

IMO Train the Trainer (TTT) Course
on
Energy Efficient Ship Operation

**Module 3 – From Management to
Operation**



I M O

ACKNOWLEDGEMENTS

The “Train the Trainer” course presented herein is based on material originally developed by WMU in 2013 under contract for the IMO. This current edition represents a major upgrade of the training package by Dr Zabi Bazari of Energy and Emissions Solutions, UK (EnEmSol) under contract for the IMO.

IMO wishes to express its sincere appreciation for WMU and EnEmSol expert assistance

Printed and published by the
International Maritime Organisation,
London, January 2016

MODULE 3

From Management to Operation

Module Aims and Learning Objectives

This module aims to provide relevant information on ships' operation management that have significant impact on a ship's energy efficiency. A number of topics are covered including:

- The legal frameworks and shipping contracts and their impacts on energy efficiency efforts;
- Fleet optimisation and slow steaming, barriers and best practice;
- Ship load lines, maximum ship capacity and planning to maximise fleet capacity usage;
- The concept of Just in Time operation, its fuel saving impacts and Virtual Arrival.
- E-Navigation and the move to digital charts and other support tools such as ECDIS, weather routing, voyage analysers as enabling technologies for future optimal management of ships.

Upon completion of this module, you should be able to:

- Give an overview of how shipping industry works, in terms of ship types, cargo types and shipping segments.
- Explain the importance of management-level activities such as fleet planning, maintenance management and fuel procurement on overall energy efficiency and energy cost.
- Explain various types of shipping contracts and how the contracts influences ship operation and energy efficiency.
- Explain the slow steaming, its impact on ship fuel consumption and relevant technical issues.
- Describe the importance of ship loading and ship capacity utilisation for energy efficiency.
- Discuss the issue of just in time operation, concept of Virtual Arrival, E-Navigation concept, use of ECDIS and weather routing and how all these could be utilised to save energy.

To support your learning process, a list of references is provided at the end of each Section. Referring to them will allow you to go deeper in areas that may be of most interest to you.

The material presented herein is current at the time of preparations of this document. Because of the evolving nature of regulations, technologies and future studies in area of MARPOL Annex VI and in particular energy efficiency of ships, some aspects may require updating over time.

The views expressed in this document are purely those of the author(s) and may not in any circumstances be regarded as stating an official position of the organizations involved or named in this document.

This document is subject to change by the IMO.

Dr Zabi Bazari, EnEmSol, January 2016

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1 Shipping operations overview

1.1 Introduction

This section provides an overview of fleet management issues and discusses how to implement sustainable fleet management practices that leads to environmental protection and reduces transport costs. The purpose of a sustainable management of a fleet is to:

- Reduce accidents and associated risks and costs through improved navigation performance, and fleet health and safety responsibilities.
- Reduce overall fleet costs including fuel costs.
- Reduce fleet environmental impacts including reduction in air emissions such as carbon dioxide (CO₂) emissions.
- Adopt efficient voyage planning techniques to reduce distance sailed, minimise exposure to adverse sea conditions and make more efficient use of the fleet.
- Adopt new, energy efficient ship technologies and low carbon fuels through fleet renewal planning that are most appropriate for a sustainable operation.
- Support corporate sustainability goals, for example, under ISO 14001 and other environmental best practice.
- Provide a competitive edge by demonstrating economics and environmental credentials of the company's ship operations to its clients.

The material presented herein is mainly those from Barnhart et al 2007 that has been reformulated to suit the case for ship energy efficiency. Additional literatures are also provided for further reading on the subject. The aim is not to provide a detailed account of shipping business and its operations management aspects but to familiarise the trainee with main aspects of the industry that would influence the energy efficiency of shipping operations. The topics discussed herein that directly relate to ship energy efficiency and CO₂ reductions are then further discussed in other sections of this module.

1.2 Shipping company structure

The structure of a shipping company is determined primarily by the nature of the trade in which it operates and by the size of its activities. For example, the structure of a tramp operator will generally be different from that of a much larger liner company. Irrespective of the size of the company, its structure should be designed to permit good and fast decision-making. An example of typical departments that a shipping company may have is shown in **Figure 1.1**.

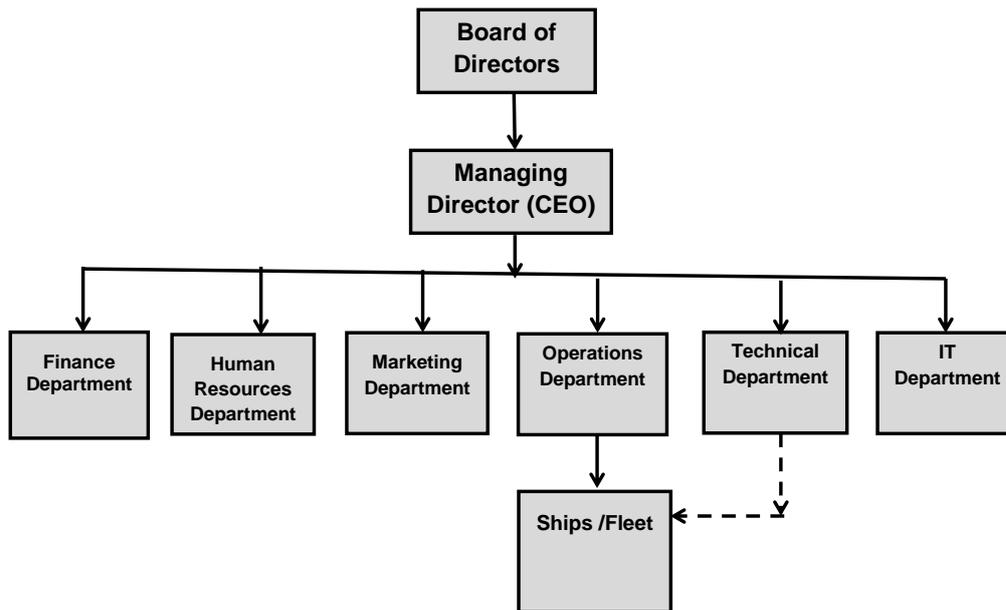


Figure 1.1: Typical organisation of a shipping company

Of the departments shown in **Figure 1.1**, the operations department and technical department are relevant to this training course.

Operations department (fleet management): This is the most important department for a shipping company. The main job of this department is to maximise the economic and safe deployment of the ships via a number of activities including planning and scheduling, i.e. deciding where to send the ships and when. A significant level of coordination is done by this department. Coordination is essential, not only with other internal departments but also with the ships, charterers, ports, agents, etc.

Technical Department: As the name implies, this department’s main responsibility is to keep the ships in a seaworthy and good maintenance conditions. It is in charge of ships’ maintenance and repairs including overhauls, technical repairs, routine maintenance, new building projects, etc.

1.3 Ship types

Ships come in a variety of sizes. The size of a ship is measured by its weight carrying capacity (deadweight) and by its volume carrying capacity (gross tonnage). Cargo with low weight per unit of volume fills the ship’s volume before it reaches its weight capacity. Deadweight (DWT) is the weight carrying capacity of a ship in metric tons. That includes the weight of the cargo, as well as the weight of fuels, lubricating oils, supplies, and anything else on the ship. Gross Tons (GT) is the volume of the enclosed spaces of the ship in hundreds of cubic feet.

Ships come also in a variety of types. Tankers are designed to carry liquids in bulk. The larger ones carry crude oil while the smaller ones usually carry oil products, chemicals, fruit juices and other liquids. Bulk carriers carry dry bulk commodities such as iron ore, coal, grain, bauxite, alumina, phosphate and other minerals. Some of the bulk carriers are self-discharging. They carry their own unloading equipment and are not dependent on port equipment for unloading their cargo. Liquefied Natural Gas (LNG) carriers carry refrigerated natural gas under very low temperatures.

Container ships carry standardized containers in which packaged goods are stowed. General cargo vessels carry in their holds and above deck all types of goods, usually packaged ones. These vessels

often have multiple decks or floors. Since handling general cargo is labour intensive and time consuming, general cargo has been containerized during the past decades, thus reducing the time that these ships spend on port cargo operations from days to hours.

Refrigerated vessels or reefers are designed to carry cargos that require refrigeration or temperature controlled cargos like fish, meat, etc. but can also carry general cargo. Roll-on–Roll-off (Ro–Ro) vessels have ramps for trucks and cars to drive on and off the vessel. Other types of vessels are ferries, passenger ships, fishing vessels, service/supply vessels, barges, research ships, dredgers, naval vessels and other special purpose vessels. Some ships are designed as combination of the above types, e.g., ore-bulk-oil, general cargo with refrigerated compartments, passenger and Ro–Ro vessels and so on.

1.4 Cargo types and characteristics

Ships carry a large variety of cargos. The cargos may be manufactured consumer goods, unprocessed fruits and vegetables, processed food, livestock, intermediate goods, industrial equipment, processed materials and last but not least all different types of raw materials such as crude oil and minerals.

These goods may come in a variety of packaging such as boxes, bags, drums, bales and rolls or may be unpackaged or even in bulk. Sometimes cargoes are unitized into larger standardized units such as pallets, containers or trailers. Generally and in order to facilitate more efficient cargo handling, goods that are shipped in larger quantities are shipped in larger handling units or in bulk. During the last decades, packaged goods that required multiple manual handlings and were traditionally shipped by liners have been containerized into standard containers. Containerization of such goods facilitates efficient mechanized handling of the cargo, and thus saves time and money.

In addition, goods that are shipped in larger quantities are usually shipped more often in larger shipment sizes. Cargoes may require shoring on the ship in order to prevent them from shifting during the passage and may require refrigeration, controlled temperature or special handling while on board the ship. Different goods may have different weight density, thus a ship may be regarded as full either by weight or by volume or by another measure of capacity.

1.5 Ports

Ships operate between ports. Ports are used for loading and unloading cargo as well as for loading fuel, fresh water, other supplies and for discharging waste. Ports impose physical limitations on the dimensions of the ships that may call in them (ship draft, length and width), and charge fees for their services. Sometimes ports are used for trans-shipment of cargo among ships, especially when the cargo is containerized. Major container lines often operate large vessels between hub ports and use smaller vessels to feed containers to/from spoke ports. In many countries, ports authorities that are in overall charge of regulating ports are different from those authorities that are in charge of regulating shipping. The impact of port operation on ship energy efficiency is covered in detail in **Module 5**.

1.6 Shipping segments

There are large numbers of ways by which the shipping business may be categorised or classified. One obvious one is by ship types. Accordingly, the ships could be segmented into tanker, bulker, container, etc. There are other methods of the shipping segmentation, two of which are briefly described.

1.6.1 Ship segments by geography of operation

Shipping routes may be classified according to their geographical characteristics as deep-sea, short-sea, coastal and inland waterways. Due to economies of scale in shipping, larger size vessels are employed in deep-sea trades between continents whereas smaller size vessels usually operate in short-sea and coastal routes, where voyage legs are relatively short. For example, smaller containerships are used on short-sea routes that feed cargo to larger vessels that operate on long deep-sea routes (referred to as feeders). Due to draft restrictions, inland waterways are used mainly by barges. Barges are used to move cargoes between the inland and coastal areas; often for transshipments to/from ocean-going vessels or to move cargoes between inland ports.

1.6.2 Shipping segments by operation

There are generally three basic modes of operation of commercial ships:

- **Liner operations:** Liners operate according to a published itinerary and schedule similar to a bus line. The demand for their services depends among other things, on their schedules / itineraries. Liner operators usually control container and general cargo vessels. Cruise industry, although not referred to as liner operations, usually follow the same model of operation.
- **Tramp operations:** Tramp ships follow the available cargoes similar to a removal van. Often tramp ships engage in contracts of affreightment (see following pages for full description). These are contracts where specified quantities of cargo have to be carried between specified ports within a specific time frame for an agreed payment per unit of cargo. Tramp operators usually control part of tankers and dry bulk carriers segments. Both liner and tramp operators try to maximize their profits per time unit.
- **Industrial operations:** Industrial operators usually own the cargoes shipped and control the vessels used to ship them either as owner or as a charterer. Their vessels may be their own or on a time charter. Industrial operators aim to minimize the cost of shipping for their cargo transport but generally operate within a wider company business framework, thus their approach to ship management may be different from those of the liner or tramp operators. Industrial operations relate to high volume liquid and dry bulk trades for large integrated companies such as oil, chemicals and ores corporations.

In shipping and in cases of excess fleet capacity, vessels may be chartered out (to other operators), laid-up or even scrapped. However, when liners reduce their fleet size, they normally would reshuffle their itineraries / schedules, which may result in reduced service frequency or withdrawal from certain markets. Industrial operators, who are usually more risk-averse and tend not to charter-out their vessels, size their fleet below their long-term needs, and complement it by short-term (time or voyage/spot) charters from the tramp segment.

Seasonal variations in demand and uncertainties regarding level of future demand, freight rates and cost of vessels affect the fleet size decision. However, when the trade is highly specialized (e.g. LNG carriers), no tramp market exists and the industrial operator must assure sufficient shipping capacity through long-term commitments and contracts. The ease of entry into the maritime industry is manifested in the tramp market that is highly private market and entrepreneurial. This market condition results in occasional long periods of oversupply of shipping capacity. This then leads to the associated depressed freight rates and vessel prices. However, certain market segments such as container lines pose large economies of scale and are hard to enter by the smaller players.

1.7 Ship/fleet planning

Ship / fleet planning problems are relatively complex as ships operate under a variety of operational conditions such as:

- A ship operates mostly in international trades which mean that they are crossing multiple national jurisdictions, with their own relevant issues.
- A ship represents a large capital investment that translates into high daily costs of capital, fuel costs, port dues, etc. Thus, it cannot remain idle and must be busy earning on a continuous basis.
- Ships have higher uncertainty in their operations due to their higher dependence on weather conditions and their operation in multiple jurisdictions and various ports.
- Although shipping may look to be the least regulated mode of transportation, there are significant legal, political, regulatory and economic aspects involved in maritime transportation.

Maritime transportation planning problems can be classified in the traditional manner according to the planning horizon into business, commercial and operational decision making levels.

1.7.1 Business planning

At the business level, aspects that relate to overall industry structure, status and future are being considered. These are cases such as:

- Market and trade selection,
- Network and transportation system design (including trans-shipment points),
- Fleet size and fleet mix decisions (type, size, and number of vessels),
- Port/terminal location, size, and design.
- Ship design and choice of ship technology.

The business planning aspect of shipping is not of direct interest in this course. At the commercial levels, most of topics of interest are more relevant and includes for example aspects such as:

- Fleet deployment (assignment of specific vessels to various trade routes),
- Ship routing and scheduling,
- Port and berth scheduling,
- Cargo operation scheduling,

At the operational level, operation management is conducted to optimally achieve the commercial requirements. These include for example:

- Voyage planning
- Ship speed selection and adjustments
- Ship loading operations
- Ship environmental/weather routing

Business decisions are long-term decisions that set the stage for commercial and operational ones. In maritime transportation business (strategic) decisions cover a wide spectrum, from the design of the transportation services to accepting long-term contracts. Most of the strategic decisions are on the supply side and these are: market selection, fleet size and mix, transportation system/service network design, maritime supply chain/maritime logistic system design and ship design. The above decisions are based on operational information and use of a variety of models.

Choice of ship size

The ship design covers a large variety of topics that are addressed by naval architects and marine engineers. They include structural and stability issues, materials, on-board mechanical and electrical systems, cargo handling equipment, and many others. Some of these issues have direct impact on the ship's commercial viability. Obvious examples for GHG emissions reduction purposes are decision making on ship size and ship speed.

The question of the optimal size of a ship arises when one tries to determine what is the best ship for a specific trade? The optimal ship size is the one that minimizes the ship operator's cost per ton of cargo on a specific trade route with a specified cargo mix; within all regulatory constraints. However, one should realize that in certain situations, factors beyond costs may dictate the choice of the ship size.

Significant economies of scale exist at sea (i.e. use of larger vessels); where the cost per cargo ton-mile decreases with increasing the ship size. These economies stem from the capital costs of the ship (design, construction, and financing costs), from fuel consumption, and from the operating costs (crew cost, supplies, insurance, and repairs). These costs per unit of cargo transport tend to reduce as the ship size increases.

However, at port the picture is different and may not be in favour of economies of scale. Loading and unloading rates are usually determined by the land-side cargo handling equipment and available storage space. Depending on the type of cargo and whether the cargo handling is done by the land-side equipment or by the equipment on the ship (e.g., pumps, cranes), the cargo handling rate may be constant (i.e. does not depend on the size of the ship), or, for dry cargo where multiple cranes can work in parallel, the cargo handling rate may be approximately proportional to the length of the ship. Since the size of the ship is determined by its length, width, and draft, and since the proportions among these three dimensions are practically almost constant, the size of the ship is approximately proportional to the third power of its length. Therefore, in the better case, cargo-handling rates will increase proportional to the one-third power of the ship size. However, when the cargo is liquid bulk (e.g., oil) the cargo-handling rate may not be related to the size of the ship.

A ship represents a large capital investment that translates into a large cost per day. Port time is expensive and presents dis-incentives for large ship scales. Thus the time of port operations may cap the optimal size of ship. Generally, the longer a trade route is, the larger the share of sea-days in a voyage, then the larger the optimal ship size will be. Other factors that affect the optimal ship size are the utilization of ship capacity at sea, loading and unloading rates at the ports, and the various costs associated with the ship. On certain routes there may be additional considerations that affect the size of the ship, such as required frequency of service and availability of cargo.

Thus, the optimal ship size is a long-term decision that must be based on expectations regarding future market conditions. During the life of a ship, a lot of market volatility may be encountered. Freight rates may fluctuate over a wide range and the same is true for the cost of a ship. When freight rates are depressed, they may not even cover the variable operating costs of the ship, and the owner has very few alternatives. In the short run the owner may either reduce the daily variable operating cost of the ship by slow steaming, that results in significant reduction in fuel consumption, or the owner may layup the ship till the market improves.

Laying up a ship involves a significant set-up cost to put the ship into layup, and, eventually, to bring it back into service. However, laying up a ship significantly reduces its daily variable operating cost. When the market is depressed, owners scrap older ships. The value of a scrapped ship is determined by the weight of its steel (the "lightweight" of the ship), but when there is high supply of ships for scrap the price paid per ton of scrap drops.

In the shorter run, ship size may be limited by parameters of the specific trade, such as availability of cargoes, required frequency of service, physical limitations of port facilities such as ship draft, length, or width, and available cargo handling equipment and cargo storage capacity in the ports. In the longer run, many of these limitations can be relaxed if there is an economic justification to do so. In addition there are limitations of ship design and construction technology, as well as channel restrictions in canals in the selected trade routes.

Modern cargo handling equipment that is customized for the specific cargo results in higher loading and unloading rates, and shorter port calls. Such equipment is justified where there is a high volume of cargo. That is usually the case in major bulk trades; under such circumstances the optimal ship size becomes very large, far beyond the capacity of existing port facilities. In addition, with such large ships the frequency of shipments drops to a point where inventory carrying costs incurred by the shipper start playing a significant role. When one includes the inventory costs in the determination of the optimal ship size, that size is reduced significantly. The resulting ship sizes are still much larger than existing port facilities can accommodate, and thus the main limit on ship sizes is the draft limitation of ports. However, for a higher value cargo or for less efficient port operations, smaller vessel sizes are optimal. In short-sea operations, competition with other modes may play a significant role. In order to compete with other modes of transportation more frequent service may be necessary. In such cases frequency and speed of service combined with cargo availability may be a determining factor in selecting the ship size.

Fleet size and mix

One of the main strategic issues for shipping companies is the choice of an optimal fleet. This deals with both the type of ships to include in the fleet, their sizes and the number of ships of each size.

In order to support decisions concerning the optimal fleet of ships for an operator, very often include routing decisions. The objective of the strategic fleet size and ship mix problem is usually to minimize the fixed capital costs of the ships needed and the variable operating costs of these ships when in operation. In a commercial routing and scheduling problem, one usually minimizes only the operating costs of the ships. However, at the business (strategic) decision making level, the routing decisions and minimisation of operating costs is combined with minimization of the capital costs needed for the fleet.

Additionally, the fleet size and mix decisions have to be based on an estimate of demand for the transportation services. This need to be included in decision making model despite the fact that the demand forecast is highly uncertain.

1.7.2 Commercial planning

The commercial planning is concentrated on medium-term decisions and the focus of this level in maritime fleet operation is primarily on optimal routing and scheduling. In industrial shipping the cargo owner or shipper normally controls the ships' operations. Industrial operators try to ship all their cargoes at minimum cost. A tramp shipping company, on the other hand, may have a certain amount of contract cargoes that it is committed to carry and tries to maximize the profit from optional cargoes. During the last decades, there has been a shift from industrial to tramp shipping. Perhaps the main reason is that many cargo owners are now focusing on their core business and have outsourced other activities like transportation to independent shipping companies. From the shipper's perspective, this outsourcing has resulted in reduced risk.

Liner shipping differs significantly from the other two types of shipping operations; i.e. tramp and industrial. However, the liner shipping involves significant commercial decisions at different planning levels. The differences among the types of shipping operations are also manifested when it comes to

routing and scheduling issues. One main issue for liners on the commercial planning level is the assignment of vessels to established routes or lines; this is referred to as “fleet deployment”.

A focus on a fleet deployment problem where the shipping company utilize the different cruising speeds of the ships in the fleet is important. The routes are pre-defined, and each route will be sailed by one or more ships several times during the planning period. Each route has a defined common starting and ending port. A round-trip along the route from the starting port is called a voyage.

The demand is given as a required number of voyages on each route without any explicit reference to the quantities shipped. The fleet of ships is heterogeneous and it can be assumed that not all ships can sail all routes. Such a specification can incorporate needed ship capacity together with compatibilities between ships and ports. With information about the feasible ship-route combinations and the company’s fleet mix, the relevant decisions on fleet deployment are taken. Of course, minimisation of cost and maximisation of profits is one main factor; however and in particular for liner operators, minimisation of fuel cost and thus reduction of fleet CO₂ emissions becomes an important decision making aspect at this level.

1.7.3 Routine (operation) planning

When the uncertainty in the operational environment is high and the situation is dynamic, or when decisions have only short-term impact, one resorts to short-term operational planning. This could happen in part of the tramp shipping segment that requires routine day to day decision making on best method of fleet deployment.

