CYPRUS UNIVERSITY OF TECHNOLOGY

FACULTY OF MANAGEMENT AND ECONOMICS

Dissertation

ECONOMIES OF SCALE AND OPTIMAL SIZE SHIP IN LNG CARRIERS

Prokopis Appios

Limassol 2013

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Supervisor Professor
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ABSTRACT

The aim of this research is to analyze and interpret the results of the total costs required in shipping LNG through five different routes. Using a mathematical model, which calculates the total cost per day at sea for LNG vessels, we drew conclusions on which size of LNG ship is most suitable for each route in creating economies of scale. In earlier years, the optimal ship was not determined accurately, leading to unprofitable choices and diseconomies of scale. However, due to the globalization of today's' markets, shipping companies try to gain competitive advantage by selecting the most suitable vessel in order to create economies of scale. The selection of the optimal ship is determined by the ship's size, trip duration, capital costs, sailing speed and the demand of LNG at the import country. The empirical results show that the optimal ship for each route is the Q-Max but as the speed decreases, the choices change.

By examining the first route, Indonesia-Taiwan, we found that the optimal ship has a capacity of 155.000 m^3, sailing with a speed of 16 knots. Moving on to the next route Qatar-Belgium, which is the second longest trip among the analyzed routes, the most suitable ship has a capacity of 216.000 m^3 sailing with either 16 or 17 knots. The third route, Qatar-US is the longest trip as it requires between 22 and 24 days for its completion. It is obvious that for this route the preferred ship is the Q-Max sailing with a speed of 19 knots and creating the biggest economies of scale as the variation in costs for this ship is greater in contrast to the other ships sailing with the same speed. The speed is subject to fluctuations based on the weather conditions and on the ship owner's decision. The next route, Algeria-France, is the shortest trip and thus the optimal size ship is the smallest one with a capacity of 75.000 m^3 and speed of 16 knots. Although this ship bears the biggest costs, it can be used in spot markets in order to benefit from the increasing rates from this type of emerging market. The final route, Nigeria-Spain, we chose the ships with capacity of 130.000 m^3 and 145.000 m^3, both sailing with a speed of 16 knots. The Q-Type vessels were not chosen for this trip, even though they had smaller capital costs than the selected ones. My recommendation to the interested parties is to use this type of mathematical model in order to choose the most cost-effective vessel for their voyages. Finally, in order for a more in depth analysis of this study, a selection of further research points is provided.

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ABBREVIATIONS

LNG = Liquefied natural gas

HSFO = High sulfur fuel oil

HFO = Heavy fuel oil

mtpa = Million tons per annum

btu = British thermal unit

TCE = Time charter equivalent

BOG = Boil- of gas

DFDE = Dual fuel diesel electric

MT = Million tones

HEEL = It is the minimum quantity of liquefied natural gas remained in an LNG vessel after unloading at the LNG facility.

Mts = Metric tones

m^3 = cubic meters

T/m = Tons per miles

nm = nautical mile

dwt = deadweight tonnage

INTRODUCTION

Over the last few years, natural gas has been one of the major sources of fuel, with benefits due to the increased demand. It is a reliable and efficient source of energy that is clean and has lower emission than other fuels when it burns. LNG carriers are used to transport liquefied natural gas around the globe. They have been in widespread commercial service since the late 1970s, but only in the 21st century have they become an integral part of the global energy market - more than 80% of the LNG carriers currently in use were built after 2000 despite extremely low scrappage rates. Today, significant natural gas discoveries at a distance from demand markets, combined with strong natural gas needs in East Asia, are driving investment in the LNG carriers needed to join supply and demand. Typically, investment in LNG carriers is determined by the rate at which LNG liquefaction terminals are developed. However, due to a range of factors, it expected that there will be a very strong growth in capital expenditure on LNG carriers over the next 10 years. Moreover, liquefaction terminals will also see strong investment over the next 10 years and will drive heavy capital expenditure on LNG carriers between 2013 - 2023. Although the global economic crisis hit the LNG industry, the shipping sector managed to recover quickly. The dramatic increase of competition has lead the ship-owners to create economies of scale by finding the optimal ship in order to minimize the costs and maximize their profits. The optimal ship for a route is defined as the ship that carries cargo of a given composition at the lowest cost per cargo ton at sea and in port.

The main objective of the research is to find the optimal ship for different routes that provides the benefits to create economies of scale. The rest of the paper is structured as follows: The first chapter gives general information with regards to the definition of LNG and some historical facts. The second chapter analyses the LNG market; types of carriers, main engine types, capacity of LNG through the years and the spot rates. Chapter three explains the different stages of the LNG value chain, shows the LNG trade volume, the exports and imports of LNG. Chapter four analyzes the LNG ship costs by presenting an example of a two-case scenario. The fifth chapter gives a brief explanation of economies of scale and optimal size ship. Chapter six examines in depth the theory regarding economies of scale. Chapter seven is concerned with analyzing the data through five different routes. Chapter eight sets out the theory of the empirical results, which is followed by analyzing each route and choosing the optimal ship size for each one. The last chapter provides a general conclusion, sets out the limitations of this paper and probable recommendations for further research.

CHAPTER 1: BACKGROUND INFORMATION

1.1 What Is LNG?

Liquefied natural gas (LNG) is natural gas that has been cooled to the point that it condenses to a liquid, which occurs at a temperature of approximately -256 °F (-161°C) and at atmospheric pressure. Liquefaction reduces the volume by approximately 600 times, thus making it more economical to transport between continents in specially designed ocean vessels. On the other hand, traditional pipeline transportation systems would be less economically viable and could be technically or politically infeasible. Thus, LNG technology makes natural gas available throughout the world (Michelle Michot Foss, 2012).

1.2 LNG History

In 1959 the Methane Pioneer, a converted dry cargo ship, was the first ship that carried about 5,000 m^3 of LNG. This ship was too small and too slow to be economically feasible. Five years later, in 1964, the first large-scale liquefaction plant was constructed at Arzew in Algeria with a capacity of 1.1 mtpa. In the period 1973-1983, a period of crisis existed and this created general uncertainty in future gas export prices. By 1983 a lot of ships were laid up, especially a third of the LNG tanker fleet. However, in the 1990's investor's confidence recovered and "the business got a new lease of life" (Martin Stopford 3rd edition 2009). In 2000 there was an exponential growth in the LNG fleet with increasingly larger ship sizes. The number of liquefaction and re-gasification plants increased dramatically. In 2007-2011 ambitious projects for new LNG production surfaced from Qatar, Russia and other countries, with large orders investigated for new capacity vessels. From the period 2008-2009 many ships were laid-up, and LNG production projects were not ready in time, which resulted in massive short term overcapacity of tonnage. In 2010 until 2012, most of the delayed projects were now under construction. Employment for LNG tankers increased while charter rates were surging. An enthusiasm from the shipping world was created and this set in motion the requirement for new ship building.

CHAPTER 2: LNG MARKET

2.1 Types of LNG Carriers

Liquefied natural gas (LNG) is carried at its boiling point, being –162°C. LNG containment systems have developed considerably. Throughout the history of LNG transportation there are many new ideas and projects for the transport style as well as the design for this type of ships. However in the last 50 years, two main types of LNG carriers have been defined. These two major types are the Membrane design and the Moss sphere design ships which are shown in the figures below.

Figure 1: Membrane Type

Source: **http://www.slideshare.net/capmanconsult/lng-report-table-of-contents**

Figure 1 shows the membrane tank concept. The cargo tanks are integrated into the double hull of the ship, conforming to its contours. They were developed during the 1960's and they use a thin flexible metal "membrane" which is in contact with the cargo. The system has the characteristics of a sandwich, where the cargo presses on the membrane. Also, insulation material presses on the membrane and at the end, everything leans on the ship's inner hull.

As per figure 2, the first LNG carrier with spherical tanks was the "Norman Lady" (87.600 m^3), which was built in Norway in 1973. These carriers had storage tanks that were made of 9% nickel-steel. These were quickly replaced by aluminum tanks, which were proved to be more resistant to mechanical stress and rupture, and it was easier to correctly form them into a sphere. These storage tanks have an insulation which makes possible only around 0,10 % of boil-off. The tanks are mostly insulated with several different layers, some of which are; glass wool, aluminum "foil" (vapor permeable) and various expansion foams. The "storage" in which the tank is located is considered to be a secondary barrier and this area is usually inert or under dry air.

Until 2000, 54% of all LNG carriers were spherical, primarily because Japanese shipyards had a license for the construction of only this type of ships, and since at the same time, the Japanese are the largest LNG importers, this was one way to enter the very strong market. Today up to 80% of trading ships are Membrane type. The Membrane containment system is today considered more favorable due to more capacity compared with spherical ships of similar size, Suez Canal toll advantages, faster cool-down of tanks and lower construction costs.

Figure 2: Moss Type

Source: http://www.meisei-kogyo.co.jp/en/dannetsu/lng_lpg/

2.2 Main Engine Types

Dual Fuel Diesel Electric & Steam Turbine

In this research we will endeavor to analyze the (DFDE) propulsion system in order to use it as a primary assumption and reach some conclusions. Traditional LNG ships were using the boil of gas as a fuel source for the boilers along with heavy fuel as required. However in recent years, medium speed diesel engine technology has been developed so that these units can now run on dual fuels, gas or liquid. The Dual Fuel Diesel Electric system improves fuel efficiency, increases the carrying capacity of cargo and reacts quickly (Gilmore et al., 2005).

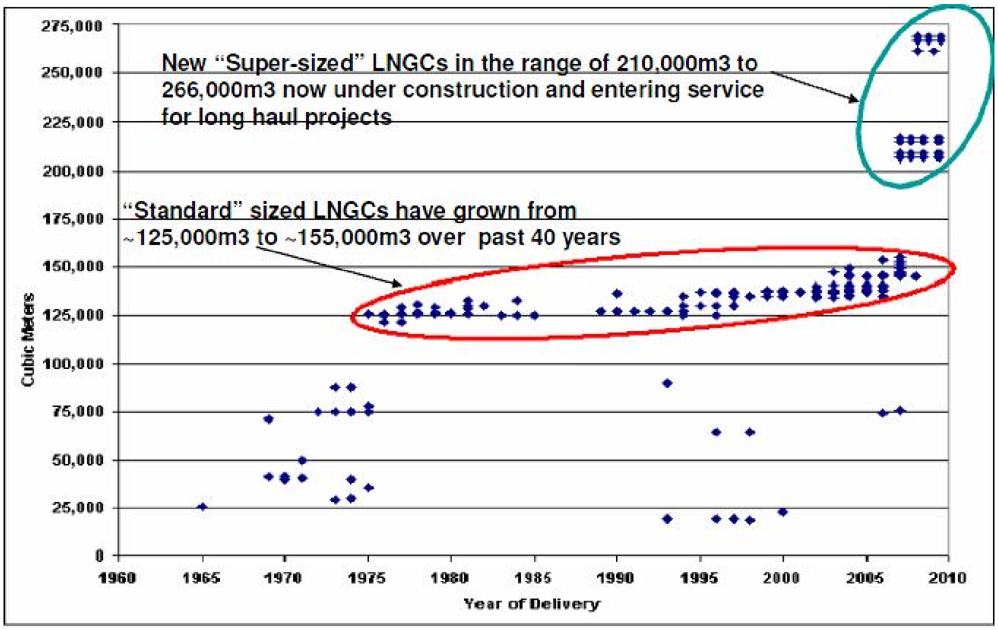
2.3 LNG Capacity through time

As illustrated in figure 3, in 1965 the capacity of the LNG ships was only 25.000 m^3. Between 1970 and 1975, the capacity reached the level of about 100000 m^3. Moreover, the standard sized LNG ships have grown from 125.000 m^3 to 155.000 m^3 over the past 40 years. From 2010 until today, new sized LNG ships are now under construction and will be entering service for long haul projects. These new super sized ships have a capacity of 210.000 m^3 to 260.000 m^3 and Qatar-Gas has pioneered the development of these two new classes of liquefied natural gas. These new vessels have many innovative features to maximize cargo deliveries and to ensure the highest levels of safety and reliability, some of which include: Twin engines and shafts; to ensure maximum propulsion safety and reliability with reduced environmental footprint and twin rudders; to ensure safety of navigation and maneuverability in confined waters.

Furthermore, these ships are more efficient than traditional ones as they produce 30% lower overall emissions. Cargo re-liquefaction plants will return cargo boil off to the cargo tanks and therefore maximize the cargo delivery at the discharge port. These vessels are currently being constructed at three shipyards in South Korea: Hyundai

Heavy Industries (HHI) at Ulsan, Samsung Heavy Industries (SHI) on Geoje Island and Daewoo Shipbuilding & Marine Engineering (DSME), also on Geoje Island.

