IMPROVING PROFITS BY OPTIMIZING SPEED ON SHIPPING ROUTES

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ABSTRACT

IMPROVING PROFITS BY OPTIMIZING SPEED ON SHIPPING ROUTES

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Master of Science in Logistics Management, Institute of Social Sciences

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Maritime transportation is the most preferable transportation mode due to large capacity without overdraft restrictions, reliability and low cost. Maritime transportation accounts for 90% of the global trade (Yenal, 2011). Increased volumes with ever expanding ship capacities draw the researchers' attention to sustainability issues including reduced fuel consumption and reduced emissions in maritime transportation. Fuel consumption depends on several factors including ship design, engine size, ship condition, payload and sailing speed. In the literature, there are studies focusing on the reduction of the international maritime transportation costs by optimizing ship routing and sailing speeds. The aim of this thesis is to review the existing studies in the literature and to develop new mathematical programming models that consider payload and sailing speed simultaneously to maximize the profit. While trying to find optimal speed, we also consider payload effect, demand variability and two types of loads, namely, time-sensitive and time-insensitive goods.

Keywords: Payload; Optimal ship speed; Ship capacity and Profit maximization

ÖZET

DENİZ TAŞIMACILIĞI GÜZERGAHLARINDA HIZ OPTİMİZASYONU ILE KAR IYILEŞTİRME

KASAPOĞLU, Cansu Saadet

Lojistik Yönetimi Yüksek Lisansı, Lojistik Yönetimi Bölümü

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Deniz taşımacılığı, geniş kapasitesi, güvenilirliği ve düşük maliyetleri nedeniyle çok tercih edilen bir taşımacılık türüdür. Küresel ticaretin 90% 'ı deniz taşımacılığı ile yapılmaktadır (Yenal, 2011). Artan gemi hacimlerinin ve kapasitelerinin emisyon azalımına olan etkisi araştırmacıların dikkatini çekmiştir. Emisyon ve yakıt tüketiminde azalıma gidilmesi için çesitli çalışmalar yapılmıştır. Başta gemi tasarımı, motor büyüklüğü, gemi şartları, yük ve seyir hızı olmak üzere deniz taşımacılığında yakıt tüketimini etkileyen birçok faktör vardır. Literatürde birçok araştırma, uluslararası gemi taşımacılığında emisyon salınımını azaltma amacıyla rotalama ve hız belirleme konularına yoğunlaşmıştır. Bu tezin amacı ise, literatürdeki mevcut çalışmaları geliştirerek seyir hızına ek olarak geminin toplam ağırlığını da göz önüne alan yeni bir kar artırımı modeli elde etmektir. Bu çalışma, maksimum karlılık sağlayan seyir hızını bulmaya çalışırken, yükleme ve boşaltma miktarları, değişken talep ve farklı yük tiplerini de ele almaktadır.

Anahtar Kelimeler: Optimal seyir hızı; Gemi yakıt tüketimi, Gemi kapasitesi ve Kar artırımı.

To My Parents

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AGENT : A person authorized to transact business for and in the name of another person or company. Types of agents are: brokers, commission merchants, resident buyers, sales agents, manufacturer's representatives.

BALLAST : (a) the material (usually water in ballast tanks) used to stabilise a vessel when partially loaded or empty, (b) In Ballast - term to describe vessel sailing empty to next loading port.

BILL OF LADING: A document that establishes the terms of a contract between a shipper and a transportation company. It serves as a document of title, a contract of carriage and a receipt for goods.

BREAKBULK CARGO: Loose, non–containerized mark and count cargo. Packaged cargo that is not containerized.

BULK CARGO: Not in packages or containers; shipped loose in the hold of a ship without mark and count. Grain, coal and sulfur are usually bulk freight.

CARRIER : Any person or entity who, in a contract of carriage, undertakes to perform or to procure the performance of carriage by rail, road, sea, air, inland waterway or by a combination of such modes.

CONSIGNMENT: A shipment of goods to a consignee, who is a person or company to whom commodities are shipped.

CONTAINER: A box for transport cargo.

CUSTOMS: Government agency charged with enforcing the rules passed to protect the country's import and export revenues.

CUSTOMS BROKER: A person who prepares documentation for imported goods.

DEADWEIGHT TONNAGE (DWT): Deadweight capacity of vessel comprising cargo, bunker fuel, fresh water, stores etc.

DEMURRRAGE: A penalty charge against shippers or consignees for delaying the carrier's equipment or vessel beyond the allowed free time. The free time and demurrage charges are set forth in the charter party or freight tariff.

ELECTRONIC DATA INTERCHANGE (EDI): Information Exchange electronic format. Electronic commerce for advantage of international markets.

FREIGHT RATES : The charge incurred to transport freight, it is changing according to shipping line.

GENERAL CARGO: The cargo include containerized and breakbulk goods. General cargo produce more jobs than bulk.

KNOT: Ship speed unit. One nautical mile (6,076 feet or 1852 meters) per hour.

TARIFF: A publication setting forth the charges, rates and rules of transportation companies.

TERMINAL: An assigned area in which containers are prepared for loading into a vessel, train, truck, or airplane or are stacked immediately after discharge from the vessel, train, truck, or airplane.

TWENTY FOOT EQUIVALENT UNIT (TEU): Container capacity measure. equal twenty foot container.

CHAPTER 1

INTRODUCTION

Maritime transportation is the most preferable transportation mode due to large capacity without overdraft restrictions, reliability and low cost. Maritime transportation is 14 times cheaper than airway, 7 times cheaper than highway and 3.5 times cheaper than railway (*Yazıcı, 2013).* Mainly for these reasons, maritime transportation accounts for 90% of the global trade. Researchers estimate that every year 350 million tons of fuel is consumed by maritime transportation worldwide. On the other hand, consumption of high volumes of low-quality fuel in maritime transportation is raising serious environmental issues. Many studies have been conducted for improving maritime fuel consumption's negative effects and transportation emissions. According to International Maritime Organization (IMO), emission rates for different transportation modes are given as 0.5% for railway 2.7% for maritime shipping, 21.3% for road and 15.3% for air and pipelines. It is also reported that fleets are expanding and ship capacities are increasing. Ship's total cost including operating and investment costs, depends on ship design. An important operating cost is the fuel consumption cost which depends on ship's sailing speed, which has to fall in ship's designed speed range.

Fuel costs constitute the largest expenses for ship operations. Ships try to reduce fuel consumption by travelling at low speeds. Depending on the ship size, a vessel may consume between 10 or 250 tons of fuel (bunker). For instance, a typical voyage from the Persian Gulf to Asia normally takes 42 days (at laden speed 15 knots and 16 knots is ballast speed). Maersk Tankers on this route decreased their speed from 15 knots to 8.5 knots on the ballast leg, thus increasing roundtrip time to 55 days and saving nearly $400,000 off the voyage's bunker bill *(Collins, 2010)*.

In general, cost expenditures of ships can be categorized as maintenance, operation and fuel cost. At this point, it is important to note different types of ship ownership in terms of determining the decision maker, who will be responsible from related cost expenditures. Firstly, shipowner or disponent owner may allow charterers to use ship. Some charterers can be hired only one or two voyage according to rental agreement. There exist different procedures for allowance such as voyage, time, or bareboat. In all cases, charterer is responsible from paying predetermined amount to the shipowner. In this Thesis, decision maker can be considered as ship operator (liner company), charterer or the ship owner itself but it is obligated to pay the costs pertaining to the operating the logistics progresses as well as the ship. The decision maker's ultimate aim is to make a profit for every voyage.

As a result of changing and improving ship designs, ship cargo capacities are increasing and unit freight costs consequently revenues are decreasing. Therefore, reducing the cost, especially the fuel cost is important for increasing profit. At the optimal speed, ship operators can reduce not only their fuel consumptions but also emissions, besides increasing their profits. At high speed, ships consume 40% more fuel compared to slow speed. Therefore, bunker companies selling fuel to shipowners; usually make more profit when ships travel at higher speeds or design speed.

Since reducing fuel costs is important for both reducing emission and increasing profit, we need to analyze factors affecting the fuel consumption. Fuel consumption is affected by shipping route, sailing speed (ballast or laden speed), waiting times at the port and the ship design. It is important to note that laden (loaded) ship consumes more fuel compared to ballast (empty) ship. In addition to these factors, waiting, loading and unloading times at the port are also important for fuel consumption. Considering that ports have different rules, e.g. some ports do not work during the weekend or holidays, timing and speed optimization are critical for ship owner's or ship operator's decision making problem. Ship owners have to consider all these factors during fleet planning, scheduling and routing. Sometimes ships have to sail at maximum speed to minimize trip time. They usually use two weeks forecast for better planning. However, the major factor affecting the fuel consumption is the ship's sailing speed. It is possible to express this relationship with different mathematical expressions or functions.

The nonlinear relationship between speed and fuel consumption can be represented by a quadratic or cubic function. In the literature, there are several fuel consumption functions, all of which are single variable function of speed (i.e. $f(v)=0.0036v^2-0.1015v+0.8848$). Note that although this function represents the quadratic relationship between fuel consumption and speed, it does not consider the effect of payload on fuel consumption. Therefore, our aim is to propose a bivariate fuel consumption function, which depends on both speed and the payload. As an additional contribution to the literature, we propose a profit maximization model besides minimizing the total fuel cost. The profit maximization model is analyzed for two different product types (perishable/time-sensitive and durable/time-insensitive) under three demand scenarios: high, medium and low. For perishable products such as fish, the freight rate is time sensitive therefore for higher revenues ships may travel at higher speed. However, for durable items freight rate is independent of the sailing time and revenue does not change with speed.

In this thesis, we try to answer following research questions;

1. How do speed and payload affect fuel consumption?
2. Given the ship type, capacity, route, supply and demand, how can we maximize the ship's profit considering related costs?
3. How different demand scenarios affect the optimal sailing speed?

When ship speed increases, fuel consumption increases too. On the other hand, if speed increases, the voyage time decreases and the ship operator gets a chance for more voyage. Thus, ship can get more payload and create more profit. We call this situation "trade-off between speed vs. number of voyages" and try to find the best point for maximum profit. In the following sections, we consider this trade-off and overview the factors affecting the ship's fuel consumption; shipping route, ship speed, relationship between fuel consumption and speed and CO_2 emissions.

1.1 Shipping Route

Every trip has a different shipping route. Ship route depends on origin-destination of the demand load. Ship-owners make routing decisions according to supply and demand. Every route has different characteristics such as length, fuel consumption, oil prices, and available ship capacity. Several studies in the literature focus on ship routing problems only. However, in this study we consider ship route as given. Table 1.1.displays eleven different ship routes and ports in a shipping network. The eleven ship routes include 87 ports. The ships' routes change according to supply and demand. Given the origin-destination information for each load, ship operator or the ship owner determines the routes and list of ports to be visited.

Therefore, loading, un-loading and transportation costs are also changing according to route and ship capacity.

Table 1.1. Some major ship routes in the world, Sourced from Wang et al. (2012)

No.	Ship type	Ports of call
1	5000- TUE	Singapore-Brisbane-Sydney-Melbourne-Adelaide-Fremantle
2	5000- TEU	Xiamen- Chiwan-HongKong-Singapore-Port Klang-Salalah-Jeddah-Aqabah-Salalah-Singapore
3	3000- TEU	Yokohama-Tokyo-Nagoya-Kobe-Shanghai
4	3000- TEU	Ho Chi Minh-Laem Chabang-Singapore-Port Klang
5	3000- TEU	Brisbane-Sydney-Melbourne-Adelaide-Fremantle-Jakarta-Singapore
6	3000- TEU	Manila- Kaohsiung-Xiamen-Hong Kong-Yantian-Chiwan-Hong Kong
7	3000- TEU	Dalian-Xingang-Qingdao-Shanghai Ningbo-Shanghai-Kwangyang-Busan
8	3000- TEU	Chittagong-Chennai-Colombo-Cochin-Nhava-Sheva-Cochin-Colombo-Chennai
9	5000- TEU	Sokhna-Aqabah-Jeddah-Salalah-Karachi-Jebel Ali-Salalah
10	10000- TEU	Southampton-Thamesport –Hamburg-Bremerhaven-Rotterdam-Antwerp-Zeebrugge-Le Havre
11	10000- TEU	Southampton-Sokhna-Salalah-Colombo-Singapore-HongKong-Xiamen-Shanghai-Busan-Dalian-Xingang-Qingdao-Shanghai-HongKong-Singapore-Colombo-Salalah

Maritime transportation has different routes in the world. The routes are divided according to major trade zones. Depending on ship capacity, ship age, maneuvera capability at the destination port, destination country and flag, ships are assigned to specific routes. In this study, we consider the route given by Fagerholt et al. (2010) and presented in Figure 1.1. We assume that ship sailing on this route has 8000 TEU capacity.

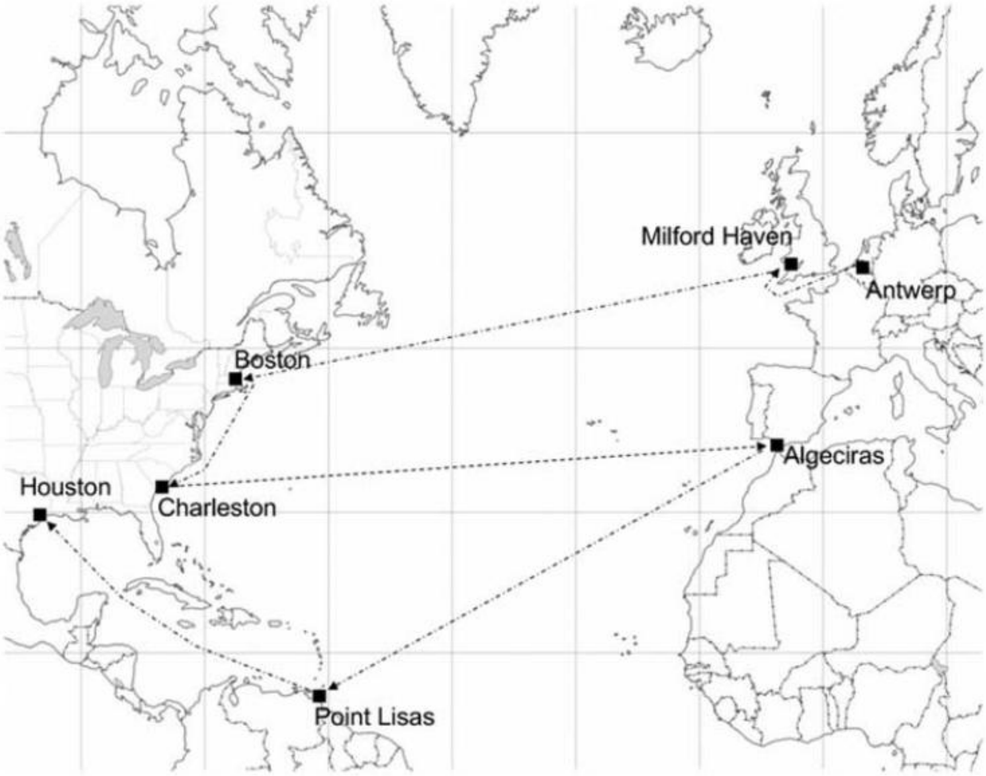

Figure 1.1. Selected ship route (Source: Fagerholt et al. 2010)

1.2. Ship Speed

Ship speed and fuel consumption differs according to ship's laden and ballast condition. The ship consumes less fuel when the ship is ballast (empty). Owners want to sail at minimum speed to save fuel but charterers aim to maximize number of voyages because excess time spent on the route does not generate revenue for them. In the maritime terminology, there exists different types of speed as discussed in the following subsections.

1.2.1. Economic speed or Optimum speed

Economic speed is the best speed for owners producing the best financial results in terms of less fuel consumption, oil price, and wearing or aging of the engine. Note that fuel consumption also depends on weather conditions, ship's safe time at port and sea. Sailing at less than optimum speed will consume more fuel rather than less. Generally economic speed is applied on deadweight capacity.

1.2.2. Safe Speed

Regardless of financial concerns, the safe speed ensures sailing safety and prevents any unwanted events. Safety speed is determined according to following factors:

- traffic density
- port distances for stop, ship's turning ability and manageability
- depth of water
- ship's background light
- weather condition

1.3. Relationship between Fuel Consumption and Speed

Due to uncertainties in sailing times and service times, every ship is given a time window specifying the earliest and latest arrival time to a port. In order to catch these time windows, ships adjust their speed and sailing time from departure port to the arrival port. On the other hand, ships may have different, pre-set sailing or manoeuvre speed at different ports. In general, ships are very sensitive to sailing speed and bunker consumption is significantly affected by the sailing speed. In recent years, oil prices have been very high. Consequently, freight rate, operating costs have been negatively affected. The sailing speed also affects round-trip time of a ship route. For instance, when ships sail at maximum design speed of 24 knots, the trip time might reduce from 39 to 37 days. However, such a reduction in sailing time increases the fuel consumption by 20-40%.

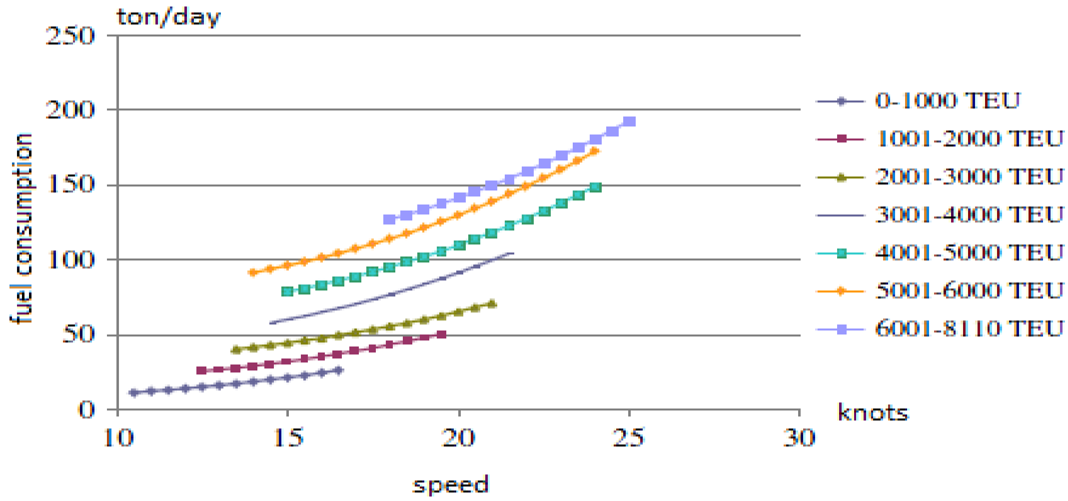

Figure 1.2 Fuel consumption vs. speed for different ship capacities (Source; *Yao et al., 2011*)

Figure 1.2. shows that as speed is increasing, large ship's fuel consumption increases faster than smaller ship's fuel consumption. For instance, when 8000 TEU ship's speed is 20 knots, the ship consumes approximately 150 ton/day fuel. However 1000 TEU ship consumes approximately 30 ton/day if the ship sails at 15 knots. The ship's size is an important determinant affecting the fuel consumption. On the other hand, larger ships can meet higher demand and their profit is higher than smaller ships. Ship operators or liners generally prefer to lower speed to reduce bunker costs. However, when the ship operators or liner companies observe high demand for container transportation, they may increase the sailing speed to maximum design speed so that they can have more trips and generate more revenue between origin and destination ports. Ideally, port times should be used only for manoeuvring, container loading and unloading. By increasing or decreasing the sailing speed, ships may

minimize waiting times at the port and generate leaner maritime operations and more effective port time utilization.

