of Royal P&O Nedlloyd. In order to re-establish profitability in Maersk Line, focus is now on strengthening earnings rather than on market shares. That is to say, whether the powerful capacity can really bring up many profits to shipping corporations is an uncertainty. And such problems will be detailed analyzed in chapter 4 and 5.

3.4 The Influence of Enlargement for Containership to The Port

The vigorous development of large and ultra large containerships, especially the fifth and sixth generation post-Panamax greatly promotes the leading role of containerships in shipping market, and thereby influences the establishment and promotion of container ports.

3.4.1 The Intensive Competition of Pivot Container Ports

Most of containerships are lines, which offer the fixed line, fixed ports and fixed time service for customers, which is relatively stable in the business operation. If one port is not able to become the pivot port or main port of call, it has no choice but to play the role as feeder port or supplying port. In such case, many countries formulate the development plan for ports in order to obtain the initiatives in the new market competition.

In Asia, China set up the strategy in building the international shipping centre as container pivot port; Korea intends to build Busan as the Circum-Pacific centre port in 21^{st} century; Kobe is regarded by Japanese as “Asian Mother Port”; Kaohsiung in Taiwan is making every effort to establish itself as “Asian operation centre”. Moreover, New York port invested 1.2 billion dollars to improve the infrastructure facilities so as to gain the more favorable position in the competition with new container port Halifax in Canada.

We can expect that the competition in international container ports is much more intensive and the status of each port will get new ranking in the next 5 to 10 years. Only the ports which are able to meet the requirement for large scale tendency can obtain the centre position in the future.

3.4.2 The Accelerating Steps in Building Deep-water Ports

For the sake of satisfy the requirement for large scale containerships, numerous ports all the world are planning to setting up deep-water terminals. There are three measures taken recently. One is to dredge the existing channels and terminals, such as New York port; another method is to move the inland port to the outport, just like Rotterdam; the last example is Yangshan part of Shanghai, which establishes a new port with good condition.

European countries plan to build the container berths around16 meter in depth:

Algeciras (Spain): owning 2 container berths of 16 meter in depth

Le Havre (France): owning 6 container berths of 16 meter in depth and plans to build 6 more after 2006

Zeebrugge (Belgium): owning 3 container berths of 16 meter in depth and plans to build 5 more. The water front will be 1820 meter.

Antwerp (Belgium): owning 16 container berths of 16 meter in depth.

Rotterdam (Holland): owning 3 container berths of 16.6 meter in depth with 1030 meter water front; 5 berths of 15.9 -16.6 meter in depth with 1665 meter water front and 3 berths of 16 meter with 1250 meter water front.

Hamburger (Germany): owning 2 container berths of 16.7 meter in depth.

At the same time, some Asian ports also make strategies to dredge the channels and set up the deep-water ports to deal with the problem of large scale containerships. Basing on berths over 15 meters, the port authorities in Singapore, Honk gong, Kaohsiung, Busan and Kobe are investing a huge sum of money in establishing new deep-water berths. The detailed scheme is in table 3-9.

Table 3-9 The Current Situation and Future Scheme of Asian Main Container Ports

Port	Singapore	Hong Kong	Kaohsiung	Busan	Kobe	Shanghai
Owning berths over 15 meter in depth	8	4	3	8	5	0
Planning to build berths over 15 meter in depth	10	6	4	15	4	5
Planning year	2006	2007	2006	2006	2005	2005

Source: www.snet.com.cn

3.4.3 The Requirement of Future Container Deep-water Port

The large scale trend, even ultra large scale trend for containerships will greatly influence the planning, operation of ports and terminals as well as the loading and discharging techniques and facilities, which will bring up higher requirement for ports:

1. The entering channel can maintain the reliable navigation for ultra large ships and there is an area for turning around which is 23-25 meter in depth and over 750 meter in diameter.

2. There are enough powerful berthing system and equipment and anti-strike facilities (100 ton/ moor column)

3. There is enough depth, land area and deep-water terminals over 22 meter; besides, increased mooring capability and large scale land bridge for smooth entry, loading and unloading.

4. The port is able to offer 10000-15000 ton bunker supplying equipment.
Ultra large land bridge should be provided with high voltage supplies and solid base for heavy trucks and heavy tractors.

5. The port is equipped with effective and economic supplying and distribution systems.

6. There are advanced navigation, towing and monitoring system for efficient, accurate and safe berthing and leaving.

3.5 Summary

In author’s opinion, the enlargement for containership is the overwhelming trend in this century; however, it also brings a lot of problems, which makes the ultra large containerships diseconomy in many aspects. Because one ultra large containership, which can be successfully opened for navigation is not only relying on the breaking through the technical problems, but also the successful cooperation with ports, lines, channels, cargo supply, loading and discharging, which are the restrictive factors of the tendency.

Firstly, powerful cargo flow is the supportive factor of enlargement trend for containership, for the goal of such tendency is to go after high economic benefits and return.

Ultra large containership brings up very high requirement of the logistics development in the port of call. Comparing with other developed countries, China faces up the bottleneck of intermodal transport development. Container transportation not only means the transport at sea, but also has close relation with different modes of transportation, such as road, rail, air and storage.

