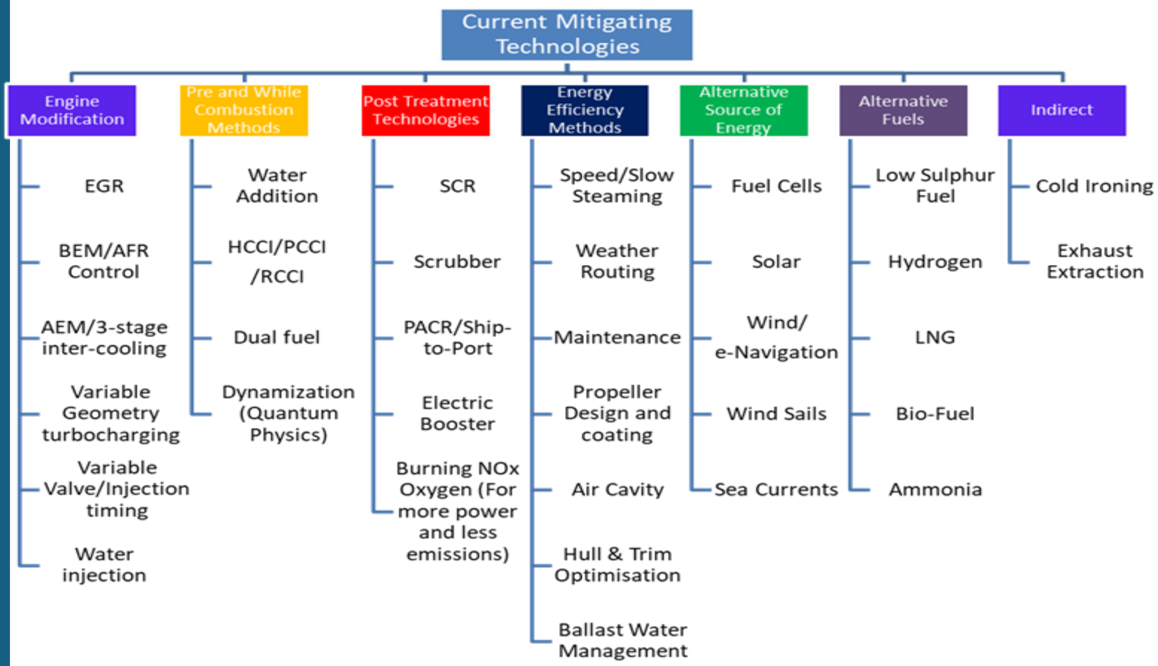
Green Ship

Maritime Energy Management System



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Preface

In line with the EU's vision of ensuring a high, uniform and effective level of maritime safety and marine environment protection, C4FF has initiated many educational and training programmes, several in the form of competence-based e-learning. A number of these have been awarded the 'Best in Europe'. All C4FF maritime courses are accredited by major and internationally well-known professional bodies such as IMarEST or co-jointly developed with well-respected European maritime universities.

In 2010, after successful launching of EGMDSS, Ship Automation (SURPASS), Emergency situations (M'aider), Test of Maritime English (MarTEL) and helping companies to develop their ERM and BRM competences, C4FF with funding from the EU initiated the UniMET project2. UniMET is a unified competence-based ECVET and ETCS compliant education and training programme for maritime academies worldwide. C4FF projects viz., Avoiding Accidents at Sea (ACTs) and ACTS Plus, attracted over 200000 users. All C4FF courses have been offered free-of-charge. ACTS Plus contains over 300 collision avoidance scenarios/simulations9.

Projects IdealShip, LeanShip and IdealPort led to a new project namely, Maritime Energy Management System (MariEMS). As part of the MariEMS project 6(https://www.mariems.com/) some 34 chapters were compiled. This book summarised the 36 Chapters and into 14 training chapters on Energy Management Systems and was developed to support IMO Train the Trainer (TTT) Course on Energy Efficient Ship Operation. MariEMS project specifically was designed for Training the Trainees in energy management and pollution reduction practices.

The MariEMS work is continuing in the form of a new programme, the Digital Twin of Ship Internal Combustion Engines, which can help engines use different types and mix of fuels enabling means to adjust valve timing, fuel injection characteristic, water injection and so forth during the various phases of the engine cycle. C4FF is of the view that the life cycle of most ships is some 30 years. To this end, means to configure engines to use different type of fuels and mixes at different part of the cycle would help reduce both fuel consumption and to reduce emissions of harmful pollutants.

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Chapter 1: Climate System and Combating Global Warming and Air Pollution

1.1. Air emission – A Local and Global Concern

1.1.1. Air Emission Overview

As the booming in industrialisation and shipping industries have taken place in last few decades, the use of fossil fuel or Hydrocarbon has also increased drastically. The fossil fuel consists of Hydrogen, Carbon and Sulphur which, when burnt, turned into water vapour, $CO2$ and CO, various kinds of Sulphur Oxides (SOx) and also during the burning process with air it composes Nitrogen Oxides (NOx).

Except the water vapour the other flue products are mainly toxic and some of them contribute to reduce the Oxygen level in the air.