Shipping companies try to deliver their goods on the right time, at the right place and in the right condition. Therefore, in case of high demand, shipping companies tend to sail at high speed and bare higher fuel costs. Growing ship size creates more transport capacity and this results in lower unit costs. When the demand and supply increase, ships would like to increase service time and turnover and prefer sailing at full speed. Slow steaming is profitable and ship-owners have more profit if they optimize their speeds. Fuel consumption which is dependent on speed is a major cost item for ships. Reducing sailing speed occur lower bunker fuel costs. A large ship has approximately 100.000 USD worth of fuel consumption per day according to Ronen et al., (1982). If the speed reduces 20%, fuel consumption may reduce 50%. Relationship between speed and fuel consumption depends on engine's type, load and un-loading performance.

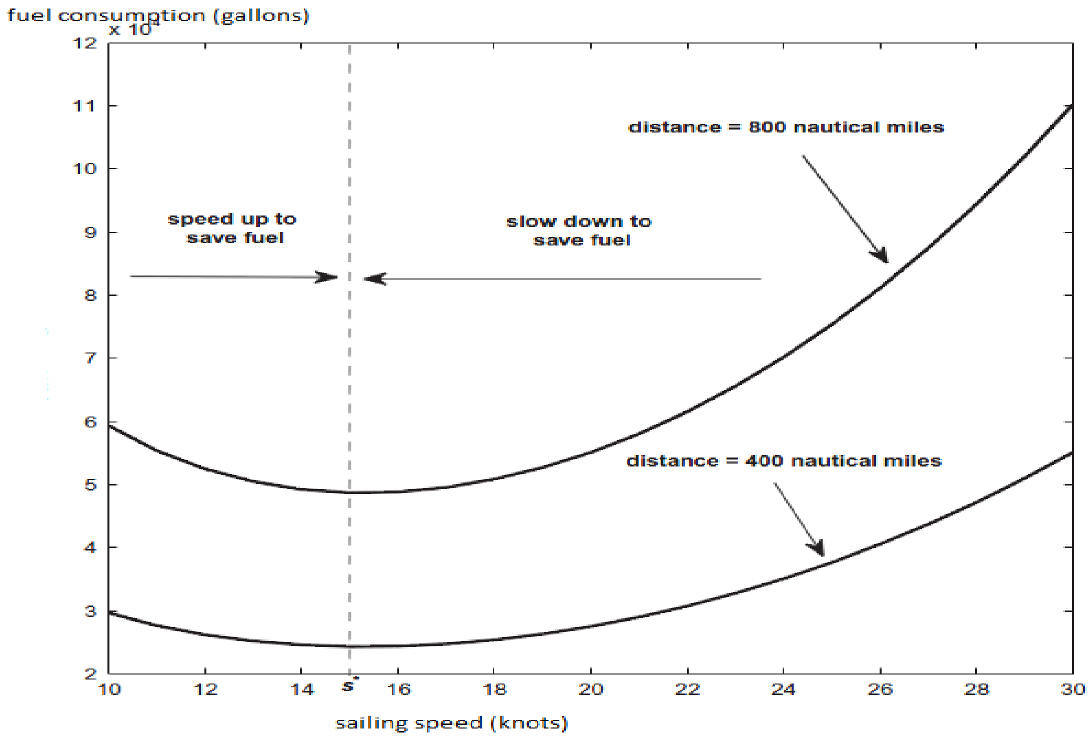

Figure 1.3. Fuel consumption between speed curve sources*; Du et al. (2011)*

The Figure 1.3. shows the nonlinear relationship between speed and fuel consumption. Every ship has design speed interval, which is typically between 10 and 30 knots. Incerased speed considerably increases the amount of fuel that ship consumes. However sailing at the lowest design speed does not necessarily minimize the fuel consumption. As shown in the Figure 1.3,optimal sailing speed is the lowest point on the speed curve. For instance in Figure 1.3, for a given distance, optimal sailing speed is observed as 15 knots.

1.4. International Convention for the Prevention of Pollution from Ships (MARPOL)

International Convention prevents pollution from ships. MARPOL was accepted in 1973 at IMO. On 19 May 2005, MARPOL has been updated and IV entered into force. The convention includes rules and regulations to minimize pollution from ships in five Annexes. The first Annex include oil, second regulates control of pollution by noxious liquid substances. Annex III includes packaging for dangerous goods. It means, packaging standards for details, documentation, storage, quality, exceptions, marking, labeling and notifications. Annex IV prevents sewage pollution from ships. The convention IV contains ships use sewage system at distance of more than three nautical miles from land. The last Annex includes garbage from ships. Disposal of different garbage types into the sea is not allowed. The last important update on MARPOL defines limitation of Sulphur oxide and Nitrogen oxide emissions. Annex five controls and put standards for SOx and NOx.

Marpol interested in NOx, SOx and emissions problem. The convention tests protocols and improve technical provisions. SOx and NOx are controlled by the

Annex VI under MARPOL. Annex VI limits sulphur content in fuel. Sulphur contents marine fuels. SOx emissions can be reduced to change fuel as; alternative of low sulphur. IMO MARPOL Annex VI responsible to reduce sulphur.

MARPOL rule is applied to new ships fore reducing NOx. Developed engine systems provide to reducing NOx. NOx is prevented to low temperature by using water such as; technology and reduce NOx up to maximum 99 %. If ships use LNG as fuel, NOx can be reduced by 60 %. NOx and SOx can be reduced by 90 %. CO_2 depends on electricity (IMO site) . SO_2 oscillation is less than CO_2. SO_2 is not greenhouse gas but SO_2 occur acid rain. SO_2 has more potential for provide saving.

1.5. CO_2 Emissions

Emissions are very important for sustainability and environmental issues. Fuel consumption affects emissions significantly. The higher the vessel speed, the more fuel is consumed and more emission is produced. International Maritime Organization (IMO) keeps records of air pollution caused by ships. The IMO records can be summarized as energy efficiency design index and market-based measures for Green House Gases (GHG). Kyoto protocol has studied about reducing emissions and IMO has made performance to reduce emissions too. Speed reduction and slow steaming reduces emissions and fuel bill. Fuel prices have increased and freight rates have remained low. Shipping emissions are calculated by fuel consumption and emissions factors including ship's weight, supply and demand at the port.

Other factors affecting the emission include engine type, horsepower, ships age. Old engines consume more fuel and create higher emissions. Every year engineers work on ship engine designs to reduce fuel consumption and emissions (Psaraftis, 2009).

CHAPTER 2

LITERATURE REVIEW

In this chapter, we review the literature and provide a summary of related literature on fuel consumption and speed optimization. Especially, we focus on studies that consider models with speed, freight rate, ship's weight, crew cost and service time. Due to sustainability issues and global environmental pressures, fuel and emission reduction in maritime transportation attracts many researches' attention.

Transportation has different types, capacities, rules and conditions. This study focuses on maritime transportation. Maritime transportation is the main transportation mode frequently used by most traders worldwide. Demand has an important role on increase in transport service capacity. Transport costs change by the trade and they depend on supply and demand. Therefore, transportation costs are closely related to the payload. Payload depends on supply and demand as well as ship capacity. On the other hand, different services in terms of speed, frequency, reliability and security may cause differences in freight rates. Ship owners should look at the economic factors in competing markets. Port selection depends on which is an important input for port selection, several criteria such as ship capacity, demand, routes, loading, un-loading. On the other hand, ships have different criteria i.e capacity physical, technical infrastructure, equipment or different geographical location. While some of ports are working 24/7, some ports have a rule for working only for weekdays for certain hours. Terminal productivity is another factor affecting cost efficiency, sailing frequency, reliability, capacity and frequency. Warehousing at ports is also important because goods are loaded and un-loaded in this area and the cost of logistics also depends on port choice.

We have searched the Scholar Google database using keywords "Payload''; ''Ship speed''; ''Ship capacity'' and ''Ship emission". Our search resulted in 61 articles published between 1982 and 2014. After scanning these studies, we included 20 articles categorized as follows;

1) 2.1. Fuel Consumption in Maritime Transportation

2) 2.2. CO_2 Emissions in Maritime Transportation

3) 2.3. Investigation of Ship Speed

4) 2.4. Route Selection,

5) 2.5. Port Selection

6) 2.6. Loading and Unloading Operation

7) 2.7. Arrival and Departure

8) 2.8. Ship Sailing

9) 2.9. Cost of Maritime Transport

2.1. Researches on Fuel Consumption in Maritime Transportation

In this section, we review literature for fuel consumption models in maritime transportation published between 1982 and 2014. Wang et al., (2013) study fuel consumption problems considering the demand for shipping. For instance, the demand for maritime transportation in 2011 was 8.4 billion tons. Oil is the main product creating demand for transportation. Notteboom (2009) analyzed the oil price increase and created a cost model showing the relationship between bunker fuel consumption. It is an important decision to determine the shipping capacities, speed and fuel consumption. Vessels try to minimize the annual operating cost of the route. Due to reduced demand and increased oil prices, containership operators try to reduce fuel costs by reducing sailing speed of their vessels. Another study, readers are referred to is by Ronen (2011), which provides a model that determines optimal speed to minimize the operating cost. A recent study bt Meyer et al. (2012) investigates the economic and environmental impacts of speed reduction focusing on optimal speed function.

Yao et al. (2012) study several bunker fuel management strategies considering different factors including port selection, ship size, ship speed and routes. Their model represents relationship between fuel consumption and ship speed.

2.2 Studies Investigating CO2 Emissions in Maritime Transportation

IMO (International Maritime Organization) sets new policies in order to reduce CO2 emissions and toincrease efficiency in martime transportation. Lindstad et al. (2011), reports that maritime transportation consumes 1046 million tons of CO_2 in 2007 according to International Maritime Organization. They also analyze the daily frequency strategies for CO_2 reductions for international container shipping carriers due to slow steaming. Emissions are affected by slow steaming. Slow steaming provides over-capacity and flexibility for cost of fuel as reported by Cariou et al. (2010). Authors try to forecast fuel consumption with the proposed model, which determines arrival and departure time. However, a policy that requires all ships to reduce CO_2 emissions increases international trade costs for small-island nations significantly, presenting an equity issue to be resolved some of the studies. Song et al. (2012) consider the transportation and handling of empty containers and related

CO_2 consumptions. Since ballast ship consumes less fuel, empty container transportation results in less CO_2 emissions. On the other hand, if the port capacity is high, ship waiting time at the port can be minimized and this also contributes to CO_2 reduction. Fleet size also has a role in emissions and Eyring et al. (2005) investigate the relationship between fuel consumption and emissions and propose models based on fleet size. Terminal efficiency, storage and ship routing planning are also important for time and fuel efficientcy. Du et al. (2011) consider significantly reducing fuel consumption and vessel emissions, while simultaneously retaining the service level of the terminal. Kontovas et al. (2009) studied and collected data focusing fuel consumption, engine and horsepower for reduced emissions.

Transport demand depends on economic growth and increased need for travel. Shipping demand has been increasing since 1995 and the results in increase in emissions. When the shipping demand is high, ship-owners try to increase number of trips by enlarging fleet or raising ship's speed. Chapman et al. (2007), Kim et al. (2012) and Streets et al. (1997) Are also studying the relationship between ship speed and CO_2 emissions from different aspects.

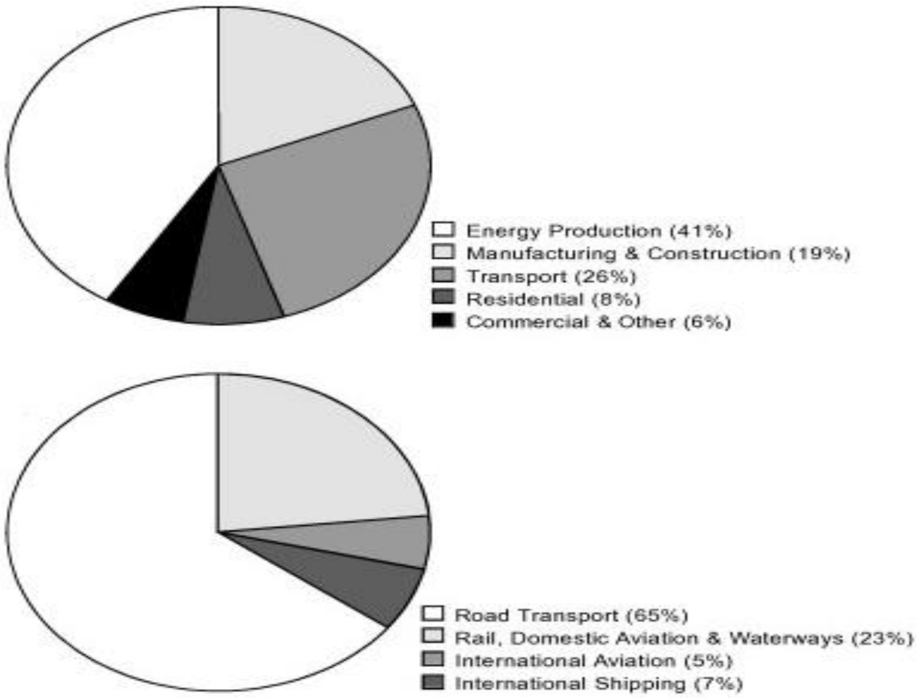

Figure 2.1. CO_2 emissions per transportation sectors by OECD (Organization for Economic Cooperation and Development), 2002.

Figure 2.1. shows that transportation systems accounts 26% of CO_2 emissions. Road transport has the biggest part in greenhouse gas production while international shipping has the lowest part of greenhouse gases in the transportation sector. Chapman et al. (2007) and Hamelinck et al. (2005) compare the emission production in other transportation systems.

2.3. Investigation of Ship Speed

Speed has important economic consequences in terms of fuel consumption and cost. Sailing speed is one of the main parameters for shipping companies or ship owners. There are numerous studies in the literature focusing on sailing speed from different aspects. Psaraftis et al. (2013) study ship's speed and try to reduce the speed for environmental effect. Reduced speed provides benefit for emissions and fuel consumption. There are several speed optimization models (Fagerholt et al. 2010, Corbett et al. 2009, Psaraftis et al. 2014) in maritime transportation, where speed is considered as the decision variable. Speed optimization results in cost reduction and/or profit maximization.

2.4. Route Selection

The shipping route is determined according to weather conditions, ports, weight, destination countries, ship's size, ship's age and capacity. Due to legal and physical restrictions, not every ship can sail on any given route. Given the company defined supply and demand information, ship-owners determine the routes. In this context, Christiansen et al. (2004, 2007) provides a comprehensive review of the research on ship routing and scheduling and classifies the literature into three categories: industrial shipping, tramp shipping, and liner shipping. Hennig et al. (2012) examine port selection according to loading weight, arrival and departure time, while minimizing the transportation costs including the fuel consumption. Shortest path problem is studied by to reduce the route distances. Möhring et al. (2005) propose a route selection model based on shortest path problem with time window constraints. This study includes real time data for different heavy traffic scenarios. Brouer et al. (2014) propose a routing model to maximize the revenue of the ship. Fagerholt et al. (2010) propose a speed optimization model for each leg on a given route and develop alternative solution algorithms. According to this study, emissions are reduced by the shortest path solution.

Fagerholt et al. (2015) consider sailing speed, and time window constraints in route selection problem. Route selection decision has significant effects on emissions, fuel consumption and total profit. Therefore, in Kontovas et al. (2014), Qi et al. (2012), Green Ship Routing and Scheduling Problem (GSRSP) is defined as a optimal scheduling problem and tackled by simulation based methods. Authors consider the same problem to define optimal route to minimize fuel consumption and emissions.

Every ship has different port time at the port for loading, unloading. Psaraftis et al. (2014) study ship routes and observe that every ship has different main routes on which they transport laden in one direction, and transport ballast in the other direction. However, liner shipping has its unique characteristics, i.e.., ships are usually deployed on a closed route with weekly frequency following a published schedule of sailings with a fixed port rotation, and laden/empty containers are loaded on/off the ships at each port-of-call (Song et al. 2005; Ronen, 2011).

2.5. Port Selection

Selecting ports depend on where the cargo is discharged, route, port capabilities, ship capacity and ship flag. There exist three main processes at the ports. The first one is delivering containers. Second one is loading, un-loading at the portand the last one is storage of containers for different arrival time at sea and land carriers. Zhang et al. (2002) and Fagerholt et al. (2010) calculate speed optimization and present a multi-start local search heuristic to solve this problem. Notteboom et al. (2006) report that port selection is very important for meeting customer's demand. If the two ports distance is far from port to port, ship waiting time increases. When the waiting time increases, the reliability decreases and logistics costs are affected. Therefore, ship operators try to develop optimal speed for each sailing leg on a given ship route. Tongzon et al. (1994) identify several indicators of port efficiency and categorize them into two broad groups; operational efficiency measures and customer-oriented measures. The first set of measures deals with capital and labor productivity as well as asset utilization rates. The second set includes direct charges; ship’s waiting time, minimization of delays in inland transport and reliability. Notteboom et al. (2005)

report that port's role is important for freight cost. Port selection has important results on transportation costs. When maritime transportation demand increases, transportation costs decrease and quality of customer service increases.

2.6. Loading and Unloading Operations

Loading and unloading operations are critical functions for the time management of all the ports and ship operators. Zhang et al. (2002), Bazzazi et al. (2009) propose model that include outbound processes before loading and inbound processes after the unloading, according to shipping type. Jafari et al. (2013) analyze number of lags for loading and delay affecting unloading operations. They also note that an important factor is the frequency of ship arrivals.