On the other hand, the distribution in port is also the essential factor, which calls for the setting economic transport management system, reasonable net collocation, advanced equipment and facilities of road and rail and avoiding repeating works leading in low average speed of vehicles, insufficient capacity of cargo freight station and unsmooth allocation of container trucks. Moreover, poor cooperation of road and rail is another problem.

If the above problems cannot be solved, the development of large scale trend of containership will be restricted. It is not difficult to imagine that the economic profits of these vessels cannot be realized in the environment of no strong cargo supply chain.

Secondly, no suitable deep-water channel or container terminal becomes the obstacles for large scale trend. For example, the fifth generation containership (6800-15000 slots) has the draft for 14-15 meters, which indicates that the depth of channel and the terminal berth can not less than 15 meter. But the number of ports with such conditions is relative small in the world.

Except the limits of depth of terminal, the mechanical equipment in the port is also the restrictive aspect, which directly affects the productive capabilities and efficiency. It is estimated that the container terminal invested for tens of thousands of dollars, even millions of dollars can bring satisfied economic benefits provided that the high working efficiency as loading and discharging 300 containers/ hour for 36 hours and start the voyage promptly.

The most crucial condition for a port to service the container vessel with 8000 slots or 10000 slots is deep-water channel, which need big investment in terminal enlargement and facilities increasing. For instance, Anterwerp invested 1 billion in building Deurganck terminal(15 meter in depth, 1260 meter quay and two loading and discharging bridges), which can offer service for ultra large containership with 8000 slots (8 layers with 20 rows).

Thirdly, the competition is not only from those powerful ocean carriers, but also from the medium and small containership operators. Because, the larger the ship, the more it is depending on the feeder lines. Those ultra large vessel only calls at big hinge ports and most of its containers need to be transferred, which requires that there exists some small or medium sized vessels to take the responsibility of transferring containers. Actually, the inland feeder transportation plays a very important role in logistics. Besides, in the situation of the increasing quantity of shipping business in near ocean and inland water, the requirement of feeder lines is also brought alone.

From the current situation, though many shipping companies are in pursuit of larger containerships, the demand for feeder container vessels is not taken off. In accordance with the statistics in the last 10 years, the vessel below 2000 TEU stands over 50% in the building works.

It is expected that the demand for feederships will increase to 2400 at the end of 2010. In addition, the cargo flow can source cannot be maintained stable due to the imbalance of foreign trade and its requirement as well as the difficulty in controlling each step of transportation. Comparing with the large ones, small and medium sized vessels have the characteristics of smaller risk, convenient adjustment and flexibility. Therefore, it is not an unwise decision to move some emphasis to small and medium sized vessels for avoiding fierce competition in larger ships for many shipping corporations.

In conclusion, the shipping companies owning ultra large containerships need to make detailed economic analysis and choose the most economic ship size into service to gain the profit maximization. And the chapter 4 will introduce the two objective function methods for study.

CHAPTER 4
Cost Function Analysis of Enlargement for Containership

4.1 The Analysis of Scale Economy for Enlargement for Containership

The advantage of large containership in scale economy can be reflected in the cost decrease per unit. Generally speaking, as the ship size increases, though the total cost for ship building will increase, the cost per unit is obviously decreased. Moreover, the operation cost as bunker, salary for crew, ship supplies and port charges will not increase with the same percentage as the slot increase but decreases as the ship size increases.

From the view of practice, the ship of 12,000TEU can increase the profit about 70 dollars per TEU compared with 2 vessels of 6,000TEU in Trans Pacific lines. The same profit difference is also in the comparison of a 12,000TEU ship for 80% capacity and an 8,000TEU ship for 90% capacity, provided that the cargo flow is large enough and the sailing frequency is adequate for shippers.

1) Investment Cost

The investment cost for ship decreases as the increase of the ship tonnage. When the deadweight excesses to 300,000 tons, such tendency becomes not obviously. However, the deadweight of ultra large containership nowadays is much less than the 300,000 ton, therefore the ship building cost can be decreased apparently. On the other hand, most large container vessels are intended to increase dramatically in beam. As we know that the length is the most influential factor in investment cost while beam does not have so much effect, thereby the unit cost for ultra large containership decreases after the tonnage increase.

In the past three years, the building cost decreased 25%-30%. Make comparison between the fifth generation containership and fourth generation, the cost for latter is about 13-1.4.7 thousand dollar while that of former is 16-16.5 thousand dollar. Take the account that the capacity of the fifth is 1000-2500TEU more than that of the fourth generation; the unit cost is great decreased for the fifth generation container vessel.

2) Voyage Cost

When the tonnage of containership increases, the bunker cost everyday not always increases by the same percentage; however, the fuel cost each unit is likely to decrease provided that the increase of tonnage will not cause the increasing dwelling time at port. From the following table, we can safely conclude that the unit voyage cost decreases as the ship size increases.