In certain circumstances, it is not practical to schedule ships beyond a single voyage. This happens when there is significant uncertainty in the supply of the product to be shipped, or in the demand for the product in the destination markets. The shipped product may be seasonal and its demand and supply may be affected by the weather. These factors contribute to the uncertainty in the shipping schedule. The shipper has to assure sufficient shipping capacity in advance of the shipping season, but does not know in advance the exact timing, quantities and destinations of the shipments. The shipper normally does not have return cargoes for the ships, so the ships are hired under contracts of affreightment or spot charters and generally do not return to load for a second voyage.

Based on product availability, demand projections, inventory at the markets and transit times, the shipper builds a shipping plan for the short term and has to decide to assign the planned shipments to the available fleet at minimal cost.

1.7.4 Speed selection and cruising speed

A ship can operate at a speed slower than its design speed and thus significantly reduce its fuel costs (see for example slow steaming in subsequent sections). However, a ship must maintain a minimal speed to assure proper steering and safe operation of main engine, etc. For most cargo vessels the bunker fuel consumption per time unit is approximately proportional to the third power of the speed (the consumption per distance unit is proportional to the second power of the speed). Thus, reducing the speed by 20% reduces the fuel consumption (per time unit) by about 36%.

When bunker fuel prices are high the cost of bunker fuel may exceed all other operating costs of the ship. Thus there may be a strong incentive to steam at slower speed and reduce the operating costs. A fleet operator that controls excess capacity (e.g. line operators), can reduce the speed of the vessels and thus reduce the effective capacity of the fleet, instead of laying-up, chartering-out or selling vessels.

Often cruising speed decisions may be an inherent part of such fleet scheduling / planning decisions. Cruising speed decisions affect both the effective capacity of the fleet and its operating costs. Under a contract of affreightment, a ship operator commits to carry specified amounts of cargo between specified loading port(s) and unloading port(s) at a specific rate over a specific period of time for an agreed upon revenue per delivered unit of cargo.

The term fleet deployment is usually used for ship scheduling problems associated with liners as discussed earlier. In such cases and because the vessels are essentially assigned to routes that they will follow repeatedly; the deployment decisions (including speeds) are medium to longer term decisions. On the other hand, tramp and industrial operators usually face shorter term ship scheduling problems. A set of cargoes has to be carried by the available fleet, and if the fleet has insufficient capacity, some cargoes may be contracted out. The cruising speed of the vessels in the available fleet can be an important factor in fleet scheduling decisions.

In addition to cost and schedules, short-term cruising speed decisions should take into account also the impact of the destination port operating times. If the destination port is closed over the weekend (or at night) there is no point arriving there before the port opens. Thus reducing the cruising speed and saving fuel makes sense. In the case where cargo-handling operations of a vessel that started when the port was open continue until the vessel is finished, even after the port closes, it may be worthwhile to speed up and arrive at the destination port to start operations before it closes. There are a variety of tactics that may be used to take advantage of more appropriate vessel scheduling. These are covered in detail in **Section 5** under just in time and virtual arrival operations.

1.8 Maintenance management

Numerous mechanical and electrical systems are installed on board a ship and they require maintenance. Proper maintenance of a ship has significant impact on overall technical performance and energy efficiency of the vessel.

A ship is usually scheduled once a year for maintenance in a port or a shipyard, and once every few years a ship is surveyed by its classification society in a shipyard. However, some maintenance is required between such planned maintenance periods. This includes both routine/preventive maintenance and repair of breakdowns (at least temporary repair until the ship reaches the next port). On-board maintenance is usually done by the crew, but the shrinking size of crews reduces the availability of the crew for maintenance work. A large ship may have less than two dozen seamen on board, and that includes the captain and the radio officer. This limited crew operates the ship around the clock.

In order to facilitate maintenance, a ship must carry spare parts on board. The amount of spare parts is determined by the frequency of port calls and whether spares and equipment are available in these ports. Large and expensive spares that cannot be shipped by air, such as a propeller, may pose a special problem and may have to be prepositioned at a port or carried on board the vessel.

To facilitate good ship maintenance despite the lowering number of crews over time, decision support tools for condition monitoring are frequently used. Also, third party maintenance contracts could be made so that external specialised organisations look after important ship-board assets (e.g. engines). The increase in data communication between ship and shore is an enabling technology to provide support to ship-board staff by the shore-based staff. All these topics further discussed in detail in **Modules 4 and 6**.

1.9 Bunker procurement

A ship may consume tens of tons of bunker fuel per day at sea and there may be significant differences in the cost of bunker fuel among bunkering ports. Thus one has to decide where to buy bunker fuel. Sometimes it may be worthwhile to divert the ship to enter a port just for loading bunker fuel. The additional cost of the ship's time has to be traded off with the savings in the cost of the fuel. Bunker procurement is overall a commercial decision making process but nevertheless it has large implications for routine operation decision making as well. Additional cost of ship diversion may not occasionally come into perspective due to split-incentive issues relating to who pays for what when it comes to ship costs. Bunker procurement not only involves operational considerations but also technical considerations. The technical issues are covered under "fuel management" in **Module 4**.

1.10 Environmental and weather routing

The terms environmental routing and weather routing are often used interchangeably although the second one is a subset of the first. Weather is part of the environment in which ships operate, for example weather affects the waves encountered by ships. Ships are exposed to prevailing sea currents, tides, waves and winds. Recognizing these conditions is the first step toward selecting routes that mitigate their effects or even take advantage of them. Generally, when a ship moves between two ports, it has to select its route. However, such a choice is very limited in coastal and inland waterway navigation. Proper selection of the route may assure on-time arrival at the destination port or even shorten the time of the passage and reduce its cost.

Environmental routing is complicated by the complexity of the continuous dynamic environment in which ship operates and the lack of the necessary timely reliable data. Due to these reasons environmental routing seems to have still some way to go to make them accessible to every type of shipping. More details of weather routing and its importance with regard to ship energy efficiency is given in **Section 6**.

1.11 Ship loading

A ship must be loaded in a safe manner in order to prevent loss of the ship or damage to the cargo. Ships are designed with certain types of cargo in mind. A ship operates in adverse weather and sea conditions and its stability must be assured during passage as well as in port.

Ballast tanks are built into the hull in order to help maintain its stability by filling them with seawater. When a ship is full with cargo of a uniform density for which it is designed, such as crude oil or iron ore, usually there are no stability problems. Stability problems arise when:

- The ship is partially loaded. In this case, the weight distribution of the cargo must be properly planned and monitored, both while sailing at sea and during loading or unloading operations in port.
- When the cargo is not properly secured and may shift during passage, for example, liquid bulk cargo may slosh in partially empty tanks.
- When the ship is fully loaded with non-uniform cargo, such as containers or general cargo. In such a case an improper weight distribution of the cargo may result in excessive rolling or pitching that may lead to loss of the ship. In extreme cases, improper weight distribution may cause excessive structural stress that may lead to break up of the ship.

Ship stability has several dimensions. The trim of a ship is the difference between the forward and aft draft and must remain within a narrow range. There should be a balance between weight of the

cargo on the port (left) side and the starboard (right) side of the ship so it will remain horizontal. The centre of gravity of the ship should not be too high in order not to make it easy to roll, and not too low so the ship will not snap back too fast from a roll which may cause on-deck cargo to break loose.

The more complex ship loading problems are encountered in loading container ships. Not only the stability of the vessel has to be assured but also the efficiency of cargo handling operations in the current and following ports must be taken into account. Containers have different weights and that may affect the vessel stability. Due to the design of container ships access to a specific container may be obstructed by other containers stowed on top of it. Therefore, in order to minimize future container shifting operations, one has to take into account the destination port of the loaded containers when one decides where to load them onboard the vessel. Moreover, one also has to consider the destination ports of the containers that will be loaded in following ports of call, and some of these containers may not even be booked yet. There may also be containers stuffed with dangerous goods. Such containers impose additional constraints due to spatial separation requirements.

The focus of research on ship loading has been on loading container ships including minimizing container shifting, planning container stowage on board. Additional considerations are reduction of the ballast required by the vessel and efficient use of cranes when loading and unloading. All these aspects have impacts on a ship's energy efficiency. More details of these aspects are covered in **Section 4**.

1.12 References and further readings

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

- 1 C. Barnhart and G. Laporte (Eds.), "Handbook in OR & MS", Vol. 14, Elsevier B.V. 2007, Chapter 4 written by Marielle Christiansen, Kjetil Fagerholt, Bjørn Nygreen and David Ronen.
- 2 "IMO train the trainer course material", developed by WMU, 2013.
- 3 GL and Fraunhofer CML, "Best practice ship management study", <http://www.cml.fraunhofer.de/content/dam/cml/de/documents/Studien/Best-practice-Studie-2013.pdf> accessed August 2015.
- 4 Rajesh Bajpae, "What is the key to successful ship management", <http://www.shippingstarnet.com/Bajpyee.pdf> accessed August 2015.
- 5 UNCTAD 2014, "Review of Maritime transport", annual publication of United Nations Conference on Trade and Development, 2014.
- 6 Knickerbocker Maritime 2004, "Technical Ship Management's Effect on Owner's Profitability", <http://www.knickerbocker-maritime.com/ShipManagementArticle.pdf.pdf> accessed August 2015.

2 Shipping contracts and energy efficiency

2.1 Introduction

The management of a shipping company has the overall responsibility for reducing GHG emissions from its fleet. Despite the ship-specific activities, the shipping company management must look at the shipping company as a whole to achieve maximum benefits in reduction of fuel consumption and fleet GHG emissions.

For this purpose, a company would develop policies and an energy management system. The company will first target internal aspects such as planning, implementation, monitoring and reviews. The company management would define and communicate the companies' values and aspirations and detail how the company intends to achieve the objectives of their energy policy including the identification of roles and responsibilities, the setting of targets and monitoring performance. The company should look at ways of improving the utilization of its fleet's capacity. The company would implement procedures, which limit any onboard administrative burden.

Other strategies for energy saving could include for example:

- Avoiding long ballast voyages through improved planning
- Reducing down time alongside in port
- Reducing the time it takes to load or discharge by improved cargo handling capability
- Installing equipment so that the ships can use shore power
- Using weather routing services to plan which vessels to use on a particular route

The company may also operate a 'fleet emissions trading' system with the company goal linked to the fleet rather than individual ships. The company may then consider buying new and more efficient ships.

Having said all the above good items, there is one major aspect of shipping that normally acts as a barrier to energy efficiency and at the same time has historically been overlooked. This includes the constraints faced by ship managers from the complex business environment within which the shipping operates. The fact is that the ship operation and shipping companies or ship managers/operators are entangled with a number of industry players; and are bound by a number of contractual and regulatory requirements that may restrict their overall control on various aspects of ship's operation management.

Thus, the process of management of the commercial operation of ships is a complex one involving many players and a large number of legal and regulatory frameworks. This will impact the move to ship operational energy efficiency and low carbon shipping. In this section, such aspects are further detailed.

2.2 Industry players

Figure 2.1 provides an overview of the various players in the shipping/maritime industry mainly from perspective of regulatory enforcement and legislative framework. Currently, the legislative framework for international shipping consists of about 50 conventions and protocols created by the IMO plus the relevant legislative measures of the International Labor Organization (ILO) for seafarers. It is the Contracting Government's (Parties to various Conventions) responsibility to transpose international law into their national legislation and enforce it. The right-hand side of **Figure 2.1** presents the various other industry players around the ship-owner, such as banks who finance ships, insurance companies who insure ships and a variety of companies who are involved in the commercial and day-to-day operation of a vessel (ship operator, manager, charterer, shipper,

etc.). It is the interaction of these players that decides the overall operational profile of a ship.

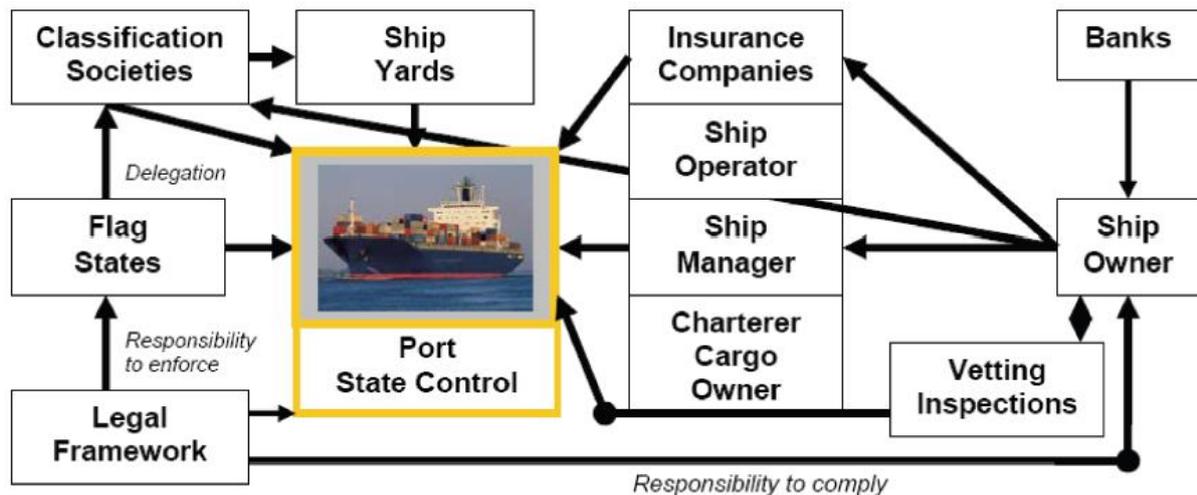


Figure 2.1: Maritime industry players within regulatory and legal frameworks [2nd IMO GHG Study 2009]

The ship owners, operators and managers should be aware of how these elements interact and manage these interactions if they are to formulate an optimum strategy for reducing GHG emissions from their fleet. Looking at individual ships in isolation will not reap the highest results. To achieve maximum reduction of GHG emissions, it is important that the company or operator has effective procedures to improve the energy efficiency of the overall fleet it operates.

2.2.1 Ship operation stakeholders

As highlighted earlier under SEEMP (see **Module 2**), the management of stakeholders in ships operation need to be given priority. **Figure 2.2** presents the main stakeholders that are involved and need to be managed.

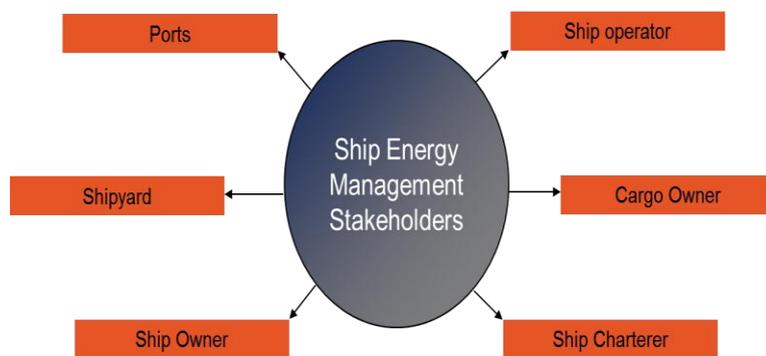


Figure 2.2: Ship energy management stakeholders

A brief description of various stakeholders engaged in ship operation and some other terms is given first.

Ship owner: A ship-owner is the owner of a commercial ship that ultimately equips and exploits a ship, usually for delivering cargo transport services at a certain freight rate. A ship-owner can be a company or an individual.

Ship operator: A ship operator is any company who operate the ship and is responsible for the operating costs, repairs and earnings of vessels. The operator may or may not be the owner of the

vessel. Costs include crew wages, port charges and hull insurance.

Ship manager: Ship managers are those who, on behalf of ship-owners or charterers or the ship operator, engaged in day to day management of the ship. In such a case, all commercial, rights, obligations and consequences are undertaken by the ship-owners or charterers or ship operators.

Charterer: A person or organization that charters (hires) a ship.

Shipper: The owner or suppliers of goods who entrusts them on board a vessel for delivery using a contract in the form of a charter-party or bill of lading or otherwise. These are individuals or companies that send or receive goods for transportation; they are usually the suppliers or owners of cargo to be shipped.

Carrier: Company that transports goods and/or people in its own or chartered vessels or equipment, and is named as the carrier in the contract of carriage.

Port manager: Organizations in charge of port operations, dealing with all aspects of port activities including the port-area movement of ships, the loading and unloading of ships, customs activities, anchorages, channels, lighters, tugs, berths, warehouse, and other storage spaces, etc. The efficient management of a port involves managing of all these activities.

Routing is the assignment of a sequence of ports to a vessel. Environmental routing or weather routing is the determination of the best ship route should use taking into account all aspects of ship environment including weather.

Scheduling is assigning times (or time windows) to the various events on a ship's route.

Deployment refers to the assignment of the vessels in the fleet to trade routes.

Voyage: A voyage consists of a sequence of port calls, starting with the port where the ship loads its first cargo and ending where the ship unloads its last cargo and becomes empty again. A voyage may include multiple loading ports and multiple unloading ports. Liners may not become empty between consecutive voyages, and in that case a voyage starts at the port specified by the ship operator (usually a primary loading port).

It has long been established that an energy efficiency policy implemented and managed correctly will not only reduce GHG emissions and other pollutants but will also reduce fuel costs which will in turn reduce the operating cost and increase the company's overall profits. This could also reduce the cost of shipment, which may then be passed on to the charterer and the ultimate consumers. However, this has not happened worldwide due to some aspects that will be highlighted in the following sections.

2.2.2 Need for incentives by all parties

The overall incentives for reducing fuel consumption and GHG emissions are reduced costs and environmental protection. While there are many opportunities to optimise and improve operational efficiency, it will require the participation of several parties as indicated above. It is essential that each of the parties has the incentives and flexibility to join the energy-saving efforts. As a minimum, it is particularly important that they do not have incentives to contribute to ship operations that are regarded as inefficient.

The following sections will highlight the many benefits there are to reducing GHG emissions. The main benefits can include not only the reduction of operation costs but also because of better maintenance that results in the ship being kept in service for longer period with decreased down time both at sea and in port.

Some savings may not be directly passed on to the shipping company such as the reduction of fuel consumption in a time charter but the ship will become more attractive to charters with the possibility of demanding a higher freight rate for a particular charter. If a ship is properly maintained to reduce fuel costs it will also have the effect of generally lower maintenance cost of the ship machinery. However, in a large number of cases, the “split incentives” prevail.

A ‘split incentive’ refers to a situation where the ship owner or the shipping company does not benefit from the energy efficiency because they are not paying for the fuel. In the shipping industry, this mainly occurs when vessels such as bulk carriers, tankers and container ships are hired under a time charter or a bareboat charter as outlined later. In this case, it is the charterer who pays for the fuel, but the ship owner who is responsible for any investment in energy- efficiency equipment will not benefit from energy saving.

This is in some part counter acted by the fact that more fuel efficient ships will have a higher charter rate but in practice it is difficult to verify the energy saving levels in a straightforward way; thus making it impossible to guarantee improved fuel consumption levels on a particular vessel. A situation can arise where the ship is on time charter and operated by the owner who may tend to minimise time in dry-dock and other maintenance costs such as anti-fouling; thus reducing the time lost off-hire while at the same time handing the fuel bill to the time charterer. These are examples of industry behaviours that may be regarded as incentives for inefficient operation. Such practices should certainly be addressed. Thus in general, the issue of “split incentives” should be handled for the benefit of all and actions regarded as dis-incentive to energy efficient practices eliminated.

2.2.3 Stakeholders’ legal aspects

Understanding the legal and contractual aspects of ship operation, that sets the tone for relationship between various stakeholders, is thus essential to reduce the “split incentive” aspects. This will then provide the business environment for facilitating a more incentivized and harmonious approach to ship management by all parties involved. To support this process, some of the standard contractual agreements between parties involved in ship operation need to be analysed and understood.

2.3 Contract of carriage

The purpose of this brief introduction to legal frameworks in relation to the carriage of goods by sea is to make you familiar with the concepts rather than making you a maritime lawyer. It is to highlight and provide some background on the importance of looking at the contract of carriage when deciding on a GHG emissions reduction strategy for both the fleet and individual ships. This is particularly true for measures that influence the overall operation of the ship including its itinerary and voyage management. Without such high level considerations, it is likely that the planned energy saving may not be successful or the ship owner may end up in legal cases for breach of relevant contracts.

While it is easy to point to areas where the present industry arrangements and system fall short, it is more difficult to find solutions that would resolve these issues to the satisfaction of all parties. For example, when it comes to contracts, some may permit options like slow speed steaming and virtual arrival and some may not. This means that the ship-manager and the chartering department of a shipping company must work closely together to ensure that for a particular ship on a particular voyage the terms of the contract are not breached, leaving the ship owner or ship operator open for potential losses.

On the other hand, they could try also to find contractual solutions to allow more energy efficient operation of a ship or a fleet. There may be the possibility for the ship owner to negotiate with the

charterer or shipper to have clauses inserted into the contract that will allow a particular GHG emissions reduction strategy to be implemented. But it is important that all parties to the contract are aware and has agreed to the changes and that the changes do not conflict with any relevant national law.

A “contract of carriage” is a contract between a carrier (e.g. a ship in this case) of goods or passengers and the shippers or passengers. Contracts of carriage typically define the rights, duties and liabilities of parties to the contract, addressing topics such as terms and conditions, exceptions; and clauses such as force majeure and jurisdiction. There will be “jurisdiction” and “arbitration” clauses in almost all the contracts of carriage.

Most contracts of carriage will be subject to The Hague Visby Rules or Hague Rules, which superseded the old “common law” rules. The ‘common law’ rules that are referred to are normally based on ‘English/Welsh’ law but in other jurisdictions will have similar provisions in their national legislation. The issue of jurisdiction is a very important consideration for any contract of carriage so it should not be assumed that this is always the same.

The Hague Rules and the Hague Visby Rules are a set of internationally agreed rules for the carriage of goods at sea and most maritime and non-maritime nations normally follow these rules. However, there are some specific situations in which these internationally agreed rules do not apply and the rights and obligations of the parties are still governed by “common law”. In this course it is not the intention to go into these specific situations but for trainees that are interested, any good maritime law book will give more details.

2.3.1 Common Law

Under common law, there are four basic obligations on the carrier and the latter two are of particular interest to any ship manager considering either changing the voyage plan from the most direct route or reducing the speed of vessels to reduce GHG emissions. The basic four obligations under common law are:

1. *The carrier must deliver the goods in the same condition as when they are shipped*, and this is a non-delegable duty. There is however four common law exceptions;
 - Act of god
 - Act of Queens/Kings enemies
 - Loss or damage resulting from inherent vice of the goods.
 - Loss resulting from jettison
2. *The carrier has an absolute duty to provide a seaworthy ship*. This is a much stricter obligation than in the Hague Visby Rules which only require due diligence on the part of the ship-owner and is one of the main reasons that the Hague Rules came about.
3. *The carrier undertakes to proceed on a voyage without unjustifiable deviation*. If there is a “deviation”, the carrier is liable for any subsequent loss unless he can rely on a common law exception (such as saving life), and can show that the loss or damage would have occurred in the absence of the deviation. The question in relation to GHG is: would an alteration of the voyage plan to take a different route to save fuel and reduce GHG emissions be regarded as an ‘unjustifiable deviation’. In nearly most cases, the answer to this would be ‘no’ as the aim would normally be to reduce the distance travelled and not increase it but there may be examples where this is not the case.