Figure 3: Capacity of LNG

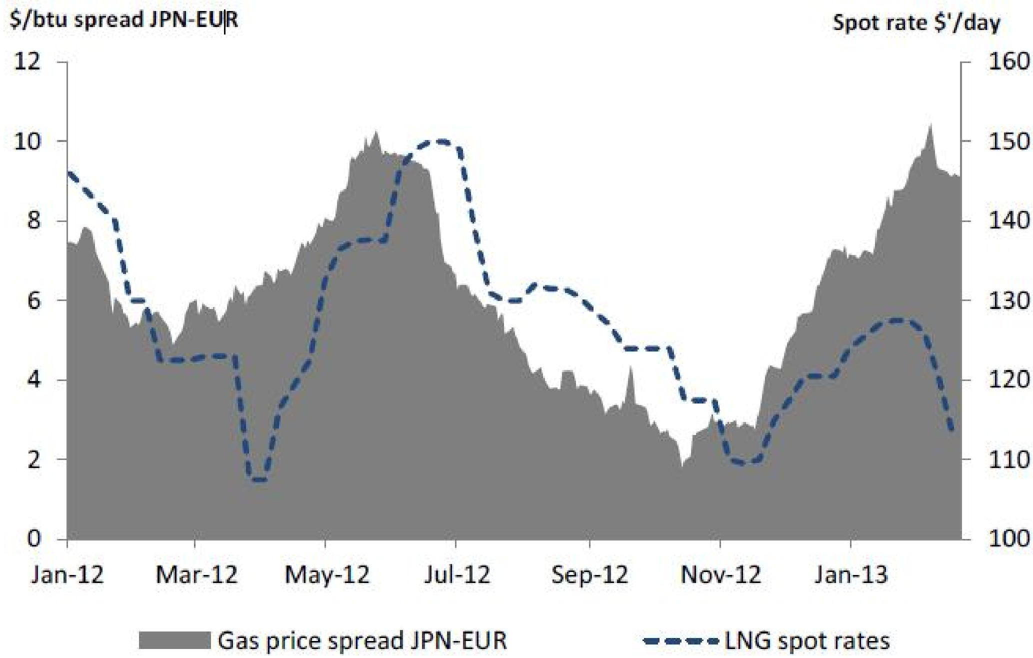


Source:http://higherlogicdownload.s3.amazonaws.com/SNAME/1dcdb863-8881-4263-af8d-530101f64412/UploadedFiles/c3352777fcaa4c4daa8f125c0a7c03e9.pdf

2.4 LNG Spot Rates

As we can see from figure 4 below, the LNG spot rates were decreasing dramatically between January 2012 and April 2012. At that point, the LNG spot rates reached the bottom price of about $105 per day. After a few years of rapid growth, the LNG supply fell in 2012 due to Asia's warm weather which led to reduced demand in this region. This issue created significant delays in project start-ups as well as to problems in existing plans. The current spot rate is nearly $115 per day (Pareto Securities Equity Research, 2013).

Figure 4: Gas price spread vs LNG spot rate



Source:http://www.cefor.no/Documents/About%20Cefor/2013/Jonas%20Kraft%20-%20Shipping%20market%20outlook.pdf

CHAPTER 3: LNG VALUE CHAIN, TRADE, EXPORTS AND IMPORTS

3.1 LNG Process

Figure 5 shows the major stages of the LNG value chain, excluding pipeline operations between the stages, consist of the following:

1) Exploration to find natural gas in the earth's crust and production of the gas for delivery to gas users. Most of the time natural gas is discovered during the search for oil.

2) The liquefaction process can be designed to purify the LNG to almost 100 percent methane. The liquefaction process entails cooling the clean feed gas by using refrigerants. The liquefaction plant may consist of several parallel units ("trains"). The natural gas is liquefied for shipping at a temperature of approximately -256^{o}F. By liquefying the gas, its volume is reduced by a factor of 600, which means that LNG at -256^{o}F uses 1/600th of the space required for a comparable amount of gas at room temperature and atmospheric pressure. LNG is a cryogenic liquid. The term "cryogenic" means low temperature, generally below -100^{o}F. LNG is clear liquid, with a density of about 45 percent the density of water.

3) Shipping LNG tankers are double-hulled ships specially designed and insulated to prevent leakage or rupture in an accident. The LNG is stored in a special containment system within the inner hull, where it is kept at atmospheric pressure and -256ºF. The main focus of this research is going to be based on this part of the LNG value chain.

4) Storage and Re-gasification: To return LNG to a gaseous state, it is fed into a re-gasification plant. On arrival, at the receiving terminal in its liquid state, LNG is pumped first to a double-walled storage tank, similar to those used in the liquefaction plant, at atmospheric pressure. It is then pumped at high pressure through various terminal components where it is warmed in a controlled environment. The LNG is warmed by passing it through pipes heated by direct-fired heaters, or seawater, or through pipes that are in heated Liquefaction that also provides the opportunity to store natural gas for use during high demand periods in areas where geologic conditions are not suitable for developing underground storage facilities.

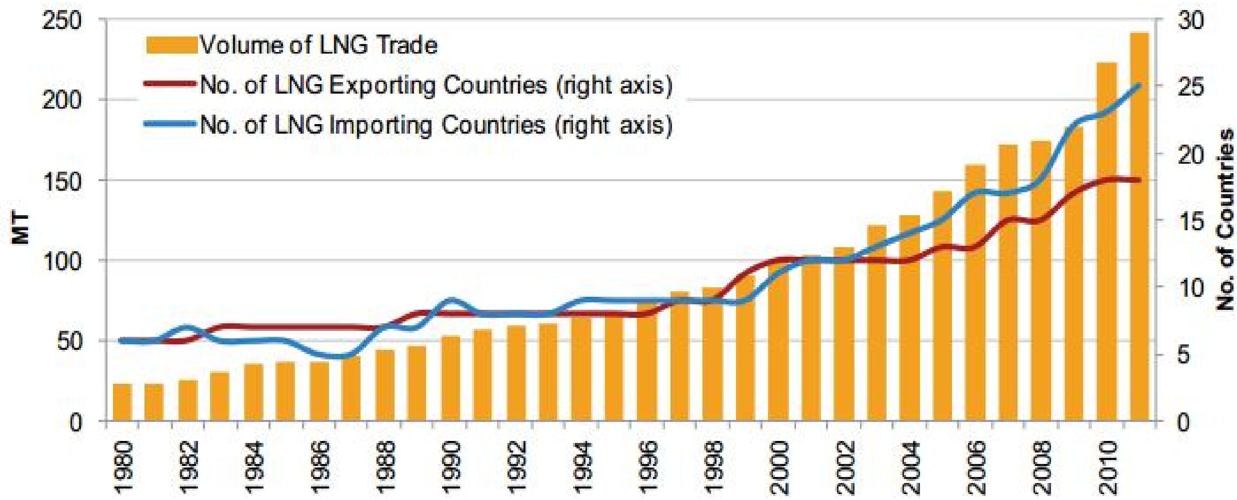
Figure 5: LNG value chain

Source: http://ebookbrowse.com/introduction-to-lng-update-2012-pdf-d360653959

3.2 LNG trade

Figure 6, illustrates the volume of LNG trade in million tons for 21 years starting from 1980 to 2011. Generally there was an upward trend in this graph. The volumes of LNG trade reaching a peak of 241 mts in 2011. Also the volume grew from 159.1 mts to 241mt from 2006 to 2011. This growth came from the countries that had historically been LNG exporters, but generally came from the Qatar supply. On the other hand, the demand growth came from existing LNG importers. This growth occurred from the increase of volume in Japan and the utmost higher imports to China, India and the United Kingdom. Also, the dramatic increase in demand pushed the volume of LNG trade to high levels arising from the natural catastrophes and the disaster at the Fukushima nuclear power plant that hit Japan in March 2011.

Figure 6: LNG trade volumes

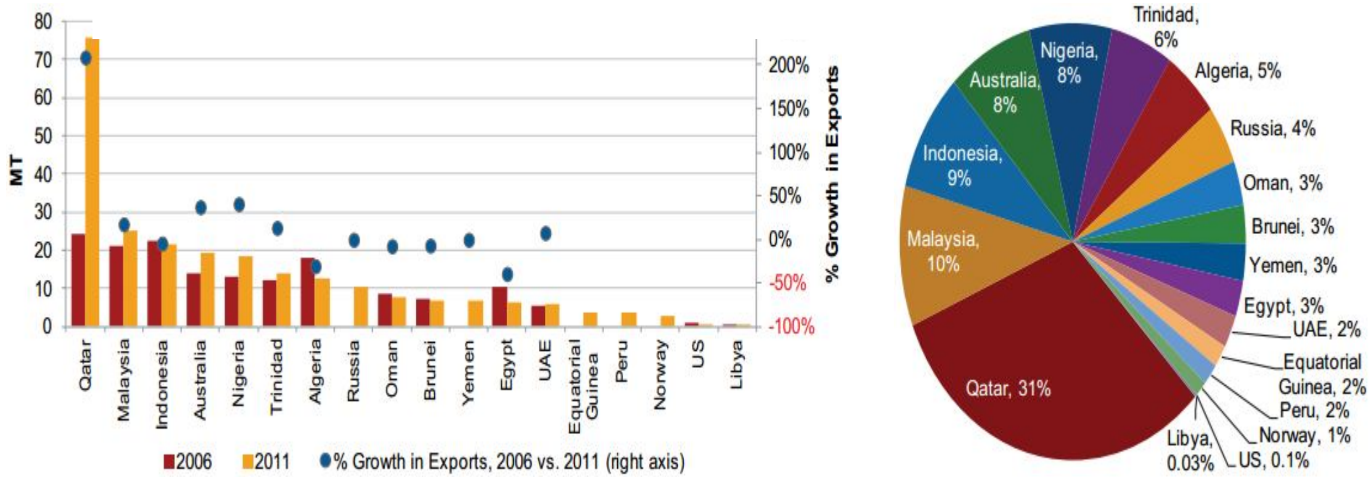


Source: www.igu.org

3.3 LNG Exports

As we can see from the below figures, 19 countries were the main exporters in the world by the end of 2011. Qatar was the largest exporter in the world, as it has 31% of the global supply in 2011, and continue to be today in 2013. Qatar had a growth of about 200% from 2006 to 2011. The other countries have a smaller rate of increase than Qatar, starting from 0,03% to 10%. Moreover, Australia has planned to build liquefaction capacity in order to affect Qatar's capacity. In addition five countries namely Belgium, Brazil, Mexico, Spain and the United States were re-exporting LNG, which previously imported from another sources (International Gas Union, 2011).

Figure 7: LNG exports

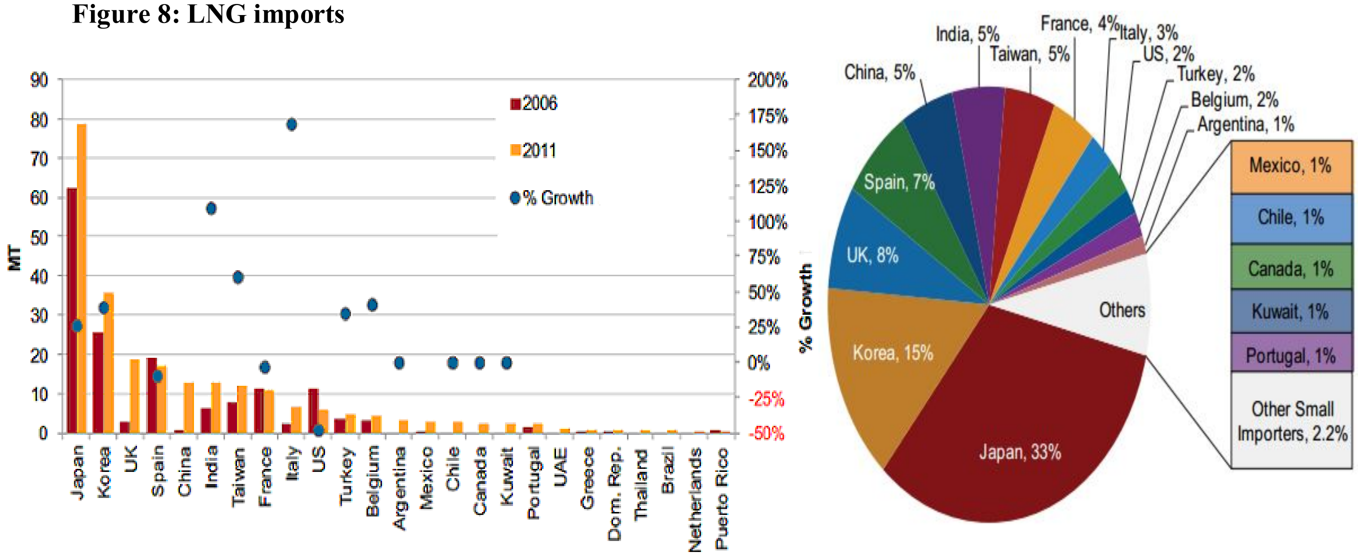


Source: www.igu.org

3.4 LNG Imports

The below figures relate to the LNG imports by country in million tons from 2006 to 2011. The pie chart also illustrates the percentage of imports in LNG that each country has. The biggest LNG importer in the world was Japan since 2011. Also, today in 2013, Japan remains the largest importer in the world. In 2011 as we can see and from the figures above, Japan holds a substantial rate of 33%, which is about 62 MT. Korea was the second importer in the world, with a rate of 15% in 2011. Also, from 2006 to 2011 it had an increase of 25 percent, while Japan had an increase of 50%. Additionally in Europe, Spanish demand fell due to the country's increased reliance on renewable energy and domestically produced coal. In France, the marginal 3% decline reflects rather flat LNG imports over the period. In the United States, rising unconventional gas supply kept gas prices low and made LNG unattractive (International Gas Union, 2011).

Figure 8: LNG imports



Source: www.igu.org

*"Small Importers" includes imports to the United Arab Emirates (Dubai), Greece, the Dominican Republic, Thailand, Brazil, the Netherlands and Puerto Rico. Each of these countries imported less than 1% of global LNG volumes in 2011.

CHAPTER 4: ANALYSIS OF LNG SHIP COSTS

4.1 Example

The scenarios below show how total costs decline as the ship's speed decreases when she uses only HFO and Gas Mode.