Table 4-1 The Voyage Cost of Different Ship Size in Chinese Ports (RMB)

	Unit	1	2	3	4	5	6
Tonnage	Ton	40000	50000	60000	80000	80000	100000
Capacity	TEU	2761	3764	4422	5250	8736	12154
Pilotage	RMB	20000	25000	30000	40000	40000	50000
Berth leaving	RMB	8800	11000	13200	17600	17600	22000
Mooring	RMB	213	213	213	213	213	213
Anchorage	RMB	8000	10000	12000	16000	16000	20000
Total	RMB	37013	46213	55413	73813	73813	92213
Unit cost	RMB	13.41	12.53	12.28	11.48	10.06	8.45

Source: China Shipping Week /2006

In accordance with the through economic analysis made by Drewry for 6000TEU containership and 4000 TEU containership, the unit voyage cost for 6000 TEU ultra large Panamax is 21% lower than that of the other type, which can be concluded as the following economic cost:

30% crew cost

20% fuel cost

15% insurance cost

25% maintenance and repairing fee

The voyage cost for large containership can be economized dramatically, which persuades most shipping corporations to go after the enlargement for containership.

3) Operation cost

Crew salary stands the biggest percentage in operation cost, which does not increase as tonnage increase. There is no difference in crew complement between the fourth generation ship and the fifth. Besides, the fuel, maintenance and materials supplies also do not increase as the increase of ship size.

Table 4-2 The Comparison of Fuel Cost in Different Ship Size (ton)

Tonnage	Consumption everyday	Loading quantity each year	Fuel cost per unit(pound/tom)
15 000	23	120 000	55
30 000	41	242 000	48
50 000	55	412 000	38
80 000	75	663 000	31

Source: Economics of Tramp Shipping 9/2004

Moreover, according to the Drewry's research paper, the operation cost for 9600TEU containership is 340 dollars less than that of 6500TEU per unit and 470 dollars less than that of 5600TEU ship.

Table 4-3 The Comparison of Operation Cost in Different Ship Size (1000 dollar)

	5600		6500		8400		9600	
	$	%	$	%	$	%	$	%
Crew Salary	168	5.72	180	5.17	192	4.63	210	4.32
Insurance	120	4.08	140	4.02	170	4.10	200	4.11
Vessel Management	36	1.23	43	1.23	50	1.21	60	1.23
Port Dues	900	30.63	1080	31.00	1305	31.45	1620	33.31
Bunker (at sea)	821.4	27.95	985.68	28.29	1149.96	27.72	1314.24	27.02
Repair	180	6.13	220	6.32	260	6.27	300	6.17
Bunker (in port)	17.982	0.61	19.98	0.57	21.978	0.53	23.976	0.49
Reserves	120	4.08	140	4.02	170	4.10	200	4.11
Materials	175	5.96	200	5.74	230	5.54	260	5.35
Devaluation	400	13.61	475	13.64	600	14.46	675	13.88
Total	2938.4	100.00	3483.66	100.00	4148.94	100.00	4863.216	100.00

Source: Drewry 03/2006

4) Service Speed

In terms of service speed, the speed for the fourth generation is 21-23kn while the fifth generation containership gets to 24-25kn, which decreases the fuel consumption and increases the transportation efficiency.

Therefore, we can safely conclude that the scale economy of enlargement for containership is the basic drive for ocean carriers in the competition in building large container vessels.

4.2 Shipping Cost Function

According to Chaug-Ing's research accomplishment, we can set a double objective function model to detailed analyze the scale economy of large containership. First of all, let's consider a multi-port route *m*, calling at n^m ports. *f* denote sailing frequency using ship type t. the ships are all containerships with dry cargo. Suppose the cargo volume from one port to another is given. Let Q_{ij}^m indicate cargo quantity from port *i* to port *j*. Then the loading and discharging volumes in port are $\frac{1}{f}\sum_j Q_{ij}^m$ and $\frac{1}{f}\sum_j Q_{ji}^m$, respectively.

As regards to the shipping cost, in order to conduct research conveniently, it can be divided into three parts: capital& operating cost, fuel cost and port charge& fee. Capital& operating costs indicate the overall expenses paid for using the ship each day, involving the cost of owning the ship, crew salary, repair and maintenance, insurance, materials and supplies, etc, which increase with the ship size, operating time and sailing frequency.

The shipping time per voyage includes the time at sea and dwelling time in port. Dwelling time includes cargo loading and discharging time spending on arrival and handling rate. If let R_i indicate the handling rate, thus the cargo loading/ discharging time in any port *i* is $\frac{1}{fR_i}\sum_j (Q_{ij}^m + Q_{ji}^m)$. (1)

Let w_i demote the arrival and departure process time in ay port *i*, the time spending in port is $w_i + \frac{1}{fR_i}\sum_j (Q_{ij}^m + Q_{ji}^m)$. (2)

Therefore, the total time a ship spends on all ports per voyage is the sum of the dwelling time of n^m ports, that is

$$\sum_i w_i + \frac{1}{f}\sum_i \sum_j \left(\frac{Q_{ij}^m + Q_{ji}^m}{R_i}\right) \tag{3}$$

If D_i^n denote the distance between any two ports and V_t indicate the sailing speed for ship type t. then the sipping time at sea is $\frac{1}{V_t}\sum_i D_i^m$ (4)

Moreover, the total time per voyage include the time at sea and dwelling time in every port. That is $\sum_i (w_i + \frac{D_i^m}{V_t}) + \frac{1}{f}\sum_i \sum_j (\frac{Q_{ij}^m + Q_{ji}^m}{R_i})$ (5)