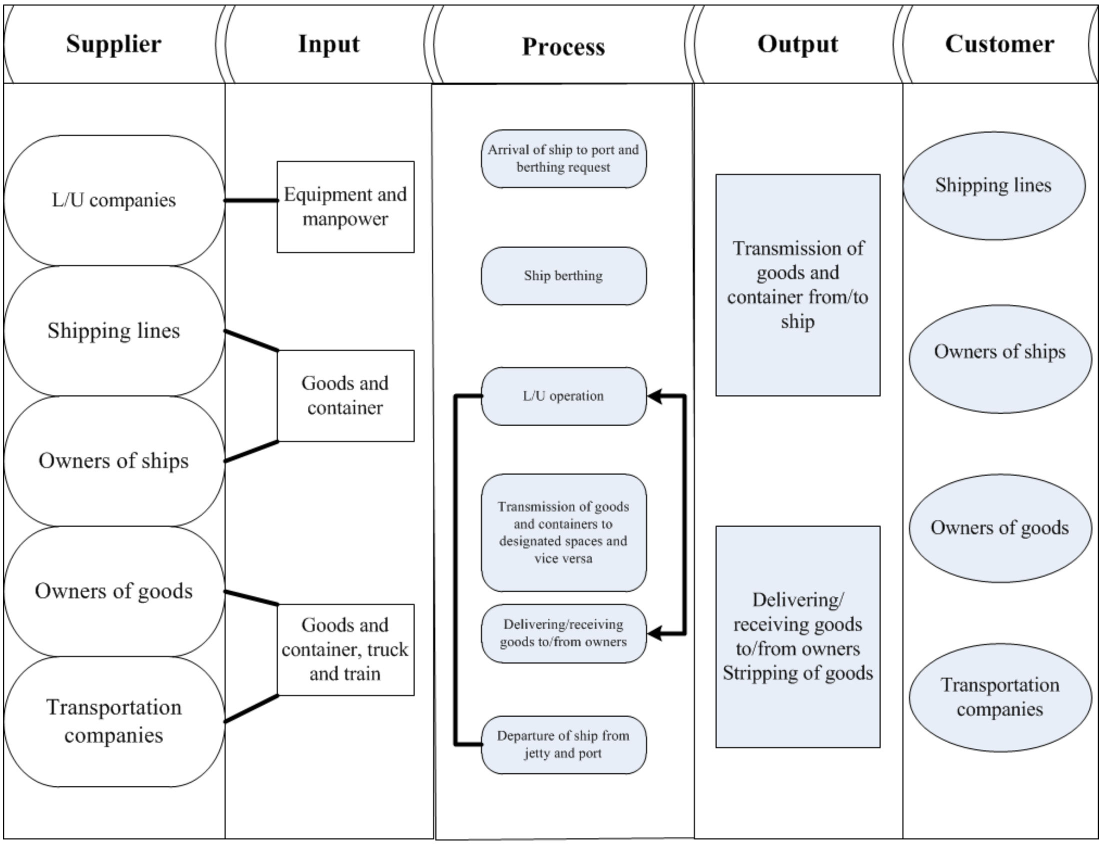

Figure 2.2. Loading, unloading processes by Jafari (2013).

Figure 2.2. shows loading and unloading processes. Customers want their goods to be delivered on time. The first operation is related to shippers or custormers on the supplier side for unloading. Inputs for the main processes include ships equipment and manpower, goods, containers, truck and train transfers. Output for loading operations is the transmission of the goods and containers to the ship, whereas output for the unloading process includes delivering goods to customers, which can be owners of the goods or transportation companies, shipping lines or ship owners.

Bausch et al. (1998) also study loading and unloading process. The loading process may take several days; duration of the unloading process depends on the destination. Amount of load depends on ship capacity and demand. The unloading process takes place after the loading process and therefore loading operations affect the unloading performance. In a more recent study, Christiansen et al. (2013) investigate loading, unloading combition and report that port's time depends on quantity loaded or unloaded with fleet capacity. They solve real instances of the problem within reasonable solution time and with good quality. Chung (1993) studies ship's priority for entering the harbor. Researchers have investigated problem and observed relation between ships deadweight and burden.

2.7. Arrival and Departure

Every ship has different arrival and departure time window constraints and ship must arrive on time at the port for reliability. On the other hand, when the ships are provided arrival time, the ships have loading time at the port. Accordingly, the ships must be provided with true departure time. Gambardella et al. (1996) behold ships arrival and departure different ports every day. They evaluate how the ship's owners manage resource allocation for ship loading, unloading. Then they provide a valid simulation model and forecast the performance based on historical data.

2.8. Ship Sailing

Maisiuk et al. (2014) examine the effects of weather conditions on sailing speed and report that when the weather conditions worsen, sailing speed is decreased. Ronen (1982) applies speed reduction models by setting the sailing speed as a decision variable. They note that some ships burn 100,000 USD worth of bunker fuel per day. Speed reduction is reducing daily bunker consumption. Fuel savings may be substantial but the additional sea days represent lost alternative profits. The optimal speed minimizes total economic cost of the voyage. Ship routes also have a role in setting the sailing speed. Port charges, ship size and sailing frequency are additional factors influencing the sailing speed. The inventory costs due to freight waiting to be shipped in a loading port depend on the sailing frequency (Hsu et al. 2007).

The sailing speed has impact on total operating cost since fuel consumption is very sensitive to sailing speed. When container ships sail at maximum speed, round trip time might decrease. When container ships sail lower speed, round trip time may increase. Wang et al. (2012) investigate optimal sailing speed of ships and ship route.

2.9. Cost of Maritime Transport

Transport services depend on trade volumes. Kavussanos et al. (2001) and Jing et al. (2008) investigate ship costs. For instance, freight rates change according to ship's size, port condition, customer's demand and ship's speed. Corbett et al. (2009) study profit maximizing considering opportunity costs. The researchers report that when ship speed is reduced by 20-30%, emissions are decreased by 20% and container fleet costs decrease $30-$200 per ton. Sánchez et al. (2003) also study transport cost at the port by investigating port efficiency. Different ports have different rules and tariffs. Their model tries to estimate costs with distances by public rules. They also consider loading, unloading processes, handling capacity and the average number of containers per ship handled in the terminals.

Table 2.1. Summary of literature review

Taxonomy parameter /paper	Psaraftis etal. (2013)	Kontovas et al. (2014)	Fagerholt et al. (2009)	Psaraftis et al. (2014)	Sánchez et al.(2003)	Ronen et al. (1982)	Tongzon (2009)	Psaraftis et al. (2009)	Christiansen et al. (2011)	Gambardella et al. (1996)	Chung (1993)	Ronen (2011)	Kontovas et al. (2009)	Tai et al. (2013)	Song et al. (2012)
Optimization criterion	cost	emissions	cost	profit	cost	profit	profit	cost	Cost	profit	cost	profit	cost	emissions	cost
Decision maker	owner	owner	owner	owner	owner	owner	owner	owner	Owner	owner	owner	owner	owner	owner	owner
Fuel consumption function	yes	yes	yes	no	no	yes	no	no	No	no	no	no	yes	yes	yes
Optimal speed	yes	no	yes	yes	no	yes	no	yes	No	no	no	yes	yes	yes	yes
Inventory cost included	yes	no	no	no	yes	no	no	no	No	no	no	no	no	no	
Fuel price an explicit input	yes	yes	yes	no	no	yes	no	no	No	no	no	no	yes	yes	yes
Emissions considered	yes	yes	no	no	no	no	no	yes	No	no	no	yes	yes	yes	yes
Port included	no	yes	no	no	yes	no	yes	no	Yes	yes	yes	no	yes	no	no
Sailing speed	no	no	yes	yes	no	yes	no	no	No	no	no	yes	yes	no	no
Routes included	no	yes	yes	yes	no	no	yes	no	No	no	no	no	no	no	yes
Freight rate input	no	no	no	yes	yes	yes	no	no	No	no	no	no	no	no	no
Load-Unload	no	no	no	no	yes	no	no	no	Yes	yes	yes	no	no	no	no
Operating cost	yes	no	no	yes	no	yes	no	no	No	no	no	yes	no	no	no
Payload for ship	yes	yes	yes	yes	no	no	no	yes	No	no	yes	no	yes	no	no

Taxonomy parameter/paper	Wang (2010)	Corbett et al. (2009)	Norstad et al. (2011)	Fagerholt et al. (2010)	Bausch et al. (1998)	Cariou et al. (2011)	Wang et al.(2012)	Du et al. (2011)	Meyer et al. (2012)	Kim et al.(2012)	Chapman et al. (2007)	Yao et al. (2012)	Psaraftis et al. (2014)	Notteboom et al. (2005)	Zhang et al. (2003)
Optimization criterion	profit	profit	cost	profit	cost	cost	sailing speed	cost	Fuel	cost	cost	cost	fuel	cost	storage
Decision maker	owner	owner	owner	owner	owner	owner	owner	owner	Owner	owner	owner	owner	owner	owner	owner
Fuel consumption function	yes	yes	yes	yes	yes	yes	yes	yes	Yes	yes	yes	yes	yes	no	no
Optimal speed	no	yes	yes	yes	no	yes	yes	yes	Yes	yes	yes	yes	yes	no	no
Inventory cost included	yes	no	no	no	no	yes	no	no	No	yes	yes	no	yes	no	yes
Fuel price an explicit input	yes	yes	yes	yes	no	yes	no	yes	Yes	no	no	yes	yes	no	no
Emissions considered	yes	yes	yes	yes	no	yes	no	yes	No	yes	yes	no	yes	no	no
Port included	no	no	no	yes	yes	yes	yes	yes	No	yes	yes	yes	yes	port	yes
Sailingm speed	no	no	yes	no	no	yes	yes	yes	Yes	yes	yes	no	yes	no	no
Routes included	no	yes	yes	yes	no	yes	yes	no	No	yes	yes	yes	yes	yes	no
Freight rate input	no	no	no	no	no	yes	yes	no	Yes	no	no	no	yes	yes	no
Load-Unload	no	no	yes	no	no	no	no	yes	No	no	no	yes	yes	yes	yes
Operating cost	yes	no	yes	no	no	no	yes	yes	Yes	no	no	no	no	no	yes
Payload for ship	no	no	no	no	no	no	no	yes	Yes	no	no	no	yes	no	no

Taxonomy parameter/paper	Bazzazi et al. (2009)	Ronen et al.,(2011)	Corbett et al. (2011)	Kavussanos et al. (2001)	Zhang et al. (2002)	Jing et al.,(2008)	Notteboom et al. (2006)	Eyring et al. (2005)	Notteboom et al. (2009)	Norstad et al.,(2011)	Streets et al.,(1997)	Lindstad et al.,(2011)	Ariel et al.,(1991)	Beenstock et al.,(1985)	Berg et al.,(2013)
Optimization criterion	storage	cost	cost	freight rate	routes	freight rate	service time	Emissions	cost	speed	emissions	speed	payload	cost	cost
Decision maker	owner	owner	owner	owner	owner	owner	owner	Owner	owner	owner	owner	owner	owner	owner	owner
Fuel consumption function	no	yes	yes	no	no	no	no	Yes	yes	yes	yes	yes	no	yes	no
Optimal speed	no	yes	yes	no	no	no	no	No	yes	yes	no	yes	no	yes	no
Inventory cost included	yes	no	no	no	no	no	yes	No	no	no	no	no	no	yes	no
Fuel price an explicit input	no	yes	yes	no	no	no	no	Yes	no	no	no	yes	no	yes	no
Emissions considered	no	no	yes	no	no	no	no	Yes	yes	no	yes	yes	no	no	no
Port included	yes	yes	no	no	no	yes	yes	Yes	yes	yes	yes	yes	yes	no	yes
Sailingm speed	no	yes	no	no	no	no	yes	No	no	yes	no	yes	no	no	yes
Routes included	no	yes	yes	yes	yes	yes	yes	No	yes	yes	no	no	no	no	no
Freight rate input	no	no	yes	yes	no	yes	no	No	yes	yes	no	yes	no	yes	yes
Load-Unload	yes	no	yes	no	yes	no	yes	Yes	no	yes	yes	yes	yes	no	no
Operating cost	yes	yes	yes	no	yes	no	yes	No	no	yes	no	no	no	yes	yes
Payload for ship	no	no	no	no	no	no	no	No	no	no	no	no	yes	yes	no

Taxonomy parameter/paper	Couper et al.,(2000)	Perakis et al. (1991)	Song et al.,(2012)	Maisiuk et al. (2014)	Agra et al. (2013)	Halvorsen et al. (2012)	Hennig et al. (2012)	Wang et al. (2013)	Wang et al. (2012)	Song et al. (2011)	Jafari et al. (2013)	Brouer et al. (2014)	Fagerholt et al.,(2015)	Cullinane et al. (2014)	Kavussanos et al. (2001)
Optimization criterion	cost	cost	emissions	cost	cost	cost	cost	cost	cost	cost	(un)loading	cost	cost	emissions	freight rate
Decision maker	owner	owner	owner	owner	owner	owner	owner	owner	owner	owner	owner	owner	owner	owner	owner
Fuel consumption function	no	yes	yes	yes	yes	no	yes	yes	yes	no	no	yes	yes	yes	no
Optimal speed	no	yes	yes	yes	yes	yes	yes	yes	yes	no	no	yes	yes	yes	no
Inventory cost included	no	yes	no	no	yes	no	no	yes	yes	yes	no	no	no	yes	no
Fuel price an explicit input	no	yes	no	no	no	no	no	yes	yes	no	no	no	no	yes	no
Emissions considered	no	no	yes	no	no	no	no	yes	no	no	no	yes	yes	yes	no
Port included	yes	no	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	yes
Sailingm speed	no	yes	yes	yes	yes	yes	yes	yes	yes	no	no	yes	yes	no	no
Routes included	no	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	yes
Freight rate input	yes	yes	no	no	no	no	no	no	no	no	no	yes	yes	yes	yes
Load-Unload	yes	no	yes	yes	yes	yes	yes	yes	no	no	yes	yes	yes	yes	no
Operating cost	no	yes	no	no	yes	no	no	yes	yes	no	no	no	yes	no	no
Payload for ship	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no

As a result of our literature review, speed optimization model provided by Fagerholt et al. (2010) is chosen as the base model and improved. Given the distances between ports, Fagerholt et al. specify time windows and minimizes fuel consumption for each leg (port to port trip). The fuel consumption model is quadratic, non-linear based on speed. They try to evaluate alternative models for fuel savings. On the other hand, other articles do not use payload with fuel consumption, crew cost and ship deadweight. According to the Fagerholt et al. (2010) model, there is a single ship route with seven ports (Antwerp, Milford Haven, Boston, Charleston, Algeciras, Point Lisas, and Houston). When the ship finishes all ports' supply and demand, the same ship turns back the follow the same route.

Table 2.2. Notation for Model in Fagerholt et al. (2010).

Notation	Defination
$k=1,2,\ldots,n$	Index for ports on the route
$d_{k,k+1}$	Distance between port k and k+1
f	Fuel function
$v_{k,k+1}$	Ship's speed between k and k+1
t_k	Arrival time to port k
$t_{k,k+1}$	Sailing time from port k to port k+1
e_k	Earliest arrival time at port
l_k	Latest arrival time at port k
f_v	Sailing consumption per distance $f(v)$.

$$Minimize \sum_{k=1,\ldots,n-1} d_{k,k+1} \; f(v_{k,k+1}) \qquad (2.1)$$

Subject to; $t_{k+1} - t_k - d_{k,k+1} / v_{k,k+1} \geq 0, \quad k = 1,\ldots,n-1,$ (2.2)

$$e_k \leq t_k \leq l_k, \qquad k = 1,..,n, \qquad (2.3)$$

$$v_{\min} \leq v_{k,k+1} \leq v_{\max}, \qquad k = 1,.,n-1. \qquad (2.4)$$

In this model, Equation (2.1) is the objective function; the aim is minimizing the fuel consumption, which is a function of ship speed. We note that objective function is convex and nonlinear. Equation (2.2) ensures that ship is not started service before it arrives at port k by ship-owners. Equation (2.3) defines earlist, latest time window (days) constraints. Equation (2.4) determines ship's lower and upper speed (14-25 knots).

According to Fagerholt et al. (2010), quadratic function $f(v)=0.0036v^2-0.1015v+0.8848$ shows the relationship between fuel consumption and speed, where fuel consumption is measured in tones *(t)*, distances are in mile *(M)*, and speed *v* is in knots *(M/h)*. Feasible speed range is between 14 and 20 knots.

In this model, there are six ports and every port has different time windows. Table 2.3. shows distances between port A to B, locations and time window constraints for each port.

Table 2.3. Ship routing and scheduling with speed optimization by Fagerholt et al. (2010)

Port	Distance (nautical miles)	t_{min}	t_{max}	Time Window(days) [ek , lk]
Antwerp	0	-	-	[0 , 0]
Milford Haven	510	510	102	[1, 5]
Boston	2699	300	208	[9,13]
Charleston	838	76	56	[11,15]
Algeciras	3625	181	151	[20,24]
Point Lisas	3437	107	95	[32,36]
Houston	2263	65	58	[35,39]

In the literature, several investigators propose models including fuel consumption function with the objective of emission reduction, ship speed optimization, and efficient use of ship capacity. However, none of these studies considers the payload affect on the fuel consumption. In this Thesis, we propose a speed optimization model considering a fuel consumtion function which is a function of both speed and the payload. Thus, we are able to observe the role of changing weight on speed and emissions.

CHAPTER 3

MARITIME TRANSPORTATION PROCESSES AND RELATED COSTS

Maritime transportation has different rules and conditions compared to other transportation modes. For instance, ship capacity, weather conditions, ship's age, flag, and freight rates impose different obligations for the ship-owner. In this Chapter, we will investigate cost categories in maritime transportation in order to create a valid profit maximization model.

3.1. Part of Maritime Transportation Costs

The costs in maritime transportation are seperated into three different categories: Fixed costs, Operating costs and Voyage costs. Fixed costs are related capital, amortisation and debt. Operating costs include crew costs, insurance, repair and maintenance, dry docking and communication. Voyage cost are associated port costs, loading and unloading costs.