LNG Capacity (cubic meters) consumption

177.000 m^3 (we have new buildings at STX) STX MAN (This is diesel electric)

(Speed 19,5 knots) – 125 mts of HFO / 1,46 mts DO

145.000 m^3 (to be main) / ME: steam turbine

(Speed 19 knots) -165 mts HFO

75.000 m^3 (to be main) /

ME: steam turbine (17 knots) - 125 mts of HFO

In LNG vessels, fuel consumption compared with the HEEL/LNG consumption, has a very important role in operating the vessel. We prepared a voyage calculation below only on bunkers consumption and TCE, in order to prove the different bunkers consumption for a voyage from Rosario (last discharge port) - Lisbon (next loading port) / Distance: 5.321 nm.

==================================

All the below scenarios are based on a ship capacity of 145.000 m^3.

4.1.1 Scenario A: HSFO consumption only

A.1) The ship's speed is 17 knots and the duration of this voyage is 13,042 days.

As derived from the following calculations the total cost is $1.426.794,8.

Theoretical consumption HFO: 13,042 x 115 mts = 1.499,83 mts

Cost HFO : 1499,83 mts x $660 = $989.887,80

Cost (time on passage) : 13,042 days x TCE $33.500 per day = $436.907

Total cost : $989.887,80 + $436.907 = $1.426.794,8

A.2) When the speed is reduced to 13,5 knots, the steaming time is extended to 16,423 days. Due to the fact that for the first 12 hours (half day), the vessel uses only gas, HFO will be only used for the remaining 15,923 days. (16,423 days – 0,5 days). From the following calculations the total costs is reduced to $1.285.813,1 as the speed reduction creates economies of scale. Thus the savings from this speed decrease is $14.981,7.

Expected consumption HFO : 15,923 x 70 mts = 1.114,61 mts

Cost HFO = 1.114,610 mts x $660 = $735.642,60

Cost (time on passage) : 16,423 days x TCE $33.500 = $550.170,5

Total cost : $735.642,60 + $550.170,5= $1.285.813,1

Savings: if the vessel proceeds with eco speed 13,5 knots :

$1.426.794,8 - $ 1.285.813,1 = $ 140,981,7

4.1.2 Scenario B: HSFO + HEEL consumption

B.1) In this scenario when the ship sails with the speed of 17 knots, the steaming time required is 13,042 days (Dual fuel: 6,042 days + HFO fuel only: 7 days).

B.1.1) As the ship uses both HFO and HEEL, we calculate the cost for each fuel separately. Regarding the calculations below, the cost of HFO is $109.662,30 and the cost of HEEL is $111.021,75.

Dual fuel : 6,042 days

Expected consumption HFO : 6,042 x 27,5 mts = 166,155 mts.

Cost HFO = 166,155 mts x \$660 = \$109.662,30

Expected consumption HEEL : 6,042 x 175 m^3 = 1057,35 m^3

Cost HEEL = 1057,35 m^3 x \$105 = \$111.021,75

B.1.2) When the ship burns only HFO, the cost is \$531.300,00.

HFO fuel only: 7 days

Theoretical consumption HFO: 7 x 115 mts = 805,00 mts

Cost HFO = 805,00 mts x \$660 = \$531.300,00

By combining the costs found in B.1.1 and B.1.2 above the total voyage cost is \$1.188.891,05.

Cost bunker (HEEL + HFO) : \$109.662,30 + \$111.021,75 + \$531.300,00 = \$751.984,05

Cost (time on passage) : 13,042 days x TCE \$33.500 per day = \$436.907

Total cost: \$751.984,05 + \$436.907= \$1.188.891,05

B.2) The speed here is reduced to 13,5 knots leading to an increase in the steaming time to 16,423 days. (Gas mode: 9,423 days + HFO fuel only: 7 days)

B.2.1) As the ship burns only gas the fuel cost is \$173.147,625

Gas mode: 9,423 days

Expected consumption HEEL: 9,423 x 175 m^3 = 1.649,025 m^3.

Cost HEEL = 1.649,025 m^3 x \$105 = \$173.147,625

B.2.2) The HFO cost is \$323.400,00 as calculated from the below equations.

HFO fuel only: 7 days Expected consumption HFO: 7 x 70 mts = 490,00 mts

Cost HFO = 490,00 mts x \$660 = \$323.400,00

By adding the cost found in B.2.1 and B.2.2 above, the total cost is $1.046.718,125. Economies of scale are also created giving a saving in costs of $142.172,925.

Cost bunker (HEEL + HFO) : $173.147,625 + $323.400,00 = $496.547,625
Cost (time on passage) : 16,423 days x TCE $33.500 per day = $550.170,5
Total cost : $496.547,625 + $550.170,5 = $1.046.718,125
Saving of Bunkers: if the vessel proceeds with eco speed 13,5 knots
: $1.188.891,05 - $1.046.718,125 = $142.172,925

Conclusion:
=========

Upon completion of discharging operations in Rosario, vessel to be ordered to proceed to Setubal with eco speed 13,5 knots in dual fuel mode (heel required 1649,025m^3).
Expected fuel economy: $1.426.794,8 (speed 17/only HFO) - $1.046.718,125 (speed13,5/Gas-mode)=$380.076,8

Thus the Time charterers to be requested to provide heel on this passage upon completion discharge operation in Rosario. Quantity of required heel is 1.649,025 m^3.

CHAPTER 5: LITERATURE REVIEW IN ECONOMIES OF SCALE AND OPTIMAL SHIP SIZE

Lee and Steedman (1970) analyze the economies of scale in the bus transportation sector. The data used in this research were taken from the Annual Summary of Accounts and Statistical Information 1967. After analyzing these, they created some ratios which they used as dependent and independent input variables. Using logarithmic equations between these variables, they found the optimal bus operation.

Kirby (1986) presents a conceptual framework in order to analyze the airline's scale of operations. An econometric model is estimated based on the economic theory. In this paper, the author finds that the estimates create substantial economies of scale in load factors, aircrafts size and stage length.

Cullinane and Khanna (2000) quantify the economies of scale in operating large container ships. They find that cause and effect has a very strong mathematical relationship and so it was included in their model. They said that "In shipping, the time taken on a voyage and the distance travelled on that voyage are two caused factors which have the strongest effect on cost". In addition, they made some assumptions and create a function like related price to capital cost, initial capital cost plus crew cost, fuel consumptions related to engines etc., in order to find the total shipping cost per TEU. The authors recognized that for the Europe – Far East and trans-Pacific liner routes, the optimal ship size is beyond 8000 TEU and for the shorter Transpacific routes the optimal size ship is between 5000 and 6000 TEU.

Daniel et al., (2003) examine economies of scale and density in urban rail transport. They have used 17 rail systems in cities worldwide. So, they outline a mathematical and economical model in order to find economies of scale. Moreover, they find that costs are correlated by large fixed components. Finally they have created a methodology that makes inter-firm comparisons on a more even basis by choosing the sources that give an increase in variation of productivity.

Kassembe and Gang (2013) investigate the economical limit for the ships increase in size. The theory of economies of scale can be used to find the optimal size in bulk carrier. The authors use a mathematical modeling based on vessel costs and ship size. The main keywords that are used in this paper are optimal size ship, voyage length, ship unit cost and maximum optimal ship size. The authors recognize that the optimal ship size is the ship with a capacity of 340,000 dwt and if the owners use optimal ships with size above the maximum size, they cannot create positive cash flows in their business.

By appreciating all the research discussed above, and based on these, we are going to create a mathematical model in order to achieve economies of scale for the data of this research.

CHAPTER 6: ECONOMIES OF SCALE

6.1 The theory of Economies of scale

Economies of scale apply in cases where as output increases, long-run average costs tend to fall. The two main forces driving this assumption in the production process of a firm are specialization and division of labor and secondly, technological factors. Generally, larger firms have more opportunities for specialization and labor division. The advantages of economies of scale are not very feasible in the short run. However, in the long run, the firm will be able to experience large gains by fully optimizing both the workers and the equipment at the same time. One technological element that affects economies of scale is the fact that by expanding the operations, new ways of cost reduction are introduced, for example automation devices. Another technological factor is that the proportionate cost of installing a large machine is less than the cost of a smaller machine.

The idea of economies of scale has given the impression that a firm is going to experience economies of scale at some point, without even being controlled by the firm. Still, managers are in a position to affect the output, since they choose the size of the firm and thus the extent of its operations. "The manager's choice of firm size is often subject to a great deal of uncertainty. Firm management sometimes makes decisions that turn out to be incorrect" (Maurice and Thomas, 1995).

"Economies of scale give countries an incentive to specialize and trade even in the absence of differences between countries in their resources or technology". Where there are economies of scale, by doubling the inputs to an industry, the industry's production is more than doubled. In order to analyze economies of scale based on the market structure, we have to decide how to increase the production in order to reduce the average costs. Two types of economies of scale are recognized by the author; external economies of scale and internal economies of scale. External economies of scale arise where there is a direct dependency between the cost per unit and the size of the industry. In this type, dependence on the size the firm is not necessary. Internal economies of scale arise when the cost per unit is dependent on the size of the firm but not necessarily the size of the industry. Large firms can't take advantage of external economies of scale, since a market structure with external economies of scale includes only small and perfectly competitive firms. On the other hand, a market structure consisting of large and imperfectly competitive firms, can take advantage of internal economies of scale. In any case, both types are important in international trade (Krugman and Obstfeld, 2006).

The above theories are used in this research in order to help us understand the economies of scale created in shipping, especially in the LNG sector.

CHAPTER 7: METHODOLOGY - DATA ANALYSIS

All the ship-owners want to minimize the cost for each additional cargo. In this paper we are going to find the optimal ship for different routes in order to create economies of scale. First we find the shipping costs for specific ships and then we reduce the speed in order to find the change in shipping costs per day. So relying on the literature reviews, a mathematical model is created. The formula that we use to make our calculations is shown below (Janson and Shneerson, 1982). In order to be more accurate, the mathematical equation below is converted so as to fit to the research's input data.

$$\text{Cost per m}^3 \text{ per day} = \left(\sum_{i}^{n} fi(s) / Hi(s) \right) / (D)$$

Total cost at sea, TC $= \sum_{i}^{n} fi(s)$ including variable cost and operating cost

Variable costs = HFO+ LNG (boil-off rate) + Suez Canal costs (depend from the currency)

Operating costs = (Manning, Insurance, Repairs and Maintenances)

Hi= remaining hauling capacity for each ship

D= distance (miles/speed*24)

By this formulation we make the following assumptions, which are based on data received from shipping companies:

- Each ship uses 10% LNG and 90% HFO
- All ships are sailing with 19 knots, except for the smallest ship that sails with 17 knots
- Each ship can load 95% of her capacity

The daily cost at sea can be transformed to a cost per m^3 as follows. We multiply the percent of boil of rate by the capacity and then multiplied again by 10%. As a result the capacity of the vessel will be reduced at the end of the route. The difference between the initial capacity and the final one is multiplied by the price of LNG. So we find the cost per dollar using the boil-off rate. In addition we multiply the mts of HFO per day that the ship burnt (consumption) by the price of HFO and then multiplied again by 90%. So we find the total cost per dollar using the fuel oil that the ship burnt. Also we add up all the above calculations with operating costs and then divide by the hauling capacity that the ship has at the end of the route (m^3). This gives us the total cost per cm at sea. Then we divide the total cost per cm at sea by the distance and this calculation gives us the total cost per day at sea.

In this research we analyze the following routes and variables:

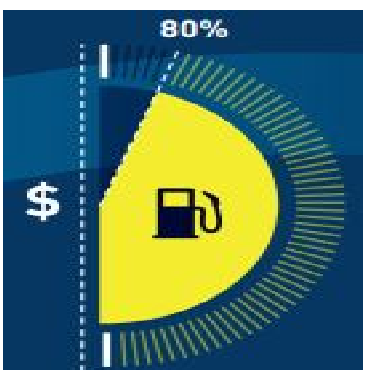
Routes	Bunker price
• Indonesia – Taiwan (Bontag – Yang An)	$633
• Qatar – Belgium (Rar Laffan- Zeebrugge)	$637
• Qatar – US (Ras Laffan – Lake Sharles)	$637
• Nigeria – Spain (Bonny-Cartagena)	$716
• Algeria- France (Arzew – Fos)	$661

Table 1: Formula's constant inputs

Capacity (m^3)	Consumption (tons)	Initial speed (knots)	Boil-off rate (%)	Operating costs ($)	Lng price ($)
266.000	145	19	0,14	20.000	105
216.000	137	19	0,13	18.500	
155.000	140	19	0,15	16.000	
145.000	165	19	0,15	16.000	
130.000	168	19	0,15	16.000	
75.000	125	17	0,15	15.000	

7.1 Fuel Consumption

Figure 9: Fuel cost

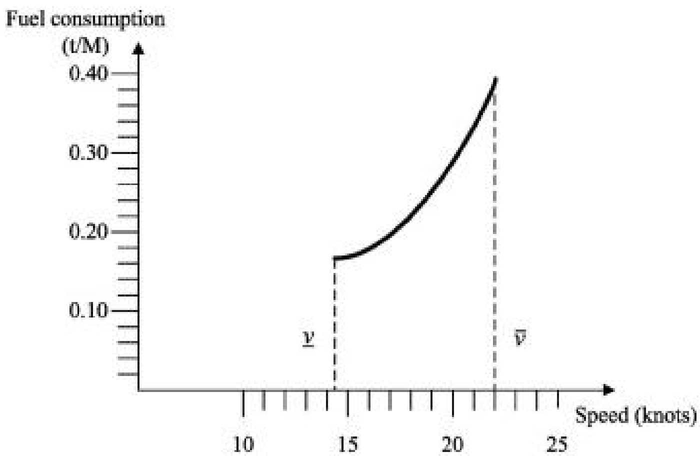


Since the bunkers costs cover 80% of the ship's total costs, by consequently reducing fuel costs, this might have a major impact on the competitiveness between the ships' owners. For this reason, in our analysis we are going to reduce the speed gradually for each ship in order to achieve lower costs.