These emissions have severe impact on human health and natural eco systems including sea and shore.

Air emissions affected the public health; the environment, sea, land, agriculture, etc. which has been deeply notified and observed by the international authorities and scientific community.

Air pollution, in the long run, is responsible for destroying the eco system and eventually it is responsible for several diseases to biological environment.

There are other kinds of emissions which are known as Greenhouse Gas (GHG) and Ozone Depleting Substances (ODS). The GHG increases the earth's temperature resulting in climate change and the ODS raptures the Ozone layers which is very important factor to filter out the cancer-causing Ultraviolet rays from the Sun.

The GHG and ODS are considered to be the issues with the global impacts while the other pollutants are mostly but not entirely responsible for the local or regional impacts.

1.1.2. Origins of Air Emissions

It is well established that the air contains a large variety of gas or vaporous components. Despite the overwhelming presence of oxygen and nitrogen, the atmosphere contains various gases, vapours and aerosols. Such substances originate from natural processes or as a result of human activities.

- Naturogenic Emissions: Natural chemical and biochemical processes release and particulates matters and gaseous substances into the atmosphere e.g. volcanoes gas eruptions, forest fires, decaying dead animals, humans or plants, etc. These are referred to as Naturogenic Emissions.

- Anthropogenic Emissions: Marine and industrial activities, produce a large amount of gases and chemicals which are released into the atmosphere. These emissions are increasing day by day as the industrialisation and shipping trade increase. These emissions are normally known as anthropogenic emissions.

Some emitted gases and particulates are inert and play no significant role to harm the atmosphere and lives while the others are toxic and harmful to the environments.

1.1.3. Air Pollutants and Humans

Clean air is of utmost requirement for breathing by human and other creatures. Human lungs breathe about 13,000 litres of air a day on a normal pace. Therefore, air quality is a very important factor for human body as the lungs has a direct access to it and Oxygen in the air is mixed with blood in the lungs. Therefore, contaminated air with harmful substance has a direct effect to damage the respiratory systems and eventually, the whole body. The negative impact to human body were first observed in the highly dense industrialised cities where the first effort to manage the air quality was initiated.

1.1.4. Justification of Action

The global industrialisation and subsequent marine transportation system growth has been solely based on the energy sources form fossil fuels. The huge increment of exploration and combustion of fossil fuels due to global trade demand is causing increment in contaminant addition to air, which in turn is causing global warming and climate change. The amount of pollutant emitted to air is so large that it cannot be ignored any further. Warming of the climate system is now evident from the observation of increases in global ocean and air temperatures, widespread melting of ice and rising global average sea level. Taking the impact into account, it would be prudent to keep the rate of increment of air pollution under control by utilising the available energy resources in a very efficient manner and to minimise the emission of ODS.

1.2.Climate System and Global Warming

1.2.1. Overview

The climate is usually defined as the average weather over long term periods. In a more scientifically accurate way, the climate can be defined as “the statistical description in terms of the mean and variability of relevant quantities over a period of time” (WMO Website definition). So, the climate differs from the weather, which is of chaotic nature and barely predictable, otherwise only on a short time basis.

The climate thus refers to an average image of the weather over time inside which the extreme short-term events are obviously invisible. The climate is a whole system which combines numerous interaction and retroactions between various complex subsystems: the atmosphere, oceans, land, ice and snow, living creatures including human beings and their activities (IPCC, 2007).

The dynamics of the earth climate are impacted by the alteration of each of the following system:

- The lithosphere (i.e. solid layer of earth); The hydrosphere (i.e. the waters); The cryosphere (i.e. frozen waters); The biosphere (i.e. the living); The atmosphere (i.e. gases).

The Lithosphere

The lithosphere contains all of the cold, hard solid land of the planet's crust (surface), the semi-solid land underneath the crust, and the liquid land near the centre of the planet. The surface of the lithosphere is very uneven (see image below). There are high mountain ranges like the Rockies and Andes (shown in red), huge plains or flat areas like those in Texas, Iowa, and Brazil (shown in green), and deep valleys along the ocean floor (shown in blue).

The solid, semi-solid, and liquid land of the lithosphere form layers that are physically and chemically different. If someone were to cut through Earth to its' centre, these layers would be revealed like the layers of an onion (see image right). The outermost layer of the lithosphere consists of loose soil rich in nutrients, oxygen, and silicon. Beneath that layer lies a very thin, solid crust of oxygen and silicon. Next is a thick, semi-solid mantle of oxygen, silicon, iron, and magnesium. Below that is a liquid outer core of nickel and iron. At the centre of Earth is a solid inner core of nickel and iron.

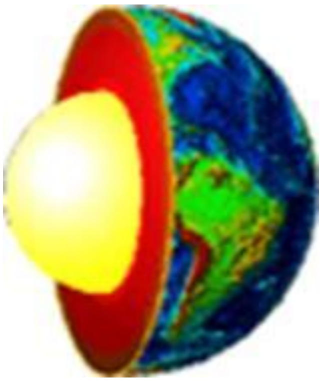

Figure 1.1: The Lithosphere

The Hydrosphere

The hydrosphere contains all the solid, liquid, and gaseous water of the planet. **It ranges from 10 to 20 kilometres in thickness. The hydrosphere extends from Earth's surface downward several kilometres into the lithosphere and upward about 12 kilometres into the atmosphere.