4. *The carrier must complete the voyage with reasonable dispatch.* If there is undue delay, the carrier is liable in damages for any loss caused by the delay, unless the loss falls within one of the excepted perils, and the carrier can show that he has not been negligent. This clause has implications for just in time operation as it could be argued that the cargo was not delivered with '*reasonable dispatch*'¹ if the ship slows down. This could particularly be the case if the cargo is lost when the ship was operating at slower speeds and it could be shown that if the ship proceeded to the discharge port at the normal speed the cargo would have arrived safely.

At common law, the carrier may limit or exclude its liability under the contract, which can mean that the buyer, who under common law has no right to dictate the terms of the contract, could end up with nothing when the loss was totally the fault of the carrier. For this reason international agreement was reached in the form of the [Hague Rules](#) as amended by the [Hague-Visby Rules](#). These rules preserve the four common law obligations in to contracts in a less strict form but protect the buyer / shipper by ensuring there is no possibility of contracting out or reducing the carriers' liability.

2.3.2 Hague-Visby Rules

The Hague–Visby Rules are a set of international rules for the international carriage of goods by sea. They are an updated version of the original Hague Rules, "International Convention for the Unification of Certain Rules of Law relating to Bills of Lading", which were drafted in Brussels in 1924 [Wikipedia 2015].

The premise of the Hague–Visby Rules is that, based on earlier English Common Law from which the Rules are drawn, a carrier typically has far greater bargaining power than the shipper, and that to protect the interests of the shipper, the law should impose some minimum obligations upon the carrier.

Under the Rules, the carrier's main duties are to "properly and carefully load, handle, stow, carry, keep, care for, and discharge the goods carried" and to "exercise due diligence to ... make the ship seaworthy" and to "... properly man, equip and supply the ship". It is implicit (from the common law) that the carrier must not deviate from the agreed route or from the usual route other than for saving life or property at sea. The carriers and shippers duties may be summarised as below:

- **Carrier's duty:** The carrier's duties are not "strict", but require only a reasonable standard of professionalism and care; and the Rules allow the carrier a wide range of situations exempting them from liability on a cargo claim. These exemptions include destruction or damage to the cargo caused by: fire, perils of the sea, Act of God, and act of war. A controversial provision exempts the carrier from liability for "neglect or default of the master ... in the navigation or in the management of the ship". This basically covers the carriers for navigation and negligence in ship navigation and management. There are other Rules that could be used to avoid this aspect.
- **Shipper's duties:** By contrast, the shipper has fewer obligations (mostly implicit), namely: (i) to pay freight; (ii) to pack the goods sufficiently for the journey; (iii) to describe the goods honestly and accurately; (iv) not to ship dangerous cargoes (unless agreed by both parties);

¹The term "reasonable dispatch" is a common law term defining the customary and ordinary obligations of a carrier to transport shipments. The term is found in most of standard bills of lading. The term generally means obligation to sail without unreasonable delay. The practical implication of not acting with "reasonable dispatch" comes from an assumption adhered to by the courts in marine insurance cases, that an unreasonable delay in performing the voyage insured is an equivalent to a "deviation", which makes the policy void.

and (v) to have the goods ready for shipment as agreed. None of these shippers' obligations are enforceable under the Rules; instead they would give rise to a normal action in contract.

The Rules, with only 11 Articles, have the virtue of brevity, but have several weaknesses in the rights and obligations of the carrier and shipper relationships depending on who is seeking more cover in the contract. Because of these, other Rules such as Hamburg Rules of 1978 and more modern Rotterdam Rules, with some 96 Articles, have far more scope for covering multi-modal and complex transport scenarios. However, these Rules remain far from general implementation.

2.4 Bill of Lading

A bill of lading is a document issued by or on behalf of the actual carrier of the goods to the person, normally the shipper, with whom the carrier has contracted to transport goods. Thus the bill of lading governs the relationship between the shipper and the carrier (who will be either a ship-owner or a demise charterer). It will provide details of a shipment of merchandise and gives "title" of that shipment to a specified party. A straight bill of lading is used when payment for goods has been made in advance of shipment and requires the carrier to deliver the merchandise to the appropriate specific party. An order bill of lading is used when the merchandise is shipped prior to payment by importer of the goods, requiring a carrier to deliver the merchandise to the importer, and at the endorsement of the exporter the carrier may transfer title to the importer. Endorsed order bills of lading can be traded as a security or serve as collateral against debt obligations.

Therefore:

- A bill of lading is a standard-form document.
- It is transferable by endorsement (or by lawful transfer of possession).
- It is a receipt from shipping company regarding the number of packages with a particular weight and markings and a contract for the transportation of same to a port of destination mentioned therein.

Thus a bill of lading is a key document used in the transport of goods. As a document of title, it is also an important financial instrument. The bill of lading therefore may perform 3 functions:

- 1 Evidence that the goods described in it has been received by the carrier (received for shipment bill), and if a shipped bill that the goods are on-board the ship.
- 2 Evidence of or the actual contract of carriage.
- 3 Document of title to the goods.

The bill of lading will normally be either a *'bearer'*, *'order'* or a *'straight consigned bill'*, which will dictate who the goods can be delivered to. The *'bearer bill'* is the most open type of bill that allows the cargo to be released to anyone who holds the bill. There are two types of *'order bills'* that basically allow delivery 'to order' to allow transferability without naming the consignee. The *'straight consigned bill'* or *'non-negotiable bill'* makes the goods only transferable to a named consignee and no other; so is very restrictive in this respect. The type of bill will have important implications for the shipper on what it can be used for; as it is only possible to raise cash from a bank on a shipped "bearer or order bill" as they are fully negotiable documents even when still documents of title.

The functions of the bill of lading for a particular contract will depend on several things. For example, how the goods are purchased. When the contract between the shipper and the buyer is a classic *'FOB'* (Free on Board), the buyer nominates the ship, procures the shipping space and is the legal shipper. In the case of goods purchased on a *'CIF'* (Cost, Insurance and Freight) basis, the seller will ship the goods at his own expense and arrange for the insurance. Other issues will be whether the "contract of carriage" is covered by just the bill of lading, a voyage or time charter and whether

the [Hague Rules](#) or [Hague-Visby Rules](#) or any other Rules will apply.

2.5 Charter Party

A “charter party” or “charter” is defined as a specific contract by which the owner of a ship lets the whole or principal part of his/her ship to another person for the carriage of goods on a particular voyage or many voyages until the expiration of a specified time. In short the charter party is the contract for mere hiring of a ship with additional conditions on how generally the ship will be used or operated. Thus a charter-party governs the relationship between the ship-owner and the charterer.

When a ship owner agrees to carry goods by and receives freight usually between specified ports with specifying a specific ship, the contract is called a “contract of affreightment” rather than a charter party; this is discussed later. While it is possible to have a charter party of less than the entire ship, as a general rule a charter party deals with the full reach of a ship while a contract of affreightment deals with carriage of goods forming only part of the cargo and coming under a bill of lading.

Charter parties are highly standardized and are grouped into three main types (1) voyage charter, (2) time charter and (3) demise or bare boat charter. Because of the highly specialized field of charter party law, most of the charter parties provide for arbitration. Because of arbitration clauses, deviations from a charter party do not normally come before a court too frequently and normally resolved at the arbitration phase.

Statements made as to the ship, her characteristics, speed, cargo capacity, classification, etc., or her position and situation/location are generally regarded as warranties and charterer is entitled to avoid the charter or sue for its breach if such warranties are broken by the owner or proved to be misleading. Thus, if the charter party states the ship is to proceed to the port of loading with “all possible dispatch” and all possible dispatch is not used by the ship, the warranty is breached and the charterer can avoid the contract.

Without a “deviation” clause, which also appears in the bill of lading in some form or other, the ship, if deviating, breaches the charter party. While the charter party may not mention “seaworthiness” of the chartered ship, the general maritime law reads into every charter party a warranty of seaworthiness as a basic requirement.

2.5.1 Voyage charter

A voyage charter is a contract of carriage for one voyage or a series of voyages. The ship remains under the control of the owner as to manning and navigation. Cargo carried during a voyage charter may also have a bill of lading so may also be covered by the [Hague-Visby Rules](#) but there is normally no mandatory application of these rules in a voyage charter unless the goods are transferred to a third person as explain in the section on bill of lading. The contract will normally have a ‘*due dispatch*’ clause that requires all reasonable speed or a stated date and a ‘*cancellation clause*’ that will allow the charterer to abandon the contract if the vessel has not arrived in a reasonable time; the ship-owner is then liable to damages.

Under a typical voyage charter-party the ship operator decides what speed of the vessel during the voyage so as to arrive at the port at the due date. There are also a number of days ‘*lay days*’ agreed in the contract for the loading and discharge of the cargo. For the commencement of lay-time three things are required;

- The vessel must be fit to load or unload.
- She must be an ‘*arrived ship*’.

- The '*notice of readiness*' (NOR) to load or discharge must be given to the charterer.

For a ship to be an '*arrived ship*' the master must tend his NOR; and where and how he can legally do this will depend on whether the contract states '*port*' or '*berth*'. Interpreting what '*berth*' means is quite clear but there have been several legal differences of opinion on what constitutes a '*port*'. Common law only requires the NOR to be tended by the master at the loading port but most voyage charter provide for NOR to be given at the discharge port.

If the ship arrives in good time to discharge or load the cargo and the port cannot provide cargo once the agreed '*lay days*' are used up, then the ship owner is also entitled to an economic compensation called '*demurrage*'. If the ship arrives ready to load the cargo and port is not able to load the ship due to port congestion the ship operator has the option to take on a new cargo if one is available or wait for the port congestion to clear and be compensated by the '*demurrage*'. The demurrage rate will depend on the particular contract but are often as high if not higher than the freight rate that the ship owner would have received.

Based on the above arrangement, the incentive is therefore for the ship operator to sail the ship as fast as it can so as to be sure the ship arrives in good time and become an "arrived ship" so that the lay days start to count. The frequent outcome of this process is that ships will steam at full speed to a port, wasting large amounts of fuel and producing extra GHG, to arrive at the port and be too early to start cargo operations. This often results in the ship sitting at anchor or alongside for possible weeks waiting for the cargo and wasting yet more fuel and producing more GHG.

2.5.2 Time charter

Here again similar to voyage charter, the ship is manned and navigated by the owner but her capacity is let to the charterer for a specified time. The time charter permits the charterer to have the ship under his control for a fixed period of time without undertaking the long term financial commitments of a ship owner or the responsibilities of ship management and navigation to finance or maintain various aspects of ship as an asset.

Time charters are set for a set period of time which may be in months or years. It is normal that the charterer pays for the fuel and port costs but the ship owner must take care of the other operating cost like maintaining the ships engine, hull, etc. and pay the crew and for insurance. Time charters will normally have a speed and fuel warranty clause stating the speed and fuel consumption of a ship. Despite its name, this term of the contract is usually an intermediate term and not a warranty. Thus the charterer can only repudiate the contract if the statement as to the fuel and speed is substantially incorrect.

The time charter is a good example of the '*split incentive*' problem mentioned earlier, as the ship owner will not pay for the fuel while will be responsible for operational and capital investments to save energy. As the benefit of saving fuel goes directly to charterer, there is no incentive for ship-owner to look at ways of reducing the fuel costs.

2.5.3 Demise charter

This is a charter party in which the charterer takes control of all aspects of a ship operation, puts his own stores, fuel oil and other provisions on board and hires the crew. It is sometimes known as a 'bare-boat' charter party. In such a charter-party, the master and the crew are like the charterers employees, and possession and control of the vessel rests with the charterer. The demise charterer is for all practical purposes the temporary owner of the ship. The test to distinguish a demise charter is "control". If the charterer has full control as if the ship is his own, the charter is a demise charter-party. Otherwise, it is a voyage or time charter or a combination of the two.

The “demise charter” arrangement is another good example of the ‘split incentive’ issue mentioned earlier where there is no incentive for the actual owner of the ship to invest in energy saving technology on the ship as he will not pay for the fuel cost or even in this case the maintenance of the ship as the charterer will have that responsibility. However, in such cases the charterer will have more control on ship, thus will have more incentive and control to achieve operational energy efficiency.

The most important legal distinction between the demise versus the time and voyage charters is that the demise charterer is regarded as the owner and as such qualifies as an owner for the benefit of the limitation of liability statutes whereas the time and voyage charterers do not.

2.5.4 Contracts of affreightment

In a contract of affreightment a ship-owner agrees to move a specified quantity of cargo over a specified period of time from one port to another without designating a particular ship. The ship owner pays for the voyage costs and the vessel. Contracts of affreightment are often set for a period of few or several years. As these contracts cover such long times, the contract will often have a clause that will allow an increase in the freight rates to cover increased fuel and other costs. Such contracts are often used in the bulk trade for cargos such as coal to supply a power station, of Bauxite to supply an aluminium manufacturer, for supply of grain, etc. The contracts of affreightment could include aspects of time or voyage charter party terms depending on type of arrangement between carrier and the shipper.

2.6 Shipping contracts and energy efficiency

A ship may arrive in a busy harbour, only to wait for days or weeks to unload. The ship operator will receive compensation from the charterer from a payment called ‘*demurrage*’ for each day of waiting which will be already agreed in the contract of carriage. On the other hand, if the ship owner does not arrive on time, it will face penalties under “due dispatch” clauses. This encourages the ship owners to be more conservative in adjusting speed for energy efficiency. Instead, he will go faster to reach the next port of call ahead of schedule. This is one example of the contractual arrangements and the incentives of the different parties of the contract that may practically have a significant influence on ship operations and hence on fuel in-efficiency of operation. This topic has been the subject of debate within maritime industry in the last several years and some amendments to standard contracts are proposed.

2.6.1 Slow steaming case examples

Slow steaming means operating the ship at lower speeds in order to reduce fuel consumption (see **Section 3** for details). Although slow steaming is very effective in reducing a ship’s fuel consumption, its practical implementation may be problematic within the current shipping legal/contractual framework, in particular for certain ship types and trades [Gard 2015].

Legal issues

In the absence of explicit statements to the contrary in prevailing contracts, under a voyage charter party or bill of lading contract, the owners of a vessel undertakes that the vessel will proceed to the loading or discharge port without unreasonable delay. Thus, the general rule is that the ship owner bears the risk of any delays unless covered by an exception clause.

If the carrier intentionally proceeds with unreasonable delay by slow steaming the vessel, he may be committing a “deviation”. Deviation is justified under common law only for saving life at sea and the Hague-Visby Rules extend this somewhat to allow deviations to save life or property at sea. In such cases, owners and operators would commit an unjustified deviation and risk losing the right to rely

on exclusions and exceptions as set out for example in the Hague-Visby Rules. As a result, ship owners and operators will lose the insurance cover for any liabilities that may arise as a result of the deviation.

In some cases a carrier may be able to rely on a deviation clause, if one is included in the charter party and/or bill of lading, although this may not provide any protection in certain jurisdictions. It is, therefore, important for a ship owner and a charterer to incorporate suitable clauses into the applicable contracts if slow steaming is planned, in order to try to avoid the consequences described above.

Under a time charter, the charterers may give the owners instructions to slow steam. The main legal issues related to slow steaming in this case relate to the ship owners' obligations to follow the charterers' slow steaming instructions, whilst at the same time ensuring the safety of the vessel, crew and cargo and also taking into account their obligations towards third parties, such as bill of lading holders. These aspects also need consideration for specific cases between owner/operator and charterer, where applicable.

BIMCO clauses

Due to the above legal issues, BIMCO has undertaken to develop relevant clauses for the charter party. After long discussions a time charter clause and a voyage charter clause for slow steaming were published by BIMCO as shown in **Appendix 1**. These are suitable for the liner, tanker and dry bulk trades. However, it is important to keep in mind that even where the owners and charterers have an identical interest in slow steaming, the bill of lading holders must be taken into account as well and the relevant contracts must be worded appropriately. The legal status of the BIMCO clause and its practical application within existing charter parties is not yet clear.

2.6.2 Virtual Arrival case example

Virtual Arrival is a method used to reduce the ship idle times at ports and use the extra time for reducing/adjusting ship speed en route in order to save fuel and reduce GHG emissions (see **Section 5** for details). By reducing speed to meet a mutually agreed arrival time, the vessel can avoid spending time at anchor awaiting a berth or port cargo space or cargo availability. It is a technique for ensuring a ship's just in time operation.

Similar to slow steaming, this would require adjustment to ship operation contracts such as charter party or bill of lading as this type of operation will be more prone to possibility of late arrival by the ship at port of call that may contractually interpreted as the unreasonable dispatch or deviation. Thus, for such just in time ship operation, contractual aspects need to be sorted one of the main barriers.

A virtual arrival clause in the charter party permits a charterer to request an owner to adjust the speed of a voyage chartered vessel to arrive at a loading or discharging port at an agreed date and time. In other words, the clause is designed to assist ship owners, charterers and ports to come to a rational agreement regarding sailing speed and arrival time to avoid port congestion. Like the slow steaming clauses, any reduction in the vessel's speed, with charterers' agreement, should not be considered a breach of owners' due dispatch obligations and should therefore not give rise to interpretation as an unjustified deviation.

BIMCO has also drafted a virtual arrival clause [e.g. see Gard 2015], but has not yet published it formally. Additionally, its practical application within existing charter parties is not yet clear.

2.7 References and further reading

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

- 1 “IMO train the trainer course material”, developed by WMU, 2013.
- 2 Gard 2015, “Slow steaming and virtual arrival”, <http://www.gard.no/ikbViewer/web/updates/content/20734104/slow-steaming-and-virtual-arrival>, cited November 2015.
- 3 Wikipedia 2015, “Hague–Visby Rules”, https://en.wikipedia.org/wiki/Hague%E2%80%93Visby_Rules, cited November 2015 2015.
- 4 Wikipedia 2015, “Affreightment”, <https://en.wikipedia.org/wiki/Affreightment>, cited November 2015.
- 5 IMO (2009); Buhaug, Ø., Corbett, J.J., Endresen, Ø., Eyring, V., Faber, J., Hanayama, S., Lee, D.S., Lee, D., Lindstad, H., Markowska, A.Z., Mjelde, A., Nelissen, D., Nilsen, J., Pålsson, C., Winebrake, J.J., Wu, W., Yoshida, K.. Second IMO GHG Study 2009. London, UK.

Appendix 1 – BIMCO Carter Parties Clauses for slow steaming

BIMCO Slow Steaming Clause for Time Charter Parties [Gard 2015]

(a) The Charterers may at their discretion provide, in writing to the Master, instructions to reduce speed or RPM (main engine Revolutions Per Minute) and/or instructions to adjust the Vessel's speed to meet a specified time of arrival at a particular destination.

(i) *Slow Steaming – Where the Charterers give instructions to the Master to adjust the speed or RPM, the Master shall, subject always to the Master's obligations in respect of the safety of the Vessel, crew and cargo and the protection of the marine environment, comply with such written instructions, provided that the engine(s) continue(s) to operate above the cut-out point of the Vessel's engine(s) auxiliary blower(s) and that such instructions will not result in the Vessel's engine(s) and/or equipment operating outside the manufacturers'/designers' recommendations as published from time to time.

(ii) *Ultra-Slow Steaming – Where the Charterers give instructions to the Master to adjust the speed or RPM, regardless of whether this results in the engine(s) operating above or below the cut-out point of the Vessel's engine(s) auxiliary blower(s), the Master shall, subject always to the Master's obligations in respect of the safety of the Vessel, crew and cargo and the protection of the marine environment, comply with such written instructions, provided that such instructions will not result in the Vessel's engine(s) and/or equipment operating outside the manufacturers'/designers' recommendations as published from time to time. If the manufacturers'/designers' recommendations issued subsequent to the date of this Charter Party require additional physical modifications to the engine or related equipment or require the purchase of additional spares or equipment, the Master shall not be obliged to comply with these instructions.

* Sub-clauses (a)(i) and (a)(ii) are alternatives; delete whichever is not applicable. In the absence of deletions, alternative (a)(i) shall apply.

(b) At all speeds the Owners shall exercise due diligence to ensure that the Vessel is operated in a manner which minimises fuel consumption, always taking into account and subject to the following:

(i) The Owners' warranties under this Charter Party relating to the Vessel's speed and consumption;

(ii) The Charterers' instructions as to the Vessel's speed and/or RPM and/or specified time of arrival at a particular destination;

(iii) The safety of the Vessel, crew and cargo and the protection of the marine environment; and

(iv) The Owners' obligations under any bills of lading, waybills or other documents evidencing contracts of carriage issued by them or on their behalf.

(c) For the purposes of Sub-clause (b), the Owners shall exercise due diligence to minimise fuel consumption:

(i) when planning voyages, adjusting the Vessel's trim and operating main engine(s) and auxiliary engine(s);

(ii) by making optimal use of the Vessel's navigation equipment and any additional aids provided by the Charterers, such as weather routing, voyage optimization and performance monitoring systems; and

(iii) by directing the Master to report any data that the Charterers may reasonably request to further improve the energy efficiency of the Vessel.

(d) The Owners and the Charterers shall share any findings and best practices that they may have identified on potential improvements to the Vessel's energy efficiency.

(e) **For the avoidance of doubt, where the Vessel proceeds at a reduced speed or with reduced RPM pursuant to Sub-clause (a), then provided that the Master has exercised due diligence to comply with such instructions, this shall constitute compliance with, and there shall be no breach of, any obligation requiring the Vessel to proceed with utmost and/or due despatch (or any other such similar/equivalent expression).

(f) **The Charterers shall ensure that the terms of the bills of lading, waybills or other documents evidencing contracts of carriage issued by or on behalf of the Owners provide that compliance by Owners with this Clause does not constitute a breach of the contract of carriage. The Charterers shall indemnify the Owners against all consequences and liabilities that may arise from bills of lading, waybills or other documents evidencing contracts of carriage being issued as presented to the extent that the terms of such bills of lading, waybills or other documents evidencing contracts of carriage impose or result in breach of the Owners' obligation to proceed with due despatch or are to be held to be a deviation or the imposition of more onerous liabilities upon the Owners than those assumed by the Owners pursuant to this Clause.