Besides, if S_t represent daily capital and operating cost, and the total capital and operating cost with *f* sailing frequency is

$$fS_t \sum_i (w_i + \frac{D_i^m}{V_t}) + S_t \sum_i \sum_j (\frac{Q_{ij}^m + Q_{ji}^m}{R_i}) \qquad (6)$$

Fuel cost plays an essential role in shipping cost of containership, which include not only the consumption in navigation, but also in port. When the ship is in navigation, the speed is normally constant, and thus the fuel cost is proportional to the sailing distance. However, fuel cost in port is different from that at sea, because a ship's speed when entering or leaving a port is various, therefore if F_t represent the fuel cost at sea per nautical and B_{it} denote fuel cost in port, then the total fuel cost with *f* sailing frequency is $f\sum_i (F_t D_i^m + B_{it})$ (7)

Port charge can be divided into two categories: charge on ship and stevedoring fee. The former is about the fee for serving the ship, such as pioltage, towage and berth occupancy charge, etc. the latter is paid including loading and discharging fee, equipment charge and rent of container yard, etc.

Generally speaking, the port charge of a ship depends on the gross tonnage or capacity of a ship and berth occupancy time. However, the pioltage, towage and handling cost are independent. If α_{it} represent the portion of port charge of a ship that is independent of berth occupancy time and β_{it} represent the portion that is proportional to berth occupancy time. Thus the overall port charge on the ship with *f* sailing frequency is $f\sum_i \alpha_{it} + \sum_i \sum_j \frac{\beta_{it}}{R_i}(Q_{ij}^m + Q_{ji}^m)$. (8)

If G_i denote average handling fee per TEU, the stevedoring fee is

$$\sum_i \sum_j G_i (Q_{ij} + Q_{ji}) \quad (9)$$

Therefore, the sum of port charge on ship and stevedoring charge is the total port charge $f\sum_i \alpha_{it} + \sum_i \sum_j (\frac{\beta_{it}}{R_i} + G_i) * (Q_{ij}^m + Q_{ji}^m)$ (10)

Then the Total Shipping Cost= Capital& Operating Cost+ Fuel+ Port Charge. That is

$$TC_1^m = f\sum_i \alpha_{it} + S_t w_i + B_{it} + D_t^m (\frac{S_t}{V_t} + F_t) + \sum_i \sum_j \left[(G_i + \frac{\beta_{it}}{R_i} + \frac{S_t}{R_i})(Q_{ij}^m + Q_{ji}^m) \right] \quad (11)$$

And average shipping cost per TEU

$$AC_1^m = \frac{f\sum_i \left[\alpha_{it} + S_t w_i + B_{it} + D_t^m (\frac{S_t}{V_t} + F_t) \right] + \sum_i \sum_j \left[(G_i + \frac{\beta_{it}}{R_i} + \frac{S_t}{R_i})(Q_{ij}^m + Q_{ji}^m) \right]}{\sum_i \sum_j Q_{ij}^m}$$

(12)

4.3 Inventory Cost Function

For a normal understanding, inventory cost means the opportunity which cannot be used in shipping process. In this thesis, the inventory cost related with containershipping process are taken into consideration, including waiting time costs in the loading port and shipping time cost when containers ate in-transit or processed. The reason why the author does not consider the cost occurred in discharging port because it is stands only small percentage.

The waiting time cost is connected with sailing frequency. The denser the sailing frequency is, the lower the waiting cost is. We suppose that the arrival procedure of containers at each loading port is one half of the shipping time cycle. If H denote the daily volume of time per TEU, and one season approximates to 13 weeks or 91 days, then the total waiting time is $\frac{91H}{2f}\sum_i\sum_j Q_{ij}^m$ (13)

Let T_{ij}^m represent the shipping time of containers from port *i* to port *j*. It should include time in loading and discharging ports. Since the time spending in discharging port is not easy to estimate. So time in port is almost equal to that in loading ports, that is

$$T_{ij}^m = \sum_k \delta_{ijk}^m (w_k + \frac{D_k^m}{V_t}) + \frac{1}{f}\sum_k\sum_l \frac{\delta_{ijk}^m}{R_k}(Q_{kl}^m + Q_{lk}^m) \quad (14)$$

Here $\delta_{ijk}^m = 1$, if there exists a link between port *i* to port *j*. Or =0 if there is no link.

Then the total shipping time cost is equal to $H\sum_i\sum_j (Q_{ij}^m T_{ij}^m)$ (15)

and can be expressed as:

$$H\sum_i\sum_j\sum_k Q_{ij}^m \delta_{ijk}^m (w_k + \frac{D_k^m}{V_t}) + \frac{H}{f}\sum_i\sum_j\sum_k\sum_l \frac{Q_{ij}^m + Q_{ijk}^m}{R_k}(Q_{kl}^m + Q_{lk}^m) \quad (16)$$

The total inventory cost is

$$TC2^m = \frac{91H}{2f}\sum_i\sum_j Q_{ij}^m + H\sum_i\sum_j\sum_k Q_{ij}^m \delta_{ijk}^m (w_k + \frac{D_k^m}{V_t}) + \frac{H}{f}\sum_i\sum_j\sum_k\sum_l \frac{Q_{ij}^m + \delta_{ijk}^m}{R_k}(Q_{kl}^m + Q_{lk}^m)$$