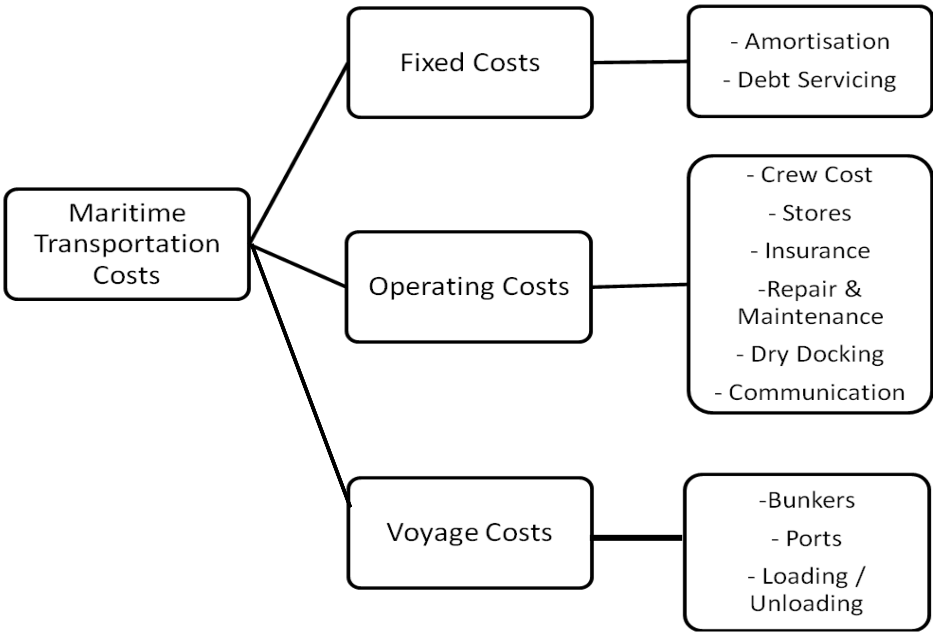

Figure 3.1 Classification of maritime transport costs

3.1.1. Capital or Fixed Costs

The costs include delivery expenses, loan payments, taxes and fees. The ship may worn out, charter equal to capital costs. Shipowner's financial resource is fixed cost if the owner purchase the ship by the mortgage.

3.1.2. Operating Costs

The operating costs are main obligations of the shipowner. Operating costs are generally calculated on a daily basis. The shipowner can easily calculate voyages' and charters' rate. The operating costs include; crew, storage, repair and maintenance, administrations and insurance costs.

3.1.2.1 Crew

Operating costs include crew cost. The crew cost is a significant part of the operating costs. Crew costs elements are; basic costs and overtime. Crew costs are also related to ship flag. Crew size depends on the ship type and capacity. Using crew agency has advantage and disadvantages. Generally crew are working on board for 12 month period.

3.1.2.2. Insurance, Repair and Maintanence

Ship-owner should have insurance for the ship against potential damages, wars and machine risks. The shipowner is also responsible from repairs of deck or engine areas. The new ships' repair and maintanence costs are relatively more expensive. Shipowner can estimate dry docking and periodical repair costs. They can spread this cost over the years. Every ship has different insurance premium, which can increase or decrease depending on several factors.

Maintenance and epairment services increase ship's productivity and physical capacity. Therefore, ships go under maintenance and repair at the end of every year. Maintenance and repairment costs change according to ships size, age and transport type. For instance, assume two ships (a passenger and cargo ship) have the same size and speed range. Passenger ship's repairment and maintenance costs are higher than the costs of a cargo ship.

3.1.3. Voyage Costs

The voyage costs vary according to port to port and time to time. The cost include bunkers, port charges, harbour, loading and unloading expenses. When the shipowner lets on time charter, ship costs are the responsibility of the time charter.

3.1.3.1. Bunker

Ship must receive fuel on routes and chooses port for fueling. Ship speed is the most important item for bunker fuel management strategy. If the bunker fuel costs are reduced, total operating costs will decrease.

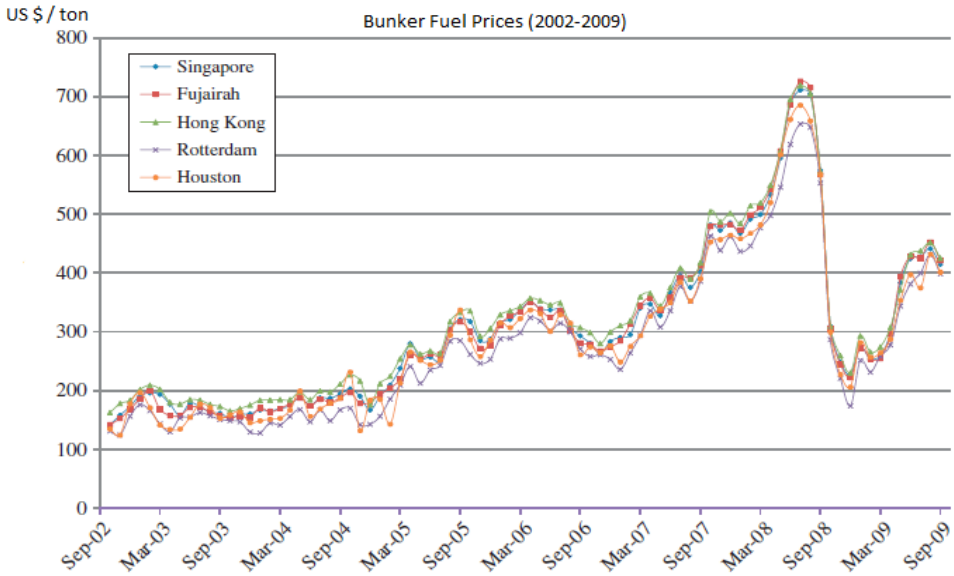

Figure 3.2. Bunker fuel prices per $/ton, Source: Bloomberg (2002–2009).

Figure 3.2 shows increasing bunker prices. The highest increases begin in 2008 and decreases suddenly in 2009 due to global crisis. In 2013, ship fuel sales amount only in Singapore was 42.68 million tons according to Bloomberg.

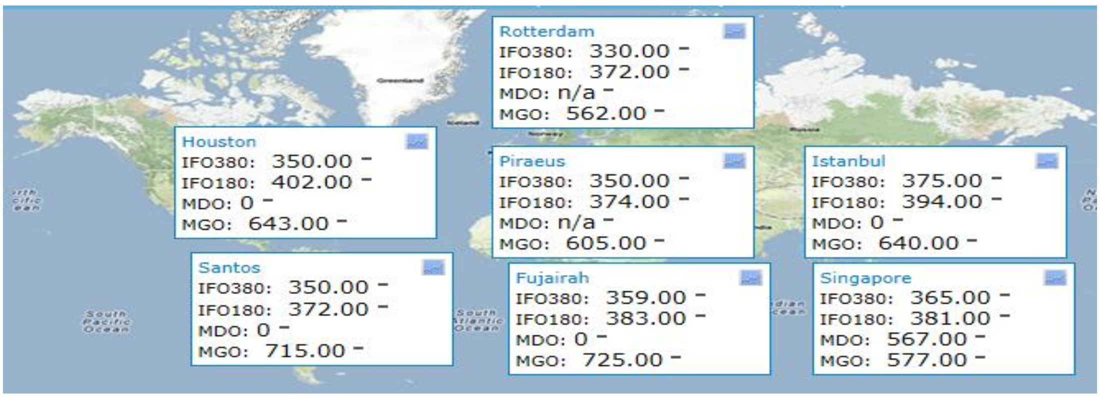

Figure 3.3. Bunker price worldwide from Bloomberg, 2015

Figure 3.8 depicts different bunker prices at major ports. All in all, Rotterdam's fuel price is cheaper than the others according to fuel types in Figure 3.8.

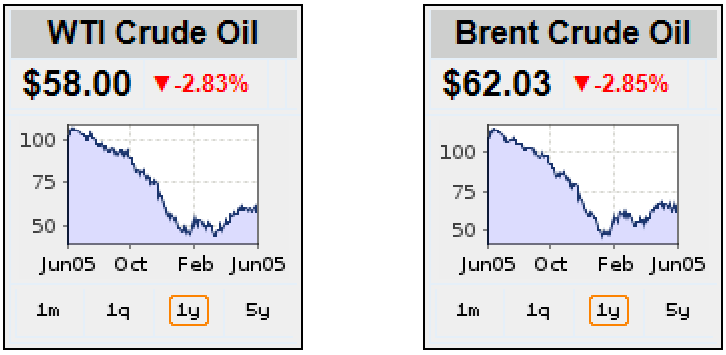

Figure 3.4. Fuel prices in USD, by Bloomberg (2015).

According to Figure 3.9, fuel prices start decreasing at the beginning of the year. This seasonality can be explained by seasonality in supply, demand and the relationships between governments.

3.1.3.2. Port

Port selection is the important for the flag because this selection affects both operating and administrative costs. Port selection include fixed and variable cost according to commerce. Commercial system includes loading, bunker and draft. Every port has different procedures and obligations. Awaiting time at port changes according to ship size, discharge amount and flag. Foreign-flagged vessels freight payment is higher than $3 billion every year. The main reason is, foreign flagged vessels generally prefer CIF transportation system for import.

3.1.3.3. Loading / Unloading of Maritime Transport

Every ship has different size, container capacity, compartments and costs. Each vessel has an employment schedule for 2-3 weeks. A ship loading and unloading time is more than one day for every trip. Time is limited for loading and unloading according to; supply forecasting, demand, capacity of transfer and store cargoes at the various ports of call. Ship-owners have to load customer's goods for on time delivery. Earliest and latest loading, un-loading date and locations are important. Sometimes loading continues several hours or days and ships need to burden then the burden is caused by different sources. Ships are loaded at one or more than one locations. Every product has different structure and shipowner has to regulate dispatching of loads; capacity of ship, storage condition according to product, forecasting demand and safety stock. Finally, the goods must be shipped. Sometimes some optional backhauls are available and the backhauls create income then may be profitable. Backhaul's profit depends on loading, un-loading port, vessel's cost and on time delivery. Every ship does not accord all ports. For instance; length, loading, un-loading limitations may be different. Ports have different work hours and days. In addition to this, ports have different rules. When ship approaches the harbor, dispatching and loading may continue throughout the day until the evening. On the other hand, Los Angeles ports work for eight hour per day if the ship stays five days. In that case, ports work two eight hour shift per day and reduce the duration at port to 2½ days. Slow speed not only reduces fuel consumption but also avoid waiting time for daylight port reach.

Shipping cost include fuel consumption (depends on speed), port fees, backhauls, daily cost, cost change by weight. It is reported that Gantt charts and forecasting are used to plan tranportation operations two weeks into the future (Bausch 1998). On the other hand, if one use Gantt charts they can analyze historical data to predict future events and optimize loading, un-loading times. The aim is reducing ship’s loading and un-loading time, which then reduces port’s time and costs. The other solution is blocking the global traffic. If one ship does not catch up arrival date and the other ship comes to port at the same time, ship with more containers is allowed to enter into the allocated berth. Every ship takes part in a row on the Gantt chart, with time on horizontal line. The line establishes relation between time and costs.

3.2. Type of Ship

Maritime transportation has different ship size and design. Separate different categories; dry cargo, tankers and miscellaneous. Every ship has different engine power, speed specialty and transport capacity.

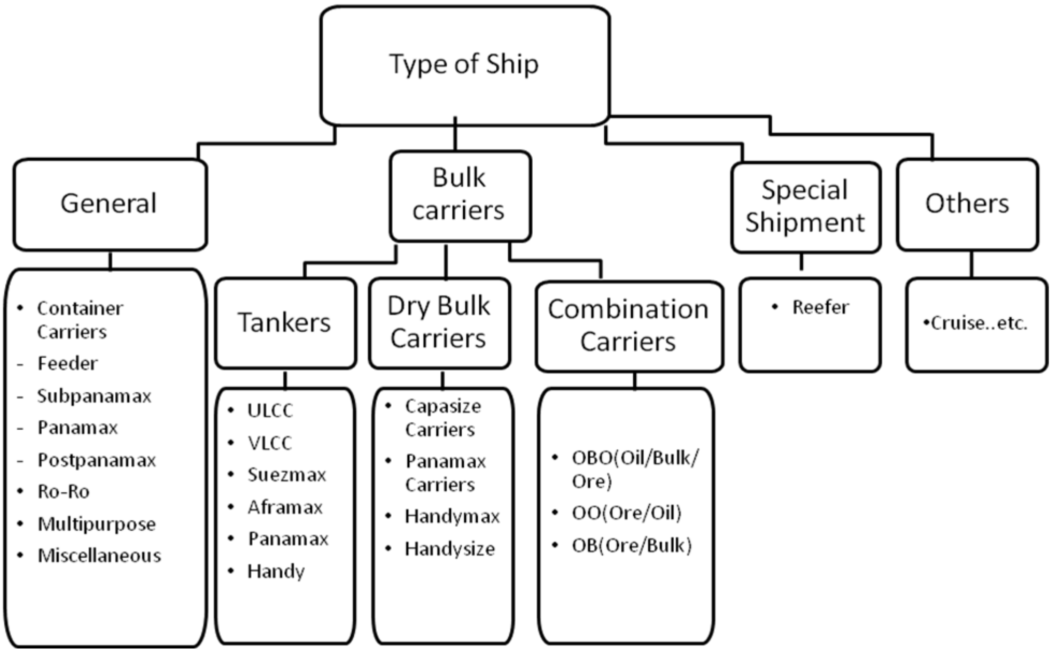

Figure 3.5. Type of Ships

3.2.1. Bulk carrier

Bulk carrier ships usually have large tonnage and carry more than 250,000 tons. It sizes 250.0000 metric tons of deadweight (DWT). The carriers have primarily design for carriage such as; grain, metals, sugar, coal. Bulk carriers have three different types; dry bulk carrier, tankers and combination carriers.

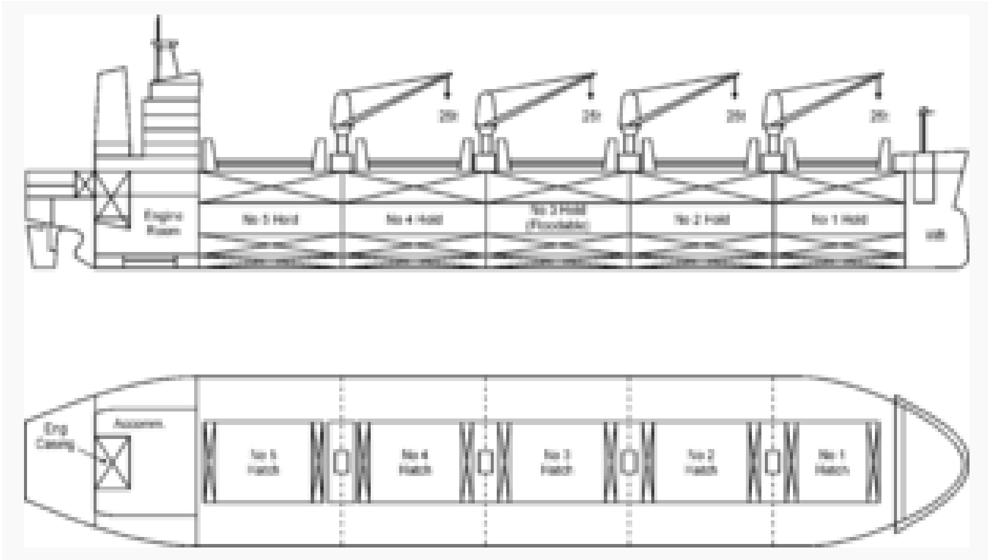

Figure 3.6. Bulk carrier

3.2.1.1. Tanker Ship

Tanker ships generally transport oil cargoes. Petrol tankers' transport capacity is between 1000-400.000 DWT. Maritime market has seven different tanker fleet categories: Panamax, Aframax, Suezmax, VLCC, ULCC, Capesize and Laker. Table 3.1 presents capacities for these seven categories.

Table 3.1. Ship capacity

Panamax	60.000-75.000 dwt
Aframax	80.000-120.000 dwt
Suezmax	120.000-200.000 dwt
VLCC (Very Large Crude Carriers)	200.000-300.000 dwt
ULCC (Ultra Large Carriers)	300.000 dwt
Capesize	150.000 dwt
Laker	19.000-30.000 dwt

3.2.1.2. Dry Bulk Cargo

Dry bulk ships have four different volume categories: Capasize, Panamax, Handymax and Handysize. Generally the ships transport iron ore, coal and grain. Capasize ship is approximately 120.000 dwt, Panamax ship is 65.000 dwt, it transports fewer products than Capasize. Handymax and Handysize ships are approximately 30000 dwt and transport grain products.

3.2.1.3. Combination Carriers

The ship designed for transporting both dry bulk and liquid products are called combination carriers. The ships are designed for both in order to prevent the return of idle time.

3.2.2. General Cargo

General cargo carriers have regular line. The carriers transport not bulk carriers. General cargo ships are separated into three different ship types: Container, Ro-Ro and multi-purpose cargo ships. Previously, they had 10.000 dwt tonnages depending on loading and unloading. However now, the loading and unloading systems are speedier than before. as below general cargo will decrease depends on container ship has faster loading and unloading system than general cargo.

3.2.2.1. Container Ship

Container ships improve day by day because of increased demand for containerized goods. Some tanker and bulk carriers are converted to container ships. The ships have 18.000 TEU transport capacity and the ships try to be energy efficient as engineers design new model ships called 'Triple E' with less CO_2 emissions.

3.2.2.2. Ro-Ro Ships

Ro-Ro ships carry automobiles, trucks, trailers and rail road cars. Loading, unloading and service time is very short cause of ships design. Ro-Ro (Roll/on-Roll/off) ships' main specialty is to ensure easy transitions between decks, faster handling of cargo and having the appropriate ramps.

3.2.2.3. Multipurpose

Generally, multipurpose ships have three or five storehouses. The size of the ship varies between 10.000-20.000 dwt. It usually has to decks. The ship transport general burden and grain at the same time.

3.2.2.4. Miscellaneous

The ship size changes between 8.000-22.000 dwt. The ships transport not being able to move with awkward container and heavy loads.

3.2.3. Special Shipment

Special ships have own reefers. The ship goes deep freezes and keeps low temperatures for products. The ships are faster than other type of ship cause of product importance. On the other hand, these ships transport chemical tanker and animals.

3.3. Ship Management

There are many different ship types in the market. For all types, main decisions are made by the shipowner. The decision types are ship size and trade condition. Whoever is responsible from the ship, the owner should provide efficiency, safety and profibility. Ship management means to carry own organisation and employed under contract. The management includes stores, crewing, maintenance and repairs. Shortly follow the shipment.

3.4. Agency

Shipping agents establishes links between customers, ship-owners, cargoes and shipping handling. On behalf of the shipping company, agencies may design documents and manage crew transfers, customs documentations. They also take part in booking and cargo trade. Some agencies collect documents and start loading, unloading operations at the ports. The other duties of agencies can be listed as follows:

- Prepare documents for customs and harbour services.