** Sub-clauses (e) and (f) not applicable in the liner trade.

BIMCO Slow Steaming Clause for Voyage Charter Parties [Gard 2015]

(a) The Owners shall be entitled to give instructions to the Master to reduce speed or RPM (main engine Revolutions Per Minute) provided that the Vessel's speed, basis good weather conditions, shall not fall below knots.

(b) Where the Vessel proceeds at a reduced speed pursuant to Sub-clause (a), this shall constitute compliance with, and there shall be no breach of, any obligation requiring the Vessel to proceed with utmost and/or due despatch (or any other such similar/equivalent expression).

(c) The Charterers shall ensure that the terms of the bills of lading, waybills or other documents evidencing contracts of carriage issued by or on behalf of the Owners provide that the exercise by Owners of their rights under this Clause does not constitute a breach of the contract of carriage. The Charterers shall indemnify the Owners against all consequences and liabilities that may arise from bills of lading, waybills or other documents evidencing contracts of carriage being issued as presented to the extent that the terms of such bills of lading, waybills or other documents evidencing contracts of carriage impose or result in the imposition of more onerous liabilities upon the Owners than those assumed by the Owners pursuant to this Clause.

(d) This Clause shall be without prejudice to any other express or implied rights under this Charter party entitling the Vessel to proceed at speeds below the minimum speed stated in Sub-clause (a).

3 Fleet optimisation and slow steaming

3.1 Introduction

Fleet optimisation for energy efficiency seeks to achieve the following two main objectives:

- Increase the ships' load capacity to as high as possible.
- Reduce the ships' operational speed to as low as possible.

Of course the above two main objectives may not be compatible with the commercial and business requirements, ship operation contracts as well as the way a ship is designed or operated. Also, occasionally it may conflict with best technical management of the ship or contractual framework under which the ship operates (for contractual aspects, see **Section 2**).

The topic of "ship load management", that addresses the first bullet above, is covered in Section 4. This section covers ship speed and its management for energy efficiency as one of the most important operational measure for reducing ship fuel consumption.

The main barriers to achieving the best use of ship speed for energy efficiency are as follows:

- Lack of clarity on optimum or economic speed of a vessel.
- Commercial environment that may dictate the use of vessels in a non-optimal way.
- Contractual frameworks that may not allow for implementing certain measures as they may constitute a breach of contract.
- Overall economics of ship operation when taking into account the commercial aspects that is important to cargo owner or charterer (such as timing of cargo delivery) that may overshadow the need for speed optimisation and adjustments for energy saving.
- Regulatory or safety requirements such as engine NOx compliance that dictates no major changes to engine settings beyond certain limits. This limits the actions needed for engine optimisation or engine adjustments for slow steaming.

In this section, various topics will be covered that not only explains the above subjects in detail but also aims to provide information on best ways of resolving these apparently conflicting requirements.

3.2 Ship speed and energy efficiency

Ship speed reduction can produce significant energy savings; this is agreed by all industry players as the most influential parameter on a ship's fuel consumption. To determine the optimum speed for a particular vessel and the optimum number of vessels in the fleet, it is required not only a good estimate of the cargo that need be transported but also the number of port calls and where they are located. The aim should be to maximise the reduction of fuel consumption and GHG over the whole fleet particularly if the ships are on set schedules that must be maintained. Also, it is often the case that it may not be possible to maintain an optimum or a low speed for the whole trip, as operational considerations may need to take priority to maintain a service.

3.2.1 Ship speed terms

Speed optimisation for fuel efficiency generally means to operate at a lowest ship speed that is technically feasible. This is referred to as "slow steaming" that will be covered in a subsequent section. Terminologies used for ship speed is often confusing, thus herein various definitions are provided first:

- **Design speed:** Technically speaking, a ship is designed for a specific operating speed (design

speed). Generally, during ship design and choice of machinery, the engine and ship hull form and main dimensions are optimised for this operating condition. Engine and hull-propeller efficiencies normally tend to reduce beyond this technically-optimal design speed. The term “design speed” has significance when relationship between ship-owner and ship-builder are considered. It is part of the contractual requirements between the two parties; and is normally assessed and confirmed during the initial speed trial (commissioning trial) of the ship.

- **Slow steaming:** This term refers to running a ship at a significantly lower speed than its design speed. Generally slow steaming refers to ship speeds that are achieved when the main engine’s load is less than 60% MCR. This is a type of agreed definition between the majority of industry experts. This means that smaller levels of speed reductions achieved under voyage and port management (as described in **Sections 5**) do not fall under the category of “slow steaming”. Despite the technically optimised hull-propeller-engine for a ship’s design speed, it can easily be demonstrated that as the ship speed reduces, the hull resistance reduces more significantly than its corresponding impacts on various propulsion efficiencies; thus reducing the ship’s fuel consumption per tonne-mile carried. This significant reduction in resistances makes the use of slow steaming such an attractive proposition for the reduction of a ship’s fuel consumption. From this perspective, generally the lower the ship speed, the lower will be the overall ship fuel consumption. The minimum speed under which a ship could operate is dictated by the engine’s capability to run at low loads. For engine’s integrity, it is not possible in all cases to reduce ship speed very significantly.
- **Ship economic speed:** This term is frequently used in shipping and in fact is normally part of the charter-party agreements. It generally means a speed at which the ship transport as a whole yields the best financial results under the given constraints of engine power, sea conditions, port and waterways dues, and other commercial/financial requirements of the charterer. In industry, generally the ship economic speed is perceived as the optimal ship speed for energy efficiency. This is not correct as explained above; under slow steaming, extreme speed reduction is always beneficial for fuel consumption reduction.
- **Service speed:** The origin of this term is to do with relationship between charterer and ship owner and refers to the average speed maintained by a ship under normal load and weather conditions. This is normally equivalent to ship design speed as described above; however, it may differ in cases where a ship’s design speed has been affected by its operation history.
- **Maximum speed:** This term defines the maximum speed of a ship that the ship-owner claims the ship practically can achieve. It is normally the speed of the vessel under full engine MCR. As such, ship maximum speed is higher than the ship design speed that is normally specified at 90% MCR (taking into account relevant sea margins). The origin of this term is from the relationship between charterer and ship owner and normally this term may appear in relevant contracts.

The above ship speeds would vary from one ship to the other and will be influenced by hull form, engine design, age of the vessel, commercial and legal requirements and so on. For example, with modern engines with electronically controlled fuel injection system, a wider range optimal operation, as a function of load, is possible thus giving more flexibility in terms of slow steaming as well as the choice of ship economic speed and so on. Thus, the engine fuel consumption characteristics and ships propellers curves should be considered when deciding on the level of optimum speed for a particular ship on a particular voyage.

In practice, the ship masters normally follow the speed orders given by the company or charterer; as this mostly has legally binding obligations. In such a case, the question of “what speed the ship should operate?” should be understood by all parties on-board so that there is no misunderstanding in the interpretation by the different speed terms and their practical implications.

3.2.2 Power and speed relationship

The relationship between a ship’s speed and power can be developed from basic ship hydrodynamics as detailed below. The total resistance of a ship in water consists of many types of resistances which can be divided into the following groups:

- Frictional (water) resistance: Due to water friction against the ship’s wetted surface areas.
- Air resistance: Due to air friction against ship hull that is out of water and ship’s superstructure.
- Wave making resistance: Due to formation of waves and energy used by ship in this process.
- Eddy-current resistance: This is the added resistance due to irregular flow of water around the ship in particular in the aft end.

Figure 3.1 shows a schematic of these resistances.

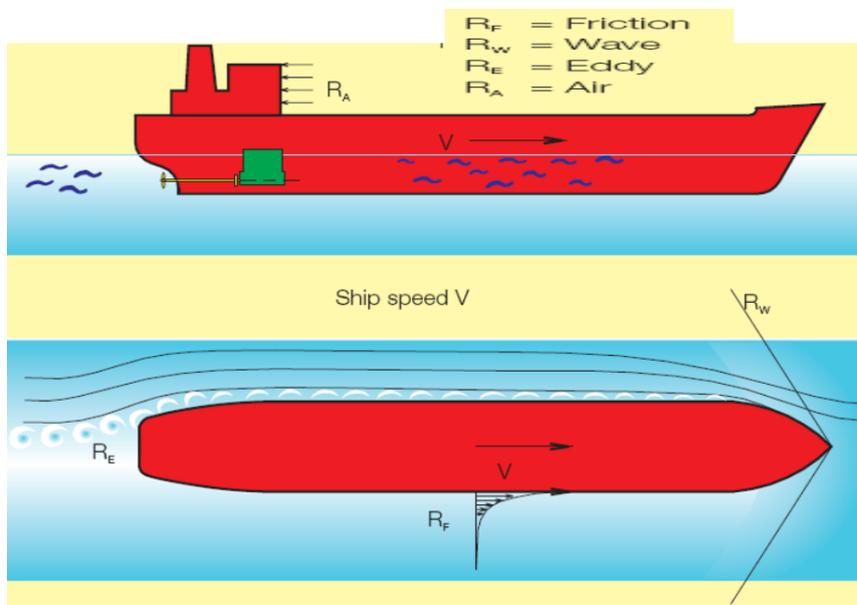


Figure 3.1 – Ship resistances [MAN Diesel & Turbo]

The above resistances (**R**) are generally proportional to ship speed squared (V_s^2) as shown in the following formulas, where **C** represents various resistance coefficient.

<p>Wave resistance $R_W : R_W = C_W \cdot \frac{\rho_s}{2} \cdot V_s^2 \cdot S_s(N)$;</p> <p>(Still) Air resistance $R_{AA} : R_{AA} = C_{AA} \cdot \frac{\rho_s}{2} \cdot V_s^2 \cdot S_s(N)$;</p> <p>Friction resistance $R_F : R_F = C_F \cdot \frac{\rho_s}{2} \cdot V_s^2 \cdot S_s(N)$; and</p> <p>Eddy-making resistance : $(C_r - C_R - C_{AA} - C_F) \cdot \frac{\rho_s}{2} \cdot V_s^2 \cdot S_s(N)$;</p>	<p>where :</p> <p>S_s = wetted surface area of the hull(m^2)</p> <p>V_s = ship speed (m/s), Note: 1 knot = 0.5144444 m/s</p> <p>ρ_s = mass density of seawater, $\rho_s = 1,025.0 \text{ kg/m}^3$</p>
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The above relationship between speed and power can be written in simpler forms as follows:

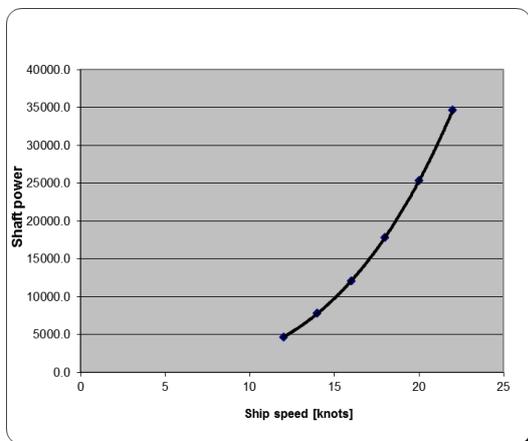
$$Resistance = c_1 * (ship\ speed)^2$$

$$Propulsion\ power = Resistance * (ship\ speed)$$

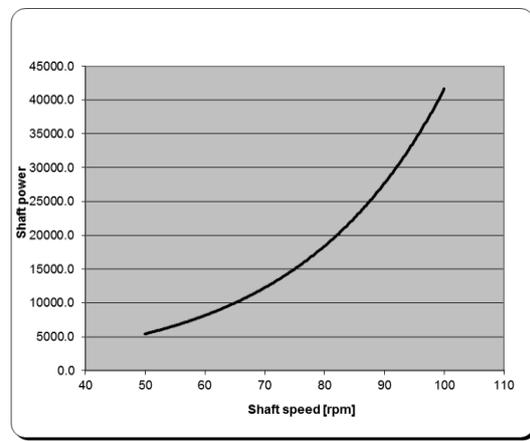
$$Propulsion\ power = c_1 * (ship\ speed)^3$$

c_1 is a proportionality factor that itself may somewhat change when ship speed changes.

Thus based on the above theory, a ship's required power increases with the cube of the ship's speed. In practice, the above relationships will be somewhat impacted by the ship hull form and speed of the vessel. Ship speed-power curve (see **Figure 3.1** as a typical one) is derived either during sea trials or by using the collected in-service data. At the same time, propeller's shaft power versus shaft speed can also be derived as shown in **Figure 3.1**.



(a) Shaft power versus ship speed



(b) Shaft power versus shaft speed

Figure 3.2 – Typical speed-power curves

In deriving the above speed-power curves during sea trials, the following ideal conditions are used:

- Clean hull
- Polished propellers
- Calm sea and minimal wind
- Design draught and zero trim

Correction factors are applied, where necessary, if the actual conditions experienced during the ship trials/testing are not as above. Under normal in-service operation, this curve may be derived by performing dedicated speed trials, or simply measuring under actual conditions over an extended period of time (extended period will minimise the impact of weather and sea conditions through averaging). The ship speed-power curve plays an important role in identifying hull fouling and ship performance. It is used as part of ship performance monitoring analysis system and monitored to identify deviations due to poor performance.

3.2.3 Ship fuel consumption versus speed

It is well known that a ship's fuel consumption generally increases with speed squared. Ship fuel consumption is a function of both propulsion and non-propulsion (auxiliary) power. In passage operation, the propulsion power is the dominant one and about 80% of commercial cargo ship's fuel consumption is due to the need for propulsion. From propulsion aspect, fuel consumption per unit of distance travelled is a function of square of ship speed as shown below:

$$\text{Propulsive power} \propto (\text{Ship speed})^3$$

$$\text{Fuel consumption} \propto (\text{Ship speed})^3$$

$$\text{Distance travelled} \propto \text{Ship speed}$$

$$\text{Fuel consumption per nautical mile} \propto (\text{Ship speed})^2$$

Based on the above formulas, an increase in ship speed by 20% will result in an increase in propulsion power by 73% and an increase in fuel consumption per nautical mile by 44%. In practice, the above proportionality factors do change with ship speed as mentioned before. This cube power-speed relationship could increase at higher speeds due to wave making resistance. For example, increasing the speed by 1 knot from 14 knots requires more power than increasing the speed by 1 knot from 10 knots. Conversely, when slow steaming is started for higher speeds, one can gain very large savings, for example from 14 to 13 knots, one saves more than the saving from 11 to 10 knots.

Also, the level of savings is impacted by ship size; normally larger ship sizes given better fuel consumption reduction with slow steaming. The importance of this effect is shown in **Figure 3.3**, which provides an estimate of daily fuel cost for a number of container ship sizes operating at different speeds.

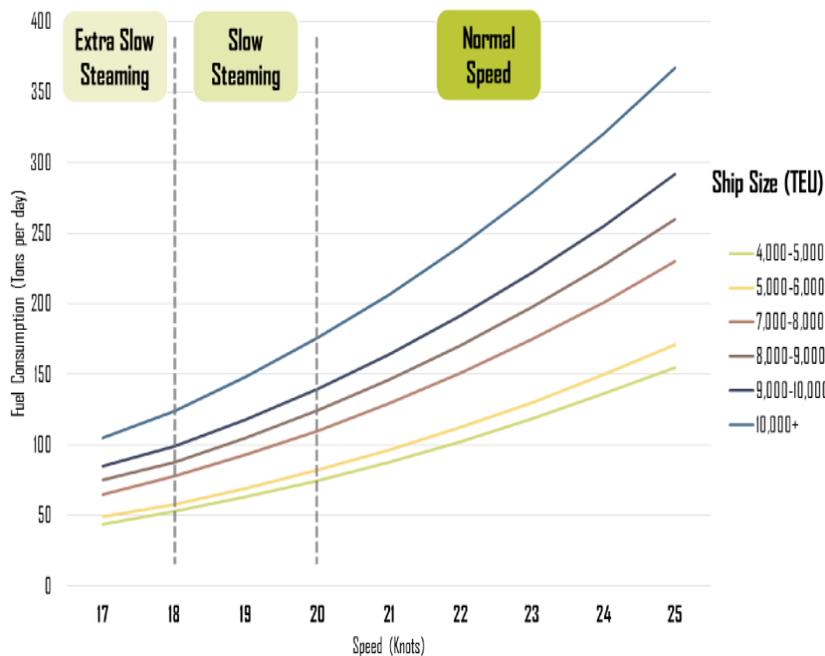


Figure 3.3 – Ship fuel consumption dependence on ship speed

[Geography of Transport System, adapted from Notteboom et al (2009)]

As **Figure 3.3** indicates, fuel consumption by a container ship is mostly a function of ship size and ship speed. While shipping lines would prefer consuming the least amount of fuel by adopting lower speeds, this advantage is counter-balanced with longer shipping times as well as assigning more ships to maintain the same port call frequency. For containerships, the main ship speed classes are²:

- **Normal** (20-25 knots): Represents the optimal operation speed as far as the engine design is concerned. It also reflects the optimal hydrodynamic efficiencies of the hull and propeller to perform within acceptable fuel consumption levels. Most container ships in the past 15 years are designed to travel at speeds around 24 knots.
- **Slow steaming** (18-20 knots): Running ship engines below capacity to save fuel consumption, but at the expense of an additional voyage time, particularly over long distances (compounding effect). This is likely to become the dominant operational speed of containerships as more than 50% of the global container shipping capacity was operating under such conditions as of 2011.
- **Extra slow steaming** (15-18 knots): Also known as super slow steaming. A substantial decline in speed for the purpose of achieving a minimal level of fuel consumption while still maintaining a commercial service. Can be applied on specific short distance routes.
- **Minimal cost** (12-15 knots): The lowest speed technically possible. The level of service is however commercially unacceptable, so it is unlikely that maritime shipping companies would adopt such speeds.

3.2.4 Port considerations

As a part of speed optimisation process, due account should be given to the need to co-ordinate arrival times with the availability of loading or discharge berths on a particular trade or route. This is covered in more detail later on. Also, operation in shallow waters under slower speeds as well as a gradual increase in speed when leaving a port or estuary whilst keeping the engine load within certain limits, all contributes to optimal operation of the vessel. The case for port aspects are further discussed in **Module 5**.

3.3 Slow Steaming

3.3.1 Overview

Based on the above analysis, it is evident that fuel consumption reduction can be gained when a vessel is slow steaming, despite the fact that, the engine's Specific Fuel Oil Consumption (SFOC) will increase when a ship is no longer operating at its design speed. As shown by formulas before, if the power consumption of individual ships is reduced by the third power, the net effect on fuel consumption reduction is a second-power reduction; hence, a reduction of speed by 10% roughly equates to a reduction in shaft power by 27% and an energy saving of 19% on a tonne-mile basis.

Generally slow steaming refers to ship speeds that are achieved with engine load of less than 60% MCR; however, **Figure 3.4** gives a more detailed definitions and terminologies appropriate for this purpose.

² Website: http://www.people.hofstra.edu/geotrans/eng/ch8en/conc8en/fuel_consumption_containerships.html

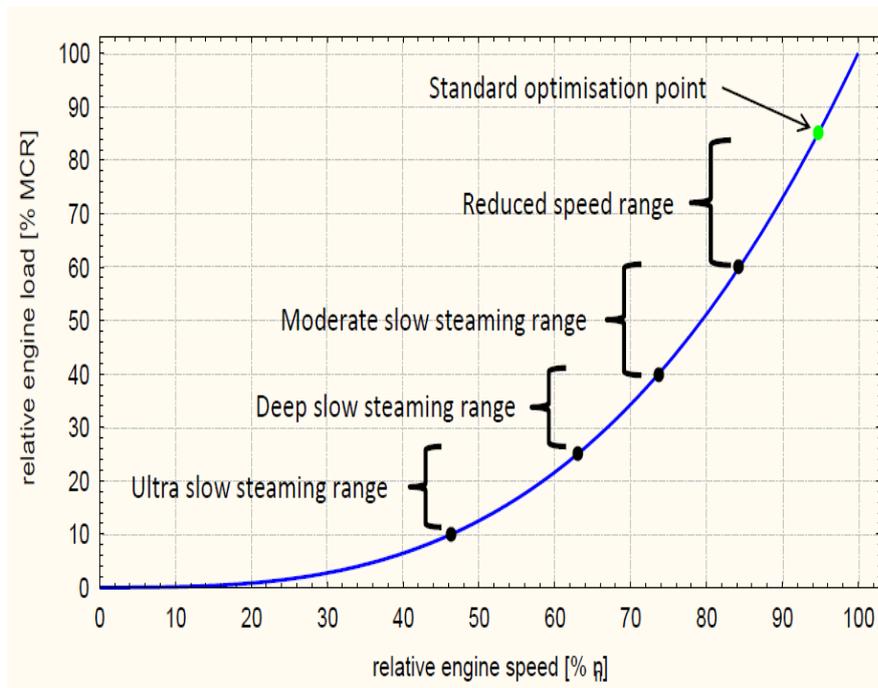


Figure 3.4 – Reduced speed range and slow steaming levels [Przemysław Kowalaks]

This means that smaller levels of speed reductions achieved under voyage (just in time) and port management (see **Sections 4 and 8**) do not fall under the category of “slow steaming”. Despite the technically-optimised hull-propeller-engine for ship’s design speed, it can easily be demonstrated that as the ship speed reduces, the hull resistance reduces more significantly than corresponding impacts on various efficiencies. This makes the use of slow steaming such an attractive proposition for the reduction of a ship’s fuel consumption. From this perspective, the lower the ship speed is the lower the overall ship fuel consumption per nautical mile cargo carried will be achieved.

The minimum speed under which a ship could operate is dictated by the engine capability to run at low loads; thus not possible in all cases to reduce speed very significantly. For some trades and shipping operations it may not be possible to implement a program of slow steaming because of these technical limitations. As discussed earlier in the section on contracts of carriage or the charter party, these contracts must be examined closely to ensure that slow steaming will not violate the contract and leave the ship-owner open to litigation. This will particularly be the case if the vessel is on a time or voyage charter party but may also apply if the contract of carriage is determined by the bill of lading.

Reductions in scheduled speed (i.e. accepting longer voyage times) will increase fuel efficiency and reduce its costs, but result in more ships being needed to maintain a particular service. The number of ships on a particular trade will therefore need to be taken into account when deciding on a fleet wide slow steaming policy. For example, slow steaming on a liner container run may require the use of another ship to maintain the service and this may not be economically viable particularly if there are only 2 or 3 ships presently on the run. Reductions in scheduled speed can be expensive, since they directly affect the amount of freight carried and hence the income of a ship. However, there is a

trade-off between freight rates and fuel cost, as when freight rates are low and fuel prices are high it may be more profitable to reduce speed and save fuel costs and live with a lower freight rate.