A small portion of the water in the hydrosphere is fresh (non-salty). This water flows as precipitation from the atmosphere down to Earth's surface, as rivers and streams along Earth's surface, and as groundwater beneath Earth's surface. Most of Earth's fresh water, however, is frozen.

Ninety-seven percent of Earth's water is salty. The salty water collects in deep valleys along Earth's surface. These large collections of salty water are referred to as oceans. The image above depicts the different temperatures one would find on oceans' surfaces. Water near the poles is very cold (shown in dark purple), while water near the equator is very warm (shown in light blue). The differences in temperature cause water to change physical states. Extremely low temperatures like those found at the poles cause water to freeze into a solid such as a polar icecap, a glacier, or an iceberg. Extremely high temperatures like those found at the equator cause water to evaporate into vapours.

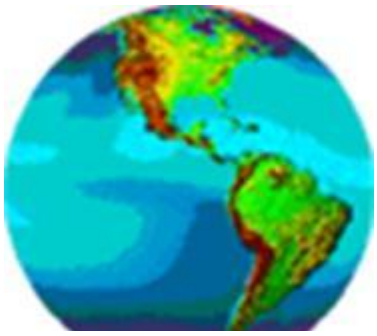

Figure 1.2: The Hydrosphere

The Cryosphere

Some scientists place frozen water--glaciers, icecaps, and icebergs--in its own sphere called the "cryosphere." For the purpose of this module, however, frozen water will be included as part of the hydrosphere. The word "hydrosphere" will be used in reference to water in all forms in Earth's system.

The Biosphere

The biosphere contains all the planet's living things. This sphere includes all of the microorganisms, plants, and animals of Earth.

Within the biosphere, living things form ecological communities based on the physical surroundings of an area. These communities are referred to as **biomes**. Deserts, grasslands, and tropical rainforests are three of the many types of biomes that exist within the biosphere.

Figure 1.3: The Biosphere

It is impossible to detect from space each individual organism within the biosphere. However, biomes can be seen from space. For example, the image above distinguishes between lands covered with plants (shown in shades of green) and those that are not (shown in brown). The Humans are placed in their own sphere called the **'Anthrosphere'**. It is also known as the **'Technosphere'**. For the purpose of this module, however, humans will be included as part of the biosphere. The word "biosphere" will be used in reference to all living creatures in Earth's system.

Figure 1.4: The Anthrosphere

The atmosphere

The atmosphere contains all the air in Earth's system. It extends from less than 1 m below the planet's surface to more than 10,000 km above the planet's surface. The upper portion of the atmosphere protects the organisms of the biosphere from the sun's ultraviolet radiation by means of the protecting layer of Ozone gas. It also absorbs and emits heat. When the air temperature in the lower portion of this sphere changes, weather occurs. As air in the lower atmosphere is heated or cooled, it moves around the planet as a result of density change. The result can be as simple as a breeze or as complex as a tornado.

The main theme of this module is the control methodology of air pollution in turn to achieve energy efficiency, therefore, we will highlight on the various layers of the atmosphere. The atmosphere is made up of many layers that differ in chemical composition and temperature which play significant roles to protect the Earth in various ways. Each layer, when suffers from air pollution, they fail eventually to protect the earth in different ways according to the type of pollution.