Source: http://www.lngmarineevent.com/pdf/LNGInfographic.pdf

From the details in figure 10 and after examining the consumption of the ships' engines, we reached the following conclusion:

Figure 10: Fuel consumption as the speed decreases



Source: http://www.sciencedirect.com/science/article/pii/S0968090X10000744

If the speed is reduced from:

- 19-18 (knots) the ship's consumption is reduced by approximately 22 tons

  The outcome of 22 tons (132-110) derived from the follow calculations:

  21,85 miles/hours * 0,25 tones/miles * 24 hours =132 tons

  (21,85 : 1,15*19)

  20,7 miles/hours *0,22 tones/miles *24 hours = 110 tons

  (20,7 : 1,15*18)
- 18-17 (knots) the ship's consumption is reduced by approximately 16 tons
- 17-16 (knots) the ship's consumption is reduced by approximately 14 tons
- 16-15 (knots) the ship's consumption is reduced by approximately 9 tons
- 15-14 (knots) the ship's consumption is reduced by approximately 5 tons

7.2 Empirical results-Economies of Scale

7.2.1 Routes

7.2.1.1 Indonesia-Taiwan (Bontag –Yang An)

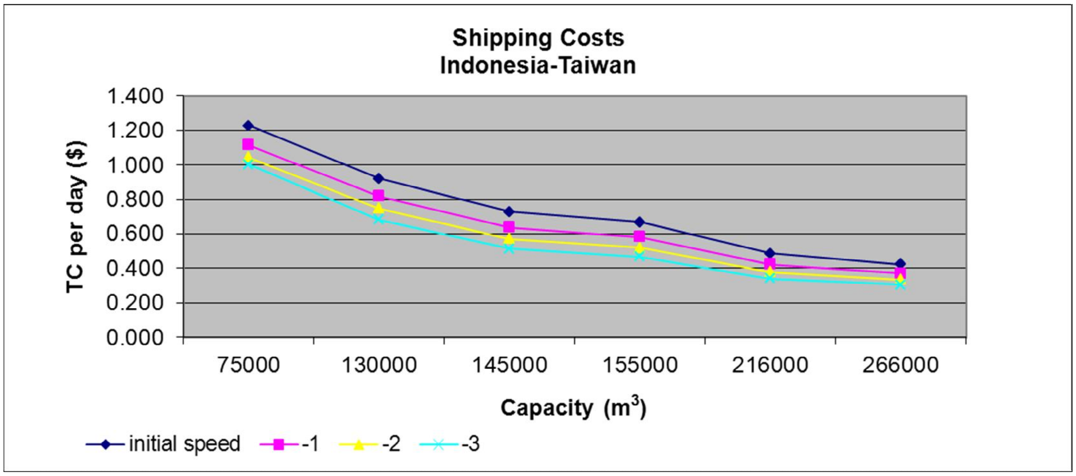
Figure 11: Possible routes of Indonesia's LNG exports

Source: World LNG distances map

Figure 11 shows all the possible routes of Indonesia's LNG exports. This route is 1.448 miles.

As shown in figure 12, the total costs per day decline as the ship capacity increases and speed decreases. Generally, the Q-Max (266.000 m^3) has the smallest cost per day for every combination whereas the smallest ship (75.000 m^3) has the highest costs. When the Q-Max ship (266.000 m^3) sails with initial speed (19 knots) the total cost per day is $0,421. This cost decreases to $0,371, $0,335, $0,304 if the speed is reduced by 1, 2, 3 knots respectively. Also, the cost per day for the ship that has a capacity of 75.000 m^3 is \$1,226 \$1,114, \$1,043 and \$1,003 respective the speed decrease.

Figure 12: Indonesia-Taiwan Shipping costs per day



7.2.1.1.1 Illustrative example

The illustrative example below explains how we reached the total cost per day of \$0,42 per m^3. The ship used is Q-Max with capacity of 266.000 m^3. Each ship can only load 95% of her total capacity so the total capacity for this ship is 252.700 m^3.

Remaining Capacity- (Remaining Capacity*0,14%*10%) = 252.664,6 for the first day

The same applies for the rest days (example Table 2)

Then the total amount of BOG used (141,482 m^3) is multiplied by the LNG price of 105 dollars giving the total cost of \$**14855,64**

The consumption of HFO per day for this vessel is 145 mts assuming that the ship speed is 19 knots.

Total consumption 522mts * \$633= **\$330.426**

The total operating costs are **\$80.000**

Total cost on passage (\$14.855,64 + \$330.426 + \$80.000)/ 252.558,5 = \$1,683 per m^3. Then \$1,683/4 days (1.448/ (24*19)) = **\$0,421** per day per m^3

Table 2: Example data

Qmax (266.000)					
ROUTE (days) Bontag-Yang An	1	2	3	4	Capacity – (*)
Capacity	252.700	252.700	252.700	252.700	
Capacity- boil-off rate- 10% (*)	252.664,6	252.629,2	252.593,9	252.558,5	141,482
LNG price*LNG that the ship burnt in dollars	14.855,64				
Consumption	145	145	145	145	522
Fuel oil*Consumption (dollars)	330.426				
Operating Cost (dollars)	20.000	20.000	20.000	20.000	80.000
((Σ fi/(H))/D)) cost time on passage ($ per m^3)	1,683				
Cost per day per m^3 in dollars	**0,421**				

7.2.1.2 Qatar-Belgium (Ras Laffan-Zeebrugge)

Figure 13 : Possible routes of Qatar LNG exports

Source: World LNG distances map

The above map shows all the possible routes of Qatar's LNG exports. The length of this trip is 6.350 miles.

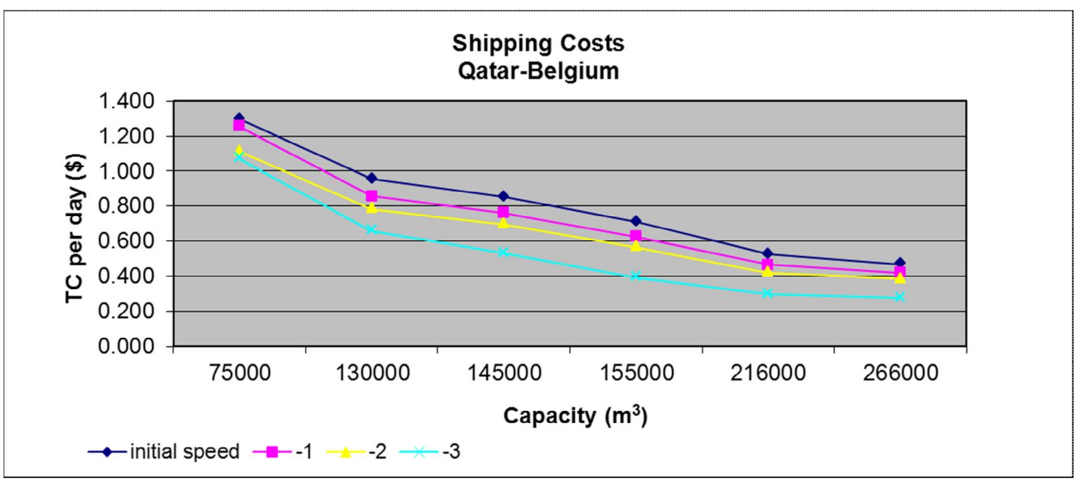
In this route, the ships have to pass from the Suez Canal in order to arrive to Belgium (Zeebrugge). So we calculate the Suez Canal cost in dollar (table 3) in order to find the total shipping cost per cm per day. Because the ships pass from the Suez Canal we add another one day. The ships burn 0,6 mts of HFO as they pass from the canal. The price of HFO that we use is $637 per mt from the Fujairah port and the price of LNG in the market is about $105 per m^3.

Table 3: Canal costs

Capacity (m^3)	Suez Canal Cost ($)
266.000	**255.000**
216.000	**191.000**
155.000	**160.000**
145.000	**151.000**
130.000	**140.000**
75.000	**140.000**

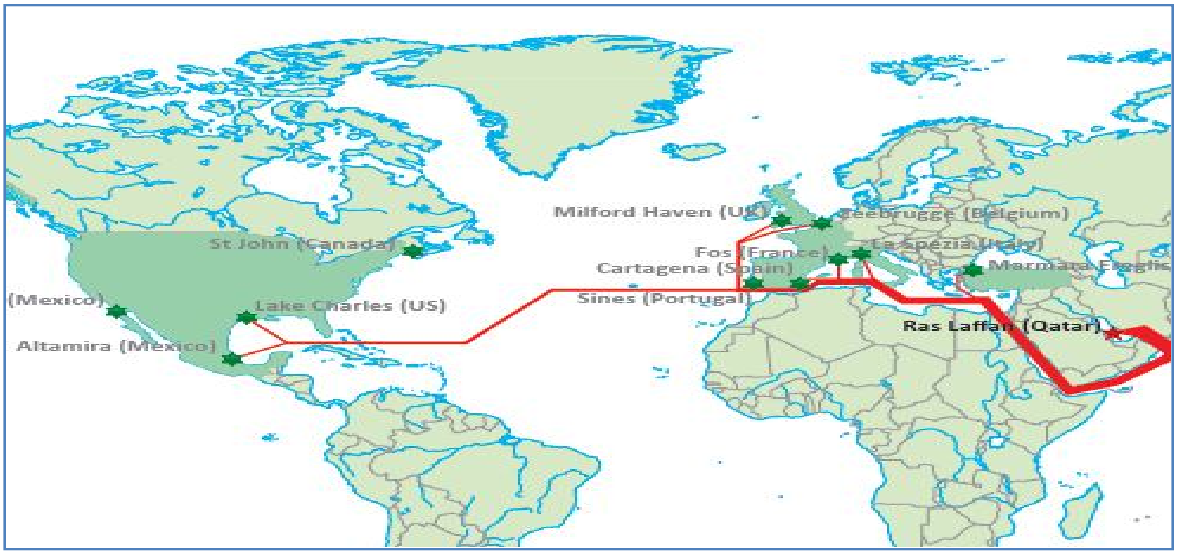
Figure 14 below, illustrates the shipping costs per m^3 per day from Qatar to Belgium. The axes x shows the capacity of different ships and the axes y represents the total cost per day for each ship. For this route the maximum cost per day is $1,296 per day per m^3, while the minimum cost is $0,47 per day per m^3 if the ships sail with initial speed of 19 and 17 knots respectively.

Figure 14: Qatar-Belgium Shipping costs per day



7.2.1.3 Qatar – US (Ras Laffan- Lake Charles)

Figure 15 : Possible routes of Qatar LNG exports

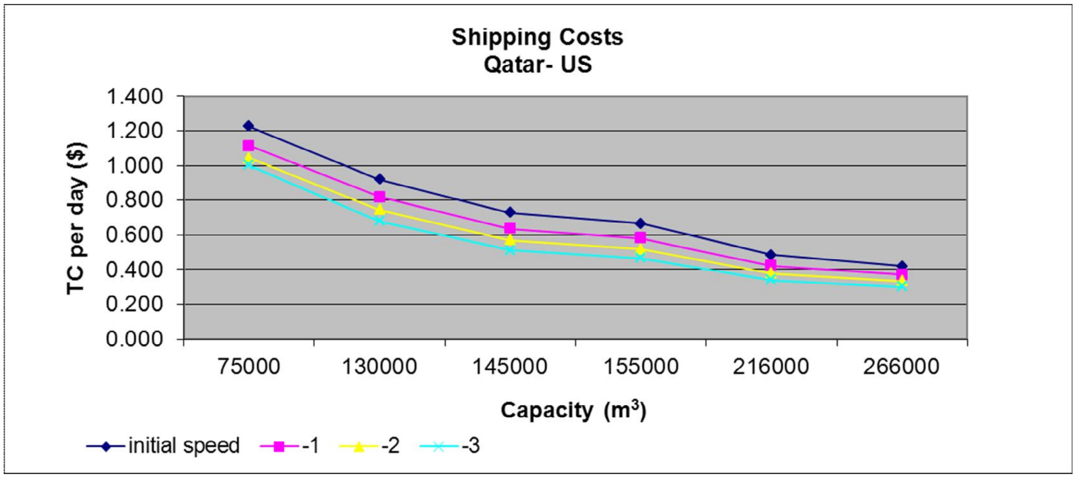


Source: World LNG distances map

In this route the ships have to pass from the Suez Canal in order to arrive to US (Lake Charles). So we calculate the Suez Canal cost in dollar in order to find the total shipping cost per m^3 per day. The length of this route is 9.770 miles.