There are two main drivers for slow steaming:

- High fuel costs
- Over capacity of container ship capacity

The above two may not prevail over long term and thus the question is that what degree of slow steaming will be exercised over the long term? Slow steaming is more applicable to faster ships such as container ships, ferries and so on. It is normally used by those owners who pay for their own fuel. A combination of high fuel prices, ship overcapacity and low charter rates gives significant economic justification for slow steaming. In addition, emerging marine GHG emissions regulatory regime is expected to encourage slow steaming.

The 2007-8 high fuel prices and subsequent economic downturn have persuaded the marine community to look at the economics of fast ships in particular container ships. Although slow steaming has been advocated for fast ships, all types of ships can benefit from this operation policy. In the following, some aspects of slow steaming are discussed.

3.3.2 Slow steaming case study - Container ship example

A major container liner company introduced slow steaming as part of a cost saving response to a down turn in business in 2008 - 2009 which resulted in surplus capacity. This strategy was so successful that around half the world's fleets of container ships later on operated on slow steaming.

The shipping company concerned has managed to get savings of fuel and reduction of CO₂ on average of 14% per vessel and 10% per service. It was found that a ship that reduces its average speed from 20.5 Knots to 19 knots can expect to release 16% less CO₂ and when speed is reduced by 20%, fuel consumption is reduced by approximately 40% per mile. To compensate for lower average speed an extra vessel (13 instead of 12) needed to be added to ensure the same frequency of service. This has still resulted in an overall reduction of fuel consumption from 12,000 MT to 10,000 MT which means a 16% savings on fuel costs as well as reducing pollutants and CO₂.

The flexibility offered by slow steaming can improve the fleet's reliability as the lower average speeds give the ships the flexibility to speed up when needed to make deadlines when other ships in the fleet are experiencing delays. This shipping company also achieved an overall reduction in supply chain CO₂ with a cut of emissions per container by 12.5% from 2007 to 2009 with a further reduction of approximately 7% over the next 2 year per moved container.

3.3.3 Slow steaming economics

Figure 3.3 shows an estimated fuel saving level due to slow steaming as a function of ship speed and ship size. Assuming a fixed bunker fuel price, it is evident that ship fuel cost will follow the same reduction trend as ship fuel consumption.

However when it comes to deciding on best speed for slow steaming, it is the overall ship costs that need to be balanced against the fuel cost. Clarkson Research Services have generated **Figure 3.4** for a VLCC taking into account ship costs versus fuel cost when slow steaming.

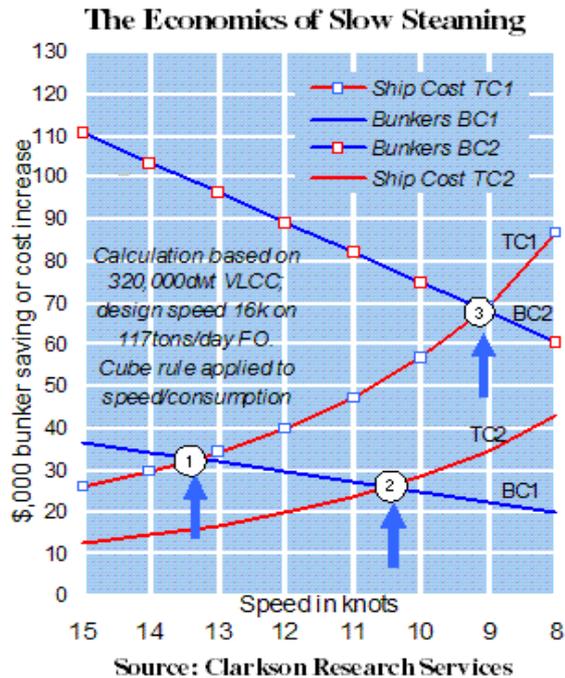


Figure 3.4 – Optimal slow steaming speed for alternative fuel prices and charter rates³
 [Shipping Intelligence Network 2015]

Figure 3.4 shows that:

- Slow steaming is highly effective in reducing a ship’s fuel cost when the fuel prices are high (compare BC2 to BC1 trends).
- At higher fuel prices, more aggressive slow steaming is beneficial (compare points 1 and 3).
- For low charter rates, and at a fixed fuel price, more aggressive slow steaming is beneficial (compare points 1 and 2).
- When fuel prices are high and charter rates are low, more aggressive slow steaming will be beneficial.

Deciding how fast to operate a ship is complex, but the basic issue is balancing the fuel saving from slow steaming against the extra charter cost of a longer voyage (this is a VLCC case; for other ships, the cost of capital could be taken into account). For example, if slow steaming saves \$37,000 in bunkers but the voyage takes a day longer and the ship charter rate is only \$20,000/day it makes sense to slow down, because the bunker saving exceeds the increased ship cost. This simple analysis suggests that low freight rates alone are not enough to trigger slow steaming – the fuel cost comes into the equation too. But the combination of rising fuel costs and falling freight rates is bound to encourage ships to go slower and slower.

3.3.4 Advantages and disadvantages

Slow steaming provides the owners/managers with the opportunity to create a balance between commercial commitments and environmental responsibilities in particular at the time of low charter rates and high oil prices. Slow steaming is one of the most effective ways of reducing ship fuel

³ Terms on the Figure: TC= Time Charter; BC: Bunker Cost

consumption. Slow steaming could provide various degrees of benefits and disadvantages as included in the following lists.

Slow steaming benefits

Generally, those who benefit from slow steaming are:

- Charterer
 - Lower fuel consumption per voyage
 - Lower bunkering frequency per voyage
- Technical operator
 - Lower average engine load
 - Lower yearly cylinder oil consumption
- Ship's crew
 - Lower bunkering frequency
 - Lower average engine load
 - Longer time between ports
- Environment
 - Lower NOx per voyage
 - Lower CO2 per voyage
 - Lower SOx per voyage

Slow steaming disadvantages

- Charterer
 - Longer voyage time and consequently higher charter fees per voyage
 - Higher auxiliaries fuel consumption per voyage
 - More tendency for a ship's hull fouling with subsequent fuel consumption penalties
 - Engaging of additional ship in the line service to deliver the same amount of cargo (unless the existing fleet is are not fully loaded; i.e. over-capacity).
- Technical operator
 - Higher auxiliaries working hours per voyage
 - Ship's hull fouling and the need for more cleaning; this will have impact on durability of hull coatings.
 - Higher maintenance and cost of spares due to engine operation at low loads. Engine operation at low load normally leads to more maintenance.
- Ship's crew
 - More frequent inspections, closely linked to engine low load operation
 - More frequent servicing, closely linked to engine low load operation
 - Higher auxiliaries working hours.

- Environment with more tendency (due to part or low load engine operation) for
 - Higher CO impact
 - Higher PM concentration
 - Higher sludge

3.3.5 Ship-owner considerations

As mentioned earlier, slow steaming leads to main engine's operation at low or very low loads. The engine is not designed or optimised for such low load continuous operation and thus it could be detrimental to engine health over the long term.

Therefore, for those owners contemplating to use slow steaming, it is recommended that the following to be considered as part of their evaluation:

- Main engine limits and the minimum load that is operationally safe for engine to work continuously.
- Economiser performance and reliability under engine's part load conditions. Normally under partial load, the economiser may not be able to generate enough steam and also its fouling will accelerate.
- Turbocharger operation, performance and maintenance. This is also closely linked to lack of energy in the exhaust during part load operation. At extreme slow steaming, there may be a need to operate the electrically driven air blowers to provide enough air and scavenging for main engine.
- Propeller performance.
- Hull paint type and fouling rate. As discussed before, the hull fouling will accelerate under slow steaming, in particular in warmer waters, and this will increase ship's fuel consumption. Frequent cleaning may also damage the hull coating.
- Ship charter rate.
- Fuel price.
- Over-capacity aspects.

It will be necessary to analyse the above before committing to extreme slow steaming. It is important to know why the above investigations are needed and how they should be carried out.

Difficulties with slow speed steaming and the main engine

It is to be borne in mind that prolonged running of mechanically controlled engines below its optimum conditions (60 to 90% loads) would require engine adjustments for not only maintenance aspects but also for improved engine efficiency. Under low load operation, if appropriate cleaning and maintenance is not carried out it can lead to a build-up of soot deposits in the exhaust gas economiser; increasing the risk of an exhaust uptake fire. In severe cases this may lead to the meltdown of the economiser or in a worst-case to situation of an uncontrolled engine room fire.

Slow steaming can lead to increased engine vibration, carbon deposits in combustion chambers and exhaust ports. Low load engine operation means a reduced exhaust gas waste heat to drive the turbocharger resulting in reduced or lack of scavenge pressure. If proper care is not taken, the excess cylinder oil can collect in scavenge box and exhaust trucking spaces with the possibility of fire or explosion. The possibility of increased wear on the stern tube bearing should also be considered

as the reduced speed can lead to the loss of the dynamic oil wedge that is required for proper lubrication. This issue is a particular problem for large slow speed engines.

Based on the above, use of slow steaming in certain market situations may be inevitable. Thus, it is the ship's technical manager who should ensure that the main engine and auxiliary units do not suffer as a consequence of employing a particular slow steaming strategy. The technical manager should liaise closely with the ship's engine manufactures to establish the correct procedures and the engine speed parameters that should be applied to take advantage of slow steaming potentials without detrimentally impacting or damaging the main engine. It should be borne in mind that this strategy may require an alternative or additional engine maintenance programs or changes to turbochargers and fuel injection settings.

3.4 References and further reading

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

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4. Marine Insight, 2012, "The Guide to Slow Steaming on Ships" <http://www.marineinsight.com/wp-content/uploads/2013/01/The-guide-to-slow-steaming-on-ships.pdf> accessed August 2015.
5. Michael Maloni, Jomon Aliyas Paul and David M Gligor, "Slow steaming impacts on ocean carriers and shippers", Maritime Economics & Logistics Vol. 15, 2013.
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7. Notteboom, T. and P. Carriou (2009) "Fuel surcharge practices of container shipping lines: Is it about cost recovery or revenue making?". Proceedings of the 2009 International Association of Maritime Economists (IAME) Conference, June, Copenhagen, Denmark
8. Geography of Transport System, "Fuel Consumption by Containership Size and Speed", http://www.people.hofstra.edu/geotrans/eng/ch8en/conc8en/fuel_consumption_containerships.html accessed August 2015.
9. MAN Diesel & Turbo, "Basic Principles of Ship Propulsion", Publication 5510-0004-01ppr, Oct 2010.

4 Ship Loading and Cargo Management

4.1 Introduction

The objective of this section is to become familiar with issues relating to ship loading, use of ballast water, use of loading or unloading equipment and their impacts on ship energy efficiency. The ship loading management is regulated for safety purposes but it has implications for ship energy efficiency as will be discussed.

4.2 Load Lines

4.2.1 Origins of the Load-Line Convention

It was Samuel Plimsol who first came up with the concept of a load line mark hence the load line mark is often called the Plimsol line. Plimsol's work on the load line was inspired by several major accidents at sea. In 1867, Plimsol as a member of UK parliament endeavored in vain to pass a bill dealing with the subject of a safe load line on ships. Cargo ships setting sail in the 1860s were very likely to be unseaworthy, both badly maintained and overloaded. If these badly maintained and badly loaded ships sank, their over-insured owners usually cashed in at Lloyd's insurance market. Plimsoll rallied for regular enforced inspections and, in 1870, proposed an idea to parliament put forward by ship-owner James Hall. The idea was a level of maximum ship submergence based on the tonnage of the ship that would give a minimum freeboard to which the ship could load. This idea was finally implemented worldwide by the International Load Line Convention.

4.2.2 The Plimsol line

The Plimsol Line or International Load Line is placed mid-way between the forward and after perpendiculars of the ship and give the draft of the ship that is the legal limit to which a ship may be loaded for specific water density and temperature so that the ship will have sufficient reserve buoyancy to safely deal with any unforeseeable sea conditions. Temperature can influence the draft of a ship because warm water provides less buoyancy as it is less dense than cold water but this factor is not really taken into account in cargo calculations except by the use of Load Line Zones of areas that have been defined in the International Load Line Convention.

The factor that is taken into account before every ships sail and must be entered in the ships official log book so that it can be inspected by the ship's Administration is the density of the water. Salt water has a density of 1025 kg/m^3 and fresh water 1000. As a ship will displace its own weight in water it is clear that the ships draft will be deeper in fresh water which is often the case in ports and reduce as it goes to sea. As the water density in different port around the world can vary widely between 1025 and 1000, the ship must take the density of the water before cargo work is completed. When the density is known a simple calculation is done using the ships stability book to find the Dock Water Allowance. This allowance can then be applied to the Plimsol line and will allow the ship to load to greater draft so that when it reaches salt water the ship will be fully loaded.

4.2.3 The International Load Line Convention

The requirements for an international load line certificate is quite interesting as it is really the starting point for all international safety certificates on commercial vessels as it applies to all vessels of over 24m length that go to sea. It is perhaps one of the main reasons that there is quite a few 23.9 meter small commercial vessels around. The requirement to have MARPOL certificates comes in at

400 GT and most of SOLAS at 500 GT unless they are passenger ships. This means that these regulations have a significant impact on quite small vessels with regard to construction and safety and some of these provisions will in turn have an impact on the amount of GHG emissions that the vessel produces.

The International Load Line regulations require that every ship is surveyed and issued with a Load-Line certificate every 5 years. The ship must also have an intermediate survey every 30 months with a 3 month window either way. The ship must also have an annual inspection and both the inspections and the intermediate survey must be stamped on the certificate. If the ship does not have its certificate up-to-date then it can be detained by the flag State or port State inspectors. The survey mainly consists of checking the vessel to ensure that the watertight integrity of the structure as a whole has been maintained. This will include watertight and weather tight doors, hatches, vents, air pipes and any other opening to outside that the sea water could get in. The survey will also check that the ship's draft marks and load lines are still in place and visible.

4.2.4 1966 Load Lines Convention

Cargo capacity is normally decided on most ships by its load-lines which are placed on each side of a ship to show the ship's maximum true mean draught that must not be exceeded. This is normally taken as the summer load line in salt water when a ship is operating in the summer zone but can vary for timber ships and ships operating in other zones. The locations of these different zones are contained in the 'Load Lines Regulations' in the form of a small map but can also be found in any good seamanship textbook. The measured load-lines on a ship is based on the freeboard and watertight integrity requirements contained in the IMO's "*International Convention on Load Lines convention 1966 as amended*", and is defined as the measurement from the uppermost continuous watertight deck to the ship's waterline at its mid-point.

To decide on any of the watertight integrity of a particular ship, the regulations contain 7 basic corrections or allowances that are applied to the initial freeboard to get the assigned freeboard. There are two types of ship which are 'type A' mainly bulk liquid ships with small hatch openings which are allowed a reduced freeboard and 'type B' with covers all other ships.

4.2.5 Multiple Load-Lines

A ship may have multiple load lines assigned that will result in the ship having assigned freeboards that are greater than the minimum. This will result in the ship carrying less cargo when using this freeboard. This increase in the maximum freeboard will have the effect of reducing the maximum allowable true mean draught and the measured gross tonnage. The question is now of course why would a ship want to have a reduced maximum true mean draft and a reduced measured gross tonnage and the answers are in the 1969 Tonnage Convention.

4.2.6 The 1969 Tonnage Convention

The IMO 1969 International Tonnage Convention is used to measure the gross tonnage of ships. The measured tonnage of a particular ship is a cubic measurement. It is different from a measurement of the deadweight, which is the maximum cargo in tonnes that the ship can carry when at her summer load-line in sea water. The gross tonnage is normally used to calculate, amongst other things, the amount of port dues that a ship has to pay. The cost of port dues can be very significant over the lifetime of the ship so any ship manager will look to reducing them where possible.

The cost of port dues is the main reason that it can be advantageous to have several assigned

freeboard. The reduction of gross tonnage of the ship by claiming the larger freeboard can result in lower port dues. If a ship is operating on a trade where there is a draught restriction in the port, lack of transport demand or where the cargo has a high volumetric value and the ship does not need to go down to its maximum assigned freeboard operating on the increased freeboard, then with a reduced gross tonnage can reduce port dues and other taxes that use gross tonnage to charge the ship.

4.3 Ship capacity utilization

4.5.1 Cargo load factor

Generally, a ship using more of its capacity during transportation will be more energy efficient when measured in terms of fuel used per tonne of cargo transported. Thus ship capacity utilization becomes an important element of overall ship/fleet energy management.

Ships may operate without utilizing their full cargo loading capacity. This may be for a number of reasons from the poor design of the ship to lack of transport demand but the ship manager should look at all options to increase the ship load factor⁴ if there is spare cargo capacity. If the load factor of the ships in a fleet is increased, then the gross emissions of these ships will also increase (assuming everything else remains as before). However, it is very simple to show that energy efficiency of the ship in terms of gFuel/tonne.mile or gCO₂/tonne.mile will reduce.

Savings can also be obtained by using fewer ships for the same operation that would outweigh any increase due to the increased cargo carried on an individual ship. To remove unused cargo carrying capacity, there must be the right ships in the right place at the right time. This means that it may not be possible to fill the space cargo capacity all the time even with a large fleet. If the cargo carrying capacity can be increased for certain voyages, this would have the effect of improving the overall efficiency of the ship as calculated for example by the EEOI. To achieve a better ship load factor, the whole issue of fleet planning and working relationship with shippers, ports and charterers will play a role. It is not necessarily a simple thing to do but it is quite rewarding in terms of energy efficiency.

4.5.2 'Stowage Factor' for bulk cargo

If a cargo is light for its volume, then the holds may be full but the ship may not be down to its load line marks. The ratio of the volumetric area to the weight of a cargo is called the "stowage factor" and is a very important factor when loading bulk cargos. If the ship's master and chief officer get their calculations wrong and either the ship is not full or they have to leave cargo that they have ordered behind, it may become an expensive operation for the ship-owner. In such cases, the ship-owner may be required to pay compensation to either the charterer or port operator. This also means that the ship will run less efficiently due to lower load factor and produce more GHG emissions. These calculations are the most important in the case of grain cargos where if the wrong amount of cargo is ordered and the ship is not completely full and trimmed as required by the stability book the cargo can shift, resulting in the ship listing and compromising the ship safety.

4.4 Energy efficient technologies and ship capacity

If new equipment is installed to improve ship energy efficiency of a ship and reduce GHG emissions,

⁴ Ship load factor is defined as the actual deadweight carried by the maximum design deadweight.

then the first questions need to be clarified are:

- Will this additional equipment alter the ship gross tonnage?
- Will this additional equipment alter the ship's lightweight?

The tonnage regulations do give some allowances for the parts of the ship that do not carry cargo. However, if a ship is designed with GHG reducing equipment (or in fact any other equipment in general) that increases the gross tonnage, there will be a financial penalty over the whole of the life time of the ship as port dues are often calculated on the gross tonnage of the ship. This situation could be resolved by amending the 1969 Convention at the IMO so that allowances can be made for installation of equipment that reduce GHG but this has proved to be very difficult to do even for safety reasons. The ship-owner or manager must take these considerations into account when deciding if it is viable to install any new equipment to reduce GHG emissions on a new or existing ship if it is to be modified leading to an increase in the measured gross tonnage.

On the lightweight side and its increases due to installed new equipment including energy efficiency technologies, it is important to note that based on Load Line Convention, this increase in lightweight will equally reduce the summer load line deadweight, thus will reduce the ship capacity. This will work against energy efficiency especially for ships that normally are operated at their maximum capacity commercially. Despite the above two cautions, it is worth noting that the great majority of energy efficiency technologies will not alter gross tonnage or maximum deadweight of a ship in any significant way. However, the issue of installation of new equipment on board, if they are heavy or add to gross tonnage, need to be taken cautiously for energy efficiency and port dues purposes.

4.5 Loading aspects, trim and ballasting

4.5.1 Overview

Ship such as bulk carriers that carry deadweight cargos such as grain do not have much scope for changing trim without shutting out cargo and reducing the load factor as the holds are often full. So it is very important in the design stage of the vessel that this is taken into account with regard to the placement of the engines, fuel tanks and fresh water tanks as well as the shape of the hull. Where the holds are not full the master and chief officer should consider carefully where the best place is to keep fuel oil and fresh water so that the need for ballast water to maintain the correct trim is minimized.

Container ships and general cargo ships will generally have a good deal of scope for improving stability and changing trim using ballast tanks as they normally have more smaller tanks rather than fewer large ones as in ships that carry bulk cargo. Ships on liner runs with several ports where they may load or discharge cargo or do both in the same port will need to carefully consider the best way to maintain stability and trim as well as maintain a high load factor as their draft may change several times in a voyage. It is also very important to make sure that the propeller and rudder are adequately submerged during the voyage for ship steering and safety purposes, particularly on ballast voyages as well as reducing fuel costs and GHG emissions. The temptation to pump out the ballast before a ship arrives alongside; particularly on a long river passage or before the ship reaches port as there is pressure from the port to start loading on arrival, should be carefully considered.

In addition to wasting fuel as the propeller may be out of the water, if the wind force increases, the ship can start to roll violently putting the safety of the crew at risk and make it extremely difficult to berth unless tugs are available; thus delaying the vessel and also wasting fuel and increasing GHG. It should also be taken into account that over the life of a ship, the light ship

displacement will increase due to a buildup of paint and bio growth on the hull and mud in the ballast tanks, thus leading to a reduced the cargo load capacity. Although not much can be done about the buildup of paint on the accommodation, regular dry-docking to have the hull blasted and the removal of mud and sand from the ballast tanks will help to reduce the problem.

4.5.2 Trim adjustment and loading

The distribution of cargo onboard and the amount of ballast needed to maintain adequate stability, particularly with ships that carry a large amount of deck cargo is critical. Also information on the ship's optimum trim and optimum amount of ballast onboard for a particular voyage is needed. Ships are designed to carry a certain amount of cargo at a certain speed for a certain fuel consumption that generally results in a particular trim for the vessel when fully loaded and in ballast.