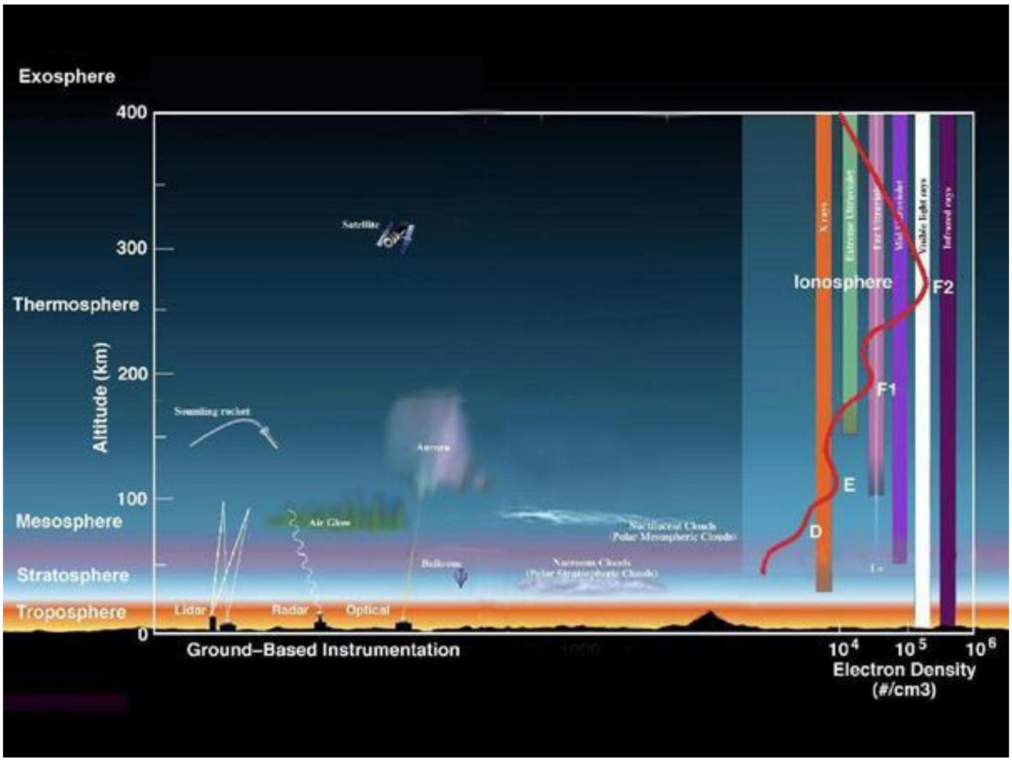

Figure 1.5: Diagram of the layers within Earth's atmosphere.

These layers are:

- **Troposphere**
  The troposphere starts at the Earth's surface and extends 8 to 14.5 kilometres high (5 to 9 miles). This part of the atmosphere is the densest. Almost all weather is in this region[1].

[1] http://www.nasa.gov/mission_pages/sunearth/science/atmosphere-layers2.html

- **Stratosphere**
  The stratosphere starts just above the troposphere and extends to 50 kilometres (31 miles) high. The ozone layer, which absorbs and scatters the solar ultraviolet radiation, is in this layer[1].

- **Mesosphere**
  The mesosphere starts just above the stratosphere and extends to 85 kilometres (53 miles) high. Meteors burn up in this layer[1].

- **Thermosphere**
  The thermosphere starts just above the mesosphere and extends to 600 kilometres (372 miles) high. Aurora and satellites occur in this layer[1].

- **Ionosphere**
  The ionosphere is an abundant layer of electrons and ionized atoms and molecules that stretches from about 48 kilometres (30 miles) above the surface to the edge of space at about 965 km (600 mi), overlapping into the mesosphere and thermosphere. This dynamic region grows and shrinks based on solar conditions and divides further into the sub-regions: D, E and F; based on what wavelength of solar radiation is absorbed. The ionosphere is a critical link in the chain of Sun-Earth interactions. This region is what makes radio communications possible[1].

- **Exosphere**
  This is the upper limit of our atmosphere. It extends from the top of the thermosphere up to 10,000 km (6,200 miles) [1].

These intertwined elements form and influence the climate system which in return influences them. Permanent retroactive feedback connects the whole and the parts of the climate system (Berkes et al., 2003). In such complex and dynamic system of interactions, there is no permanent stability. Figure below shows such a complex interaction schematically.

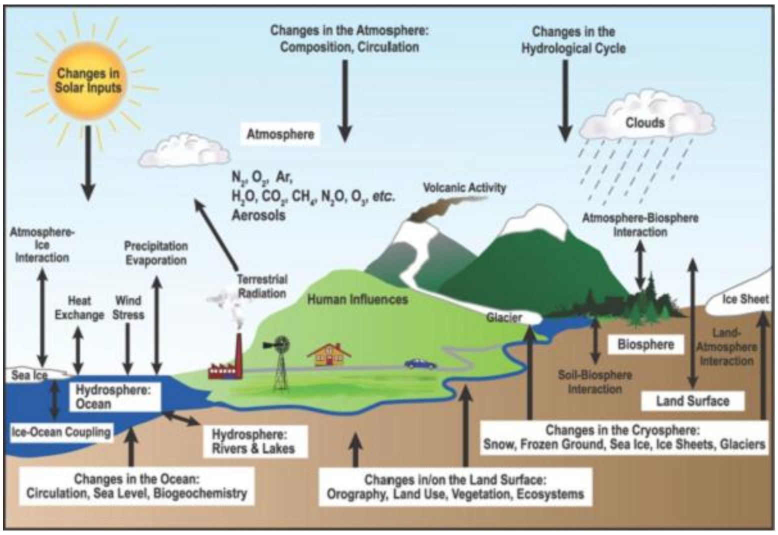

Figure 1.6: Schematic view of the components of the climate system, their processes and interactions [IPCC Fourth Assessment Report, Climate Change 2007 (AR4) WG I]

In such a complex system of interactions, the alteration of one system would affect the whole set patterns. The modification of the atmospheric properties affects the other systems which by retroaction influence again the atmosphere. As an example, the global warming increases the ice melting which retroactively increases the warming effect by reducing the radiation reflection of the sun. This is a massive chain reaction with huge impact of global warming that gives so much prominence and urgency to control of climate change.