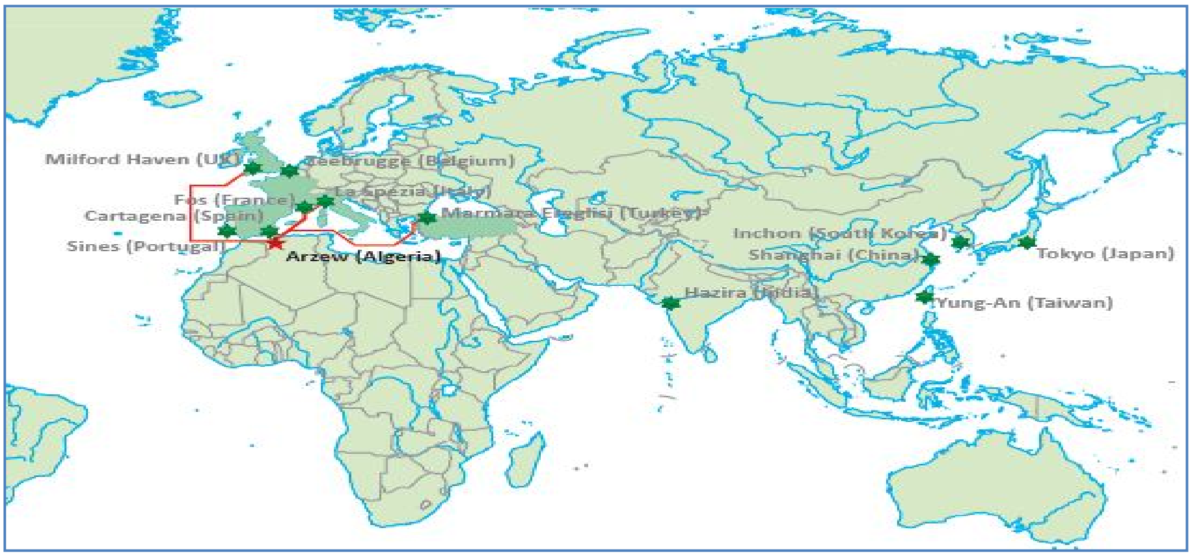
As per figure 16 the Q-Max (266.000 m^3) has the smallest cost per day for every combination, whereas the smallest ship (75.000 m^3) has the highest costs. When the Q-Max ship sails with initial speed (19 knots) the total cost per day is \$0,421. This cost decreases to \$0.371, \$0.335, \$0.304 if the speed is reduced by 1, 2, 3 knots respectively. Also, the cost per day for the ship that has a capacity of 75.000 m^3 is \$1,241 \$1,129, \$1,057 and \$1,017 respective the speed decrease.

Figure 16: Qatar- US Shipping costs per day



7.2.1.4 Algeria- France (Arzew - Fos)

Figure 17: Possible routes of Algeria's exports

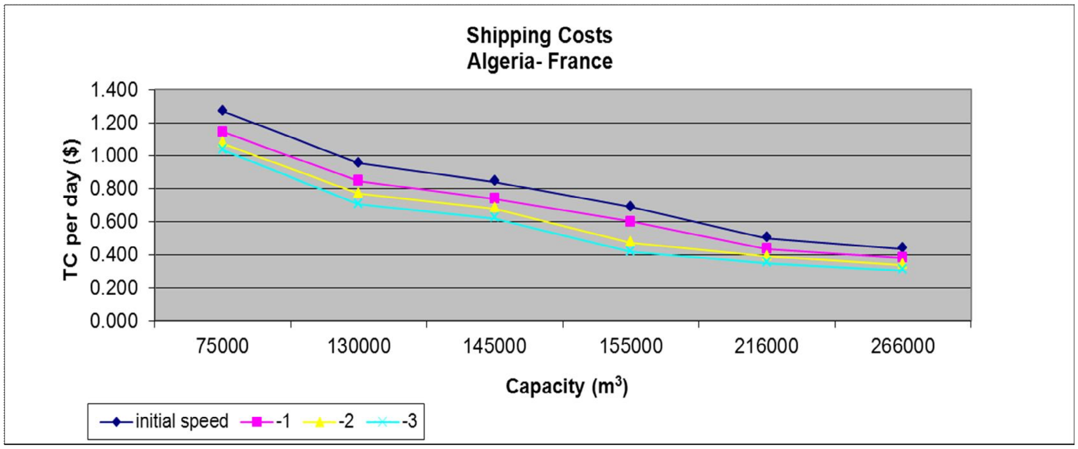


Source: World LNG distances map

From figure 17, we can see that Algeria exports to Italy, France, Turkey, UK and Spain. For this research we analyze the distance between Algeria and France. The length of this route is 523 miles. So the duration of this trip is only 2 days for the initial speed of 19 knots and 17 knots.

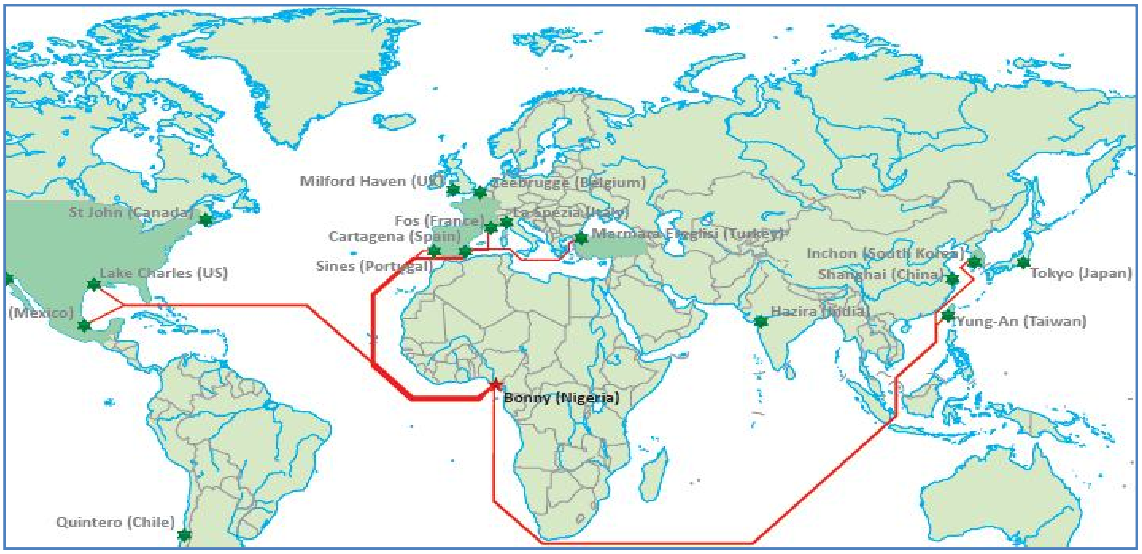
As we can see in figure 18, the ship with capacity 75.000 m^3 and initial speed 17 knots has a cost of \$ 1,270 per m^3 per day but if we decrease the speed to 14 knots, the cost decline to \$ 1,036 per m^3 per day. Regarding the Q-Max ship with the initial speed 19 knots, cost per day equal \$0,435 per m^3. When the speed is reduced to 18, 17 and 16 knots the costs per day are \$0,384 per m^3, \$0,338 per m^3 and \$0,305 per m^3 respectively. As illustrated in the graph, the ship with capacity 155.000 m^3 has the biggest variations in cost per day, respective of the speed decrease as opposed to the others ships.

Figure 18: Algeria- France Shipping costs per day



7.2.1.5 Nigeria- Spain (Bonny- Cartagena)

Figure 19: Possible routes of Nigeria's LNG exports

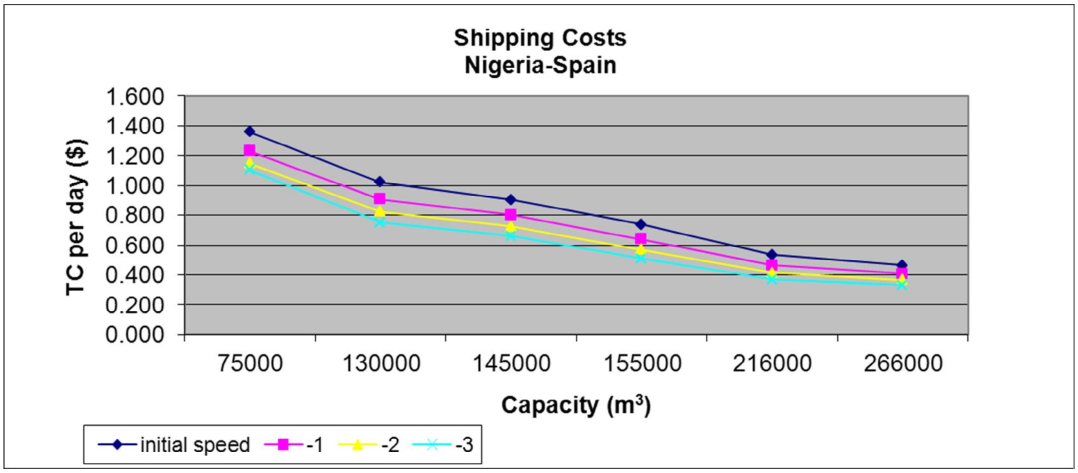


Source: World LNG distances map

The duration of this distance is 3.590 miles. All the ships with a speed of 19 knots need 8 days for this route, whereas the smallest ship with speed of 17 knots needs 9 days.

The graph below represents the costs per day regarding the ships and speed that we earlier assumed. The costs per day for the smallest ship (75.000 m^3) with 15 knots speed is \$1,150 per m^3, while the ship with capacity of 155.000 m^3 with its speed reduced by 2 knots as well, has a cost per day of \$0,572 per m^3. So economies of scale are also applied in this route.

Figure 20: Nigeria- Spain Shipping costs per day



CHAPTER 8: FINDING THE OPTIMAL SHIP FOR EACH ROUTE

8.1 The theory of the optimal size ship

It is very important for ship-owners to determine the most suitable ship that creates higher economies of scale for different routes. During the last 20 years there was an increase in the sizes of ships. In addition the primary determinants that affect the size ship are volume of trade, length of route and value of product (Kendall, 1972).

The authors Eaton et al. (2004) analyze how to find the optimal train size by lowering the unit costs through large and efficient liquefaction trains. They concluded that LNG trains as large as 8 mtpa are feasible and could be cost-effective. However, these trains might not be useful for everyone. The "mega" train can be used for larger distances and unlimited gas supply. The design of large ships will keep accelerating because of their safety, reliability and high operating factors.

8.2 Empirical results and Analysis (Optimal size ship)

8.2.1 Finding the optimal ship

Based on the theories above and in the literature review, we reached the optimal size ship for each route. Generally, as derived from the graphs analyzed above, the ship that has the lowest shipping costs per day for all the routes is the Q-Max because she has the biggest capacity, thus creating economies of scale. However, for each route we need to take into account different factors in order to reach a conclusion regarding the optimal ship.

8.2.1.1 Indonesia- Taiwan

This journey takes only four days when the ship sails with initial speed. While the speed decreases, the number of days required decreases as well, (Miles/ Speed). For example, if the speed decreases to 16 knots the ship with the smallest capacity needs five days in order to reach their destination in contrast to the others vessels that need four days. Since the distance is short, we didn't choose a Q-Max or Q-Flex ship and so we prefer a standard ship with capacity of 155.000 m^3 .This ship has grater costs than the Q-Vessels. Although this ship is the optimal for this route, because of the fact that the capital costs for Q-Vessels are higher than the 135.000 m^3 ship, for a ship-owner this ship will be the best choice in this route. Also if the selected ship sails with 16 knots, it has a lower cost per day than the Q-Flex sailing with 19 knots. Moreover, the ship with capacity 155.000 m^3 and sailing speed 16 knots has a slight difference in cost compared to the Q-Max vessel that sails with a speed of 19 knots. This difference is too small to decide to select the Q-Max vessel in this journey. As a result, the vessel with capacity of 155.000 m^3 sailing with speed of 16 knots is the most appropriate for this route.

Table 4: Costs per day Indonesia-Taiwan

Speed (knots)	Capacity (m^3)					
	75.000	130.000	145.000	155.000	216.000	266.000
0	1,226	0,921	0,728	0,666	0,484	0,421
-1	1,114	0,819	0,637	0,581	0,423	0,371
-2	1,043	0,745	0,570	0,519	0,379	0,335
-3	1,003	0,681	0,512	0,465	0,340	0,304

* 0 is the initial speed

8.2.1.2 Qatar-Belgium

This is the second biggest journey among the five routes analyzed above. The duration is 14 days for all the ships, except the smallest that needs 16 days when the ship sails with its initial speed. If the speed is reduced by one knot, then the duration is 15 knots for all the vessels, unlike for the smallest ship that needs 17 days. From the following calculations, we find that the optimal ship is the Q-Flex after taking into consideration all the necessary factors as the distance and Zeebrugge's port authority. This port accepts all types of LNG ships from the smallest ships to the enormous Q-Max and Q-Flex types of vessels. Furthermore, from table 5 we observe that if the Q-Flex sails with 19,18 or 17 knots, it has a smaller cost per day per m^3, than the Q-Max sailing with initial speed (19 knots). Moreover, if the Q-Flex ship sails with 17 knots, it has the same cost with a Q-Max sailing with 18 knots. So the Q-Flex ship is better than the Q-Max because with a slight difference in the sailing speed, it has the same cost but lower capital costs, so the ship-owners prefer them. Adding to this, the selected ship sailing with 16 knots has a minor difference in cost compared to the Q-max sailing with the same speed ($0,336 for the Q-Max and $0,368 for the Q-Flex). This minor difference however, has a significant impact on the capital cost, since for a Q-Max ship these costs are more than $250 million whereas for the Q-Flex they are less than $200 million.   So, for this route we prefer the ship with capacity 216.000 m^3 sailing with the speed of 17 knots or 16 knots.