(17) And

$$AC2^m = \frac{91H}{2f} + \frac{H\sum_i\sum_j\sum_k Q_{ij}^m \delta_{ijk}^m (w_k + \frac{D_k^m}{V_t})}{\sum_i\sum_j Q_{ij}^m} + \frac{H\sum_i\sum_j\sum_k\sum_l \frac{Q_{ij}^m + \delta_{ijk}^m}{R_k}(Q_{kl}^m + Q_{lk}^m)}{f\sum_i\sum_j Q_{ij}^k}$$

(18)

4.4 Ship Size Decision

There is a trade-off between average shipping cost and inventory cost. If the sailing frequency is dense, the average inventory cost is low and the average shipping cost is high and visa versa. However, a two-objective minimizing both the shipping cost and inventory cost does not exist. Therefore, Cohon introduced Parto optimality "where no objective can be researched without simultaneously worsening at least one of the remaining objectives."

Let $r_t^{11,m}$ and $r_t^{21,m}$ denote the fixed components of average shipping cost and inventory cost; then let $r_t^{12,m}$ and $r_t^{22,m}$ indicate the marginal shipping cost and inventory cost for increasing one more sailing frequency.

$$r_t^{11,m} = \frac{\sum_i \sum_j \left[(G_i + \frac{\beta_{it}}{R_i} + \frac{S_t}{R_i})(Q_{ij}^m + Q_{ji}^m) \right]}{\sum_i \sum_j Q_{ij}^m} \quad (19)$$

$$r_t^{21,m} = \frac{H \sum_i \sum_j \sum_k Q_{ij}^m \delta_{ijk}^m (w_k + \frac{D_k^m}{V_t})}{\sum_i \sum_j Q_{ij}^m} \quad (20)$$

$$r_t^{12,m} = \frac{\sum_i \left[\alpha_{it} + S_t w_i + B_{it} + D_i^m (\frac{S_t}{V_t} + F_t) \right]}{\sum_i \sum_j Q_{ij}^m} \quad (21)$$

$$r_t^{22,m} = \frac{91H}{2} + \frac{H \sum_i \sum_j \sum_k \sum_l \frac{Q_{ij}^m \delta_{ijk}^m (Q_{kl}^m + Q_{lk}^m)}{R_k}}{\sum_i \sum_j Q_{ij}^m} \quad (22)$$

$$AC_1^m = r_t^{11,m} + r_t^{12,m} f \quad (23)$$

$$AC_2^m = r_t^{21,m} + r_t^{22,m} (f)^{-1} \quad (24)$$

After the detailed analysis of the shipping cost function and inventory cost function, the author will make a practical shipping economic analysis towards Maersk AE10 by taking advantage of Maersk internal report from Shanghai Branch.

CHAPTER 5
Shipping Economic Analysis of Maersk AE10

5.1 The Analysis of Optimal Ship Size in Maersk AE10

According to Chapter 4, the author will set Maersk AE10 as an example to analyze the optimal ship size and minimum sailing frequency using the two-objective functions.

Maersk AE10 is an important East Asia –Europe route, which mainly calls Shanghai, Hong Kong, Tanjung Pelepas, Le Havre, Antwerp and Hamburg. Now the containership serving AE10 are mainly around 5468 TEU , which will be definitely changed to larger ships in very near future. The author intends to demonstrate decision-making on the optimal ship size and sailing frequency and analyzing shipping economics for large ships. The total distance per round voyage is 21933 nautical miles.

Shanghai-Hong Kong: 875 nm

Hong Kong- Tanjung Pelepas: 1459 nm

Tanjung Pelepas- Le Havre: 8139 nm

Le Havre- Antwerp: 241 nm

Antwerp-Hamburg: 401 nm

Hamburg-Shanghai: 10818 nm

The study considers four types of large or ultra large ships, involving 5468 TEU ships, which are currently used in AE10, like Nedlloyd Tasman; 7000TEU like Gudrun Maersk which is used in AE2, 8450TEU Maersk Santana which is used in AE6 and the world’s existing largest containership Emma Maersk with 11,000 TEU. The author firstly demonstrates some tables of the basic information of each type of ship. Table 5-1 shows capacity, gross tonnage, draft, service speed, daily capital and operating costs, fuel cost per nautical mile, and fuel cost in port for each type of ship. Secondly, table 5-2 shows fixed and variable port charges, and average cargo handling fee per TEU for each type. Moreover, table 5-3 illustrates cargo flow between any two ports of call. Since the cargo flow between Le Harve and Hamburg is very small, it can be taken out of the consideration. Cargo flows are estimated by the container loading and unloading volumes of AE10 in Maersk internal information in Marketing Department. Besides, the average gross handling rate R_i and port arrival and departure times w_i are 2000 TEU per day and 0.125 day respectively, which are estimated from related data of Shanghai WaiGaoqiao Port.