- Ensuring doctor for crew any emergency

- Ensuring storage, packaging

- Collects cargo and freight

- Contacts with ship-owner and goods owner

- Procurement of oil

- Prepare ports document (port agency)

- Inland haulage

- Technical support

And all services may be requested by ship-owner and captain.

3.5. Tax / Freight rate

Voyage expense has five different categories as listed below:

1) Port Expense
2) Strait Fee
3) Committee
4) Fuel Exprense
5) Total Voyage Time (day)

Freight rate is calculated by considering the five voyage expenses. Freight rate constitutes the main income source for maritime lines. Maritime lines calculate their freight rate based on

- Voyage time
- Strait fee
- Port expense
- Broker expense
- Fuel expense
- Total maritimeline expense
- Total Freight – Total expense

Shipowner should calculate total expenses, which are made of fixed costs and operating costs, in order to calculate profit on a route. Fixed costs are consisted by capital expense and firm outcome. Operating costs are based on trip type. Daily operating cost distribution is presented in Table 3.2.

Table 3.2. Distribution of daily costs

Personnel
Office Expense
Flag
Insurance
Oil
Water
Maintenance and Repair
Classy
Stationery Expenses
Communication
Unexpected Expense

Maritime industry is developing day by day. Forty years ago, ships consumed more engine power and labor but now shipping saves the power. Ship's engine has been continuously improved to provide more efficient maritime transport and affordable freight rates. Different vessel sizes have different freight rates. Three major ship categories determine the freight rate. The first ship is handy size (around 30.000 dwt), the ship transports grain. Panamax vessels around 65,000 dwt and used for grain and iron ore transportation. Cape size fleet around 120,000 dwt and transports iron. When ship horsepower is changed to 3.000 from 60.00 then the ship's speed was increased to 23 knots from 14.75. As a result of this, transportation time period was reduced to 5 days. Freight rate is changing according to different sizes and horsepowers. The larger ships usually have higher freight rates. This situation creates more demand for smaller ships. Smaller ships have different routes for services. On the other hand, freight rate is also affected by loading, unloading processes and labor.

3.6. Depreciation

Depreciation is calculated at end of the year. Firstly, every ship has different voyage and days. Daily depreciation is equal to voyage costs divided by voyage days. When ships voyage finish, the ships voyage days are multiplied by daily depreciation and voyage depreciation cost is obtained. Table 3.3. shows yearly depreciation rate according to Resmi Gazete and shipping transport data in 2015.

Table 3.3. Depreciation Rate about Vessel from Resmi Gazete, 2015

Depreciation (economic assets)	Useful Life (year)	Normal Depreciation Rate (%)
Cargo and Passenger Ship	18	0.0555

3.7. Port Facilities

Ports are the most important facilities in the maritime transportation infrastructure. Also, port related costs take a significant part in the total maritime costs. Port charges have two elements; fixed and variable costs.

3.7.1. Payload

Ship has a role on payload and payload affects on fuel consumption. If the ship is full or empty, different payload conditions have different effects on fuel. A ballast ship consumes less fuel, while a laden ship consumes much more. Therefore, fuel consumption depends not only on sailing speed but also ship payload.

3.7.2. Storage

Port’s traffic is impacted by its storage and handling capacity. Some ports have huge storage capacity for goods. Every product has different storage condition i.e. regular, empty and refrigerated containers. Containers storage's is the most important services and the fast storage and handling of containers create better economic performance for terminals and shipping companies. The storage performance includes time for allocation, moving place and loading container. These items need higher operating time and cost. But if the ports have efficiency storage program, transportation costs are reduced.

3.7.3. Ship Capacity

Cargo ships have different types and sizes depending on demand of cargo transportation. Cargo ships are categorized by capacity, goods variety and routes. For instance; hand size model can carry 10.000-30.000 DWT, while tankers can carry more than 200.000 DWT.

3.8. Part of Transportation Market

Every transportation systems have the same market structure as shown in Figure 3.7. In this Thesis, we investigate maritime transportation and analyze related risks, markets, charters, supply and demand.

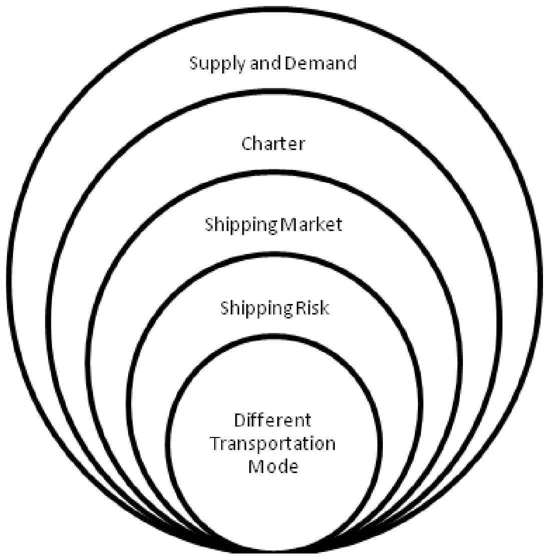

Figure 3.7. Transportation markets structure and obligations

3.8.1. Environmental Impact of Different Transportation Modes

Transportation industry has rapidly developed since 21th century. Among the different transportation systems, it is important to notewhich one is the cheapest, which one is the fastest, reliable, frequency and least emissions yield. According to observations, transportation process is the same but costs, time, frequency, emissions yields are different.

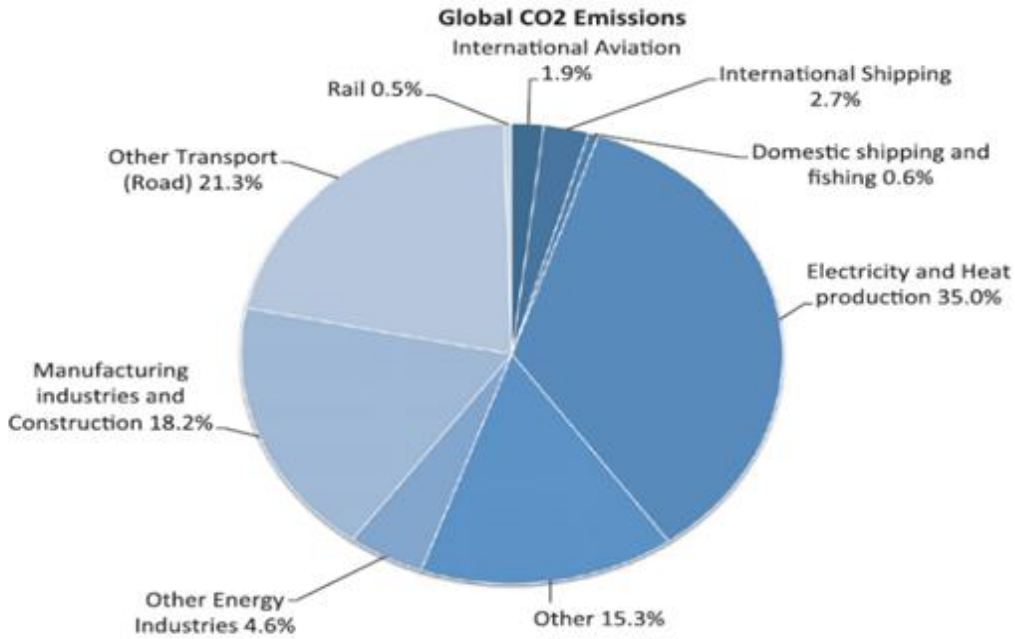

Figure 3.8. IMO (2009) compared CO2 emission the other transportation type.

Figure 3.8. Shows CO_2 emissions for different transportation modes. When you look at the Figure, actually shipping does not consume high emission but shipping transportation system is very prevalent worldwide and emission problem is very important. As you can see, all of the transportation system has environmental effect but maritime transportation has more protectable transportation because it has lots of solution for reducing emissions.

Figure 3.9. shows environmental effects of transportation. IMO reported that transportation industry produces 800000 tons of air pollutions every year. This idea' causes vehicle operations, maintenance and facilities.

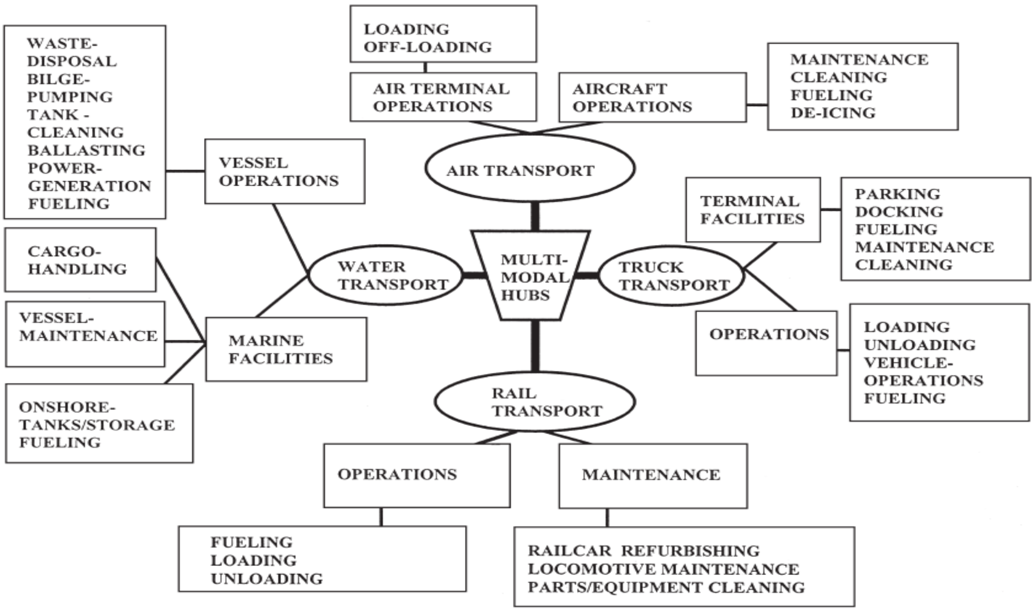

Figure 3.9. Components of Transportation Logistics System with Environmental Impacts (Source: Rondinelli et al. 2000).

Air transportation creates engine emissions, noise pollution and waste treatment problems. Air transportation generally transports emergency goods or expensive goods. Terminal operations are generally cargo loading, un-loading, airplane operations, maintenance of equipment, fill fuel. Aircraft's engines exhale carbon dioxide (CO_2) and damp more than 3 per cent of emissions. Railway transportation threatens air pollution. Because railway transportation transports dangerous goods and sometimes these goods can be leakage or spillage and mix water and soil, creating serious threats to human health. Trucking transport has the same processes i.e; loading, un-loading, freight cost, fill fuel and it can threat air, water pollution. Sometimes this cause creates emissions problems at terminals. Terminals, which do not protect for environmental degration create emissions problem.

Maritime transportation can also create threats to environment but slow steaming and more efficient ship design can help reducing emissions. On the other hand, efficient cleaning of ship, fueling, power of engine and pumping is very important for reducing CO_2.

3.8.2 Shipping Risk

Shipping industry has several risks. The risk can be taken by shipper or shipowner. Who is doing shipping investment it must be flexible. When ships have short supply, freight rates trigger ordering. If there is a surplus, freight rates reduce and the ships are using a long time. The ship-owner generally uses their ships for twenty years. As the ship's technology is developing, there is more stimulation to investment in new ships. The new ships have different efficiency standards, high demand and higher freight rates.

3.8.3. Shipping Market

Sale and purchase market is changed by freight rate. Because, generally markets are affected by cash. Maritime Economics Book provides the shipping flow shown in Figure 3.10. The black line shows outputs and the dashed lines show changing ship-owners but these never changes the cash balance in the industry. The main item is freight revenue. Freight rates sometimes change and these changes are related to ship-owner's decision.

The other profit market is demolition market. For instance, the sale of a tanker for $20 million just transfers' $20 million cash from one shipping bank account to another, leaving the aggregate cash balance unchanged. According to Figure 3.10, shipping market only earn from freight. Figure shows cash flows for shipping companies. Cash is changable according to ship-owners and companies. Freight rate is input for companies. Ship value is 20 million and the ship-owners want to meet cost over five years. The main market is freight. Freight market affects the other markets. When freight rate increases, cash decreases and ship-owners want to buy second hand ships.

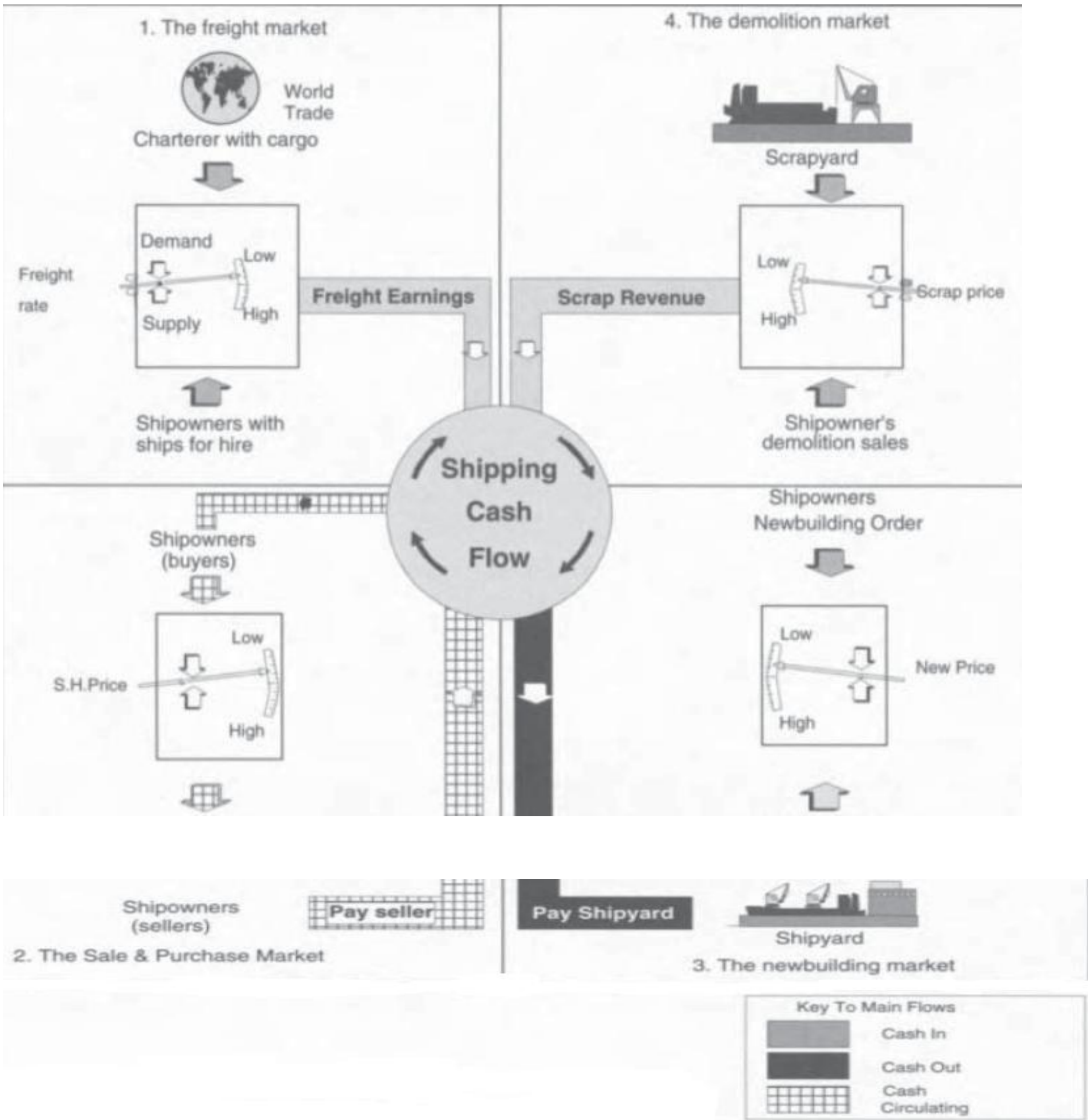

Figure 3.10. The four markets which control shipping by Martin Stopford, (1997)

3.8.4. Charter

Charters have different rules according to investigation and negotiation, namely. Charterer calculates ship's details (size, cargo capacity), and bill. Charters have contract about loading, unloading, discharging, lay time and payment. Charter rates are reported for every trip or once every 6 months, 12 months and 3 years.

3.8.5. Role of Supply and Demand

Maritime economy is very complex. Because, ship's income and outcome are changeable according to supply and demand. Table 3.4 shows supply and demand affect for shipping. Demand is changing according to world economy, seaborne trades, average haul, political events and transportation costs. On the other hand, supply is changing according to fleet, fleet productivity, shipbuilding production, scrapping- loosed and freight rate. Our model has three components; freight rate (r), supply (supk) and demand (demk). Freight rate is the most important thing for the thesis.

Table 3.4. Shipping market model by Maritime Economics Book.

Demand	*Supply*
1. The world economy	1. World fleet
2. Seaborne commodity trades	2. Fleet productivity
3. Average haul	3. Shipbuilding production
4. Political events	4. Scrapping and losses
5. Transport costs	5. Freight rates

On the demand side, several sectors produce different goods. The goods transportation is generally expensive in the world economy. The producer firms prefer maritime transportation because maritime transportation is cheaper than the other transportation systems. Especially, oil price's role is very important on demand

and ship's payload. Shipping companies measure demand for distances and transported cargo according to ton miles. The demand is measured by ton miles.

On the supply side, supply depends on stock and discharge at the port. Supply is affected by speed, service time and ship's operated by fleet. Tanker ships steams at 11 knots and the ship carries less cargo than the bulk carriers in a year. The bulk carriers are steaming at 14 knots. This scenario shows fleet productivity, which is defined in ton miles per dwt per annum. Ship-owners and producers have supply side of market developments.

CHAPTER 4

FUEL CONSUMPTION FUNCTION

In this chapter, we analyze the mathematical relationship between the fuel consumption, sailing speed and the payload. After overviewing different fuel consumption functions, we propose our own fuel consumption function, which depends on both speed and payload.

4.1. Ship Speed and Fuel Cost

Many models include maritime transportation problem in literature. In these models, fuel and emissions depend on speed. Fuel cost is an important topic on emissions, payload, service time and ship capacity and crew cost.