Table 5: Costs per day Qatar-Belgium

Speed (knots)	Capacity (m^3)					
	75.000	130.000	145.000	155.000	216.000	266.000
0	1,296	0,954	0,851	0,710	0,526	0,470
-1	1,255	0,857	0,763	0,627	0,466	0,421
-2	1,113	0,785	0,698	0,566	0,421	0,384
-3	1,072	0,658	0,531	0,394	0,297	0,276

*0 is the initial speed

8.2.1.3 Qatar- US

The journey from Qatar (Ras Laffan) to US (Lake Charles) is the longest trip selected as input for this study. It takes 22 days for all the types of ships except for the smallest one, which needs 24 days, all sailing with their initial speed. Since this port is capable of accepting Q-Max trains and as this train has the smallest shipping cost as shown on the below table, we choose this as the optimal ship. Also the "mega" train can be used for larger distances and unlimited gas supply (Eaton et al., 2004). As we mentioned before, Qatar is the largest exporter of LNG, so the ship-owners prefer the "mega" train because of its duration and the supply prospects with capacity of 266.000 m^3. As we can see from the table below, the Q-Max vessel has the smallest costs than the other vessels through the reduction in speed. In addition the "mega" ship has a substantial difference in costs of $0,726 ($1,096 - $0,370) if we compare this with the smallest ship. It is very important to note that if the "mega" train is sailing with the speed of 19 knots, she has the biggest variation in cost in contrast to the other ships sailing with the same speed. As a result, the Q-Max is better when sailing with the initial speed because of the big difference in costs. The most optimal ship in this journey is the Q-Max when sailing with the speed of 19 knots. However, the ship might probably not reach this speed because of the weather conditions and the decisions of the ship-owner.

Table 6: Costs per day Qatar-US

Speed (knots)	Capacity (m^3)					
	75.000	130.000	145.000	155.000	216.000	266.000
0	1,279	0,946	0,841	0,697	0,513	0,455
-1	1,167	0,847	0,752	0,614	0,453	0,405
-2	1,096	0,776	0,688	0,554	0,410	0,370
-3	1,053	0,711	0,629	0,498	0,368	0,336

*0 is the initial speed

8.2.1.4 Algeria – France

For this trip, it takes only 2 days for ships to reach their destination. Based on the below analysis, the ship-owner has three strategies to choose from. The first choice is to use the smallest ship and benefit from the rising rates in the emerging spot market (Lloyds list, 2012). The second strategy is to use the ships with the capacity of 130.000 m3, 145.000 m^3 and 155.000 m^3 in a long term contract and benefit from the constant amount received each day for a long time duration. Based on the third strategy, the ship-owner has the ability to use the Q-Vessel in a time charter contract and in a bareboat contract. In addition, in this route the demand is not too high because France's demand is only 4 % of the world demand. Furthermore, because the capital cost for smallest LNG ships are less than $200 million, a ship-owner could exploit this route and buy for example, 3 of these ships rather than one Q-Max and so achieve higher economies of scale. In this case, the most suitable type of ship is the smallest ship with capacity of 75.000 m^3. Although this type bears the highest shipping costs, it can be used in spot markets to benefit from the higher rates with a sailing speed of 16 knots. Depending on the decision of the ship-owner, selecting Q-Vessels would not be appropriate since Q-Vessels are designed for longer trips.

Table 7: Costs per day Algeria-France

Speed (knots)	Capacity (m^3)					
	75.000	130.000	145.000	155.000	216.000	266.000
0	1,270	0,955	0,845	0,690	0,501	0,435
-1	1,146	0,849	0,742	0,601	0,437	0,384
-2	1,078	0,772	0,681	0,474	0,391	0,338
-3	1,036	0,704	0,620	0,418	0,350	0,305

*0 is the initial speed

8.2.1.5 Nigeria- Spain

This trip is the third longest among the others with duration of eight days or nine days for the smallest ship sailing with the initial speed. If the speed is reduced by one knot, then the smallest ship needs 10 days to reach its destination while the other ships need nine days. As we can see from the table below, the ships with capacity of 130.000 m^3 and 145.000 m^3 are the most suitable for this trip. The ship with capacity of 145.000 m^3 has lower cost when she sails with the speed of 16 or 17 knots than the ship with capacity of 155.000 m^3 sailing with the initial speed (0). Also the difference in cost is too small when we compare the ship with capacity of 130.000 m^3 with sailing speed of 16 knots and the ship which has a capacity of 155.000 m^3. The Q-Vessels cannot be used in this route because of the duration and the capital costs which are higher for these types of ships. Therefore the selected optimal ships that create the higher economies of scale for this distance are the standard vessels with capacity of 145.000 m^3 and 130.000 m^3 and sailing speed of 16 knots.

Table 8: Costs per day Nigeria-Spain

Speed (knots)	Capacity (m^3)					
	75.000	130.000	145.000	155.000	216.000	266.000
0	1,359	1,023	0,905	0,738	0,535	0,464
-1	1,232	0,906	0,802	0,642	0,465	0,408
-2	1,150	0,825	0,727	0,572	0,415	0,367
-3	1,105	0,752	0,662	0,510	0,371	0,331

*0 is the initial speed

CHAPTER 9: CONCLUSION

The dramatic increase in competition leads the shipping companies to manage and select the most suitable ships to carry LNG. This management technique constitutes the main source of performance and effectiveness of their operations. Thus the choices of the optimal size ship pushes in creating economies of scale and the parties can benefit from this competitive advantage. The majority of the studies are focused in other transport methods and in different types of ships and destinations in contrast to this research.

This paper is based on the ships that carry LNG, in specific routes, giving a higher weight to the total cost per day at sea for the different routes. Moreover, due to huge exploration and resources discovered, this research determines as utmost importance, that the ship-owners, in order to choose the most suitable ship for their routes and to benefit from the vast earnings, to charter their vessels for a long time. The transportation of LNG will soon be transferred through shorter distances because the demand of LNG will be broadened to even closer countries. As a result, the smaller LNG vessels will be used in the spot market in order to sail in a voyage without chartering in a time charter, and so the ship-owners will benefit from the higher rates of earnings in this emerging market.

The main subject of this research was to find the optimal size ship in LNG carriers in a sample of five different routes that have been selected. Also for the purpose of this research we took into account some major assumptions that helped us to analyze and produce the empirical results. A mathematical model was developed in order to estimate the economies of scale based on other research with relative ideas. Furthermore in this mathematical model, we included important variables for example the boil-off rate and the canal costs.

For each route, a figure regarding economies of scale, meaning that as the capacity of ship increased the total cost at voyage is decreased, was created. The empirical results show that the most appropriate ship for each route is the Q-Max that is creating the most economies of scale than the other ships. However, as the vessel's speed decreases by one knot at a time, the optimal ship is changed. Analyzing the first route

(Indonesia-Taiwan), we observed that the ship with capacity 155.000 m^3 sailing with a speed of 16 knots has the lower costs of \$0,465 per m^3 per day than the ship with a capacity of 216.000 m^3 which has a cost of \$0,484 per m^3 per day. In this route we couldn't select the new generation types of ships, even if we have to bear lower costs, because of the higher capital costs that these ships have. So the optimal ship for this journey is the ship with capacity of 155.000 m^3 and sailing speed of 16 knots, thus creating higher economies of scale than the ships with smaller and bigger capacities than these.

Examining the second route (Qatar-Belgium) which is the second biggest route than the other sample routes, we found that a new generations ship with higher capacity must be selected because of the duration of this journey. The ship with capacity of 216.000 m^3 sailing with the speed of 16, 17 and 18 knots has costs of \$0,466, \$0,421 and \$0,297 per m^3 per day respectively, which are lower than the Q-Max's costs of \$0,470 per m^3 per day sailing with the initial speed of 19 knots. We also noticed that the ship with capacity of 216.000 m^3 sailing with a speed of 17 knots has the same costs as the ship with capacity of 266.000 m^3 sailing with a speed of 18 knots. Thus, it would be better for a ship-owner to choose the ship with 216.000 m^3 capacity, since the capital costs for this ship are smaller, leading to greater economies of scale.

Moving on, we analyzed the longest trip (Qatar-US). The empirical results state that the ship with capacity of 266.000 m^3 bears the minimum costs for each speed type. If this ship sails with 19 knots, we observe the biggest variations in costs for any other speed as compared to the rest types of ship. As a result, this ship creates the biggest economies of scale.

For the next trip (Algeria-France), in order to choose the optimal ship, we assumed that the ship-owner has to choose between three strategies. The first strategy is to choose the smallest ship with capacity of 75.000 m^3 in the spot market. The second one is to charter the standard types of ship (130.000 m^3, 145.000 m^3 and 155.000 m^3) in order to benefit from constant profits. For the third strategy, the ship-owner has the option to charter the new generation ships for more time than the other two strategies. In addition, the demand of LNG in France covers only four percent of the total LNG demand and thus ship-owner can choose to buy three small ships which have the same costs as buying a Q-Type ship. As a result, the 75.000 m^3 ship with sailing with 16 knots can be used in the spot market creating the biggest economies of scale.

Finally, by analyzing the final route (Nigeria- Spain), we concluded that the ship with capacity of 145.000 m^3 sailing with 16 knots bears smaller costs, compared to a 155.000 m^3 ship sailing with a speed of 19 knots. Adding to this, the ship with 130.000 m^3 capacities and speed of 19 knots has slightly higher costs than the ship with capacity of 155.000 m^3. The conclusion therefore is that the most suitable ships sail with 16 knots and have a capacity of 130.000 m^3 or 145.000 m^3. It is important to note that although the total costs per day of the selected ships are bigger than the costs of the new generation type of ships, their capital costs are less.

The selection of the optimal ship size and the creation of efficient economies of scale are fundamental for the shipping companies in order to gain a competitive advantage among their rivals. My recommendation to the interested parties is to use this type of mathematical model in order to select the most cost-effective vessel for their voyages.

9.1 Limitations

In order to estimate the shipping costs in this paper, we didn't include an error measure in order for the results to be more precise and accurate. The extent of the impact that this will have on the outcome, is not pre-specified as different factors are taken into account for each route. For example, in the long-run new routes might be introduced and canal costs as well as fuel and LNG costs might change. Moreover, the actual demand levels of LNG in each country are changing on a continuous basis leading to a probable misstatement in the selection of the optimal ship size for each route. Last but not least, one of the major limitations of this paper is the method of selecting the data. Our data is based on a small population due to the fact that we didn't have full access to the entire data from the shipping companies.

9.2 Further research and Recommendations

Including the daily charter rates, costs of piracy - in cases where the ships pass through dangerous areas – in the formula will be strong indications that could help in any future, more in depth research on this topic. Adding to this different routes can also be analyzed like for example: Oman (Sur) – Taiwan (Yang An), Nigeria (Arzew) – US (Lake Charles), Norway (Hammerfest) – Spain (Cartagena), Australia (Dampier) – Japan (Tokyo). It will be very interesting to see the impact that these will have on the results found and the percentage variation. Also, it will be significant if the port costs are calculated and how this affects the optimal size ship selection.

Shipping companies need to analyze in detail the total costs required for each journey in order to provide their customers with more cost-effective solutions in choosing the optimal ship, and thus creating economies of scale. Our recommendation for Indonesia – Taiwan is to invest in a ship with capacity of 155.000 m^3 sailing with 16 knots. Regarding Qatar – Belgium the optimal ship has a capacity of 216.000 m^3 sailing with 16 or 17 knots. For Qatar – US a Q-Max ship is recommended sailing with 19 knots. A small ship with capacity of 75.000 m^3 and sailing speed of 16 knots is preferred for the trip between Algeria – France. Finally, for Nigeria – Spain the most suitable ship has a capacity of either 130.000 m^3 or 145.000 m^3 sailing with 16 knots.

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APPENDICES

In this research, all the calculations are estimated in the same way as the below examples using Microsoft Excel 2007.