1.2.2. Greenhouse Gas (GHG) emissions and Climate change

The GHG act as a blanket for the earth, leading to warming of the planet (see figure below). The existence of GHG in the stratosphere is highly valuable because they reflect back the energy of the infrared emitted by the earth surface. Without such effect, the planet would be too cold. The GHG represent a tiny fraction of the atmosphere, less than 1%. Except purely man-made chemicals like CFCs and HFCs, the GHG emissions naturally, and from natural sources, are present in the atmosphere.

The issue of GHG is not their presence in the atmosphere but their quantity and concentrations which affects the level of temperature at the Earth's lower atmospheric layers. Ideally and to sustain human life on earth, not too much warming and not too much cooling is desirable.

Presently and with support of scientific evidence, the man-made air emissions perturb the long-term established atmospheric general equilibrium and the mechanisms which increase the warming effect on the climate tend to overwhelm the others. With the rise of the anthropogenic sources of GHG and the perturbation of the natural sinks – e.g. forests, sea and land; the amount of GHG present in the atmosphere increases and, therefore, amplify the GHG effect and the warming of the planet.

“Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years (see figure below).

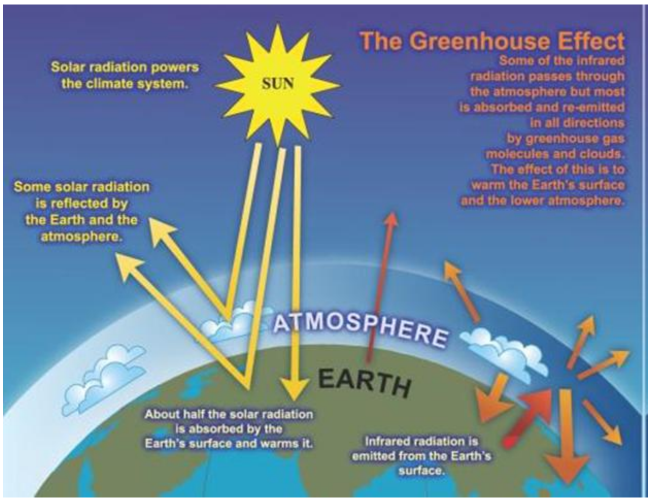

Figure 1.7: An idealised model of the natural greenhouse effect [Source: IPCC AR4 WG I]

The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land use change, while those of methane and nitrous oxide are primarily due to agriculture.” (IPCC, 2007c)

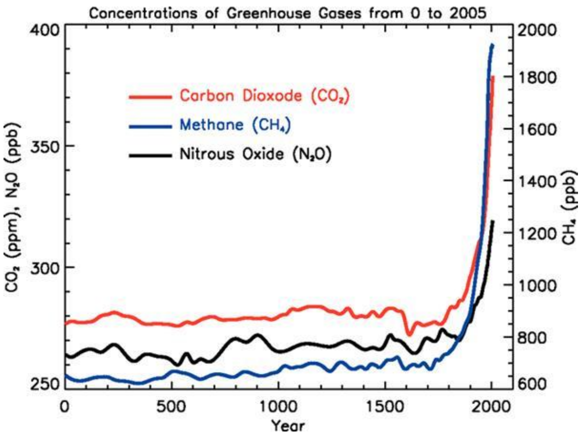

Figure 1.8: Evolution of atmospheric concentration of a number of GHG emissions [IPCC (2007a)]

Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years. Increases since about 1750 are attributed to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion air molecules, respectively, in an atmospheric sample.

The impact of the industrial era on the GHG amount in the air shows an increment of around 25% for CO2, 120% for CH4 and 9% for N2O (IPCC, 2007) as shown in figure above.

1.2.3. Main GHG Emissions

The main GHG heat-trapping gases are:

Carbon dioxide (CO2): According to IPCC, this gas influences the most the global warming (IPCC, 2001) because of the quantities released and its lifetime in the atmosphere. However, as a natural compound, the carbon dioxide belongs to a large carbon circulation between land, atmosphere and oceans in which carbon sources (release) and carbon sinks (capture) co-exists (see Figure 1.1)

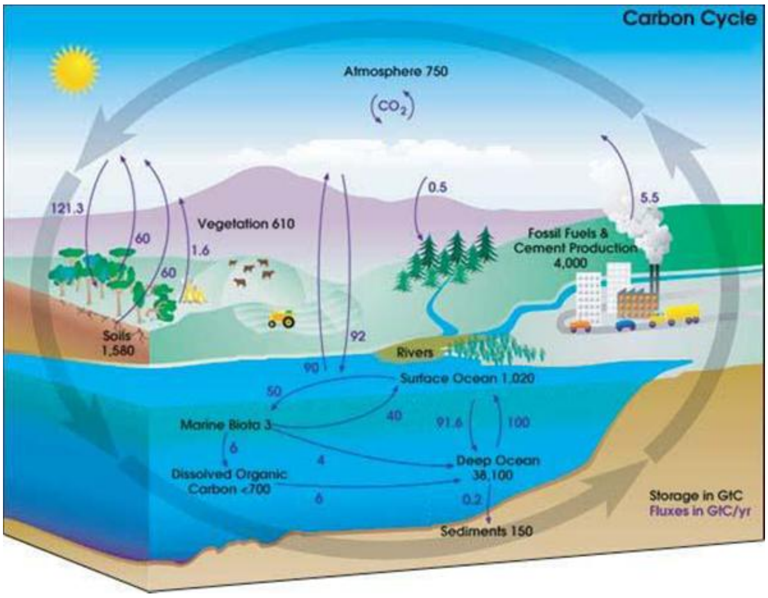

Figure 1.9: Major Carbon pools and fluxes of the global carbon balance [FAO website]

Main sources of human-related CO2 emissions are fossil fuels burned for electricity generation, transportation, and industrial and household uses, by-product during the manufacturing of cement, and deforestation.