Table 5-1 Basic Information of Each Type of Ship

Type	1	2	3	4
Typical ship	Nedlloyd Tasman	Gudrun Maersk	Maersk Santana	Emma Maersk
Capacity(TEU)	5,468	7,000	8,450	11,000
GrossTonnage(G.T.)	67,624	93,000	97,612	156,900
Draft(m)	12.7	14.5	15.0	16.0
Service Speed, V_t (nautical miles per day)	600.0	600.0	600.0	600.0
Daily Capital and operating Cost, S_t (US$)	25,413	27,275	28,687	32,000
Fuel Cost per nautical mile, F_t	35.8	43.50	50.50	65.50

(US$)				
Fuel Cost in Port, B_{it} (US$)	149.20	187.60	220.80	280.90

Source: Maersk Line, Shanghai Branch Internal Report 04-06/2006

Table 5-2 Fixed and Variable Port Charges and Average Cargo Handling Fee per TEU for Each Type of Ship

Type	1	2	3	4
Fixed Port Charge, α_{it}	4,141	5,327	6,877	10,220
Variable Port Charge, β_{it}	4,202	5,155	6,245	9,021
Average Cargo Handling Fee per TEU, G_i	62	62	62	62

Source: Maersk Line, Shanghai Branch Internal Report 04-06/2006

Table 5-3 Cargo Flows between Any Two Ports (TEU)

Origin/ Destination	Shanghai	Hong Kong	Tanjung Pelepas	Le Havre	Antwerp	Hamburg
Shanghai	-	0	0	7950	7820	8900
Hong Kong	0	-	0	10160	11320	15700
Tanjung Pelepas	0	0	-	11490	11030	16880
Le Havre	7450	7940	7010	-	0	0
Antwerp	7030	8330	8570	0	-	0
Hamburg	8010	8990	8930	0	0	-

Source: Maersk Line, Shanghai Branch Internal Report 04-06/2006

The results of the trade-off equation, minimum sailing frequency, minimum shipping cost per TEU, and maximum inventory cost per TEU for each type of ship on serving AE10 are shown in table 5-4.

In table 5-4, it shows that the larger ships have the higher advantage of ship size economies on serving AE10 route and the minimum shipping cost per TEU decreases as ship size increases. If the ocean carriers ignore the inventory cost and sailing frequency constrains, they might provide services with the minimum sailing frequency to reduce the shipping costs and obtain the advantage of ship size economies. Let's denote 11, 9, 7 and 5 for T1, T2, T3 and T4's sailing frequency per season (3 months).

Table 5-4 Trade-off Equation, Minimum Sailing Frequency, Minimum Shipping Cost per TEU, and Maximum Inventory Cost per TEU for Each Type of Ship for AE10.

Ship Type	Trade-off Equation	Minimum Sailing Frequency per season	Minimum Shipping Cost (US$/TEU)	Maximum Inventory Cost(US$/TEU)
1	$(AC1^m - 153.615)(AC2^m - 559.575)=19684.3$	11	262.762	739.922
2	$(AC1^m - 156.43)(AC2^m - 559.575) = 36759.0$	9	257.135	924.592
3	$(AC1^m - 158.932)(AC2^m - 559.575) = 41837.3$	7	248.079	1028.882
4	$(AC1^m - 165.021)(AC2^m - 559.575) = 50720.7$	5	242.218	1216.605

Moreover, in reality, that sailing frequency for the liner service generally is weekly and sailing frequency less than fortnightly are commonly regarded as inadequate. The study determines the optimal ship size and sailing frequency that could be possibly chosen by ocean carrier in reality. Those practical results are shown in table 5-5. It shows that the t1 ship is optimal size when ocean carrier would like to provide service frequency equal to or higher than the weekly sailing frequency service. And the shipping companies would choose ship type T2, if they prefer providing 3 sailing frequency per month.

Table 5-5 Practical Shipping Services for the AE10 Route

Sailing frequency per season	Optimal ship size	Shipping cost	Inventory cost
2*3	Infeasible	-	-
3*3	T2	257.135	924.592
4*3	T1	274.750	833.334
5*3	T1	305.033	779.585
6*3	T1	335.317	742.083
7*3	T1	365.601	716.011
8*3	T1	395.885	724.893

From the above analysis, we can safely conclude that the ship size of T1, which is used in reality, is the optimal one for meet the current requirement of cargo flow. When shipping company make choice for the usage of ship, it may take every essential factor into account, which is not only aims at lowering shipping cost, but also provide high quality, high sailing frequency and reliable services.

5.2 Cargo Flow Effect to Maersk AE10

Although the bigger ships, like 9000 TEU or 11,000TEU ships have more advantage of ship size economy, the smaller ships, like T1 are more competitive. However, with the step of increasing cargo flow in Asia-Europe route, the ship size definitely tends to be larger. From the statistics of Far East Freight Conference (FEFC), there would be a 15% increase in box volumes on Asia-Europe services, especially westbound. Based on delivery schedules, the FEFC forecasted that 53 vessels of 6,500teu and larger will enter service on Asia-Europe trade routes this year, compared with 47 in 2006. They also believed that it is inevitable that some boxes would be left on-dock during busy periods, while overall utilization is expected to average 95% in 2007.

Therefore, we can forecast that the current ship size could not satisfy the demand in the near future, which will need some amendment in the practice.

In order for easier analysis, we denote Q^n as changing cargo flow, and suppose the share of cargo flow between two ports is constant. Then, the thesis further studies variation in the trade-off equation, the minimum shipping cost per TEU, and the maximum inventory cost per TEU due to changes in route flows.