Trim has a significant influence on the resistance of the ship through water and of the effectiveness of the rudder and propeller (for full details, see **Module 4**). The trim of the ship is important both to carry the maximum amount of cargo safely and maximize the fuel efficiency of the ship. Optimized trim can give significant fuel savings and for any draft there is a trim condition which will give minimum resistance and increase the efficiency of the engine. There are two main factors that affect the trim of the ship; one is the shape of the underwater form of hull/water plane area at particular draft and the other is the distribution of weights such as ballast water, cargo and fuel in the vessel. The center of floatation of the hull is not normally at the center of the vessel and changes with a change in draft. This also has a major impact on how the vessel trims and handles in a seaway.

The optimum trim for a particular ship at a particular draft will be computed at the design stage and the ship builder should make reference to the ship design data provided. For bulk ships this normally relatively simple as the ship is normally either fully loaded or in ballast. For ships on liner runs that may visit many ports and often have different drafts the situation is more complex and careful consideration must be taken when developing both the cargo and passage plan to ensure optimum trim is maintained. In some ships it may be possible to access and apply optimum trim condition for fuel efficiency throughout the voyage.

Trim can be adjusted and improved by arranging bunkers, by positioning cargo or by varying the amount of ballast water but taking extra ballast more than needed can lead to an increased displacement and therefore increased fuel consumption. However, it may not be possible to achieve optimum trim at all times because of;

- Draft restrictions in a port
- Stability requirements
- Fully loaded condition
- Locations of fuel and ballast tanks as designed restricting their use for trim optimisation
- Carriage of deck cargo and cargo safety

Once a ship is fully loaded to her load-line marks, it is not possible to put in any more ballast to change the trim. This may be a particular problem with ships carrying deck cargo such as timber deck cargo that are required to leave a port with a minimum trim. If they load fully to their load line marks, they will not be able to load any ballast to achieve optimum trim until they have used sufficient fuel or fresh water. The trim optimization for fuel efficiency is further discussed in **Module 4**.

4.5.3 Cargo load factor and ballast

The ship may need to take on ballast either when loaded to take out a list and change the trim, or in ballast to submerge the propeller and rudder. The position and weight of all cargo should be included in the cargo and lashing plan before the ship sails from any port to ensure that adequate stability is maintained.

Some other environmental restriction to ballasting or de-ballasting that will apply will be contained in the ship's ballast water management plan. The need to keep the ship seaworthy in the open sea, protected waters and when berthing; must always be considered when both loading and ballasting a ship takes place.

The use of ballast water will involve attention to the following considerations:

- Once a ship is down to its load-line marks no more ballast can be pumped on board.
- Ballast water management plan may contain some restrictions.
- Stability requirements particularly with regard to free surface effect and list.
- Requirement to keep a safe and efficient trim
- Minimum stability requirements under the load line rules
- Steering conditions
- Propulsion submersion to prevent cavitation and reduction of thrust.
- Cargo planning
- Ship too stiff or too tender
- Damage to ship due the panting, pounding and racking.

When a ship is on a ballast voyage, there is generally no problem with pumping and transferring ballast as long as the ship remains upright with no list and the correct trim is maintained. This is because ships in ballast tend to be very stiff anyway and any free-surface effect will have no or very little impact on the ships minimum stability requirements. The case is different for ships that are carrying ballast such as timber carriers or in some cases container ships. The main reason that these ships need to carry ballast is to ensure that they comply with the minimum stability requirements and any reduction of stability by pumping ballast from low down with the additional problem of free surface effect before the tank is empty could result in the ship having negative stability and listing to an angle of roll.

4.5.4 Case for container ships

It is very important to be fully aware of the cargo to be loaded and discharged so that the route, cargo and ballast plan can be defined and calculated accurately before the ship sails. In the transport of containers by sea, there is currently a problem with the accurate declaration of the weight of the container before it arrives at the port from an inland location. This is a problem that is difficult to address as the packing of the container is not under the control of the ship.

Container packing

A container will normally be packed in a warehouse some miles from the port and transported to the dock by a truck. As the packing of the container is relatively low paid work, often the persons packing the container will have little knowledge of the importance of lashing the cargo properly and declaring the weight accurately. This leads to the situation where the container is often packed

poorly with little regard to the true weight of the cargo being packed. The container is then moved to the docks by either truck or rail. When the container arrives at the dock with its manifest of cargo containing the declaration of weights that were declared to the freight forwarder by the person wanting the cargo shipped, there is not normally a check of the weight of the container before it is removed from the truck or rail carriage. This has led to a situation where the declared weights on the cargo declaration are often incorrect.

Accurate weight of the container

The weight of the container will often be measured by the equipment used to load the container on to the ship but by then it is too late as the particular slot will already have been assigned and the stevedores loading the ship may have little or no interest in the weight of the container unless it exceeds the safe working loads of the equipment used to load it. Once on the ship and loaded and secured, it is impossible to weight or in most cases even open the container to check that the weight inside it are as declared.

In some occasions, the first the ship may know that there is a problem is when the cargo is discharged and it is found that it is too heavy to be lifted by the ships crane or shore facilities. This has led to a situation where it is difficult for the ships master to rely on the weights declared. This means that the loading plan and the final cargo plan provided to the ship, which will have the declared weights, are often inaccurate. This can lead to major problems particularly if the container is carrying dangerous goods that have not been declared correctly in a poorly packed container with incorrectly declared weights.

The other issue is that if the cargo weight is not declared correctly, loading heavy containers on top of light container outside the requirements contained in the ships, cargo-securing manual can lead to a failure of the structure of the containers on deck and the parting of the container lashings. Such poor loading could and has led to containers collapsing on-deck in heavy weather.

Reefer containers using water-cooling systems for condenser

Reefer containers can be stored on deck or inside the cargo holds and a large amount of heat from their condensers is removed from the inside of the container through the evaporative cooling system. When reefer containers are stored on deck in the open air, heat from the condensers can be discharged into the atmosphere, allowing air cooled condensers to be used. Heat given out by the condensers from the reefer containers operating inside the cargo hold should be vented outside, otherwise heat will build up inside the cargo hold and the refrigeration machinery will not function efficiently.

The ship's cargo hold ventilation system should be designed to allow the required number of air changes to maintain the temperature inside the hold within the pre-set limits. Water cooled reefer plants have a much lower energy consumption so can lead to substantial reduction in the production of GHGs emissions than current systems. When water-cooled condensers are used, the cargo hold is equipped with a water circulating system. Pipelines running along the sides of the cargo hold can be connected to the individual reefer containers through a pair of flexible pipes, one each for the inlet and the outlet. Although reefer containers are usually equipped by default with air-cooled condensers, some are designed to run as water-cooled units.

To improve the heat transfer across the condenser coil, all reefer units have a condenser fan. When fitted with an optional water cooled condenser and running as a water cooled unit, a pressure switch turns off the condenser fan once the water pressure is high enough, and turns it on again if the pressure drops. Care should be taken that reefer containers are not positioned with their machinery

facing each other; otherwise the hot air discharged from the condensers will simply be cycled back through, adversely affecting each condenser's performance. In addition, enough space should always be left around condensers to allow air to flow freely to and from them, ensuring optimum performance. The ship's power supply is usually designed to handle the power needed by the maximum number of reefer containers the ship can carry. Each reefer container is estimated to consume about 5KW of power and a 4,600 TEU Panamax container ship will typically have capacity for 700 reefer plugs. With a full load, 18 tonnes of HFO per day will be consumed in powering these reefer containers.

All the above including how best to cool down the reefer refrigeration system, how to optimally ventilate the cargo holds and how to minimize electrical use by reefer containers could be the subject of improve energy efficiency that relate to cargo operation and cargo carriage.

Pre calculation of cargo for stability and trim

The importance of knowing accurately the weight of each container is that if the ship's officers do not know exactly the weight and physical location of each cargo transport unit or container they cannot accurately calculate the draft, trim and stability of the vessel. This means that it is not possible to pre-set the optimum trim or optimum ballast so that the ship has adequate stability at the start of the voyage. The ships master must therefore rely on the ship loading computers and ships final drafts to ensure that stability is maintained throughout the intended voyage, taking into account the consumption of fuel oil and any international load-line requirements. The master will then ballast the ship to get the optimum trim for the actual draft. This situation does not normally apply to general cargo ships with block stowage as such weights are normally accurately declared.

4.6 Cargo equipment upgrade for energy efficiency

The ship operator should consider all ships in the fleet when considering the upgrade of the ships' cargo handling and stowage equipment to reduce GHG emissions but the methods that can be used will depend on the type of ship, where it is operating and the cargo it intends to carry. The loading, discharging and cargo care equipment that may be considered would include the following:

- Ventilation(all ships)
- Mooring (all ships)
- Cargo and hold lighting (all ships)
- Reduction of CFCs (reefer)
- Heating coils (tankers)
- Cooling system (reefer)
- Cooling system (container)
- Cargo temperature optimisation (tanker)
- Cargo vapour control procedures (crude carriers)
- Ballasting/de-ballasting (all ships)
- Water cooled reefer plant with lower energy consumption
- Insulation of heating pipes (tankers)
- Optimisation of reefer container stowage
- Use VOCs to power engine or process and send ashore (Norway shuttle tankers).

It may be possible in some situations to upgrade the cargo equipment either fitted to the ship or used ashore to improve the energy efficiency of the operation. This will require the development and installation of more advanced equipment which will be expensive, however, this cost may well

be offset by a more speedy as well as efficient loading or discharge functions as well as a reduction in use of energy by the cargo-related equipment.

Both the owner and the ports concerned should consider such options. The port mainly dictates the cargo handling equipment available for loading and discharge of the ship. The ship-manager and the cargo handling facility in the port should look at the ship shore interface and formulate and decide ways of optimizing the facilities to match the ship with the port. Small changes in the way the operation is carried out can reap benefits in terms of ship fuel consumption. It may be possible in some situations to upgrade the cargo equipment either fitted to the ship or used ashore to improve the energy efficiency of the operation.

4.7 Economies of scale

Ship overall efficiency is a function of ship size. The larger the ship, it will have a lower fuel consumption per unit cargo transported and lower CO₂ generated (see **Figure 4.1**).

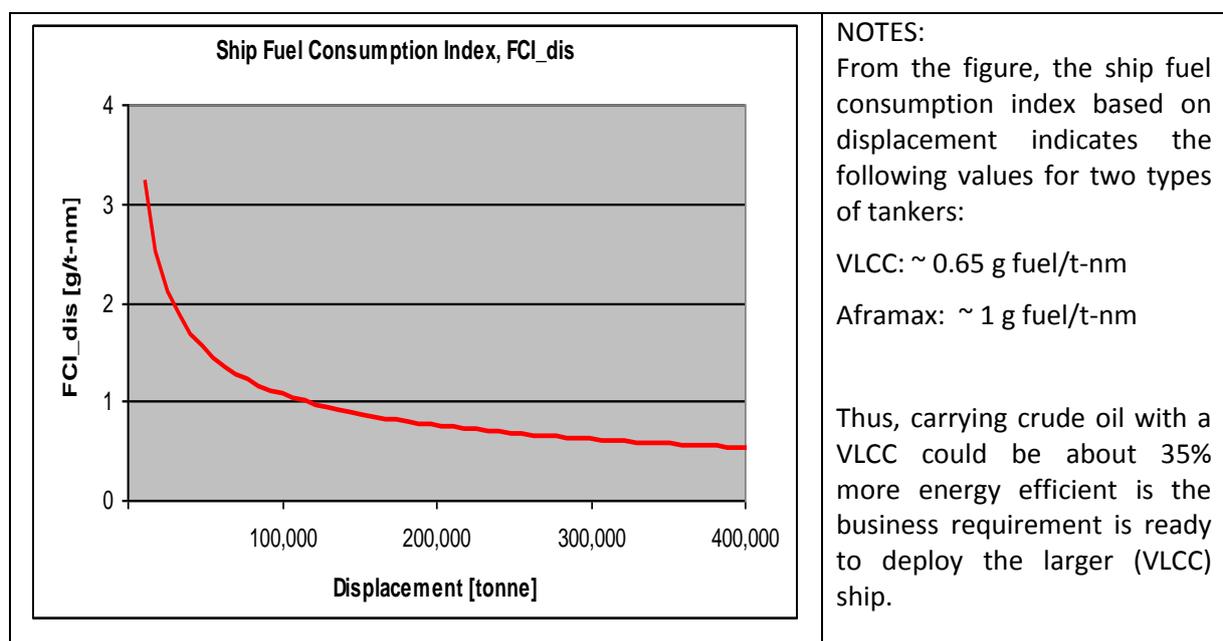


Figure 4.1 - Ship energy efficiency as a function of ship size [Bazari 2006]

Operationally, energy efficiency can be increased by concentrating the transportation of cargo on larger ships that can reduce the energy consumption of the shipping industry as a whole. However, few practical considerations should be taken into account. These large ships will be limited to a few deep-water hub ports; this means that the cargo will still need to be trans-shipped to its final destination. This can result in the overall door-to-door logistical performance of the movement of the cargo being reduced unless smaller ships that can take the cargo to smaller ports to support these large vessels could perform their part efficiently. These smaller feeder ships will be less efficient anyway than the large ships and there will also be some extra GHG emissions penalties in the additional discharging and loading operation for trans-shipment.

So, the use of economies of scale is effective but clearly a balancing act as it may in-fact turn out that on a particular trade it is more GHG efficient to use medium size ships that can take the cargo straight to the final destination. It goes without saying that larger ships are not efficient if not enough cargo is available and sail partly loaded (i.e. with low load/capacity factor) due to lack of transport demand. This means that overall energy efficiency may also be improved for smaller ships

with access to more ports and cargo types and able to fill cargo holds to full capacity.

4.8 References and further reading

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

- 1 “IMO train the trainer course material”, developed by WMU, 2013
- 2 Martin Stopford, “Maritime Economics” (Routledge).
- 3 Alan E Branch, “Economics of shipping practice and management”, Chapman and Hall.
- 4 C B Barrass & D R Derrett Ship “Stability for masters and mates”.
- 5 Bazari 2006, “Ship energy performance benchmarking /rating: methodology and application” Presented at: World Maritime Technology Conference (WMTC), ICMES 2006, 6-10 March 2006, London.

5 Just in Time (JIT) and Virtual Arrival (VA)

5.1 Definitions

Just In Time (JIT): Just in Time (JIT) concept and practices originate from the manufacturing industry where it is used to improve business performance via reducing the inventory levels and associated costs. This concept then moved to other industries and today normally refers to process improvements for the reduction of the unnecessary and idle periods of capital assets. In the case of shipping, JIT normally refers to process improvements that reduce the unnecessary waiting and idle periods of ship operations.

Itinerary optimisation: A ship itinerary optimisation refers to deciding on the best ship operation schedule/profile for a certain purpose via adjustments to voyage durations; thus voyage average speeds. Itinerary optimisation for energy efficiency normally means the choice of ship schedules that would yield an overall lower ship average speed and fuel consumption. Itinerary optimisation for energy saving may conflict with the commercial aspects of shipping as dictated by the market dynamics and the wishes of shipping clients (cargo owners or passengers).

Voyage management: Voyage management refers to all ship management activities that lead to the optimal planning and execution of a voyage. To ensure best-practice voyage management, all aspects of planning, execution, monitoring and review of a voyage are included in this concept.

5.2 Current practices

It is well known that ship speed reduction leads to fuel economy (see **Section 3**). Speed can be reduced during the voyage, if the amount of time in passage can be increased or the ship itinerary could be optimised. Thus improved itinerary and optimal voyage management are regarded as two major areas that could be used for this purpose.

A ship's movement commercially is influenced by many factors, some of which are listed below:

- The requirements of the “cargo owner” (mainly shipper or charterer) on when and where the cargo should be loaded and discharged. This is normally mentioned as the most likely reason for changes to the ship operation plan, schedules and time tables.
- The slotting issue in ports in terms of berth or cargo storage availability. Early arrival and competing for early loading/discharge is common industry practice.
- Regulatory issues that may lead to delays, prevention of entry to certain ports or ship detention for some period of time. The lost time normally recovered later via over-speeding.
- Technical failures that require fixing while in port or at anchor (reduces ship availability).
- Lack of business (cargo), resulting in short or long idle periods.

Itinerary optimisation, proper voyage planning and voyage execution are areas of interlink between shore managers and ship's masters. As such, the link between the shore managers (charterer and ship operator) and the ship's master is critical for optimal ship operation management.

In practice, the simplest models of working relationship are normally established between the above parties. For example, the shore-based managers specify the ports of call and timings. In some cases, they change their orders and ship itinerary while the ship is underway. The master then decides how to move and at what speed in order to meet the above timings. Normally, the master tries to reach the port of destination as soon as possible within the contractual limits.

The above processes generally lead to the following anomalies:

- Ship voyage speed is normally maximised with an early arrival at the next port.
- Total ship stay in ports and waiting in anchor is normally maximised.

This practice is not energy efficient. To make it efficient, the shore-based manager and the vessel's master should be given the responsibility to do the opposite; maximise the sailing periods and minimise the waiting periods. Unfortunately, itinerary optimisation and voyage management could easily be sacrificed by either poor planning or poor execution due to commercial and other non-technical pressures.

The improvement to ship itineraries requires efforts to be made by all the parties involved. For this purpose, the collaboration and coordination of the following bodies are essential:

- Charterer operation department: The charterer is ultimately responsible for decision making on the ship itinerary and overall steaming speed. Orders issued by the charterer to the ship are normally the basis for master's decision on ship movement.
- Ship master: The master, based on the orders received, operates the ship and ensures that the designated dates and times are achieved; within the terms of the charter party. The master can play a major role in improving the ship itinerary via more interaction with the charterers/owners decision makers.
- Port authorities: The Port authorities influence the plans drawn up by both the commercial department and master through the management/planning of the port operation.

It is the interaction between the above parties that leads to the actual (achieved) ship itinerary. Better communications, coordination and awareness of the impact of their decisions on ship fuel consumption could improve operations.

5.3 Just in Time (JIT)

Contrary to the current practices as described above, Just-In-Time (JIT) operation represents the optimal ship's operation management from the perspectives mentioned. The JIT operation differs from slow steaming as the aim of JIT is not to go for drastic slow steaming but use all the measures possible within the voyage constraints (e.g. weather, charter party contracts, etc.) to reduce the voyage speed and thereby save fuel.

The main purpose of the JIT operation is to ensure that the ship's operations are performed according to a "planned and optimised itinerary" with minimal time deviations. This means that vessels should never leave ports late or arrive in port of destination earlier than the planned itinerary. This will lead to the overall efficiency of the ship and port operations and to significant ship energy efficiency. The JIT operation benefit arises from the ship's less waiting times and more passage time; thereby scope for speed reduction and thereby fuel efficiency.

5.3.1 Best Practice

To approach the JIT operation, there is a set of good practices that ships and ship managers could follow. It is proposed that the following sets of guidelines should be observed for this purpose:

- Avoid waiting periods in all phases of a voyage or modes of operation (loading, discharging, bunkering, early arrival, late departure, etc.).
- Aim for early communications with the next port in order to give maximum notice of berth availability and facilitate the use of optimum speed.

- Encourage good communications between fleet department, master and charterer in support of JIT operation.
- Improve cargo handling operation and avoid delays at berth to the extent possible. Cargo handling in most cases is under the control of the port and optimum solutions matched to ship and port requirements should be explored.
- Operate at constant shaft RPM while en-route and avoid sprint-loiter phases.
- When leaving ports or estuaries, increase the shaft rpm gradually in harmony with increases in ship speed.
- Avoid going fast in shallow waters. Reduce speed in shallow water if possible.
- Measure, monitor and report the “ship duty cycle” in terms of time duration in various phases of operation, including period of times in passage, port, waiting, bunkering, etc.
- Perform benchmarking of the “ship duty cycle” against the fleet and similar ships; this will help with continuous improvement.

5.3.2 Barriers to JIT

The JIT operation is hampered by a significant number of major constraints. The following gives the list of constraints put on the master as far as the execution of the voyage is concerned:

- **Contract of carriage (e.g. charter party) constraints:** These include clauses on various aspects of ship operation that practically restrict some aspects of voyage management for energy efficiency. Charter party contracts, for example, normally put most of the power for ship speed management in the hands of the charterers. Financial impacts of deviation from charter party can be significant; thus ship managers would do everything possible to avoid for example late arrival.
- **Weather constraints:** The weather along the route has impacts on the voyage management and vessel itinerary. To limit this impact, weather information and weather routing can be used.
- **Route constraint:** The route of the vessel may involve channel crossings, passing through pirate areas and the need for operations such as bunkering.
- **Port constraints:** Various ports impose various constraints on vessels. One major aspect is the competition between ships to arrive at port of destination in order to beat the queue. The system that dominates now is that most ships try to arrive early to the port in order to give their notice of readiness and stay in the berth queue.
- **Other ship/owner/charterer specific constraints:** These are specific constraints that may apply to various parties involved in ship operations including for example unexpected failures, delay in bunkering, etc.

All the above basically work against the JIT operation. They need to be avoided via improvement to the ship operation, charter party terms and conditions, staff culture, use of modern information technologies (e.g. see **Section 6** on e-navigation) and systems such as weather routing and voyage monitoring systems.

5.4 Virtual Arrival (VA)

5.4.1 Introduction

One major initiative for the removal of some of the Just-In-Time barriers that were explained in the previous section, is the adoption of the “Virtual Arrival (VA)” concept that has been introduced in recent years, mainly in the tanker segment. VA aims to reduce waiting times and achieve longer

passage times and thereby reducing the ship's voyage average speed. A significant level of energy saving is expected with virtual arrival [Intertanko and OCIMF 2010]. It is worth mentioning that port-related air emissions are also reduced significantly via this initiative.

The justification for VA is that it is not efficient for a vessel to steam at full speed to a port where known delays to cargo handling / transfer have already been identified. By mutually agreeing to reduce speed to make an agreed arrival time, the vessel can avoid spending time at anchor, awaiting a berth, tank spaces or cargo availability. Emissions can thus be reduced, congestion avoided and the safety improved in port areas.

For VA to succeed, there is a need to establish an "agreement or contract" between the parties involved in ship operations (e.g. ship operator, ship owner, charterer, port, etc.). The contract aims to remove the barriers that are currently in place by existing charter party contracts and also facilitates the sharing of any financial benefits that result from VA implementation. As part of the agreement, all the parties will commit to reduce a vessel's speed during the voyage in order to meet a revised arrival time when there is a known delay at the destination port, cargo delivery date, etc. The reduction in speed will result in reduced fuel consumption, thereby reducing GHG and other exhaust emissions.

The VA agreement, by virtue of reducing emissions and costs, is of mutual benefit to vessel owners and charterers. Furthermore, by minimising vessel waiting times, a reduction in emissions and improved safety within the port areas are also realised.