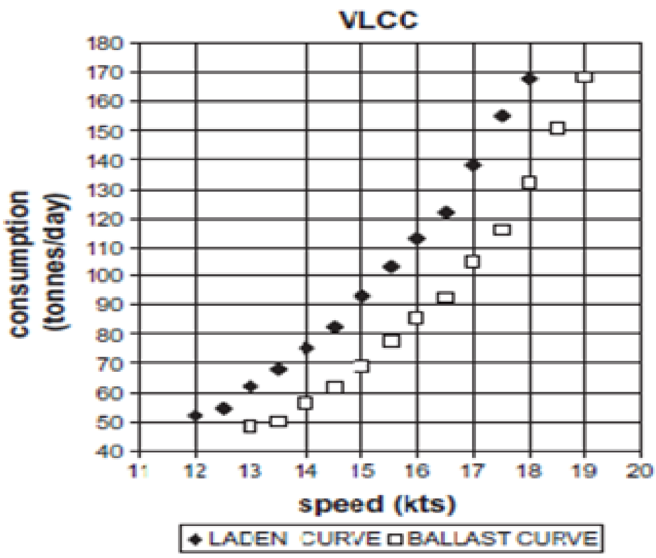

Figure 4.1. Fuel consumption versus speed (knots) for a Very Large Cruise Carrier (VLCC) by Psariftis, (2012)

We investigate laden and ballast ship condition and observe that when ship is laden, and sailing at 12 knots, ship consumes 50 tons of fuel. If the ship ballast and sailing at 13 knots, its consumption is 50 tons again. Optimal ballast speed is typically higher (by 1-1.5 knots) than optimal laden speeds.

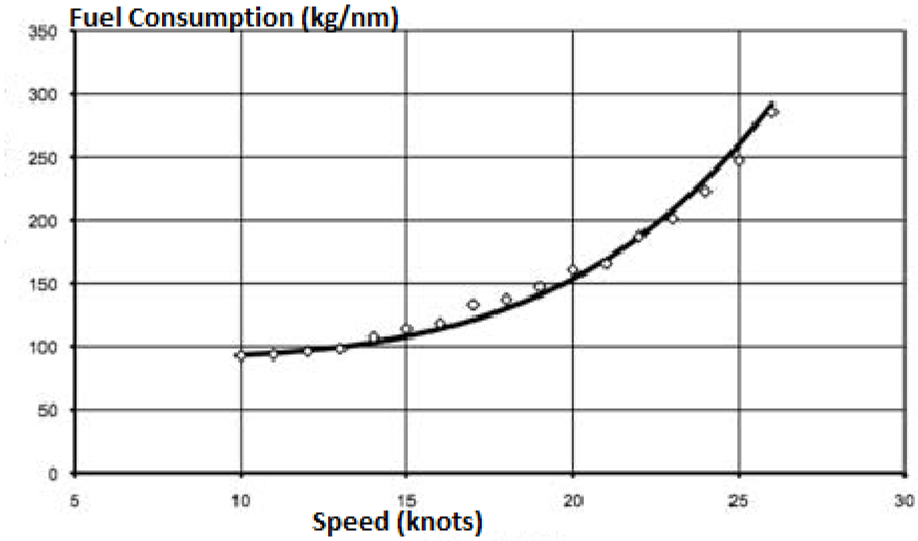

Figure 4.2. Fuel consumption between ship speed (8,000 TEU container ship); by Meyer, (2012)

Different ship size results in different rates of fuel consumption. According to Figure 4.1, ship's is smaller than Figure 4.2 of ship. The ship of Figure 4.2. is 8000 TEU ship and consume more fuel and has a different function of speed. In general, the nonlinear relationship between fuel consumption and speed can be represented by a quadratic or a cubic function. For instance, Ronen et al. (1982) proposes the following cubic function. $F=\frac{f}{v^3}V^3$, where f is fuel consumption, v is sailing speed, V is ship speed. We try to find optimal speed and maximum, minimum limit for ships. We accept service time is zero at port similar to Ronen et al. (1982). The cubic function's aim is minimizing inventory cost between fuel consumption and CO_2 emissions.

Several studies refer ship speed formulation and try to measure daily fuel consumption. Norstad et al. (2011) study on cubic function of speed on route. The other cubic function studies ship speed belongs to Psaraftis et al. (2014). They examine different ship conditions along transportation. This model assumes full and empty type of container and uses following function.

$$f(v,w)=k(p+v^{q})(w+A)^{2/3},$$

where v is ship speed, $k>0$, $p>=0$, $q>=3$ p and q are independent according to payload w and A is empty ship's weight. *Corbett et al. (2009)* defined shipping emissions have several types as, CO2, SOx and NOx. CO2 emissions relationship between marine diesel fuel consumption. Every voyage follows cubic design speed. Authors examine fuel consumption between sailing speed and operational speed. Different routes consume different fuel rate per trip. They define the following fuel consumption function in their model;

$$\mathrm{F}_{ijk}=\left[MF_k.\left(\frac{s_{1k}}{s_{0k}}\right)^3+AF_k\right].\frac{d_{ij}}{24_{s1k}}$$

where, k is service at the port, i and j are destination. F_{ijk} is fuel consumption per every trip. MF_k is fuel consumption/daily. AF_k is auxiliary fuel consumption. S_{0k} and S_{1k} is operational and sailing speed. K is miles per hour. The last one, d_{ij} is the distance from i to j. This model explains the relationship between fuel consumption and CO_2 emissions rate and design sailing, operational speed use for every trip. The study has two scenarios. The fist one is; When the ship capacity increases or when the ship improve loading time at port, the ship transports more container than before The second scenario is, if the vessels count increases on a route, demand will be increased.

4.2. Proposed Fuel Consumption Function

There are several models in literature including time windows, ship speed, emissions reduction and fuel consumption. However we assumed fixed weight of shipping emissions and develop the Model 1 using the following quadratic function as in Fagerholt (2010):

$f(v)$=0.0036v²-0.1015v+0.8848.

Every ship has different design and capacity. According to this, ships use different amount of fuel. According to Barras (2005), fuel consumtion is proportional to ship's weight with function $(w+L)^{2/3}$, where w is load and L is the weight of ship including fuel weight. $W_{k,k+1}=0$ is defined ship going on ballast (ship has not burden, loading anything). Since fuel consumtion of a ship changes with respect to its payload, we propose a new bivariate nonlinear fuel consumption function which depends on both speed (v) and the payload (w) from port k to the next port.

$$
\begin{aligned}
f(v_{k,k+1},\mathrm{w}_{k,k+1}) &= f(v_{k,k+1})\mathrm{w}^{2/3}{}_{k,k+1} \\
&= \left(0.0036\, v_{k,k+1} - 0.1015 v_{k,k+1} + 0.8848\right)\mathrm{w}^{2/3}{}_{k,k+1}
\end{aligned}
$$

Speed and weight change from port to port and according to this situation occur fuel consumption on a route. The route distances change according to port k to port k+1. This formula's aim is minimizing fuel consumption and emissions. $d_{k,k+1}$ determines distances port to port, $f(v_{k,k+1},\mathrm{w}_{k,k+1})$ shows weight and speed affected on fuel consumption.

CHAPTER 5

MATHEMATICAL MODELS OPTIMIZING SHIP SPEED

Our aim is to maximize profit while reducing the fuel consumtion and emissions of the ships. Using the nonlinear fuel consumption function, we construct several non-linear optimization problems (as summarized in Figure 1) based on set of assumptions. Given the port distances on single ship route, we solve the nonlinear optimization problems and find optimal solutions using different nonlinear solvers such as, Snopt, Baron, Couenne, Lgo and Ipopt. We compared different model solution and observed that different solvers gave the same optimal solution.

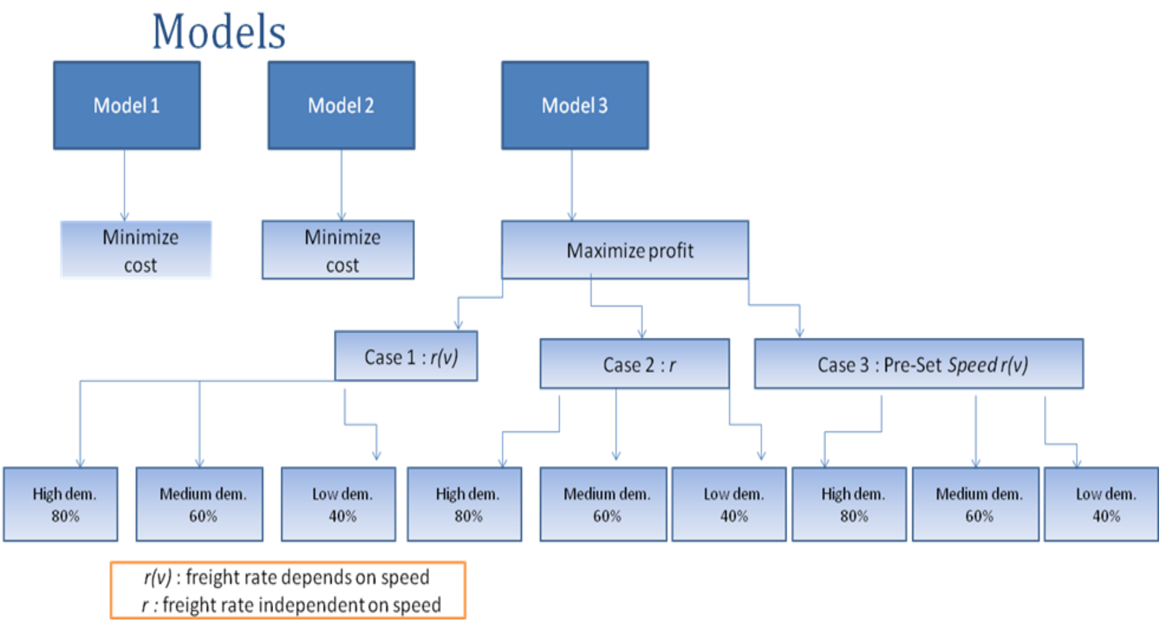

Figure 5.1. Summary of the proposed models

As summarized in Figure 5.1, Models 1 and 2 aim to minimize the fuel consumption cost whereas Model 3 aims to maximize the profit under two different cases for freight rates. In the first case, revenue or freight rate depends on the sailing speed as in the case for time sensitive, i.e., perishable or similar special products. In the second case, we consider time-insensitive products and assume freight rate is independent of the sailing speed. Each case of Model 3 has been analyzed under three different market conditions: high, medium and low demand. Notation, assumptions and models are presented in the following sections.

5.1. Model 1: Fuel consumption with Speed

Model 1 is based on the model proposed by Fagerhol et al. (2010). However, since service time affects fuel consumption and arrival times, we added the service time into the model. We make the following assumptions for Model 1:

1. Service time at the ports are given and known
2. Fuel consumption is a function speed only
3. Route (sequence of ports to be visited) is given.
4. Time windows for each port in the route are known and given.

Table 5.1. Notation for minimizing fuel consumption

$k=1,2,\ldots,n$	Index for ports on the route
$d_{k,k+1}$	Distance between port k and k+1
f	Fuel function
v	Ship's speed
t_k	Arrival time to port k
$t_{k,k+1}$	Sailing time between port k and k+1
e_k	Earliest arrival time at port k
l_k	Latest arrival time at port k
f_v	Sailing consumption per distance $f(v)$
dem_k	Demand (loading) at port k
sup_k	Supply (unloading) at port k
s_k	Service time at port k

$$Minimize \sum_{k=1,\dots,n-1} d_{k,k+1}\ f(v_{k,k+1}) \tag{4.1}$$

$$\text{Subject to;}\ t_{k+1}-(t_k+s_k)-d_{k,k+1}/v_{k,k+1}\geq 0, \qquad k=1,\dots,n-1, \tag{4.2}$$

$$e_k \leq t_k \leq l_k, \qquad k=1,\dots,n, \tag{4.3}$$

$$v_{\min} \leq v_{k,k+1} \leq v_{\max}, \qquad k=1,\dots,n-1. \tag{4.4}$$

In this model, Equation (4.1) is the objective function; the aim is minimizing the total fuel consumption along the route. Equation (4.2) represents the relationship between speed, distance, arrival and service time at the port. Basically, it states that when the ship departs port k at time (t_k+s_k), it arrives to port k+1 at time t_{k+1} if it travels the distance between these ports at speed $v_{k,k+1}$. Equation (4.3) defines earliest and latest time window (days) constraints. Equation (4.4) determines ship's lower and upper speed as the range for design speed

5.2. Model 2: Fuel Consumption Minimization Model

Consider the Model 1, if the ship’s service time is high, this means that ship’s loading and unloading operation is slow or supply and demand is high. Supply and demand affect ship’s weight and ship’s weight has a role on fuel consumption. Therefore, in addition to all the assumptions in Model 1, we consider following bivariate nonlinear fuel consumption function and define payload variable in Model 2:

$$\begin{aligned} f(v_{k,k+1},\mathrm{w}_{k,k+1}) &= f(v_{k,k+1})\mathrm{w}^{2/3}{}_{k,k+1} \\ &= \left(0.0036\ v_{k,k+1} - 0.1015 v_{k,k+1} + 0.8848\right)\mathrm{w}^{2/3}{}_{k,k+1} \end{aligned}$$

Table 5.2. Notation for Model 2

Notation	Definition
$k=1,2,\ldots, n$	Index for ports on the route
$d_{k,k+1}$	Distance between port k and k+1
$f(v,w)$	Fuel function
v	Ship's speed
w	Ship's payload according to supply and demand
t_k	Arrival time to port k
$t_{k,k+1}$	Sailing time from port k to port k+1
e_k	Earliest arrival time at port k
l_k	Latest arrival time at port k
f_v	Sailing consumption per distance $f(v)$
c	Ship's capacity according to ship's size
L	Ship's deadweight
dem_k	Demand (loading) at port k
sup_k	Supply (unloading) at port k
s_k	Service time at port k

$$Minimize \sum_{k=1,\ldots,n-1} d_{k,k+1}\ f(v_{k,k+1}, w_{k,k+1}) \quad (5.1)$$

Subject to; $t_{k+1}v_{k,k+1} - (t_k + s_k)v_{k,k+1} \geq d_{k,k+1}, \quad k=1,\ldots,n-1,$ (5.2)

$$w_{k,k+1} = w_{k-1,k} - dem_k + \sup_k \quad k=1,\ldots,n \quad (5.3)$$

$$w_{k,k+1} \leq c \quad k=1,\ldots,n \quad (5.4)$$

$$e_k \leq t_k \leq l_k, \qquad k=1,\ldots,n, \quad (5.5)$$

$$v_{min} \leq v_{k,k+1} \leq v_{max} \qquad k=1,\ldots\ldots n, \quad (5.6)$$

In the formulation of Model 2, Equation (5.1) is the objective function that minimizes the fuel consumption with payload and speed. $f\ (v_{k,k+1},\ w_{k,k+1})$ is ship's fuel consumption level with travel speed $v_{k,k+1}$ and payload travel speed $w_{k,k+1}$ for leg from port k to k+1. Fuel consumption depends on distances and ships' payload. Equation (5.2) represents the relationship between time and speed for each leg. We assumed the model travel time from port k to port $k+1$ is equal to $t_{k,k+1}$. Equation (5.3) is flow conservation constraint. Equation (5.4) ensures that for each leg, ship cannot take more load than its deadweight capacity from k to $k+1$. Equation (5.5) defines earliest and latest time window constraints. Equation (5.6) determines ship's lower and upper speed limits.

5.3. Model 3: Profit Maximization Model

Shipping transportation has huge market and companies want to increase their profit. We propose a model for profit maximization on a single shipping route. On the other hand, freigt rates are changing according to emergency, distances, tones and order structure. For instance, crew costs are given on the hourly basis and important because affecting loading and unloading times at the port. When ships stay long time at the port it is important to consider additional cost for the ship-owner. Since time affects total operating hours and related costs, we add crew cost (cr) to out profit calculation. In addition to the notation in Model 2, we add container weight (cw) since container weight affects revenue when multiplied by freight rate (r). Then our aim is to observe how profits change according to distances, speed and demand for a company in the long term.

5.3.1. Assumptions

In this section, we develop model of fuel consumption and emissions with payload. We identified and developed optimal speed with payload on a single route.We make the following assumptions:

1. We have assumed that waiting; loading/unloading time at the ports are given and known

2. Fuel consumption is functions of both speed and the payload.

3. Route (sequence of ports to be visited) is given.

4. We have presumed crew cost is important for ship owner and added unhourly basis.

5. Working schedules or time windows for each port in the route are known and given.

6. The ships operate on a route have different size and capacity and produce different emissions.

Table 5.3. Notations for maximizing profit for case 1 and 2

Notation	Definition
$k=1,2,\ldots, n$	Index for ports on the route
$d_{k,k+1}$	Distance between port k and k+1
$f\,(v,w)$	Fuel function
v	Ship's speed
w	Ship's payload according to supply and demand
t_k	Arrival time to port k
$t_{k\,,k+1}$	Sailing time from port k to port k+1
e_k	Earliest arrival time at port k
l_k	Latest arrival time at port k
f_v	Sailing consumption per distance $f(v)$
c	Ship's capacity according to ship's size
L	Ship's deadweight
dem_k	Demand (loading) at port k
sup_k	Supply (unloading) at port k
s_k	Service time at port k
c_r	Crew cost (hourly)
c_{w}	Container weight
r	Revenue (freight rate)

In the long term, demand is the most important determinant for the shipping company. Therefore, we developed three different (high, medium, low) demand scenarios to study to different cases for Model 3. The profit function is equal to total freight revenue minus the total cost including crew cost, deadweight and fuel consumption costs.

5.3.2. Model 3: Modified Formulations

Freight rate is also changing with respect to product type to be transported. In other words, some products such as fish or frozen foods are perishable and time-sensitive. Therefore their freight rate depends on the trip duration, i.e. freight rate is higher if ship is to sail faster. However, durable products such as iron or grains are not time sensitive and therefore the freight rate is independent of trip duration or sailing speed. For two different product types, we select 8000 TEU capacity container ship. The ship should meet demand because the ship gets profit in five years. The three scenarios are;

1. The best scenario: 8000 TEU ship's demand should be 80% for profit.
2. The optimist scenario: 8000 TEU ship's demand should be 60 % for profit.
3. The worse scenario: 8000 TEU ship's demand must be 40% for not loss not profit. (less profit)

We implement to entire scenario and compare in the Thesis for helping literature. Figure 5.2. Explains a ship visits four ports on a route. In Figure 5.2. has one route and optimal speed ship receives nodes. Every trip has different time window according to order and ships flow one route and regulate speed. Speed changes fuel consumption.