Appendix 1: Route Indonesia- Taiwan (Initial speed)

Bontag- Yang An	**Knots**	**Days**	**Days**	**Operating costs $ per day**	**Capacity m^3**	**Capacity 95%**	**Boil-off rate**	**LNG price $ per m^3**	**HFO price (Singapore)**	**Consumption mt**
1.448 miles	19	3,17	4	20.000	266.000	252.700	0,0014	105	$633 per tone	145
1.448 miles	19	3,17	4	18.500	216.000	205.200	0,0013	105		137
1.448 miles	19	3,17	4	16.000	155.000	147.250	0,0015	105		140
1.448 miles	19	3,17	4	16.000	145.000	137.750	0,0015	105		165
1.448 miles	19	3,17	4	16.000	130.000	123.500	0,0015	105		168
1.448 miles	17	3,54	4	15.000	75.000	71.250	0,0015	105		125

Q-Max							Q-Flex				
Route Bontag-Yang An (days)	1	2	3	4	Remaini		1	2	3	4	Remaining
Capacity	252.70	252.70	252.70	252.70			205.200	205.20	205.20	205.200	106,6
Capacity- boil off rate - 10%	252.66	252.62	252.59	252.55	141,4		205.173	205.14	205.11	205.093	
LNG price*LNG that the ship burnt	14.855,						11.201,7				
Consumption - 90%	145	145	145	145	522		137	137	137	137	493.2
Fuel oil*Consumption ($)	330.42						312.195,				
Operating Cost ($)	20.000	20.000	20.000	20.000	80.000		18.500	18.500	18.500	18.500	74.000
((Σ f/(H))/D)) (cost of all the voyage)	1,6						1,9				
Cost per day $ per m^3	**0.421**						**0.484**				

155.000 m^3							145.000 m^3				
Route Bontag-Yang An (days)	1	2	3	4	Remaining		1	2	3	4	Remaining
Capacity	147.25	147.250	147.25	147.250	88,33012		137.75	137.75	137.75	137.750	
Capacity- boil off rate - 10%	147.22	147.205	147.18	147.161			137.72	137.70	137.68	137.667,	82,6
LNG price*LNG that the ship burnt ($)	9.274						8.676				
Consumption - 90%	140	140	140	140	504		165	165	165	165	594
Fuel oil*Consumption ($)	319.03						376.00				
Operating Cost ($)	16.000	16.000	16.000	16.000	64.000		16.000	16.000	16.000	16.000	64.000
((Σ f/(H))/D)) (cost of all the voyage) $	2,6						2,91				
Cost per day $ per m^3	**0.666**						**0.728**				

	130.000 m^3						75.000 m^3				
Route Bontag-Yang An (days)	**1**	**2**	**3**	**4**	**Remaini**		**1**	**2**	**3**	**4**	**Remaining**
Capacity	123.50	123.500	123.50	123.500	74,08333		71.250	71.250	71.250	71.250	42,7
Capacity- boil off rate - 10%	123.48	123.463	123.44	123.425			71.239	71.228	71.217	71.207	
LNG price*LNG that the ship burnt ($)	7.778						4.487				
Consumption - 90%	168	168	168	168	604.8		125	125	125	125	450
Fuel oil*Consumption ($)	382.83						284.85				
Operating Cost ($)	16.000	16.000	16.000	16.000	64.000		15.000	15.000	15.000	15.000	60.000
((Σ f/(H))/D)) (cost of all the voyage) $	3,6						4,9				
Cost per day $ per m^3	**0.921**						**1.226**				

Appendix 2: Route Indonesia- Taiwan (Speed-1)

Bontag- Yang An	Knots	Days	Days	Operating cost $ per day	Capacity m^3	Capacity 95%	Boil-off rate	LNG price per m^3	HFO price (Singapore)	Consumption mt
1.448 miles	19	3,17	4	20.000	266.000	252.700	0,0014	105	$633 per tone	123
1.448 miles	19	3,17	4	18.500	216.000	205.200	0,0013	105		115
1.448 miles	19	3,17	4	16.000	155.000	147.250	0,0015	105		118
1.448 miles	19	3,17	4	16.000	145.000	137.750	0,0015	105		143
1.448 miles	19	3,17	4	16.000	130.000	123.500	0,0015	105		146
1.448 miles	17	3,54	4	15.000	75.000	71.250	0,0015	105		111

Q-Max						Q-Flex				
Route Bontag-Yang An (days)	**1**	**2**	**3**	**4**	**Remaining**	**1**	**2**	**3**	**4**	**Remaining**
Capacity	252.7	252.70	252.7	252.7		205.200	205.200	205.2	205.2	106,6
Capacity- boil off rate - 10%	252.6	252.62	252.5	252.5	141,48	205.173,3	205.146	205.1	205.0	
LNG price*LNG that the ship	14.85					11.201,73542				
Consumption - 90%	123	123	123	123	442,8	115	115	115	115	414
Fuel oil*Consumption ($)	280.2					262.062				
Operating Cost ($)	20.00	20.000	20.00	20.00	80.000	18.500	18.500	18.50	18.50	74.000
((Σ f/(H))/D)) (cost of all the	1,4					1,6				
Cost per day $ per m^3	**0.37**					**0.423**				

155.000 m^3						145.000 m^3				
Route Bontag-Yang An (days)	**1**	**2**	**3**	**4**	**Remaini**	**1**	**2**	**3**	**4**	**Remaining**
Capacity	147.250	147.25	147.250	147.2	88,33	137.750	137.7	137.7	137.7	
Capacity- boil off rate - 10%	147.227	147.20	147.183	147.1		137.729	137.7	137.6	137.6	82,63
LNG price*LNG that the ship	9.274,663					8676				
Consumption - 90%	118	118	118	118	424.8	143	143	143	143	514.8
Fuel oil*Consumption ($)	268.898					325.868				
Operating Cost ($)	16.000	16.000	16.000	16.00	64.000	16.000	16.00	16.00	16.00	64.000
((Σ f/(H))/D)) (cost of all the	2,3					2,5				
Cost per day $ per m^3	**0.581**					**0.637**				

130.000 m^3						75.000 m^3				
Route Bontag-Yang An (days)	**1**	**2**	**3**	**4**	**Remaini**	**1**	**2**	**3**	**4**	**Remaining**
Capacity	123.500	123.500	123.5	123.500	74,08	71.250	71.25	71.25	71.25	42,7
Capacity- boil off rate - 10%	123.481	123.463	123.4	123.425		71.239	71.22	71.21	71.20	
LNG price*LNG that the ship	7.778,7					4.487,74				
Consumption - 90%	146	146	146	146	525.6	111	111	111	111	399.6
Fuel oil*Consumption ($)	332.704					252.946,8				
Operating Cost ($)	16.000	16.000	16.00	16.000	64.000	15.000	15.00	15.00	15.00	60.000
((Σ f/(H))/D)) (cost of all the	3,2					4,4				
Cost per day $ per m^3	**0,819**					**1,114**				

Appendix 3: Route Indonesia- Taiwan (Speed-2)

Bontag-Yang An An	Knots	Days	Days	Operating cost $ per day	Capacity m^3	Capacity 95%	Boil-off rate	LNG price per m^3	HFO price (Singapore)	Consumption mt
1.448 miles	17	3,549	4	20.000	266.000	252.700	0,0014	105	$633 per tone	107
1.448 miles	17	3,549	4	18.500	216.000	205.200	0,0013	105		99
1.448 miles	17	3,549	4	16.000	155.000	147.250	0,0015	105		102
1.448 miles	17	3,549	4	16.000	145.000	137.750	0,0015	105		127
1.448 miles	17	3,549	4	16.000	130.000	123.500	0,0015	105		130
1.448 miles	15	4,022	5	15.000	75.000	71.250	0,0015	105		102

Q-Max					Q-Flex					
Route Bontag-Yang An (days)	**1**	**2**	**3**	**4**	**Remaining**	**1**	**2**	**3**	**4**	**Remaining**
Capacity	252.700	252.700	252.700	252.700		205.200	205.200	205.200	205.200	106,6831945
Capacity- boil off rate - 10%	252.664	252.629	252.593	252.558	141,4	205.173.	205.146	205.120	205.093	
LNG price*LNG that the ship burnt ($)	14.855					11.201				
Consumption - 90%	107	107	107	107	385,2	99	99	99	99	356,4
Fuel oil*Consumption ($)	243831					225601				
Operating Cost ($)	20.000	20.000	20.000	20.000	80.000	18.500	18.500	18.500	18.500	74.000
((Σ f/(H))/D)) (cost of all the voyage) $ per m^3	1,3					1,5				
Cost per day $ per m^3	**0.335**					**0.379**				

	155.000 m^3					145.000 m^3				
Route Bontag-Yang An (days)	**1**	**2**	**3**	**4**	**Remaining**	**1**	**2**	**3**	**4**	**Remaining**
Capacity	147.250	147.250	147.250	147.250	88,33	137.750	137.750	137.750	137.750	
Capacity- boil off rate - 10%	147.227	147.205	147.183	147.161		137.729	137.708	137.688	137.667	82
LNG price*LNG that the ship burnt ($)	9.274					8.676				
Consumption - 90%	102	102	102	102	367.2	127	127	127	127	457.2
Fuel oil*Consumption ($)	232.437					289.407				
Operating Cost ($)	16.000	16.000	16.000	16.000	64.000	16.000	16.000	16.000	16.000	64.000
((Σ f/(H))/D)) (cost of all the voyage) $ per m^3	2,0					2,2				
Cost per day $ per m^3	**0.519**					**0.570**				

	130.000 m^3					75.000 m^3					
Route Bontag-Yang An (days)	**1**	**2**	**3**	**4**	**Remaining**	**1**	**2**	**3**	**4**	**5**	**Remaining**
Capacity	123.500	123.500	123.500	123.500	74,0833	71.250	71.250	71.250	71.250	71.250	53.421
Capacity- boil off rate - 10%	123.481	123.463	123.444	123.426		71.239	71.229	71.217	71.207	71.197	
LNG price*LNG that the ship burnt ($)	7.778,75					5.609,3					
Consumption - 90%	130	130	130	130	468	102	102	102	102	102	459
Fuel oil*Consumption ($)	296.244					290.547					
Operating Cost ($)	16.000	16.000	16.000	16.000	64.000	15.000	15.000	15.000	15.000	15.000	75.000
((Σ f/(H))/D)) (cost of all the voyage) $ per m^3	2,9					5,2					
Cost per day $ per m^3	**0,745**					**1,043**					

Appendix 4: Route Indonesia- Taiwan (Speed-3)

Bontag-Yang An An	**Knots**	**Days**	**Days**	**Operating cost $ per day**	**Capacity m^3**	**Capacity 95%**	**Boil-off rate**	**LNG price per m^3**	**HFO price (Singapore)**	**Consumption mt**
1.448 miles	16	3,77	4	20.000	266.000	252.700	0,0014	105	$633 per tone	93
1.448 miles	16	3,77	4	18.500	216.000	205.200	0,0013	105		85
1.448 miles	16	3,77	4	16.000	155.000	147.250	0,0015	105		88
1.448 miles	16	3,77	4	16.000	145.000	137.750	0,0015	105		113
1.448 miles	16	3,77	4	16.000	130.000	123.500	0,0015	105		116
1.448 miles	14	4,30	5	15.000	75.000	71.250	0,0015	105		97

Q-Max					**Q-Flex**					
Route Bontag-Yang An (days)	**1**	**2**	**3**	**4**	**Remaining**	**1**	**2**	**3**	**4**	**Remaining**
Capacity	252.70	252.700	252.700	252.700		205.200	205.200	205.200	205.200	106,7
Capacity- boil off rate - 10%	252.66	252.629.2	252.593.9	252.559	141,5	205173.32	205146.6515	205120	205093.3168	
LNG price*LNG that the ship burnt ($)	14.855					11.201,7				
Consumption - 90%	93	93	93	93	334,8	85	85	85	85	306
Fuel oil*Consumption ($)	21192					193698				
Operating Cost ($)	20000	20000	20000	20000	80000	18500	18500	18500	18500	74000
((Σ f/(H))/D)) (cost of all the voyage) $ per m^3	1,2					1,3				
Cost per day $ per m^3	**0.304**					**0.340**				

155.000 m³						145.000 m³				
Route Bontag-Yang An (days)	**1**	**2**	**3**	**4**	**Remaining**	**1**	**2**	**3**	**4**	**Remaining**
Capacity	147.250	147.250	147.250	147.250	88,33	137.750	137.750	137.750	137.750	
Capacity- boil off rate - 10%	147.228	147.205	147.183.7	147.162		137.729	137.708	137.688	137.667	82,63
LNG price*LNG that the ship burnt ($)	9274,66					8676,29				
Consumption - 90%	88	88	88	88	316,8	113	113	113	113	406,8
Fuel oil*Consumption ($)	200.534					257.504,4				
Operating Cost ($)	16.000	16.000	16.000	16.000	64.000	16.000	16.000	16.000	16.000	64.000
((Σ f/(H))/D)) (cost of all the voyage) $ per m³	1,8					2,0				
Cost per day $ per m³	**0.465**					**0.512**				

130.000 m³						75.000 m³					
Route Bontag-Yang An (days)	**1**	**2**	**3**	**4**	**Remaining**	**1**	**2**	**3**	**4**	**5**	**Remaining**
Capacity	123.500	123.500	123.500	123.500	74,08	71.250	71.250	71.250	71.250	71.250	53,42
Capacity- boil off rate - 10%	123.481	123.463	123.444	123.426		71.239	71.229	71.217	71.207	71.197	
LNG price*LNG that the ship burnt ($)	7.778					5.609					
Consumption - 90%	116	116	116	116	417.6	97	97	97	97	97	436.5
Fuel oil*Consumption ($)	264.340					276.304.5					
Operating Cost ($)	16.000	16.000	16.000	16.000	64.000	15.000	15.000	15.000	15.000	15.000	75.000
((Σ f/(H))/D)) (cost of all the voyage) $ per m³	2,7					5,0					
Cost per day $ per m³	**0,681**					**1,003**					

Appendix 5: Abstract in Greek

Περίληψη

Η σωστή διαχείριση και η κατάλληλη επιλογή ανά ταξίδι, πλοίων τα οποία μεταφέρουν φυσικό αέριο, αποτελεί σημαντικό πυρήνα στην αποδοτικότητα και αποτελεσματικότητα της κάθε ναυτιλιακής εταιρείας. Έτσι η απόδοση θα εξαρτηθεί από το πλοίο, το όποιο θα επιλεχτεί σε κάθε ταξίδι και η κατάλληλη ταχύτητα έτσι ώστε να επιτευχθούν μέγιστες οικονομίες κλίμακας. Η δραματική αύξηση του ανταγωνισμού και η διεθνής παγκοσμιοποίηση ώθησε τους πλοιοκτήτες να προσπαθούν με κάθε τρόπο να επιλέγουν το βέλτιστο πλοίο, το οποίο θα δημιουργεί οικονομίες κλίμακας, ως αποτέλεσμα να επωφελούνται από το ανταγωνιστικό πλεονέκτημα που θα δημιουργείται.