"Globally, over the past several decades, about 80 percent of human-induced carbon dioxide emissions came from the burning of fossil fuels, while about 20 percent resulted from deforestation and associated agricultural practices. The concentration of carbon dioxide in the atmosphere has increased by roughly 35 percent since the start of the industrial revolution." (Karl T.L. et. al., 2009)

The fuel used releases CO2 in the atmosphere supplementing the existing carbon cycle and the CO2 present in the air. In addition, deforestation, land-use change, and soil degradation are affected by human activities which reduce their abilities to capture carbon as sinks. Moreover, there are serious uncertainties in the capacity of the ocean to retain increasing amount of CO2.

Methane (CH_4): Main sources of human-related CH_4 emissions are: agriculture and livestock, mining, transportation, and use of certain fossil fuels, sewage, oil and gas production and processing, and decomposing garbage in landfills. Methane quantities in the air are far less than the CO_2 but its warming capacity is very high despite its short lifetime.

Nitrous oxide (N_2O): The industrial farming using large quantities of fertilizers accounts for the majority of the Nitrous oxide release. The second position is taken by the combustion of the fossil fuels.

Halocarbon (CFCs, HCFCs,): They are non-natural but manufactured compounds. They are extensively used as refrigerants but may be found in other industrial processes. Despite their very low concentration in the air, their radiative forcing effect is important, and they may remain active for a very long time:

"Therefore, these compounds, even with relatively small emissions, have the potential to influence climate far into the future. For example, Perfluoromethane (CF_4) resides in the atmosphere for at least 50,000 years." (IPCC, 2001)

Their quantities seemed to have peaked in 1994 and are now declining slowly. The regulations on O_3 Depleting Substances (ODS) contribute to this decay.

Other gases like O_3 or water vapour have GHG properties. In addition, the particulate matters emitted in the atmosphere may have varying properties and "depending on their type, aerosols can either mask or increase the warming caused by increased levels of GHGs." (Karl T.L. et. al., 2009)

1.2.4. Climate Change Impacts on Oceans

The global warming and the air substances absorbed by the oceans deeply affect their health. Ecosystems and habitats are disturbed by the modification of the ocean properties in relation with the absorbing of air emitted compound and global warming. Another consequence of the warming is the ocean dilatation and sea-level rise which endangers the coastal ecosystems and accelerates erosion.

In addition, the carbon dioxide combined with other atmospheric compounds possesses another important impact: oceans acidification. As part of the natural carbon cycle, oceans absorb the CO_2. While the CO_2 increases in the air, its amount dissolved in the oceans increases. In the sea water, the CO_2 reacts with H_2O and forms carbonic acid, and the overall acidification process of the ocean begins.

$$CO_2 + H_2O = H_2CO_3$$

*"As pointed out by Hunter et al. (2011), "*the acidification of the surface ocean by anthropogenic carbon dioxide (CO_2) absorbed from the atmosphere is now well-recognized and is considered to have lowered surface ocean pH by 0.1 units" (corresponding to an approximately 25% increase in the acidity of the surface oceans) since the mid-18th century." (GESAMP, 2012)

The present rate of increase in ocean acidification has no precedent for the last 30 million years. The high-speed acidification may impair the ability of many organisms to cope with changing oceanic properties.

"Ocean acidification is known to have significant impacts on ocean areas, including reduced ability of many key marine organisms, including calcareous phytoplankton, the base of much of the marine food chain, to build their shell and skeletal structures; increased physiological stress, reduced growth and survival of early life stages of some species." (IOC/UNESCO, 2011).

Despite the worrying effects of the global warming and atmospheric changes and alteration, there remain a large number of uncertainties lying in the complexity of ecosystems and social world.

For example, the impact of the CO2 is particularly difficult to predict because it belongs to the carbon circulation system of the planet and the land and ocean feedback to increasing concentration of CO2 remain uncertain. The future releases into the atmosphere are not completely predictable because they largely depend on the evolution of the economic and social choices.

1.3.Combating Air Pollution: The Role of International Bodies

1.3.1. Historical Developments

The great smog in UK and USA during the 1950s and 1960s, the groundings of Torrey Canyon (1967) and Amoco Cadiz (1978), damages related to acid rain in the 1970s, the release of poisonous chemicals in Bhopal (1982) and the nuclear accident of Chernobyl (1986), etc. demonstrate the rising "risk to society" of modern industrial activities. The existence of such risks plus wider evidence of impacts of air emissions on human health, global temperature and ecosystem have fully shifted the individual and social perceptions of risks and particularly of those affecting the environment.