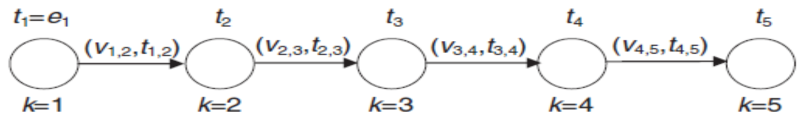

Figure 5.2. Single ship route port to port by Fagerholt et al. (2010)

5.3.3. The Case 1: Freight Rate Depends on Speed

The case generally includes food or emergent orders. Revenue is affected by speed, distances and weight. This formulation observes speed and distance's changing.

$$Maximize \sum_{k=1,\ldots,n-1} \mathrm{r}(v_{k,k+1}) d_{k,k+1} - \left(\sum_{k=1,\ldots,n-1} \mathrm{d}_{k,k+1} \, f(v_{k,k+1}, (\mathrm{cw}(\mathrm{w}_{k,k+1}))) + (t_k + \sum_{k=1,\ldots,n-1} \mathrm{s}_k) \mathrm{cr} \right) \tag{5.7}$$

Subject to ; $t_{k+1} v_{k,k+1} - (t_k + s_k) v_{k,k+1} \geq d_{k,k+1}, \qquad k = 1, \ldots, n-1,$ (5.8)

$$w_{k,k+1} = w_{k-1,k} - dem_k + \sup_k \tag{5.9}$$

$$w_{k,k+1} \leq c \tag{5.10}$$

$$e_k \leq t_k \leq l_k, \qquad k = 2, .., n, \tag{5.11}$$

$$v_{min} \leq v_{k,k+1} \leq v_{max} \qquad k = 1, \ldots, n-1, \tag{5.12}$$

Equation (5.7) is the objective function maximizing profit for company and ship-owners. Equation (5.8), (5.9), (5.10), (5.11) and (5.12) is the same subject to for Model 2, Case 1 and 2. The Case 1 depends on speed. Revenue is computed using speed and distances, and it is changing according to speed in this case. On the other hand, container's weight and ship weight calculate differences. Crew cost is another affected value by the time. The case explains markets profit according to ships speed with freight rate depends on fuel, time and payload conditions.

5.3.4. The Case 2: Freight Rate is Independent of Speed

The Case 2 assumes transported goods are durable such as grain, wood, iron. Revenue is not affected by speed. Our aim is to understand how speed changes according to type of the product transported.

$$Maximize \sum_{k=1,....,n-1} \mathrm{r}_k \, d_{k,k+1} - (\sum_{k=1,....,n-1} \mathrm{d}_{k,k+1} \, f(v_{k,k+1}, (\mathrm{cw}(\mathrm{w}_{k,k+1}))) + (t_k + \sum_{k=1,....,n-1} \mathrm{s}_k) \, \mathrm{cr}) \qquad (5.8)$$

Equation (5.8) is the objective function, which maximizes the profit for each port k=1,….,n. This Case's constraints are same as Model 3 and Cases 1 but objective function is different. In Case 2, revenue is not changing with respect to speed; revenue is changing according to distances only. In addition to this, cargo's and container's weight determine different. We accept container weight is 10 ton in this model and crew cost is 15 hourly. The case explains markets profit according to distances between freight rates depends on fuel, time and payload condition.

5.3.5. Case 3 : Pre-Set Precision for Speed

When we look the Case 1 and Case 2, speed is a continuous variable and we can not define speed precision. In the solution, we oberve speed values (e.g. 15.768 knots) which are not attainable in real life. Therefore, we create a parameter for rounding speed values to the nearest integer. Besides we can put limit for speed and observe the effect of the limited precision on maximum profit. When we modify our model to include nearest integer value for speed, profit changes. For instance, 14 knot's objective is 25,041 whereas 14.1 knot's objective value is 26,175. We can see that firm's profit is affected even with a single decimal but the results are more attainable.

CHAPTER 6

NUMERICAL RESULTS

In this Chapter, we present numerical results obtained after solving the models proposed in Chapter 5. Numerical data for the shipping route, list of ports and earliest-latest arrival times are obtained from an earlier study by Fagerholt et al. (2010). All the additional data including distance calculations, freight rate, supply, demand information are obtained from industry data or expert interviews. Ship speed ranges between 14-24 knots. Models are solved by different solvers i.e, Snopt, Baron, Couenne, Lgo) through GAMS interface. Note that different solvers provided the same solution, which was accepted as an optimal solution.

6.1. Optimal Solutions for Model 1 and Model 2

In this Section, we analyze the results for the fuel consumption minimization models. We assume that ship capacity is 700 TEU and our ship's initial load is 200 to start with. Table 6.1 shows that optimal speed for Model 1 is same for every leg depending on the arrival time. The computer program tried to find a good solution that ensures all arrival times to fall in given time windows. According to Model 1, optimal objective function value or total fuel consumption is 2,321 tons of fuel.

Table 6.1. Numerical results and optimal solution for Model 1

Route	Knot	Arrival Times (days)
Antwerp		
Milford Haven	15.178	1.5
Boston	15.178	9.1
Charleston	15.178	11.8
Algeciras	15.178	22.2

When we use the same data to solve Model 2, Table 6.2 presents the optimal solution as well as variable demand as the payload data. Note that optimal sailing speed is different at every leg depending on loading, un-loading times at the port. The ship's speed is increasing when payload is decreasing and therefore arrival times are different than the ones in Model 1 results. According to Model 2, optimal objective function or the amount of fuel consumption is 34.770 tons.

Table 6.2. Numerical results and optimal solution for Model 2

Route	Knot	Arrival Times(days)	Supply	Demand	Payload (TEU)
Antwerp			0	30	0
Milford Haven	14.758	1.5 day	0	50	200
Boston	14.997	9.2 day	0	10	120
Charleston	15.045	12 day	0	10	110
Algeciras	15.100	22 day	0	20	100
Houston	15.590	39 day	0	500	50

When we assume that supply is changing port to port, such as; ship is discharging 10 tons of load at port k and 50 tons of load at port k+1. Changing payload affects the optimal ship speed. We can see this affect clearly when we change the supply-demand data solver program. When ship's load is increased, the ship speed is decreased. On the other hand, if the ship load is decreased, for instance when it is reduced from 400 to 200, ship speed increases so as the fuel consumption. This solution's objective function is 36,511. Normally, if ship has a load, ship is not expected to transport at high speed. But this assumption is different because supply is changeable in this case and ship's payload is changing from port to port. As a result of this solution, ship arrives port on time.

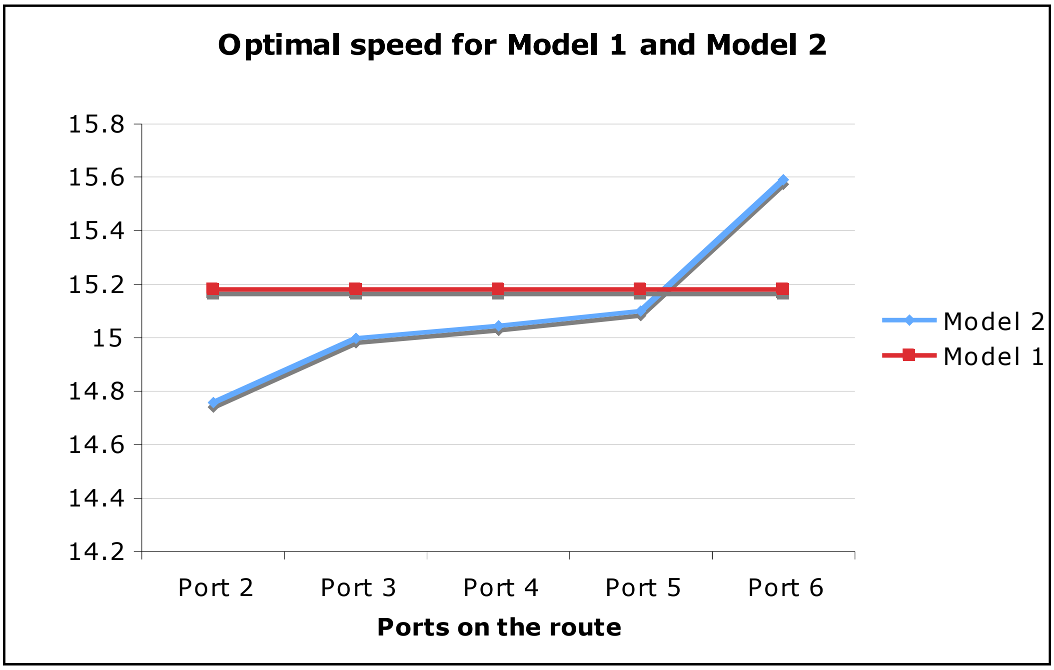

Figure 6.1. Optimal speed comparison for Model1 and Model2

As a result of our analyses with Model 1 and Model 2 (see Figure 6.1); we observe that speed is affected by payload; and payload is affected by supply and demand. Arrival times also change according to speed and emissions depend on the total fuel consumption. Ships have different size, capacity and design, on the other hand customers demand and supply is changed by the location. Shipowners always investigate how to reduce costs and as well as emissions.

6.2. Optimal Solutions for Model 3

Model 3 assumptions are; ship capacity is 8000 teu and demand is changing according to scenario (the high, medium and low demand). In the high demand scenario, ship's payload is 6,400 (80% of capacity); in the medium demand scenario ship's payload is 4,800 and finally in the low demand scenario, payload is 3200 TEU. We assume ship is empty at the initial port. Since demand is changing from port to port, we expect speed to change at every leg depending on port time windows as well as loading, un-loading amounts. The ship's speed is increasing when the payload is decreasing. Travel time is changing according to speed. As summarized in Table 6.3, speed and payload condition changes the objective function values in the optimal solution.

We also assume that the ship's freight rate is 2.525 per ton mile and revenue is calculated based on this freight rate. For time-sensitive products, revenue is calculated based on the freight rate of 2.525 per ton/mile and for time-insensitive products, freight rate is $39.3 per mile. The revenue changes between $30-60 with respect to order and mile.

Table 6.3. Numerical results for objective function of different cases

Objective Function	**High Demand Scenario**	**Medium Demand Scenario**	**Low Demand Scenario**
Freight rate depends on Speed	26,185,028	10,524,944	2,224,600
Freight rate independent of Speed	39,706,000	14,002,711	906,690

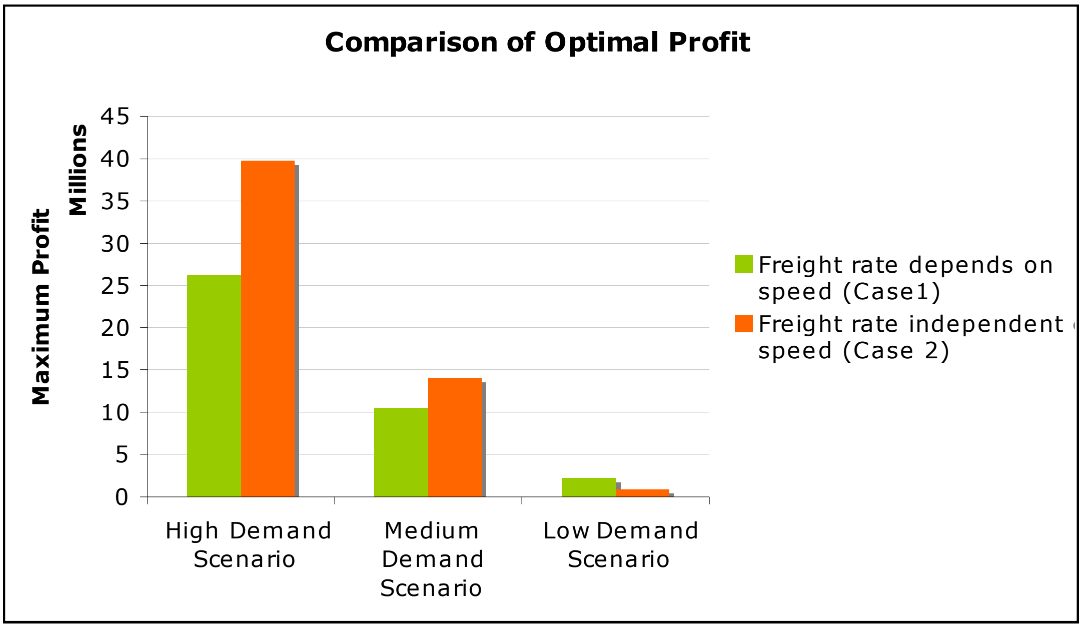

Figure 6.2. Comparison of Optimal Profit

As we expected, profit for time sensitive and time-insensitive products are significantly different. Figure 6.2. shows that when freight rate is independent of speed (as in the case of durable time-insensitive products), profit is higher when there is a high or medium demand. This is mainly because of lower speeds, lower fuel consumptions and higher profit margins. On the other hand when we look the low demand scenario, we can easily see that abundance of available capacity lowers the rated and affects the profit for transporting durable goods. Whereas, urgent need for transporting time-sensitive products such as fish keeps profit relatively higher in Case 1 compared to Case2. In Figure 6.2, we also observe that market condition or demand has an important role on profits, ship speed and sailing times. When the ship has more payload, the ship does not prefer to sail at high speed in order not to increase its fuel consumption. On the other hand, if the ship travels faster, the ship meets more demand and the shipowner gets more profit. These assumptions are different in different scenarios because supply is changing from port to port. The Table 6.4. shows different demand scenarios and the ship's maximum profit.

Table 6.4. Numerical results for three demand scenarios and two cases for a 8,000 TEU capacity vessel

Ports	High Demand Scenario (80% full 6,400) Case 1	High Demand Scenario (80% full 6,400) Case 2	Medium Demand Scenario (60% full 4,800) Case 1	Medium Demand Scenario (60% full 4,800) Case 2	Low Demand Scenario (40% full 3,200) Case 1	Low Demand Scenario (40% full 3,200) Case 2
1-2	14,097	14,163	14,761	14,153	14,271	14,176
2-3	17,212	14,378	14,701	14,224	19,620	14,572
3-4	16,884	14,209	15,042	14,255	15,896	14,363
4-5	14,811	14,239	14,816	14,296	16,306	14,222
5-6	14,811	14,269	15,956	14,316	15,479	14,201
6-7	14,706	14,336	15,897	14,344	15,429	14,183
7-8	15,691	14,098	15,597	14,098	14,655	14,097
8-9	14,098	14,098	16,175	14,098	16,529	14,098
9-10	16,750	14,097	14,997	14,098	15,161	14,097
10-11	15,770	14,097	16,205	14,098	16,881	14,098
11-12	15,305	14,097	17,605	14,098	16,728	14,097
12-13	17,891	14,097	21,111	14,098	14,793	14,097
13-14	21,111	14,097	18,481	14,097	24	24