Table 5-6 Variations in the Trade-off Equation, Minimum Sailing Frequency, Minimum Shipping Cost per TEU, and Maximum Inventory Cost per TEU for Each Type of Ship for AE10 as Cargo Flow Changes

Ship type	Trade-off equation	Minimum shipping cost (US$/TEU)	Maximum inventory cost (US$/TEU)
T1	$(AC1^m - 153.615)(AC2^m - 559.575) = 26{,}272 + \frac{1.195*10^9}{Q^n}$	262.762	$800.278 + \frac{1.095*10^7}{Q^n}$
T2	$(AC1^m - 156.43)(AC2^m - 559.575) = 29{,}936 + \frac{1.360*10^9}{Q^n}$	257.135	$856.839 + \frac{1.350*10^7}{Q^n}$
T3	$(AC1^m - 158.932)(AC2^m - 559.575) = 32{,}596 + \frac{1.483*10^9}{Q^n}$	248.079	$925.218 + \frac{1.664*10^7}{Q^n}$
T4	$(AC1^m - 165.021)(AC2^m - 559.575) = 13{,}394 + \frac{1.828*10^9}{Q^n}$	242.218	$733.079 + \frac{2.368*10^7}{Q^n}$

In table5-6, it shows that as cargo flow increases, the minimum shipping cost per TEU is independent of cargo flow, and the maximum inventory cost per TEU decreases as cargo flow increases. It implies that the relative economies of different ship sizes do not change as cargo flow varies.

Besides, the optimal ship size of AE10 route with respect to route flow and inventory cost per TEU can be determined using the trade-off equation and the minimum sailing frequency point for each type of ship. When both the inventory cost per TEU and cargo flow are low, the optimal ship size is T1.However, as the increase of either inventory cost or cargo flow, the optimal ship size tends to be become large and changes from T1 to T2,T3 or T4. Therefore, the cargo flow is an important role for shipping companies in ship size decision making and the ship size tends to be larger as cargo flow increases.

5.3 Summary for Shipping Economic Analysis of Maersk AE10

The case study regarding Maersk AE10 route is made to analyze shipping economies for ultra large ships. Feasible solutions for different types of ships and practical statistics solutions in reality are determined. And the optimal ship size and sailing frequency with respect to inventory cost and cargo flow effect are shown. From the result, it shows that if the weekly service is provided, the optimal ship is 5,468 TEU, which is the same as ship currently being used on AE10 in reality. However, it is just the result on the condition of current cargo flow and real situation. With the increase of cargo flow between Asia and Europe, the ship tends to be larger and larger. In fact, Maersk line has already use large ships like Maersk Santana and other ships over 8000TEU into usage of other routes between Asia and Europe. We also can forecast that as the port efficiency increases, the shipping costs of larger ships decreases, the total shipping distance increases, the number of ports of call decreases or the cargo flow is unbalanced, the possibility of using ultra large ships tend to increase. In other words, though the tendency of using ultra large ships is irresistible, the optimal ship size is not the largest ship in current situation. Shipping companies should consider all key factors comprehensively and make the best choice in this crucial decision.

CHAPTER 6 Conclusion

In the current years, the size of containership tends to be larger and larger along with the rapid development of global economy and international transaction as well as the advancement of ship building technology.

After analyzing the current situation and trend for large-scale containerships, the author detailed studies the influential factors of such enlargement, such as increasing cargo flow of global economy, the necessity of economize the transportation costs, the containerization of cargoes, the accelerating function of multi-national companies and development of ship building techniques and ship capability. Besides, the author holds the opinion that although the enlargement of containership gains the scale economies, it still has a lot of limits for its development, like unsatisfied port conditions, lacking of powerful cargo flow, competition from other smaller shipping companies, etc. That is to say, the realization of ultra large containership should be based on many key factors, like shipping distance, port efficiency, number of ports of call and etc. Therefore, in case study of chapter 4 and 5, the author takes all the factors into account and constructs a model to analyze the shipping economies of ultra large ships and determine flows that realizes scale economies.

In fact, the powerful shipping companies, like Maersk, not only aims at lowering shipping costs but also enhancing services to attract more shippers and setting up good image in shipping field. Maersk always enjoy the reputation of high reality, flexible and reliable service in all the corners of the world. The author constructs a two-objective model by individually minimizing shipping cost and inventory costs for decision making on the optimal ship size and sailing frequency for Maersk AE10 for analyzing shipping economies of ultra large containerships, which is different from previous studies in the similar research filed.

In the detailed analysis of Maersk AE10, shipping cost function and inventory cost function are taken into account. Shipping costs include ocean carriers' capital and operating cost, fuel cost, and port charge on serving the route, while inventory costs include costs due to freight waiting to be shipped in a loading port and on a ship along the shipping route. The study derives a relationship equation for exploring trade-off between shipping costs and inventory costs for using different sizes of ships. Based on this, all feasible solutions for the two-objective model are determined, and the optimal ship size and sailings frequency can also be obtained, simultaneously. From the study result, we can safely conclude that although the ultra large ships have the advantage of scale economies, the smaller ships are more competitive on condition that the cargo flow is not so powerful. Just like AE10, the optimal ship size is 5,468 TEU which is currently used in practice nowadays. However, the cargo flow between Asia and Europe will obtain a rapid increase in the next few years from experts' forecast; the ship size tends to be larger and larger in the near future.