5.4.2 Virtual Arrival process

Figure 5.1 shows the steps that are involved when VA processes are agreed [Intertanko and OCIMF 2010]. The implementation of these steps is essential to the success of VA objectives.

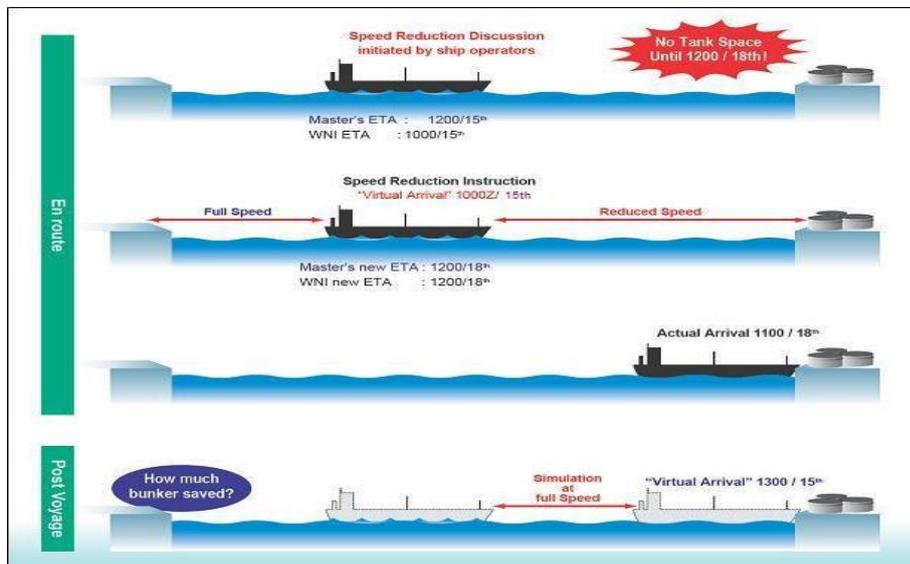


Figure 5.1 - Virtual Arrival processes [INTERTANKO and OCIMF 2010]

Accordingly, the processes may be described as below:

- **Identification of a change in itinerary:** The main part of the process is to identify a delay at the next port of destination, for example, due to congestion at the berth or lack of receiving cargo spaces.

- **Agreement to new itinerary:** The next step is for parties involved including the vessel owner/operator and the charterer and possibly port to agree on the change of itinerary. In particular the port, charterer and owner/operator agree to a new “Required Time of Arrival” at the destination port.
- **Speed adjustment:** As a result of the newly agreed Required Time of Arrival (or itinerary), the ship’s speed or the engine RPM is reduced.

VA is intended to be a dynamic and flexible process and, thus if conditions change during a voyage, the orders can be revised to enable the ship to achieve, for example, a new arrival time. Therefore, the above processes are best supported by ship scheduling software systems accessible to all parties to VA agreement in order to facilitate better control and monitoring.

The following summarizes the steps that are typically involved when implementing the Virtual Arrival process [Intertanko and OCIMF 2010]:

1. Before a vessel’s departure from the load port, or while en route to the destination port, a delay is identified at the destination port, for example, due to congestion at the berth or lack of receiving space.
2. In view of the known delay, the vessel owner/operator and the vessel charterer may agree to consider entering into a Virtual Arrival agreement for the voyage.
3. The ship owner/operator is requested to provide ship performance information to enable an initial assessment of the voyage to be made based on the service speed of the ship.
4. The charterer and owner/operator agree a Required Time of Arrival⁵ at the destination port and agree on the methodology for calculating voyage data and the associated reporting requirements, or alternatively agree on a WASP⁶ to be used for calculating voyage data and to provide supporting reports.
5. An agreement to undertake Virtual Arrival is implemented using an agreed charter party clause.
6. The initial report should include:
 - a. The methodology to be used to determine speed and consumption calculation
 - b. The calculated Estimated Time of Arrival (ETA⁷), based on normal service speed
 - c. The calculated ETA, based on normal service speed and anticipated weather, the “Virtual Arrival” ETA
 - d. The Required Time of Arrival (RTA)
 - e. The speed or RPM to achieve RTA
 - f. The bunkers on board at the Virtual Arrival decision point
7. The vessel reduces speed in order to make the RTA.
8. On completion of the voyage, if agreed, a WASP or an entity that specializes in weather and or vessel performance analysis produces a final report providing the post-voyage analysis and data to support confirmation of the vessel’s Virtual Arrival time and the calculations of the fuel saved and emission reductions.
9. In finalizing the Virtual Arrival time⁸, an assessment is to be made of the impact of the weather, sea and current conditions on the voyage by comparing the actual weather encountered with that anticipated when establishing the provisional Virtual Arrival ETA.

⁵ A mutually-agreed time for a vessel to arrive at a named destination

⁶ Weather Analysis Service Provider

⁷ The date and time a vessel is expected to arrive at a named destination based on a stated speed.

10. The agreed time of Virtual Arrival, the “Deemed Arrival” time⁹, is used as the time when considering demurrage exposure.

Based on the above process and for VA to work, significant level of activities is required and uncertainties in various estimation processes exist. This makes use of VA a difficult process in practice; however, industry should make all it could to resolve relevant barriers to VA.

5.4.3 Virtual Arrival agreement

To facilitate the implementation of the VA, there is a need for contractual arrangements either as part of the current charter party agreement or a new agreement. This new arrangement is referred to as “VA agreement”. As part of the VA agreement, the charterer and owner/operator will be able to change the “Required Time of Arrival” at the destination port (or new ship itinerary) and also agree on the methodology for calculating voyage data and the associated reporting requirements. For estimation purposes, the parties to a VA agreement may choose service providers such as the weather routing service providers to support the implementation.

At the end of the voyage, or based on the terms of the VA agreement, the voyage estimates are made and the financial and contractual arrangement is settled. To reduce post-voyage disputes, it is important that there is a clear understanding of, and agreement to, the method of calculation of the vessel's voyage performance, the speed and other data to be used, the reports to be issued and the timing of these reports.

Therefore, the charter party agreement (see **Section 2**) will need amending to allow for the additional VA agreement. It should be noted that VA aims to create win-win scenarios for all parties that have influence/impact on the ship itinerary and operation via creating not only workable methodologies but also shared financial incentives.

5.4.4 Other benefits of Virtual Arrival

The adoption of VA has benefits beyond those associated with fuel savings. Its effective implementation requires good cooperation and a dialogue between the vessel owner/operator and the charterer; this serving to remove many of the commercial obstacles in reducing emissions that have hampered some past initiatives. Such obstacles have been associated, for example, with third party and contractual implications; the fact that the party paying for the fuel may not be the technical operator of the ship and the lack of flexibility for speed adjustment.

The improved cooperation between vessel owners/operators and charterers also has benefits associated with overall voyage planning. For example, parties can agree that some of the available time may be used for planned maintenance activities, statutory surveys, crew changes or vessel storing.

The improved planning of in-port activities that is possible through the early identification of an agreed arrival time may also assist in reducing crew fatigue. Operations can be planned well in advance and uncertainties associated with waiting time and periods at anchor are reduced.

Just in Time operation heavily depends on improved port operations. When it comes to port operations, among others, the berth operation is closely related to the schedules of ship's arrivals

⁸ An estimation of a vessel's time of arrival at a named destination at normal service speed, taking into account the anticipated weather

⁹ An Arrival Time that takes into account the actual weather experienced on a passage. The “Deemed Arrival Time” may be used as the time laytime starts when considering demurrage exposures.

and the next major concern is the turnaround time of ships in port. The best operation will include the provision of on-arrival berthing services to shipping lines; thus minimizing ship's waiting times. As discussed earlier the JIT operation will help port with reduced air pollutants from ships, thus improved local air quality. Further aspects of port operation are given in **Section 8**.

5.5 Potential for energy saving

For a review of the current ship operational profiles and their analysis, refer to Reference [Charlotte Banks et. al.] that presents a research in this area. According to work done by these researchers, the percentage of time spent in port and sailing in either ballast or laden each year are calculated for a number of ship types and ship sizes and documented. An overview of the findings is given here.

Figure 5.2 shows the “time loaded”, “time in ballast” and “time in port” for a number of ship types. It demonstrates that in the case of bulk carriers, they spend the least amount of time in port (similar to that of the case for container ships). They also have a comparatively high loaded utilization levels compared to the case of Handysize tanker ships which only spend around 40% of the year under loaded conditions.

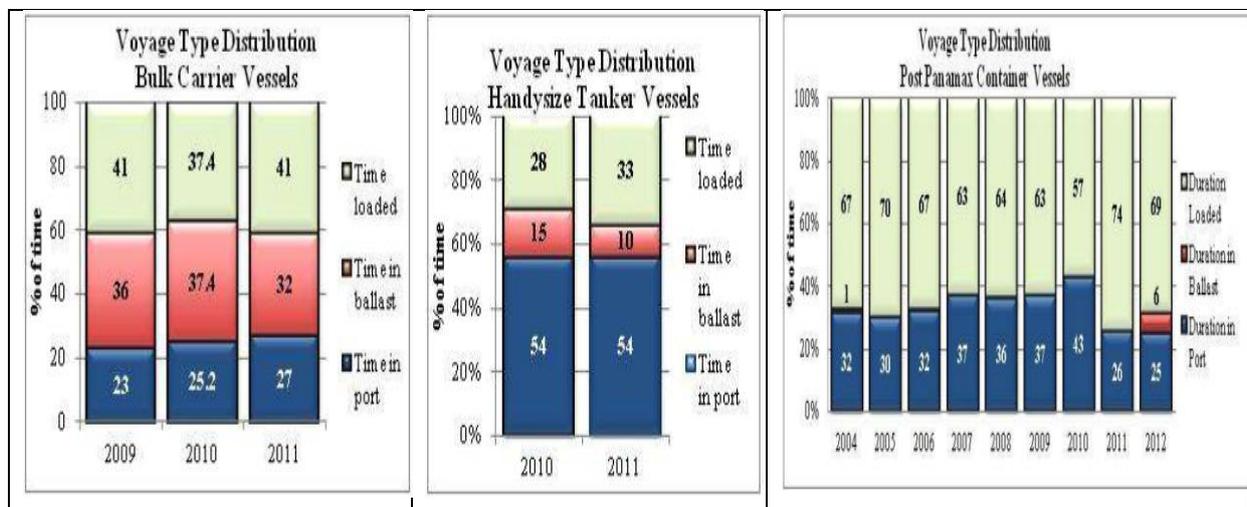


Figure 5.2 - Voyage profiles for typical bulk carriers, tankers and containerships [Charlotte Banks et. al.]

The same reference shows that the larger tankers spend less time in port: the average is 54% for Handysize, 42% for Aframax and 32% for Suezmax over the years. The proportion of time spent loaded also increases for the Suezmax case vessels with an average of 33.8% over the years, compared to 30.5% for Handysize and 30.6%, for Aframax tankers. The Handysize tankers demonstrate reduced time in ballast (average of 12.5%) compared to Aframax (average 26.7%) and Suezmax (average of 33%) case tankers. These trends are expected with the type of operation for each ship. For example, Handysize tankers tend to offer services for transporting refined products; generally on shorter and more coastal routes.

It can be shown that normally a Handysize tanker makes more voyages in one year resulting in more port stops and the voyage days are shorter in comparison to the Suezmax tankers. Dependent on the geographical location of the ports and the availability of products to transport, this may be the reason for the Handysize tankers being able to reduce the amount of time they operate in ballast condition. On the contrary, the Aframax and even more so the Suezmax tankers tend to make longer voyages. Whilst this means that they spend a lesser proportion of time in port, the ballast leg appears to increase: this will particularly be the case when operating between locations with high oil production and no oil production.

The first difference between the containers vessels and the tankers and the bulk carriers, is that they do not operate with a ballast leg. Also, evidence shows that Post-Panamax plus container vessels spend less time in port and a larger percentage of time sailing: a likely influence of operational route. It can be argued that the amount of port time varies and this will greatly depend on many logistical issues, such as: ship arrival, berthing availability, unloading/loading resources and personnel, cargo readiness, commercial voyage agreements, ship inspections and certificates, etc.

Despite certain delays being inevitable due to the long and complicated logistic chains, there are certainly elements that can be improved to increase the utilization (days sailing laden, cargo loaded) of ships. This includes the installation of efficient port resources as well as early and good communication and resource management between all stakeholders involved. For example, where an inevitable inefficiency is observed (such as a port delay), then good communication and management can allow for alternative operational energy efficient measures to be implemented, such as just in time arrival as advocated by VA. This piece of research clearly shows a significant potential for improvements.

5.6 References and further reading

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

1. "IMO train the trainer course material", developed by WMU, 2013
2. INTERTANKO and OCIMF 2010 "Virtual Arrival", a 2010 publication, <http://www.intertanko.com/upload/virtualarrival/virtualarrivalinformationpaper.pdf> accesses August 2015.
3. Jussi Pyörre, 2012 "Overcoming the challenges in vessel speed optimization", <http://www.eniram.fi/wp-content/uploads/2013/10/2012-10-Hansa-Overcoming-the-challenges-in-vessel-speed-opt.pdf> accesses August 2015.
4. Charlotte Banks, Osman Turan, Atilla Incecik, G. Theotokatos, Sila Izkan, Catherine Shewell, Xiaoshuang Tian "Understanding ship operating profiles with an aim to improve energy efficient ship operations", Low Carbon Shipping Conference, London 2013. Available on: http://www.lowcarbonshipping.co.uk/files/ucl_admin/LCS%202013/Banks_et_al.pdf. accesses August 2015.

6 E-Navigation and Weather Routing

6.1 What is e-navigation?

It has long been recognized that there was a clear need to provide the master of ships and those responsible for the safety of the vessels ashore with modern proven tools to make marine navigation and communication more reliable and hence reduce errors, especially those with the potential for loss of life, injury, environmental damage and undue commercial costs.

It was also noted from information disclosed over time that navigational errors and failures had been significant in overall incidents that required a full investigation. This inspired the development of new technologies such as Automatic Identification System (AIS), Electronic Chart and Information System (ECDIS) Integrated Bridge and Navigation Systems, Automatic Radar Plotting Aids (ARPA), Long Range Identification and Tracking (LRIT) systems, Vessel Traffic Services (VTS) and the Global Maritime Distress Safety System (GMDSS). The aim was to develop a strategic vision for the utilization of existing and new navigational tools, in particular electronic tools, in a holistic and systematic manner. The proposed solution was named e-navigation.

As a result of proposals made to IMO MSC (Marine Safety Committee) on the subject, a Strategy Implementation Plan (SIP) was developed in the past and five solutions were agreed to provide a basis for this purpose that are;

- S1: Improved, harmonization and user friendly bridge design;
- S2: Means for standardised and automatic reporting;
- S3: Improved reliability, resilience and integrity of bridge equipment and navigational information;
- S4: Integration and presentation of available information in graphical displays received via communication equipment; and
- S5: Improved communication of VTS service portfolio.

The solutions S2, S4 and S5 are designed to improve communication between ship and shore for safe ship management purposes. These same initiatives may have the highest potential to reduce GHG emissions from ships as any reduction in the waiting time to enter port or a delay in the passage of a river or estuary can have a positive impact on reducing fuel consumption of a voyage and thus its GHG emissions.

IALA¹⁰ defines the e-navigation as “e-navigation is the harmonised collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment”. The implementation of e-navigation involves the development of onboard navigation systems that integrate all relevant ships sensors and supporting information.

ECDIS is the main item of the broader e-navigation initiative that has evolved as a result of IMO activities. There are currently over 40 different approved ECDIS systems installed on ships and most if not all have different user interfaces using different methods of implementing requirements and alarms. The IMO considers the implementation of e-navigation in the world’s fleet as a long term objective rather than a short term fix. It should also be noted that the on-board e-navigation system will have a shore based e-navigation to support it that will require other challenges. It is hoped that

¹⁰ International Association of Marine Aids to Navigation and Lighthouse Authorities

e-navigation will be an enabling technology that would facilitate more efficient ship scheduling and routing, thus leading to more energy efficient shipping and a reduction in the amount of GHG emissions it produces.

The IMO and IALA have provided the following e-navigation model (see **Figure 6.1**) to describe the overall concepts and outline the basic elements of the system.

A Descriptive Model for E-Navigation

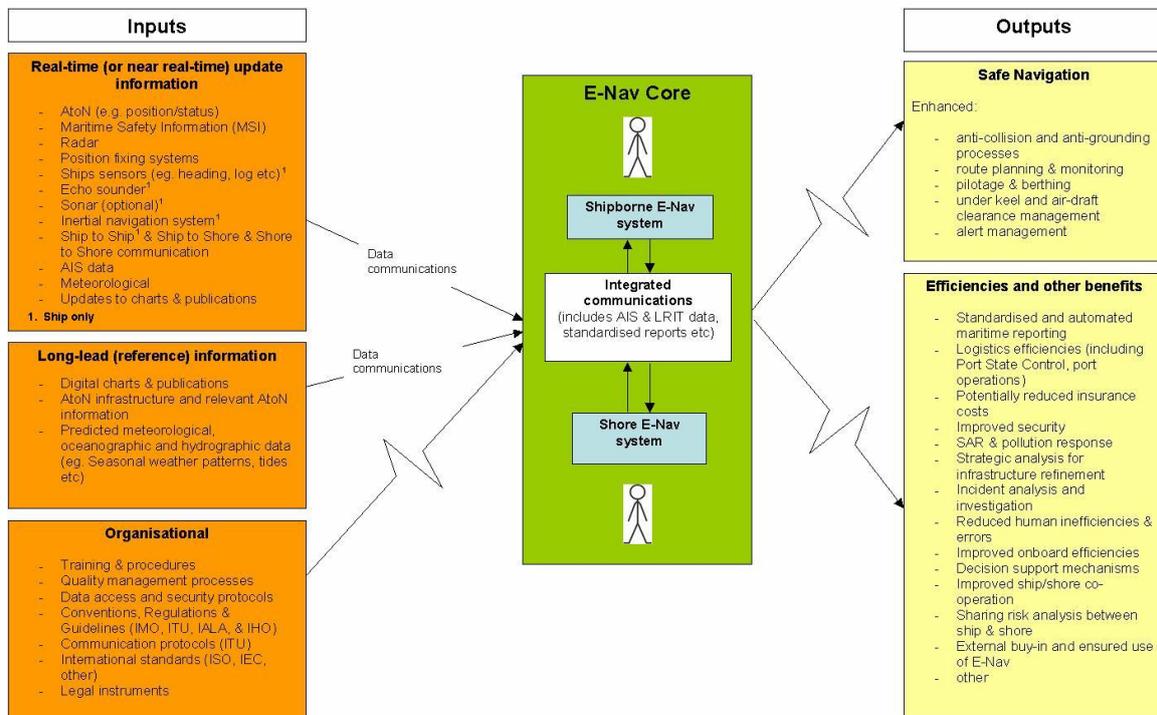


Figure 6.1: The IMO model of the principle outline and basic elements of the e-Navigation concept

It can be seen that this model implements many other shipboard and shore side management elements and not just navigation with the aim of ensuring the highest standard in environmental protection and safety.

The system intends to combine measures like passage planning with dynamic real time monitoring to ensure that the pre-planned under-keel clearance is maintained during the whole passage. There could be on-line monitoring of ships' routes that could be analyzed in relation to GHG emissions to look for ways to reduce fuel consumption and cost. The system would have built-in decision support system to assist both the masters and officers on navigational watch. The system would be berth-to-berth management including route monitoring, pilotage and berthing.

6.2 E-navigation tools and GHG emissions

It is clear that any reduction in collision and grounding will lead to the reduction of ship generated pollution. The IMO and IALA are also looking at the possibility of using e-navigation to reduce carbon, sulphur and nitrogen emissions from ships. This would be done through more efficient vessel route handling at sea and also while on pilotage and berthing. It has also been proposed to use e-navigation data to audit the measurement of emissions data if and when they need to be

reported. The main and fundamental change with the introduction of e-navigation will be the closer relation between the “officer of the watch” on the bridge and the assistance provided from shore-based stations in carrying out the safe navigation of the ship.

There are of course still many legal obstacles to this particularly with regard to who will be responsible for the navigation of the ship if directed by shore side, particularly in a collision avoidance situation in open sea. The developments of centralized shore-based traffic organizations that have the authority to modifying voyage plans and make dynamic route changes from ashore for the purpose of safety and efficiency of the overall traffic in a monitored coastal area, are the subject of several research projects. These are currently under discussion but still some way off from introduction. It is still difficult to predict what the technological developments will be in the future to allow the development of e-navigation so the potential impacts on efforts to reduce GHG emissions are still difficult to estimate. However, the ship navigational information (GPS data) has successfully been used to estimate shipping fuel consumption and GHG emissions for example under Third IMO GHG Study 2014 as discussed in **Module 1**.

There is currently equipment or systems either in use or at an advance state of development that will form part of a shipboard e-navigation system that may be used to reduce GHG emissions. Examples are:

- Voyage performance analysis: This system can measure ship speed, shaft propulsion power and external environmental situation such as wind and waves that could be used for monitoring voyage performance and to identify performance deviations. These performance deviations that may be positive as well as negative could be used to improve the ships environmental performance. Such a system could rely on data collected as part of e-navigation system.
- ECDIS (Electronic Chart Display and Information System): The electronic chart and information system has the potential for improving navigational practices and reduce GHG emissions. In this respect, weather routing may become a more effective tool than is today.
- Autopilot precision and effectiveness: A new generation of autopilots is under development that can automatically adapt the steering actions to prevailing weather conditions and sea state. These systems include dedicated functions such as 'precision' and 'economy' modes depending on the requirement of the ship. If the autopilot is operating in economy mode it would reduce rudder movements, thus reducing the drag of the rudder that will save fuel. If the ship is in restricted waters where very accurate course and position is required, the autopilot will be put in precision mode providing for the better accuracy and ensuring safe navigation.
- Maneuvering assistance tools: With the introduction of modern information and communication technologies, more and more assistance tools have been introduced additionally to standard mandatory navigational bridge equipment. Among those integrated systems there are tools for planning and monitoring purposes on the macro and micro level. Macro planning deals with waypoint planning for the sea trail of any voyage from point A to B. Micro planning is dedicated to the planning of detailed steering sequences for complex maneuvers in harbor areas, even including berthing operations. Once the planning process is completed and approved, the bridge team can follow the steering sequence using any dedicated display to check the plan is being kept. The use of sophisticated planning and

monitoring tools optimizes the number of elementary maneuvers in order to meet the requirements for the safety of navigation while also meeting the requirements for the minimum use of the steering equipment and saving fuel and time and simultaneously reduce GHG emissions when operating in coastal and harbour areas.