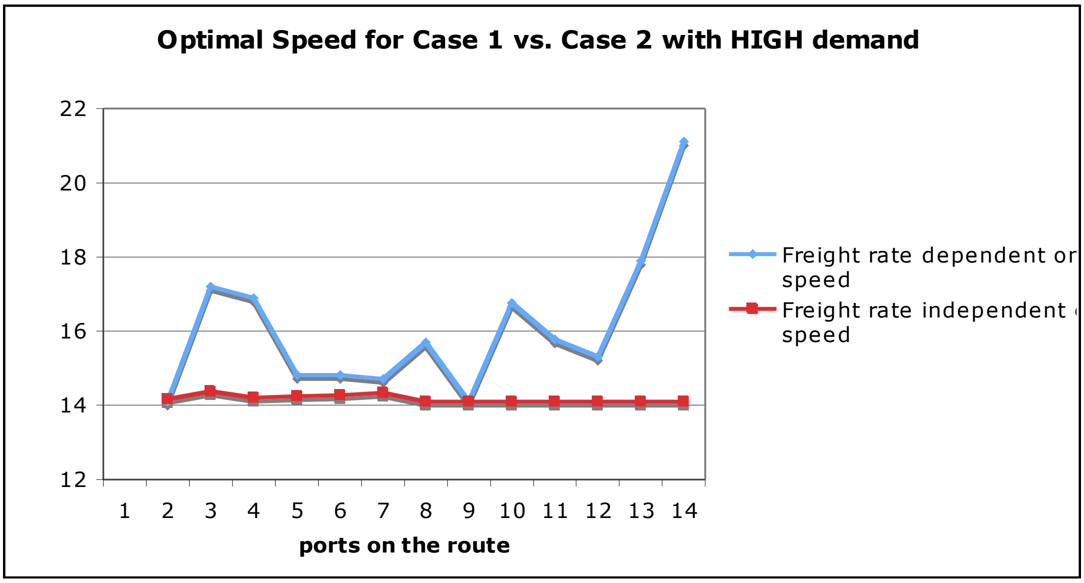

Figure 6.3. Optimal speed for Case 1 and Case 2 in high demand scenario

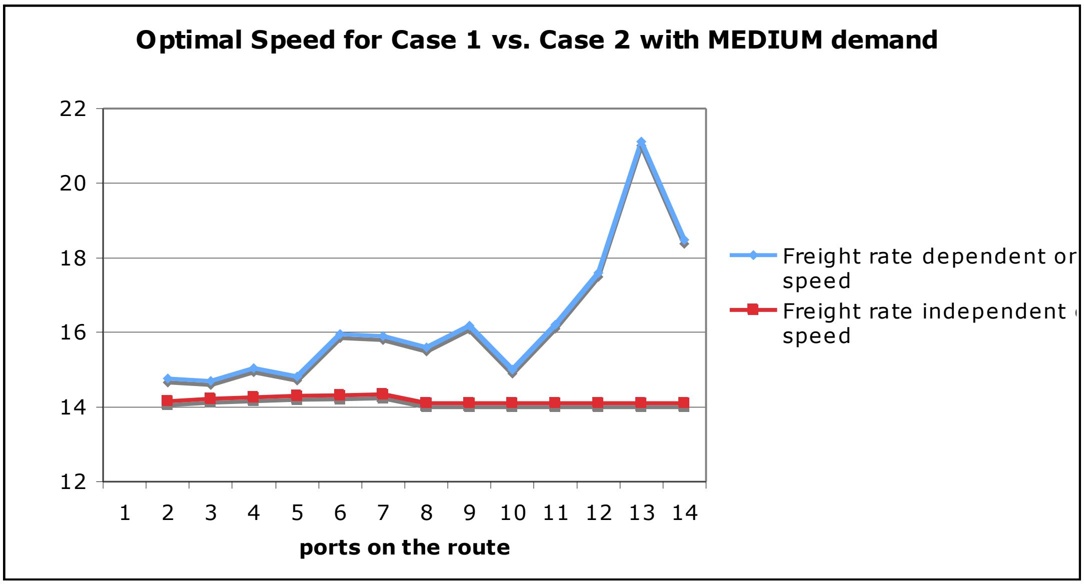

Figure 6.4. Optimal speed for Case 1 and Case 2 in medium demand scenario

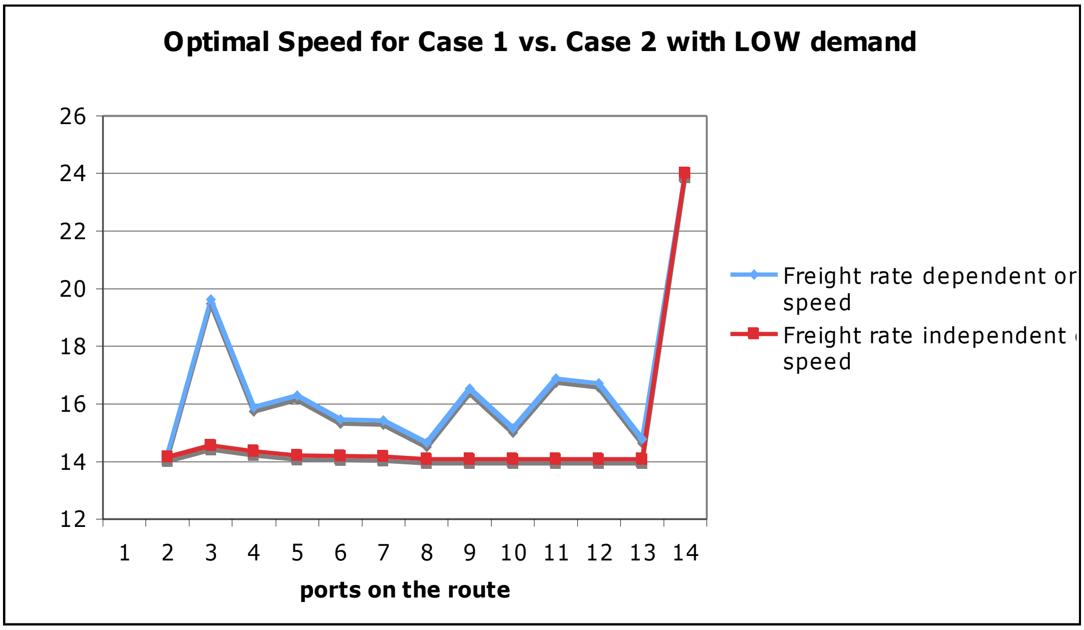

Figure 6.5. Optimal speed for Case 1 and Case 2 in low demand scenario

Figures 6.3, 6.4 and 6.5 shows the comparison of optimal speed for time-sensitive (Case 1) and time-insensitive (Case 2) products according tohigh, medium and low demand scenarios. Although speeds are affected by port to port distances and time windows, time-sensitive products in all scenarios are transported at higher speeds. Results in also indicate that in case of high demand, ships sail at higher speed in order to make more trips and to make more profits. Having expected results justifies the validity of our models.

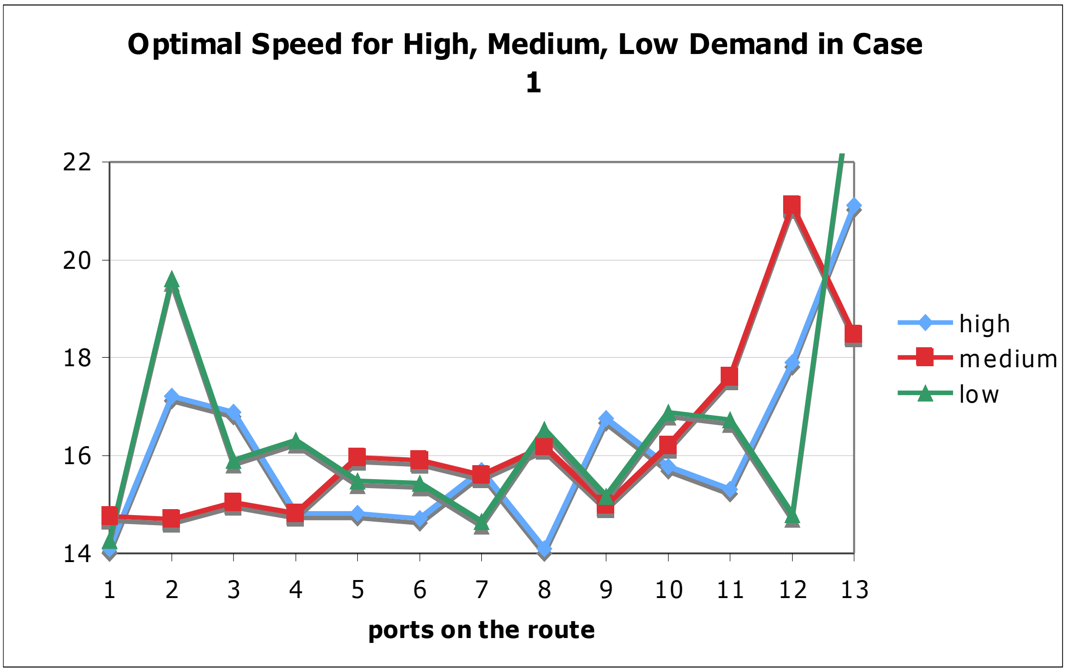

Figure 6.6. Optimal speed for all scenarios for Case 1

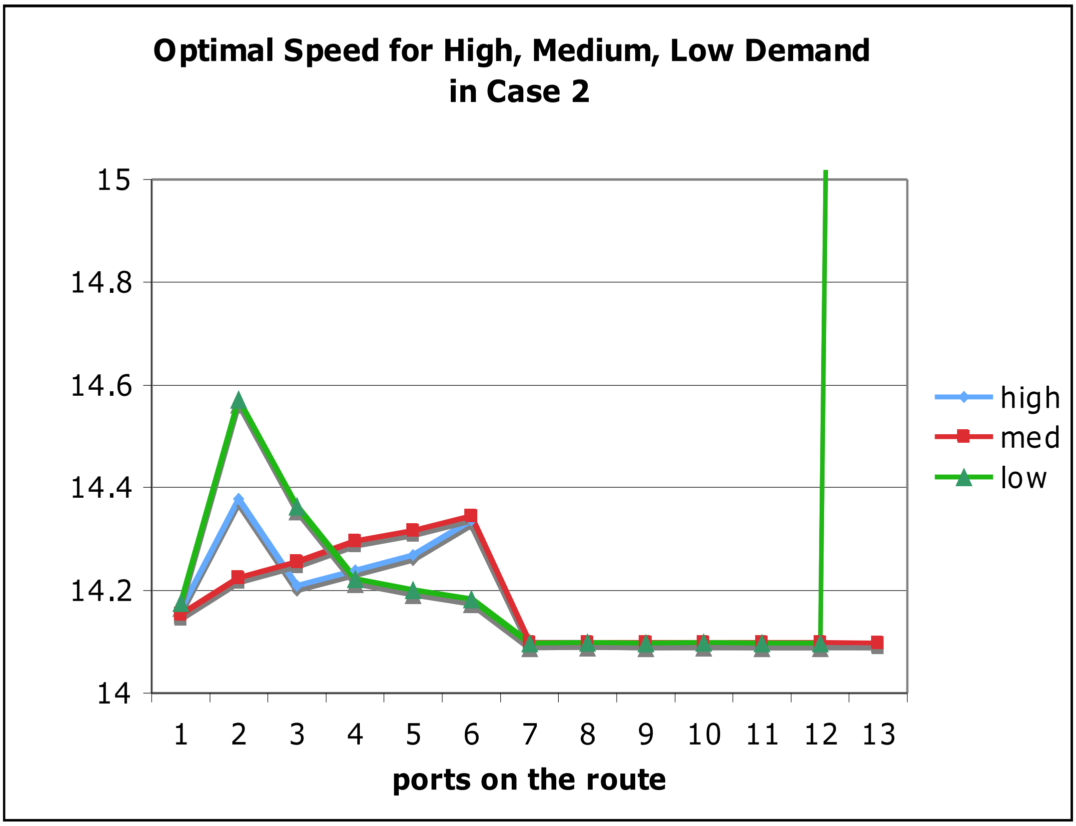

Figure 6.7. Optimal speed for all scenarios for Case 2

Figure 6.6. and 6.7. shows comparative trends in optimal speed for all demand scenarios. Due to different supply and demand quantities and time windows at each port, Case 1 and Case 2 results indicate different trends. Specifically, in Case 1, optimal speed is indicating an increasing trens whereas in Case 2, speed has an decreasing trend. According to this result, we can conclude that for durable, time-insensitive products it is relatively easier to reduce fuel consumtion and CO_2 emissions.

Table 6.5. Comparison of arrival times in all scenarios and two cases

Ports	High Demand Scœnario (80% full 6,400) Case 1	High Demand Scœnario (80% full 6,400) Case 2	Medium Demand Scœnario (60% full 4,800) Case 1	Medium Demand Scœnario (60% full 4,800) Case 2	Low Demand Scœnario (40% full 3,200) Case 1	Low Demand Scœnario (40% full 3,200) Case 2
1-2	1.5	1.5	1.4	1.5	1.4	1.4
2-3	9	9	9	9.4	9	9.2
3-4	11	11.2	11.4	11.8	11.1	11.6
4-5	21.2	21.3	21.6	22.4	20.4	22.2
5-6	32	32	32	32.4	32	32.3
6-7	38.4	37.4	37.9	39	38.1	39
7-8	50	48.3	49.6	51.9	50.5	51.9
8-9	51.5	49.8	50.9	53.4	51.8	53.4
9-10	58.2	56.8	58.4	61.4	59.2	61.4
10-11	60.4	59	60.5	63.9	61.3	63.9
11-12	70.3	69.1	69.1	74.6	70.3	74.6
12-13	78.3	78.4	75.9	84.7	80	84.7
13-14	82.8	83.8	81	91.4	83.9	88.7

Table 6.5. Shows optimal arrival times to the ports in both cases and all three scenarios. We can conclude that ship's arrival times are earlier in Case 1 (time sensitive products) compared to arrival times in Case 2 (time insensitive products). Note that arrival times are also affected by type of the product, market condition and speed as we expected.

Table 6.6. Comparison of payloads (in TEU) in all scenarios and two cases

Ports	High Demand Scœnario (80% full 6,400) Case 1	High Demand Scœnario (80% full 6,400) Case 2	Medium Demand Scœnario (60% full 4,800) Case 1	Medium Demand Scœnario (60% full 4,800) Case 2	Low Demand Scœnario (40% full 3,200) Case 1	Low Demand Scœnario (40% full 3,200) Case 2
1-2	6,400	6,400	4,800	4,800	3,200	3,200
2-3	700	700	1,400	1,400	200	200
3-4	2,900	2,900	1000	1.000	500	500
4-5	2.000	2.000	700	700	1.600	1,600
5-6	1,500	1,500	600	600	2,100	2,100
6-7	900	900	500	500	2,800	2,800
7-8	600	600	500	500	2,900	2,900
8-9	600	600	1.000	1.000	900	900
9-10	1,700	1,700	500	500	1,100	1,100
10-11	1,200	1,200	300	300	400	400
11-12	1,400	1,400	100	100	800	800
12-13	300	300	100	100	400	400
13-14	100	100	100	100		

Table 6.6. shows payload for each leg in all scenarios and both cases. According to high demand scenario, the ship utilizes 80% of its capacity (8000 TEU). In the medium demand scenario, ship utilizes 60% of its capacity (8000 TEU). Finally, in the low demand scenario, ship utilizes 40% of its capacity. We can compare two cases. Weight is also changing according to supply and demand in two cases. Dependent case's objective function is higher than independent case. The important cause is product structure. On the other hand you can see the Table 6.6; weight condition is the same for two conditions. Only freight rate is changed by ship's order.

Table 6.7. Numerical results for high demand on case 3

Demand Scenario	**Objective Function** 380,760.000	**Objective Function** 383,170.000	**Objective Function** 384,920.000	**Arrival Days**
Ports	**Unlimited Knots**	**Limited Knots**	**Limited Knots (0.1)**	
1-2	18.274	18	18.3	1.5
2-3	21.963	22	22	10.5
3-4	20.650	21	20.6	12.2
4-5	14.669	15	14.7	22.3
5-6	15.243	15	15.2	32
6-7	24	24	24	35.9
7-8	24	24	24	43.6
8-9	17.715	18	17.7	44.8
9-10	15.480	15	15.5	52.3
10-11	17.613	18	17.6	54.3
11-12	16.091	16	16.1	63.7
12-13	12.372	12	12.4	75.7
13-14	23.098	23	23.1	79.8

For Models 1, 2, 3 (include case 1 and 2) and for all scenarios, freight rate is accepted as $2.525 per ton-mile. In this scenario, freight rate is accepted as $2.49 per ton-mile. On the other hand, we created a new parameter (rounding function). This parameter aim is apply to data on a real life. Because it is impossible to implement the ship speed exactly as 14.758 knots. If we round the speed values, it would be possible to implement it and thus we can still satisfy time window constraints for every port and it is acceptable decision for our model. Table 6.8 presents different objective functions and optimal speeds for medium demand scenario when speed precision is adjusted at different levels.

Table 6.8. Numerical results for medium demand on case 3 and 4 speed

Medium Demand Scenario	**Objective Function** 1,000,700	**Objective Function** 124,650	**Objective Function** 992,110
Ports	**Unlimited Knots**	**Limited Knots**	**Limited Knots (0.1)**
1-2	14.752	15	14.8
2-3	14.693	15	14.7
3-4	15.029	15	15
4-5	14.806	15	14.8
5-6	15.930	16	15.9
6-7	15.872	16	15.9
7-8	15.576	16	15.6
8-9	16.146	16	16.1
9-10	14.985	15	15
10-11	16.176	16	16.2
11-12	17.556	18	17.6
12-13	21.014	21	21
13-14	18.420	18	18.4

When we look the table 6.7 and 6.8, we can see if the ship speed rounds upper knots, shipping companies are gotten more profit maximization. .If maritime market has an engine for regulated speed, the companies can regulate the ship speeds for every voyage time as a result of this assumption they can be generate more profit.

The high demand scenario's objective function is higher than case 2 and 1. But our aim is to maximize the profit for the firm. When the ship speed increases, companies' profit increases too. In this case include more demand and this scenario is rounded to the next digit rates.

In conclusion; ship tries to catch up time window for every voyage and when the ship's voyages speed fast, freight rate will increase. We can see speed is affected by payload and revenue; payload is affected by supply and demand. Time window is changing according to speed and emissions depend on the entire item. Ships have different size, capacity and design on the other hand customers demand and supply is changed by the location. Ships owners always investigate reduce the costs. Consequently, they try to find reduce emissions. Our aim is to find optimal solution and improve the model.

CHAPTER 7

CONCLUSION AND THE FUTURE WORK

In this Thesis, we emphasize the importance and the need for reduced fuel consumption and reduced emissions in maritime transportation. We review and present main cost categories and focus on cost reduction for increased profits. Indicating that fuel constitutes the most important operational cost category in maritime transportation, we consider factors affecting the fuel consumption. By pointing out the nonlinear relationship between fuel consumption, speed, and the payload we develop alternative models to minimize cost and to maximize profit from the ship-owner's or ship operator's point of view.

There exits numerous studies in the literature focusing on ship's fuel consumption by optimizing speed. After presenting a comprehensive literature review, we point out two important gaps in the literarure. First one is about the need for a new fuel consumption function, which considers not only speed but also payload at the same time. The second need arises from long term perspective in the sense that when researchers consider only a single voyage cost minimization by speed reduction seems to be the only choice. However, when one considers multiple voyages over longer term e.g. a year, then speed reduction may not be a good choice since it increases the voyage duration and cuts back the number of voyages and the total profit. Therefore, in this Thesis, by focusing on maximizing profit in the long term, we try to fill these two gaps and contribute to the literature.

The Thesis examines profit maximization problem for the ship owner. Based on realistic assumptions, we develop three different models and obtain relavant data both from literature and from shipping industry We have determined and solved the optimal ship speeds on a given shipping route with different scenarios. The proposed models are then solved in GAMS program and results are anayzed.and compared. solutions.

In the cost minimization model's,vessel's shipping caacity is accepted as 700 TEUs. Demand and supply are assumed to be changing from port to port and service time. Speed valid between 14 and 24 knot. When we solve the optimization model under this assumption, we can find to optimal speed approximately 15 knots and optimal objective function value is found to be 47,679. It is the optimal solution because ships waste of time at port and port distances are very different according to route. In addition to this supply and demand is changable. When the demand is high, fuel consumption increases. On the other hand, model 3 includes profit maximization and we have used 0 instead of using service time and we accept payload is 2.525 for dependent on speed; independent on speed's payload is 39.3. We have used to real data for specific ship. We put 10 tons for container's weight, crew cost is accepted as 15 hourly and we gave 400 for fuel consumption cost. Investing relationship for fuel consumption per mile, the speed valid between 12-20 knots and how to affects payload at port and sea. The problem includes non-linear objective function but problem linearized. We have studied on optimal arrival time between time window for each node and investigate speed is changed by the weight. We can see how ship the speeds reduce cost and fuel consumption. We assume an engine for limited knots. If the machine can be increased 0.1 rate of speed, firms profit increases. Hence environmental emissions are substantial. We have compared our solution method with computer programming. The results indicate our solution is optimal. We based on cost and load, un-load effects on ship speeds and fuel consumptions, on the other hand we notice earliest and latest time but our report is important thing on cost. Our solution method becomes cost profit for shipping company. Furthermore, Fagerholt's solution does not include service time, supply, demand, crew cost, container's weight and payload but I developed the Fagerholt method and I added service time and I accept 0, supply, demand and payload are changed by ship capacity. Thus the solution was close to the optimal.

In summary in this Thesis we examine shipping model on solve program. We suggest weight, crew cost and freight rate. We determine an optimal solution in shipping for logistics.

We define several alternative scenarios. Employing model results in many assumptions give several solution and variable. The results may be affected directly proportional by the real data. Maritime transportation is affected by optimizing the speed along the route. When fuel consumption reduces, it helps to reduce environmental emissions. Companies want to improve their profit and they constitute time windows and they calculate optimal speed for cost. Thus, while the company's profit margin increases and sensitivity to environmental issues create a competitive edge in developing world.

As a future work, proposed models can be implemented with real data collected from a liner company. After the real life implementation, numerical results can be compared to existing results. Also, Model 3 formulation can be improved by incorporating randomness in demand values. Finally, a new algorithm to nonlinear optimization problems can be developed as a more theoretical study.

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