In global risks context, local and national regulations could be deemed ineffective and insufficient as this needs a global response. The progressive recognition of this context offered opportunities to the United Nations bodies to drive adequate international governance.

In the 1970s, the presence of acid rain led to realisation of the magnitude of air pollution and triggered the necessity to build a cooperative agreement. Acid rain is formed when large quantities of NOx and SOx released in the air, react with water vapour or rainwater and form acids. The inability to control when and where acid rain impacts the environment forced regulators to identify pollution sources contributing to the creation of acid rain. Once identified, those sources could be controlled through the regulatory process.

In 1972, the United Nations Conference on the Human Environment (UNCHE) adopted a body of principles which would later support international instruments. Examples of these principles are:

- Principle 2 recalls the importance of preserving the present "resources of the earth" for the future.
- Principle 21 sets out that States should "ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction."

The latter principle 21 provided the grounds for governing the international responsibility of States with regard to the environment (Zaelke, Durwood & Cameron, 1990). This principle is also echoed in U.N. General Assembly Resolution 3281, in Article 30 of the Charter of Economic Rights and Duties of States, and in Article 194(2) of the 1982 UNCLOS (United Nations Convention on the Law of the Sea), which provides:

"States shall take all measures necessary to ensure that activities under their jurisdiction or control are so conducted as not to cause damage by pollution to other states and their environment, and that pollution arising from incidents or activities under their jurisdiction or control does not spread beyond the areas where they exercise sovereign rights in accordance with this Convention."

In 1982, the Third United Nations Conference on the Law of the Sea integrated some of the UNCHE principles into the UNCLOS, particularly in Part XII (provisions on prevention of pollution of the marine environment).

In parallel to the international law development, the first legally binding instrument to address air pollution was adopted in 1979 under the auspices of the United Nations Economic Commission for Europe (UNECE). The 1979 Convention on Long Range Transboundary Air Pollution (LRTAP) entered into force in 1983.

In February 1979, the First World Climate Conference was organized by the World Meteorological Organization (WMO) as a major scientific meeting. The international gathering made an appeal to Nations: "[…] the Conference finds that it is now urgently necessary for the nations of the world: […] (c) to foresee and prevent potential man-made changes in climate that might be adverse to the well-being of humanity" and recalled the importance of acting internationally for the climate:

"The climates of the countries of the world are interdependent. For this reason and in view of the increasing demand for resources by the growing world population that strives for improved living conditions, there is an urgent need for the development of a common global strategy for a greater understanding and a rational use of climate. […] There is serious concern that the continued expansion of man's activities on earth may cause significant extended regional and even global changes of climate. This possibility adds further urgency to the need for global co-operation to explore the possible future course of global climate and to take this new understanding into account in planning for the future development of human society." (The Declaration of the World Climate Conference, 1979).

The early 80s discovered the global consequences of the air emission through the development of the Ozone Holes above poles. This global threat was directly addressed at an international level that lead to Montreal Protocol on Ozone Depletion issues. Adopted in 1985, the Vienna Convention for the M1 Climate Change and the Shipping Response Module 1 – Page 25

Protection of the Ozone Layer is a framework Convention aimed to address the issue of the ozone depletion.

The adoption of the Montreal Protocol on Substances that Deplete the Ozone Layer in 1987 (entered into force on January 1, 1989) enabled binding implementation of the Convention's provisions. These instruments are considered the first action towards the control of substances impairing global atmosphere balance. The Protocol banned man-made compounds known as stratospheric Ozone Depleting Substances (ODSs). These substances increased ultraviolet radiation at Earth's surface as a result of damage to ozone layer; that was observed as "ozone hole" above the Earth's Polar Regions. ODSs have also significant global warming effect; thus their control also positively impacts the control of climate change.

The Montreal Protocol has had lasting impact in both protecting the ozone layer and reducing climate change.

"Since most ODSs are also potent greenhouse gases, actions under the Montreal Protocol have had the very positive side effect of substantially reducing a main source of global warming." (UNEP, 2011)

Efforts during the 1970s and 1980 produced multiple international regulatory instruments to protect air quality. These instruments aimed to control identified substances but did not intend to holistically address the issue of climate change. In parallel to the creation of such instruments, several international conferences were organized on climate change but no internationally binding instrument was adopted.

1.3.2. The United Nations Environment Programme (UNEP)

Another important outcome of the UNCHE was the creation of the United Nations Environment Programme (UNEP), whose mandate is to coordinate the global response to established and emerging environmental challenges. The need for such an organization is clearly expressed in the UN Resolution 2997. The mission statement of UNEP is:

"To provide leadership and encourage partnership in caring for the environment by inspiring, informing, and enabling nations and peoples to improve their quality of life without compromising that of future generations." [UNEP]

UNEP activities cover the atmosphere, marine and terrestrial ecosystems, environment governance and green economy. After the Brundtland Report 'Our Common Future' and its validation during the 'Rio Summit' in 1992, the concept of sustainable development took centre stage in the UNEP's research and policy activities.