- Integrated navigational systems: This can achieve fuel savings by keeping cross track error to a minimum while in passage. This technology has been brought about by extremely accurate GPS position information, which can calculate the ships position down to a few meters with the capability of giving accurate heading information. With this system, better course control is achieved by requiring less frequent and smaller corrections to minimize rudder resistance. Generally a ship is most efficient with regard to rudder position, when the rudder is mid-ships and not carrying any helm in either direction due to wind or sea conditions. The superstructure and hull form designs above the water can affect the amount of helm the ship needs to carry for a particular wind direction. Advances in the shape of the above water profile of the hull and superstructure to reduce the effects of wind resistance could have a positive effect in this area.
- Computerized maneuvering assistance tools: This takes into account the prevailing environmental conditions such as wind and current, ship condition, current course, speed, draught and the trim of the vessel. The systems can adapt the manoeuvring characteristics to the external environmental condition to ensure efficient use of energy and resources and minimise emissions of GHG. The intended passage is split into a number of pre-planning manoeuvres called elementary manoeuvres. Elementary manoeuvres are defined as each single manoeuvre or command of rudder, engine and thrusters or other steering equipment. Once the planning process is completed and approved, the bridge team can follow the steering sequence using any dedicated display to check the plan is being followed. The use of these sophisticated planning and monitoring tools optimises the number of manoeuvres for safe navigation while maintaining minimum use of the steering equipment to saving fuel and time reducing GHG emissions when operating in coastal and harbour areas.

As can be seen, e-navigation provides significant new opportunities for optimizing navigation actions in favour of safety and environmental protection.

6.3 ECDIS (Electronic Chart Display and Information System)

The international convention for safety of life at sea SOLAS will require in the near future that the paper charts to be replaced by approved electronic charts that must be used in conjunction with an approved ECDIS. Paper charts will only be able to be used as a backup or on small ships of less than 500 GT. These electronic charts are currently in two formats the main one being “vector charts” which can be scaled up or down and not lose any definition, as the information on them is purely digital. The other type which should only be used where there is no “vector chart” available is the “raster chart” which is a copy of the paper chart and cannot be scaled up in too much without losing definition.

The ECDIS takes the information from the approved electronic chart and reproduce an image on a display system. The ECDIS can however do much more as it also has, as a minimum, the speed, water depth and position input from sensors so these other ship’s information are accessible by it and can be seen at all times. Many ECDISs also have the capability of showing radar, ARPA and AIS data so other ships can also be seen on the ships ECDIS display unit but this is not mandatory. **Figure 6.2**

shows a concept of how ECDIS as linked to other ship-board systems.

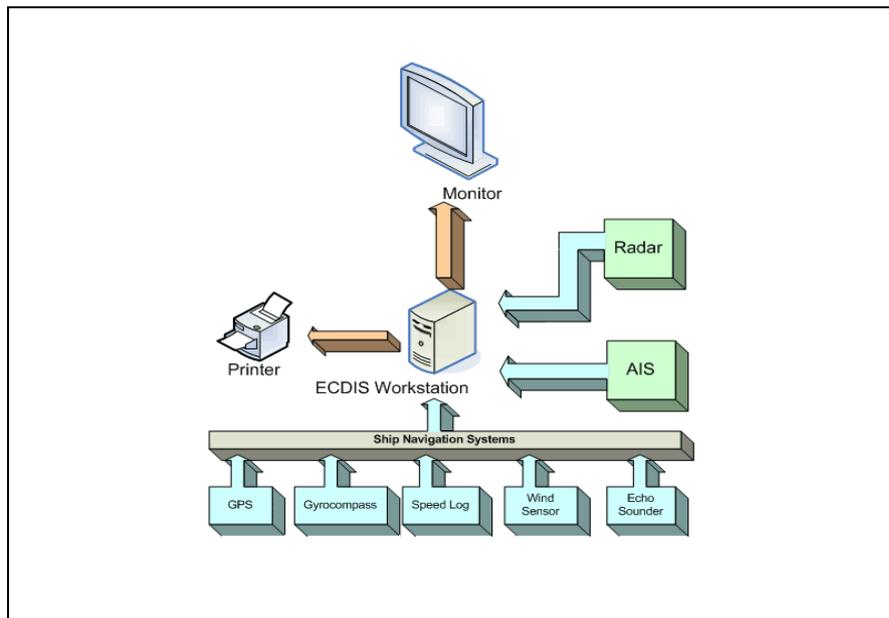


Figure 6.2: Concept of ECDIS and its integration with other system [Fredrik Larsson]

The ECDIS should however not be used for collision avoidance as an ECDIS is not approved as a radar so such information can only be used as an aid to navigation. The ECDIS is used to include the ships passage plan on and it has the ability to analyse the ships route and provide alerts for better ship course control. The ECDIS will also alert the “officer of the watch” of deviations from any pre-programmed safety zones set by the officer or master. All the above capabilities are relevant to some important energy efficiency measures such as weather routing and route planning, course control and so on.

With ECDIS, the latest navigational information is introduced automatically, saving companies a significant amount of time that would otherwise be spent researching and gathering. In terms of communication, electronic data has far more advantages than paper-based information. It is easy for updates to be transmitted electronically to several recipients, which is vital for shipping companies.

6.4 ECDIS use for GHG reduction

The ECDIS main advantage over the traditional paper plot method of getting from A to B is that it is capable of accurately plotting and monitoring the ships position in real time to ensure that the ship follows the optimum course to the destination. In the old systems, the ships position was normally plotted between every 15 minutes to an hour in coastal situations and every watch when in open oceans. Course adjustments were then made, where necessary, to make the next alter course position. An ECDIS fitted to the ship has the ability to be linked to an advanced automatic pilotage system called a track pilot that can improve the vessels ability to keep on track and alter course at just the right time to minimise the distance travelled this will ensure that the ship take the minimum distance between the departure and destination port, thus reducing GHG emissions.

There are however at present dangers to altering the course of a ship without the knowledge of the “officer of the watch”, particularly in restricted waters with lots of ships around. These systems as yet fully cannot take into account other ships and the requirements of the *International Regulations For the Prevention of Collision at Sea* commonly known as the ‘Rules of the Road’ but when the

principles of e-navigation are fully implemented the possibility is there. An ECDIS can give a quick method of calculating estimated time of arrivals (ETAs) at the port of arrival taking into account the current position of the ship, the distance to go and the tidal rates and directions without doing a complicated calculation. This information gives the officer of the watch the information to accurately adjust the speed of the vessel so that it arrives at the pilot station or start of the pilotage passage at exactly the right time when on coastal passages or approaching the port taking into account the height of tide for entry or any other environmental factors.

This tool can also be used when slow streaming on ocean passages to adjust the speed for better fuel efficiency and more convenient time of arrival but as mentioned in previous section on shipping law any reduction of speed to reduce fuel consumption when on charter should be verified. The ECDIS has the potential to improve voyage planning and fuel efficiency of a vessel on an ocean passage when the ship is operating at her full service speed. For example, as the ECDIS can continually monitor the ships position to ensure that it is on the intended track. The ECDIS can follow a Great Circle curved track that requires the ship to constantly alter the ship's course, as the ship will be following a circular path. The Great Circle path which is the shortest distance between two points on the earth's surface will always be curved unless the ship is travelling due North, South, East or West when the ship is following the same latitude or longitude.

6.5 Passage planning

The passage plan is the most important part of the voyage plan. Careful planning and execution of the passage plan can achieve an optimum route and improved efficiency. The ECDIS can be an important part of any passage planning and implementation. The stages of a passage plan are as follows [IMO Resolution 893(21)]:

1. **Appraisal:** An overall assessment of the intended voyage will be made by the master, in consultation with the navigating officer and other deck officers who will be involved, after all relevant information has been gathered. This appraisal will provide the master and his bridge team with a clear and precise indication of all areas of danger and safe navigation taking into account the calculated draught of the vessel and planned under-keel clearance.
2. **Planning:** Once a full appraisal has been carried out the navigating officer carries out the planning process. The detailed plan would cover the whole voyage, from berth to berth, and includes all waters where a pilot will be on board. The plan would be completed and include all the relevant factors listed in the IMO guidelines. The appropriate charts should be marked clearly showing all areas of danger and the intended track plus all other safety related information. The main details of the voyage plan should also be recorded in a bridge logbook used specially for this purpose to allow reference to details of the plan at the conning position without the need to consult the chart. Supporting information relative to the voyage, such as times of high and low water, etc. will also be recorded in the logbook.
3. **Execution:** The execution of the finalised voyage plan would be carried out taking into account the factors listed in the IMO guidelines. The master would take into account any special circumstances which may arise, such as changes in weather, which may require the plan to be reviewed or altered.
4. **Monitoring:** This is where the passage plan is monitored to affirm that the vessel follows the intended route. Monitoring of the vessel's progress along the pre-planned track is a continuous process. The officer of the watch, whenever in any doubt as to the position of the vessel should immediately consult the master to ensure safety of the vessel.

Information on passage planning is contained in the IMO resolution 893(21) 'Guidelines for voyage planning' that describes in detail what needs to be done under the above 4 stages and the ISF¹¹ / ICS¹² publication "Bridge Procedures Guide". It should be noted that the above IMO guidelines address the voyage planning from the safety of navigation purposes rather than energy saving. For energy saving purposes, the route planning needs to take extra dimensions such as avoiding shallow waters, avoiding sea currents, etc. thus will be combined with overall voyage planning using weather routing and so on. Thus, a fuel-efficient operation should be part of the 'passage planning' and taken into consideration at the appraisal stage above.

6.6 Operation in congested routes

When operating in areas of high traffic density, it may be necessary to deviate substantially from the intended track by an alteration of course to comply with the collision regulations. There may also be a need to slacken speed, stop or reverse the means of propulsion. In cases such as this, any considerations to reduce CO₂ emissions are outweighed by an international obligation to comply with the international regulations for the prevention of collision at sea.

It is very difficult to include such requirements in any GHG reduction plan. Ships are required to proceed at a safe speed in restricted visibility waters. This will require the master to reduce the speed of the vessel and if necessary stop the vessel until all danger of a collision is over. The international regulations for prevention of collision at sea require all ships to comply with its regulations. It may be necessary to ignore energy saving measures when operating in such areas and again navigational safety and good seamanship must always take priority.

Ships may operate in an area of restricted visibility for several days which may require them to reduce speed significantly or even wait with subsequent need for over steaming that overall will result is a significant increase in fuel consumption but yet again navigational safety must take priority. The main questions answered is weather with e-navigation systems and ECDIS and weather routing information, such areas of operations that lead to significant increase in fuel consumption could be avoided? These are certainly issues that may be tackled once the relevant data are mature and e-navigation is fully in place.

6.7 Shallow waters and narrow channels

In shallow water both frictional and wave making resistances increase. The reasons are:

- Flow velocities under the hull increase as well as the wetted surfaces increase. Both of these increase the ship's frictional resistance in shallow waters.
- The waves created under shallow water take more energy from the ship than those in deep water for the same speed. This increases the wave making resistance.

Because of the above, shallow water can have a significant impact on ship resistances. **Table 6.1** shows the fuel consumption increase (%) for different water depths D in meter and speeds X in knots.

¹¹ International Shipping Federation

¹² International Chamber of Shipping

X	D	Increase (%)
10	8	5
10	10	3
10	100	0
17	8	20
17	15	10
17	100	0
20	8	30
20	15	20
20	100	0

Table 6.1: Increase in fuel consumption (%) as a function of speed and water depth [Mariners Handbook]

In shallow water, the deep draft vessels can experience “squat”¹³ which, depending on the hull form of the vessel will generally increase ship draft and increase the trim either by the head or the stern. This can result in the ship virtually dragging itself along the bottom. Signs of squat are erratic steering, large amount of helm required and a trail of muddy water from the stern. Squat can seriously increase fuel consumption. The solution to the problem is simply slow down where possible.

It has to be realised that a ship in a narrow channel making for a tidal port with a draft restriction, may have to increase speed to make the tide even if it results in a significant increase in the use of fuel. So, there are exceptions to the above general rules. However, in the future with the increased planned accuracy of satellite navigational systems, improved tidal information and the use of ECDIS the ships will have the capability of resolving the above issues in a better way. If a ship is operating on a trade where tide heights and depth of water in the channel or on berth is a major consideration, the operator may need to look for other ways to reduce the ships energy use as some of these limitations cannot be overcome.

The use of ECDIS capability plus weather routing services can provide savings via avoiding inappropriate operations in shallow water, restricted areas and narrow channels.

6.8 Weather routing

6.8.1 History

Weather routing has been around for a long time and was originally developed by the shipmasters in the time of sailing ships that often develop their own weather charts. The ship would also take their own weather observations of temperature, pressure, wind direction, wind force, direction of swell and cloud type and cover; all of which were recorded in the ship’s log book as is still done today. In

¹³ The squat effect is the hydrodynamic phenomenon by which a vessel moving quickly through shallow water creates an area of lowered pressure that causes the ship to be closer to the seabed than would otherwise be expected. This phenomenon is caused when water that should normally flow under the hull encounters resistance due to the close proximity of the hull to the seabed. This causes the water to move faster, creating a low-pressure area with lowered water level surface. This squat effect results from a combination of (vertical) sinkage and a change of trim that may cause the vessel to dip towards the stern or towards the bow [Wikipedia]

the 19th and early 20th century this information was collected nationally by such organizations as the predecessors of the United Kingdom Hydrographic Office. From this information, publications such as 'Ocean Passages of the World', Mariners Handbook (particularly for ice navigation) and weather routing charts were developed and have become mandatory publications on ships of many Flag states.

At the turn of the 20th century, the development of radio enabled ships to transmit weather data over long distances using 'Morse Code' giving ships advance warning of storms and hurricanes. Long wave low frequency radio communication was also used to transmit to the shore up-to-date weather data. Morse code was still used for ship radio communication right up to 1999 when the GMDSS (Global Maritime Distress and Safety System) was fully implemented and the use of long wave and similar low frequency radio frequencies that could only be sent by experienced radio officers was no longer required. All radio communication could then be sent in plain language via satellites with little training.

These data enabled shore side forecasters to develop and send up-to date weather forecasts and charts to all ships in a particular sea area. It was not until the late 60s and early 70s that weather routing as we know it today was developed. This major change was happened because of the increased accuracy of weather information that could be provided by the various met offices using satellite technology viewing from space in real time on various aspects of weather developments.

6.8.2 Fuel consumption and weather

The fuel consumption for a ship not only depends on speed, but also on water depth and weather conditions. The impact of shallow water operation on fuel consumption was discussed in the previous section. The weather condition includes wind and wave. To demonstrate the typical impact of wind on a ship's fuel consumption, **Table 6.2** provides a typical and approximate relation between increased wind strength, direction, and increased fuel consumption for each unit of Beaufort unit. Accordingly, a one Beaufort increase in sea state would result in 4% increase in fuel consumption due to the head wind.

W_d	Type	Increase (%)
315-360, 0-45	Head wind	4
45-135, 225-315	Side wind	2
135-225	Tail wind	1

Table 6.2: Increase in fuel consumption due to wind from different directions [Mariners Handbook]

Waves may have a significant impact on route selection. In order to take waves into account one has first to know their height and direction along the contemplated route as a function of location. Such knowledge may allow selection of the route and of power setting that minimize the transit time. However, the waves' height and direction may change over time and may not be known in advance.

In most oceans, there are regular currents that ships may be able to exploit for faster passage. Ocean currents are not constant but change over time. Thus getting reliable timely information regarding the ocean current at the location of a vessel poses a major obstacle. Satellite may provide timely reliable estimates of dynamic current patterns that are necessary for routing a vessel through such currents. The major question is whether there is a sufficient market to justify development of a system for collection of the necessary data.

Based on the above, the ship speed and route is best not only to be decided by commercial and contractual considerations but also using data on sea condition, sea currents, water depth and wind characteristics. The optimal speed distribution along the route can be calculated in advance, if a weather forecast is available. These techniques are used by weather routing service providers as part of their ship modeling and analysis.

The advantages of including weather routing in a ships passage plan is that a ship on an ocean passage can significantly reduce its fuel used by reducing the time taken for a particular voyage, even if the route taken is longer. Weather routing is mainly applicable to ocean going vessels that have some flexibility in which route they take. The abatement potential is quoted at between 1 and 4% but some providers do quote much higher for individual ships on particular routes of up to 8%. A significant proportion of the world's fleet already use weather routing and often included in the charter party so the possible abatement potential worldwide is believed to be less than the above. Some weather routing services also provide advance and accurate current and tidal predictions which can also be used on coastal routes. There are many weather routing providers throughout the world so there is plenty to choose from. Owners may wish to look at providers that specialise in the type of trade and area they operation in.

6.8.3 Use of weather routing

If a ship is operating in a sea area which has a high occurrence of bad weather, the owner may consider using weather routing services to reduce fuel cost and ship and cargo damage. For example, ships that are fine-lined and are fast often suffer from panting and pounding¹⁴ at the forward section of the ship when the wind and sea is ahead. Panting and pounding can result in significant damage below the waterline forward on the hull plating and it may be necessary to reduce the ships speed to save both fuel and expensive dry-dock bills repairing or renewing hull plating. These fast ships are often container ships or reefers or LNG ships and are on a set schedule and slowing down because of bad weather can mean that fleet management will suffer.

Weather routing service can direct the ship away from sea areas where such weather conditions are exist with the likelihood of damage and increased fuel costs. Heavy rolling with a beam sea can result in significant damage to both the ship (racking stresses) and the cargo, particularly if it is carried on deck so it may be necessary to alter course lengthening the distance. The ship may not be going exactly the right way, but at least it will be safer and may be using the minimum level of fuel for the distance travelled.

Weather routing service can use long-range weather forecasts to route the ship away from these heavy beam sea conditions, optimising the distance and time travelled. In the case of extreme heavy weather conditions such as Tropical Revealing Storms (TRS) or hurricanes, it may be necessary to make substantial changes to the intended track resulting in a much larger distance travelled. Weather routing services with their up-to-date and accurate information of the direction of the storm can direct the ship on the safest and shortest route to avoid dangerous sea conditions.

In some cases the weather routing service may advise delaying the ships departure until the weather improves by either staying in port or finding a safe anchorage until a storm passes; saving fuel and avoiding damage to the ship and cargo.

¹⁴ "Pounding" is a term which describes the heavy contact of the ship's fore body with sea water when pitching due to bad weather. It is sometimes referred to as slamming and may cause ship damage. The effect of pounding can usually be reduced by a reduction of the ship speed.

6.8.4 Weather routing services

Weather routing services can help to optimise the route a ship takes given the prevailing weather conditions. It was primarily used for avoiding rough seas and for ship safety purposes. Weather routing can be effectively used for a reduction in travel time and a reduction of fuel consumption. Weather routing depends on the accuracy of the data provided by the various met offices around the world.

The types of weather routing services offered are;

- Own ship using current and wind charts.
- Weather routing software onboard that is kept up to date by weather routing services ashore with the route being planned by the master of the ship.
- Shore based weather routing where the shore based weather routing service provider advises the master on a regular basis of what route to take.

If the owner or in some case charterer of the ship decides to use external vessel weather routing service providers, they will have to decide which category of route the ship should follow. The owner will be aided to choose one of the following routes, as examples:

- Fastest route.
- Fastest route least fuel.
- Fastest route least damage
- Fastest route least fuel and least damage

The route that the owner requests from the weather routing provider will depend on a number of factors including the type of cargo, the type of ship, the area of operation, the conditions of the charter party. If for example the ship is carrying an expensive cargo that is very susceptible to damage from heavy rolling and pitching, the owner may decide to ask for the least damage route and accept that the ship may take longer and use possibly more fuel to reach its destination. If there is no time constraint because the port of discharge or loading is blocked with traffic the owner or charterer may choose the least fuel route. If there are no such constraints and it is of utmost importance that the ship arrives at the port in time the owner or charterer may decide to ask for the fastest route.

It should of course be recognised that the navigation of the ship is ultimately the master's decision and he can at any time ignore the advice given by the weather routing services if he believes that following that particular advice would threaten the ship, its cargo or crew. For example, if the ship enters thick fog area, the International Regulations for the Prevention of Collision require the master to slow down and if the ship gets a distress message, the ship is obligated to go to help the ships under distress.

6.8.5 Data used for weather routing

Weather routing service providers play more and more a stronger role in voyage planning and choice of route. They rely on information about ship, sea and weather to provide their service. They would normally do this via building a computer-based ship model in their system. If possible, the weather routing service provider will visit the ship and collect the ship data from the master. They would look in particular for characteristics of the vessel so that it can be built into their model for best route planning. If the ship visit is not an option, the service providers will either request the data from the ship owner or use data from a sister ship.

The weather routing service providers will require ship specific information such as:

- Ship type
- Ship dimensions
- Ship summer load line and ballast passage draft
- Ship draft for the planned voyage
- Carriage of deck cargo
- Service speed
- Max speed

Additionally, weather routing service providers will take into consideration the following data when putting together a plan for ship on a particular voyage;

- Historic data on currents, wind, pressure, temperature, water temperature, paths of depressions, Tropical Revealing Storms (TRSs) and wave heights.
- The latest information on wind, waves, wave heights, temperature, pressure, cloud cover and type provided by national and private weather meteorological data suppliers. This information is gained from ships at sea, satellites, and shore observations.

The weather routing services provider use advanced computer-modeling tools to predict the weather pattern and how this will affect the ship at a particular course and speed. From this information, the model can then produce a voyage route or routes that will reduce the fuel consumption or voyage time for these conditions taking into account the safe navigation aspects. It should however be kept in mind that these predictions still rely on the accuracy of the data for both the ship and assumption that “the weather pattern will do as it did in the past”. These models are getting better but the weather is such a complicated system that mistakes in forecasting are always possible; but much less than before.

6.9 References and further reading

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

1. “IMO train the trainer course material”, developed by WMU, 2013
2. ‘Ocean Passages of the World’ (HMSO)
3. Mariners Handbook (HMSO)
4. Bridge procedures guide (International Shipping Federation)
5. Meteorology for Mariners (HMSO)
6. IMO resolution 893(21) ‘Guidelines for voyage planning”, see <https://mcanet.mcg.gov.uk/public/c4/regulations/safetyofnavigation/annexes/Annex25.htm> accessed August 2015.
7. Fredrik Larsson, “Marine Issues”, Intertanko presentation to Northern European Panel – HAMBURG 2009.