The research in enlargement of containership is a complicated and systematic one with lots of related factors. Doe to the limits of time, space and data source as well as lack of experience, the author has not finished all tasks, for instance, the identity of time of data, average loading ratio and opportunity lost of slots studies. Therefore, the topic still has much space for discussion and improvement.

Reference

Baird,A.J. (1999) Container vessels in the new millennium: implications for seaports. *In: Proceedings of the IAME Conference Liner Shipping: What's Next? Halifax, September 13–14,* 141–173

Baird, A.J. and Lindsay, A.J. (1996) Strategic Choice in the Global Container Shipping Industry: *A Resource-Based Approach, IAME '96 Conference,* International Association of Maritime Economists, Vancouver.

Brennan, J.R. (2002) Brave New World, *Containerisation International, 35,* 39-41

Chaug-Ing HSU and Yu-Ping HSIEH (2005) Shipping economic analysis for ultra large containership. *Journal of the Eastern Asia Society for Transportation Studies, 6,* 936 – 951.

China Shipping Week /2006

Cullinane, K. and M. Khanna (1999) Economies of scale in large containerships, *Journal of Transport Economics and Policy, 33(2),* 185-208.

Containerization International 03/2007; 07/2006; 04/2003-05/2004

Cullinane, K. and M. Khanna (2000) Economies of scale in large containership: optimal size and geographical, *Journal of Transport Geography, 8,* 181-195.

Daganzo, C.F. (1991) *Logistics system analysis*. Berlin: Springer-Verlag Press, Heidelberg.

Drewry Shipping Insight 03/2007; 03/2006

Economics of Tramp Shipping 9/2004

Frankel, E.G. (2002) New generation container terminal technology, *Port Technology Journal*, *Edition 15, Section 1*.

Fremont, A. and Soppe, M. (2003) The Service Strategies of Liner Shipping Companies, *Research Seminar: Maritime Transport, Globalisation, Regional*

Integration and Territorial Development, Le Havre.

Gilman, S. (1999) The Size Economies and Network Efficiency of Large Containerships, *International Journal of Maritime Economics*, *(1)*, 1.

Hall, R. W. (1987) Direct versus terminal freight routing on a network with concave costs, *Transportation Research B, 21(4)*, 287-298.

Jansson, J.O. and Shneerson, D. (1987) *Liner shipping economics.* London: Chapman and Hall.

Jonathan Roach.(2005) The Development of world container fleets, *Containerization International, 2005(6),* 5-6

Lim, S.M. (1998) Economies of scale in containershipping, *Maritime Policy and Management*, *25(4),* 361-373.

Maersk Line, Shanghai Branch Internal Report 04-06/2006

McLellan, R.G. (1997) Bigger vessels: how big is too big? *Maritime Policy and Management*, *24(2),* 193-211.

Midoro, R. and Pitto, A. (2000) A Critical Evaluation of Strategic Alliances in Liner Shipping, *Maritime Policy and Management*, *27,* 31-40.

O' Mahony H. (1998) *Opportunities for container ports: a cargo system report*. London: Cargo System

Port 01/2005

Robinson, R. (1998) Asian hub/feeder net: the dynamics of restructuring, *Maritime Policy and Management*, *25(1),* 21-40.

Ryoo, D.K. and Thanopoulou, H.A. (1999) Liner Alliances in the Globalisation Era: A Strategic Tool for Asian Container Carriers, *Maritime Policy and Management*, *26,* 349.

Shipping Intelligence 05/2004

Slack, B., Comtois, C. and Sletmo, G. (1996) Shipping Lines as Agents of Change in the Port Industry, *Maritime Policy and Management*, *23,* 289-300.

Slack, B., Comtois, C., McCalla, R.J. and Guy, E. (2001) Global Reach: The Evolving Pattern of Container Shipping Networks, *paper presented at World Conference o*

Transport Research, Soeul, July 2001.

Van Slobbe, R. (2002) Larger Volumes, Increasing Scale, Environmental Aspects and Road Congestion Require Intermodal Solutions, *ITMMAPS-conference*, Antwerp.

Wijnolst,N. (2000) Ships, larger and larger: containerships of 18,000 TEU: impacts on operators and ports. *Dynamar Liner Shipping 2020 Workshop, 19th May*, 13–29.

Wang, J. (2003) "Port Governance in China, A Review of Policies in an Era of Internationalising Port Management Practices," *Transport Policy*, forthcoming.

Yap, W.Y., Lam, J.S.L. and Notteboom, T. (2003) "Developments in Container Port Competition in East-Asia," *Proceedings of IAME 2003 Conference*, International Association of Maritime Economists, Busan (South Korea), 715-735.

Zhen Louxian(2005) Analysis on the advantages and disadvantages of large scale trend for containership. *Navigational Engineering, 167,* 79-80

Zhuhua (2001) The influence of large international containership on the world's container port Development. *Journal of SSS, 24(1),* 46-51

www.snet.com.cn