Οι περισσότερες μελέτες επικεντρώθηκαν σε άλλα μέσα μεταφοράς και σε διαφορετικά πλοία και δρομολόγια σε σχέση με αυτήν την έρευνα. Αυτή η έρευνα στηρίζεται σε πλοία τα οποία μεταφέρουν φυσικό αέριο σε καθορισμένες αποστάσεις, δίνοντας μεγαλύτερη σημασία στο συνολικό κόστος ανά μέρα ανά κάθε ταξίδι ξεχωριστά. Ωστόσο, λόγω της ραγδαίας αύξησης του φυσικού αερίου και τα τεράστια κοιτάσματα τα οποία ανακαλύφθηκαν, αυτή η έρευνα καθορίζεται ως υψίστους σημασίας για τους πλοιοκτήτες έτσι ώστε επιλέγοντας με προσοχή το βέλτιστο πλοίο να ωφελούνται από τις οικονομίες κλίμακας οι οποίες θα δημιουργούνται.

Είναι γεγονός ότι τα πλοία τα οποία μεταφέρουν υγροποιημένο φυσικό αέριο ναυλώνονται για μεγάλο χρονικό διάστημα, αφήνοντας τους πλοιοκτήτες ευχαριστημένους λαμβάνοντας τεράστια κέρδη ανάλογα με τους όρους που έχει το κάθε ναυλοσύμφωνο. Λόγω όμως των κοιτασμάτων που έχουν ευρεθεί τα τελευταία χρόνια και τις κοντινές αποστάσεις μεταξύ των διαφόρων χωρών και νησιών, τα μικρά πλοία υγροποιημένου φυσικού αερίου θα χρησιμοποιούνται και πλέον και σε άμεση παράδοση. Επομένως αυτά τα πλοία να πλέουν σε περιοχές που έχει φορτίο και ως αποτέλεσμα οι πλοιοκτήτες να εκμεταλλεύονται τα ψηλά ποσοστά κερδών που θα λαμβάνονται.

Ο κύριος στόχος αυτής της μελέτης είναι η επιλογή του βέλτιστου πλοίου μεταφοράς υγροποιημένου φυσικού αερίου και οι οικονομίες κλίμακας που δημιουργούνται σε ένα δείγμα πέντε διαφορετικών ταξιδιών που έχει επιλεχθεί. Τα

ταξίδια που λήφθηκαν υπόψη είναι Ινδονησία-Ταιβάν, Κατάρ-Βέλγιο, Κατάρ-Αμερική, Νιγηρία-Ισπανία και Αλγερία-Ισπανία. Για τους σκοπούς αυτής της έρευνας δημιουργήθηκε ένα μαθηματικό μοντέλο αποτελούμενο από διάφορες μεταβλητές όπως (μεταβλητά και σταθερά κόστη, χωρητικότητα και απόσταση των πλοίων που έχουμε επιλέξει. Παράλληλα χρειάστηκε να υπολογίσουμε το συνολικό κόστος που χρειάζεται το κάθε επιλεγμένο πλοίο διασχίζοντας την διώρυγα του Σουέζ. Το κόστος αυτό συμπεριλήφθηκε στα μεταβλητά κόστη μαζί με τις υπόλοιπες μεταβλητές. Επιπρόσθετα ορισμένες υποθέσεις διαδραμάτισαν σημαντικό ρόλο για την επίτευξη των αποτελεσμάτων όπως (κάθε πλοίο το οποίο έχει χρησιμοποιηθεί καίει 10% υγροποιημένο φυσικό αέριο και 90% μαζούτ, όλα τα πλοία πλέουν με ταχύτητα 19 ναυτικά μίλια έκτος το πιο μικρό πλοίο το οποίο πλέει με ταχύτητα 17 ναυτικά μίλια και το κάθε πλοίο μπορεί να χωρέσει φορτίο ίσο με το 95% της χωρητικότητας του). Τα διάφορα πλοία που χρησιμοποιήθηκαν για αυτήν την έρευνα έχουν χωρητικότητα 75.000, 130.000, 145.000, 155.000 κυβικών μέτρων και πλοία καινούργιας τεχνολογίας υγροποιημένου φυσικού αερίου χωρητικότητας 216.000 και 266.000 κυβικών μέτρων.

Επιπλέον για κάθε ταξίδι δημιουργούσαμε και ένα γράφημα δείχνοντας τις οικονομίες κλίμακας που πραγματοποιούνταν. Δηλαδή αυξάνοντας την χωρητικότητα των πλοίων το συνολικό κόστος στην θάλασσα ανά μονάδα κυβικών μέτρων μειωνόταν. Τα εμπειρικά αποτελέσματα έδειξαν ότι το βέλτιστο πλοίο σε κάθε απόσταση είναι αυτό και με τη μεγαλύτερη χωρητικότητα δηλαδή των 266.000 κυβικών μέτρων. Όμως μειώνοντας την ταχύτατα κατά ένα ναυτικό μίλι κάθε φορά και λαμβάνοντας σημαντικούς παράγοντες υπόψη ανά ταξίδι επιλέγεται το βέλτιστο πλοίο. Για το πρώτο ταξίδι (Ινδονησία- Ταιβάν) παρατηρήσαμε ότι εάν το πλοίο των 155.000 κυβικών μέτρων έπλεε με ταχύτητα 16 ναυτικά μίλια έχει μικρότερο κόστος από το πλοίο με χωρητικότητα 216.000 κυβικών μέτρων πλέοντας με ταχύτητα 19 ναυτικών μιλίων. Ακόμη στο συγκεκριμένο ταξίδι δεν μπορούσε να επιλεγεί καινούργιας τεχνολογίας πλοίο, έστω και αν είχε μικρότερα κόστη λόγω των υψηλότερων κεφαλαιουχικών κοστών αλλά και λόγω της απόστασης η οποία ήταν μόνο 4 μέρες πλέοντας το κάθε πλοίο με αρχική ταχύτητα. Ωστόσο, το βέλτιστο πλοίο για αυτήν την απόσταση είναι αυτό με χωρητικότητα 155.000 κυβικών μέτρων πλέοντας με ταχύτητα 16 ναυτικά μίλια την ώρα, δημιουργώντας έτσι την μέγιστη αναλογία οικονομιών κλίμακας.

Το δεύτερο ταξίδι (Κατάρ-Βέλγιο) είναι το δεύτερο κατά σειρά μεγαλύτερης διάρκειας από τα επιλεγμένα δρομολόγια. Η διάρκεια αυτού του ταξιδιού είναι 14 μέρες για όλα τα πλοία που λάβαμε υπόψη μας σε αυτήν την εργασία εκτός από το πιο μικρό πλοίο το όποιο χρειάζεται 16 μέρες για να φτάσει στο προορισμό του. Αναλύοντας αυτό το ταξίδι καταλήξαμε στο συμπέρασμα ότι πρέπει να χρησιμοποιηθεί πλοίο καινούργιας τεχνολογίας των 216.000 ή των 266.000 κυβικών μέτρων λόγω και της μεγάλης διάρκειας του ταξιδιού. Έπειτα παρατηρήσαμε ότι εάν το πλοίο χωρητικότητας 216.000 κυβικών μέτρων όταν πλέει με ταχύτητα 16,17 και 18 ναυτικά μίλια αντίστοιχα έχει μικρότερο κόστος από το μεγαλύτερο σε χωρητικότητας πλοίο εάν πλέει με ταχύτατα 19 ναυτικά μίλια. Επιπλέον παρατηρήσαμε ότι το πλοίο με χωρητικότητα 216.000 κυβικών μέτρων έχει το ίδιο κόστος εάν πλέει με ταχύτητα 17 ναυτικών μιλίων από το αντίστοιχο εκείνο με χωρητικότητα 266.000 κυβικών μέτρων πλέοντας με ταχύτητα 18 ναυτικών μιλίων την ώρα. Έτσι θα ήταν καλύτερα για ένα πλοιοκτήτη να επιλέξει το πλοίο με χωρητικότητα 216.000, το οποίο έχει και πιο χαμηλά κεφαλαιουχικά κόστη και δημιουργεί περισσότερες οικονομίες κλίμακας πλέοντας με ταχύτητα 17 ή 16 ναυτικά μίλια.

Στην συνέχεια αναλύσαμε το τρίτο ταξίδι (Κατάρ-Αμερική) το όποιο είναι και μεγαλύτερης διάρκειας σε σχέση με τα υπόλοιπα ταξίδια. Αυτό το ταξίδι έχει διάρκεια 22 μέρες για όλα τα πλοία εκτός από το πιο μικρό πλοίο το οποίο χρειάζεται 24 μέρες. Τα εμπειρικά αποτελέσματα που πηγάζουν κάτω από αυτό το σενάριο είναι ότι το πλοίο με χωρητικότητα 266.000 κυβικών μέτρων έχει τα μικρότερα κόστη για κάθε ταχύτητα. Εάν το πλοίο αυτό πλέει με ταχύτητα 19 ναυτικών μιλιών ανά ώρα έχει την μεγαλύτερη διαφορά στα κόστη από οποιαδήποτε άλλη ταχύτητα συγκρίνοντας το με τα υπόλοιπα πλοία. Ως αποτέλεσμα αυτό το πλοίο να δημιουργεί τις περισσότερες οικονομίες κλίμακας. Έτσι ως βέλτιστο πλοίο επιλέγεται αυτό με χωρητικότητα 266.000 κυβικών το οποίο πλέοντας με ταχύτητα 19 ναυτικά μίλια δημιουργεί τα μεγαλύτερα πλεονεκτήματα. Η ταχύτητα όμως εξαρτάται από τα ακραία καιρικά φαινόμενα και στην κρίση του πλοιοκτήτη και του καπετάνιου ωστόσο η ταχύτητα μπορεί να αλλάξει.

Μελετώντας το τέταρτο ταξίδι (Αλγερία-Γαλλία) το οποίο είναι και το μικρότερο σε διάρκεια από όλα τα επιλεγμένα ταξίδια σε αυτήν την έρευνα καταλήξαμε στο συμπέρασμα ότι ίσως το μικρότερο πλοίο σε χωρητικότητα θα ήταν και το καλύτερο. Εξετάζοντας και αναλύοντας τα εμπειρικά αποτελέσματα καταλήξαμε στο συμπέρασμα ότι ο πλοιοκτήτης έχει τρεις σημαντικές στρατηγικές. Η πρώτη στρατηγική είναι να ναυλώσει το μικρό πλοίο στην άμεση παράδοση έτσι ώστε να επωφεληθεί από τα αυξανόμενα ποσοστά ναύλου σε αυτές τις αναδυόμενες αγορές. Η δεύτερη στρατηγική είναι να χρησιμοποιήσει τα πλοία με χωρητικότητα 130.000, 145.000 και 155.000 κυβικών μέτρων αντίστοιχα έτσι ώστε ο πλοιοκτήτης να επωφεληθεί από τα σταθερά κέρδη τα οποία θα κερδίζει. Όσον αφορά την τρίτη στρατηγική ο πλοιοκτήτης έχει την ικανότητα να ναυλώσει τα πλοία καινούργιας τεχνολογίας σε μεγαλύτερης διάρκειας χρόνου. Επιπλέον σε αυτό το ταξίδι η ζήτηση που προέρχεται από την Γαλλία είναι μόλις 4% της συνολικής ζήτησης παγκόσμια, έτσι ο κάθε πλοιοκτήτης θα μπορούσε να το εκμεταλλευτεί αυτό και αγοράσει 3 μικρά πλοία παρά ένα μεγάλο πλοίο καινούργιας τεχνολογίας το οποίο στοιχίζει και περισσότερα. Ωστόσο, το πλοίο με χωρητικότητα 75.000 κυβικών μέτρων, ταχύτητα 16 ναυτικά μίλια και χρησιμοποιώντας το στην άμεση αγορά θεωρείται ως το βέλτιστο πλοίο δημιουργώντας τις περισσότερες οικονομίες κλίμακας.

Τα εμπειρικά αποτελέσματα που εξάγαμε από το τελευταίο ταξίδι (Νιγηρία-Γαλλία) είναι ότι το πλοίο με χωρητικότητα 145.000 κυβικών μέτρων πλέοντας με ταχύτητα 16 ναυτικά μίλια έχει λιγότερο κόστος ανά μέρα στην θάλασσα σε σχέση με το πλοίο των 155.000 κυβικών μέτρων πλέοντας με ταχύτητα 19 ναυτικά μίλια. Ακόμη το πλοίο με χωρητικότητα 130.000 κυβικών μέτρων πλέοντας με την αρχική ταχύτητα έχει ελάχιστα πιο μεγάλο κόστος σε σχέση με το πλοίο τον 155.000 κυβικών μέτρων. Έτσι εδώ τα βέλτιστα πλοία είναι αυτά χωρητικότητας 130.000 και 145.000 κυβικών μέτρων πλέοντας με ταχύτητα 16 ναυτικών μιλίων. Αξίζει να σημειώσουμε ότι παρόλο που τα κόστη είναι μεγαλύτερα σε σύγκριση με τα καινούργιας τεχνολογίας πλοία, επιλέξαμε αυτά τα πλοία ως βέλτιστα λόγω των μεγαλύτερων κεφαλαιουχικών κοστών που κοστίζουν τα μεγαλύτερα πλοία. Επιπρόσθετα σε αυτήν την έρευνα παρέχεται η πλήρης ανάλυση των εμπειρικών αποτελεσμάτων και τέλος γίνεται αναφορά στους περιορισμούς της παρούσας έρευνας και έπειτα γίνονται προτάσεις για περαιτέρω έρευνα.