In the field of climate change, the UNEP supports countries and, in particular, developing nations with integrating the climate problem in their domestic development process. Four elements foster the achievement of this objective:

- Adapting to climate change: The purpose is to reduce vulnerability and improve resilience.
- Mitigating climate change: The UNEP supports technologies, policies and investments designed to reduce GHG emissions as well as energy efficiency and conservation programs.
- Reducing emissions from deforestation and forest degradation: The purpose is to valorise forests and sinks as well as promoting sustainable management of forest ecosystems.
- Enhancing knowledge and communication: The UNEP support education and awareness programs.

1.3.3. Intergovernmental Panel on Climate Change (IPCC)

Created under the auspices of the UNEP and the WMO, the Intergovernmental Panel on Climate Change (IPCC) was endorsed by the UN in 1988. The objective was to build an internationally recognized structure capable to regularly monitor and diagnose the evolution on the climate system and its consequences. Its mission is to review [UN, 1988]:

- The state of knowledge of the science of climate and climatic change.
- Programmes and studies on the social and economic impact of climate change, including global warming;
- Possible response strategies to delay, limit or mitigate the impact of adverse climate change;
- Identification and possible strengthening of relevant existing international legal instruments having a bearing on climate; and
- Elements for inclusion in a possible future international convention on climate.

In other words, the purpose of the IPCC is to provide a clear scientific view on climate change and its potential environmental and socio-economic consequences as well as propose control measures and solutions. IPCC is thus the ultimate expert authority on environmental issues in particular those related to climate change. The IPCC gathers the data published worldwide and produces assessments reports on the situation of climate change. Thousands of scientists participate in the IPCC in order to provide accurate, rigorous and reliable data to policy makers.

In 1990, the IPCC published its First Assessment Report (AR1-1990) with subsequent Assessment Reports at planned intervals. The most prominent one was the Fourth Assessment Report 2007 (AR4-2007). Assessment Reports are part of a series of reports intended to assess scientific, technical and socio-economic information concerning climate change, its potential effects, and options for adaptation and mitigation. The report is the largest and most detailed summary of the climate change situation ever undertaken, produced by thousands of authors, editors, and reviewers from dozens of countries, citing over 6,000 peer-reviewed scientific studies.

AR4-2007 supersedes the Third Assessment Report (2001), and in turn was superseded by the Fifth Assessment Report 2014 (AR5-2014). The headline findings of the AR4 were:

"Warming of the climate system is unequivocal", and "most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."

The IPCC's AR5-2014 (Fifth Assessment Report) was released in four principal sections that reflect the contributions of the following IPCC's Working Groups:

- Contribution of W/G I (WGI): The Physical Science Basis
- Contribution of W/G II (WGII): Impacts, Adaptation and Vulnerability
- Contribution of W/G III (WGIII): Mitigation of Climate Change
- Contribution of W/G I, II, and III: The Synthesis Report (SYR)

The AR5-2014 puts greater emphasis on assessing the socio-economic aspects of climate change and its implications for sustainable development. Some new features of AR5 as a whole include:

- M1 Climate Change and the Shipping Response Module 1 – Page 27
- A new set of scenarios for analysis across Working Group contributions.
- Dedicated chapters on sea level change, carbon cycle and climate phenomena.
- Much greater regional detail on climate change impacts, adaptation and mitigation interactions; inter- and intra-regional impacts; and a multi-sector synthesis;
- Risk management and the framing of a response (both adaptation and mitigation), including scientific information relevant to Article 2 of the UNFCCC referring to the "...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system".

The reports issued by the IPCC have to be endorsed during its plenary session by the governments' representatives which, subsequently, validate the scientific authority of the IPCC. However, despite its policy relevance, the work completed by the IPCC is not prescriptive. In addition to these assessments, the IPCC provides expertise to the Conference of the Parties (COPs) to the UNFCCC that is held annually, and other bodies as requested.

1.3.4. The United Nations Framework Convention on Climate Change (UNFCCC)

After years of intensive negotiation through the Intergovernmental Negotiating Committee on Climate Change, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted and opened for signature in 1992 in the Rio Summit (also known as Earth Summit). The UNFCCC entered into force in March 1994.

This Convention was drafted in accordance with the format designed for the Vienna Convention for the Protection of the Ozone Layer. The UNFCCC is another framework Convention which focuses on promoting cooperation by means of systematic observations, research and information exchange on the effects of human activities on climate and adopting legislative or administrative measures against activities likely to have adverse effects. This instrument does not set precise objectives. It is the reason why such a framework Convention is followed by Protocols detailing obligations such as Kyoto Protocol.

The UNFCCC was adopted on the following grounds:

- Climate change is a common concern of humankind requiring a global response.
- Human activities increase GHG emissions.
- Historically, developed countries played the first role in GHG release and should act immediately.
- Developing countries have a high degree of reliance on fossil fuels and may have difficulties addressing GHG issues. In addition, sustainable social and economic development of these countries may need additional energy consumption.
- Predictions have to deal with numerous uncertainties.
- States have the responsibility to make sure the activities under their jurisdiction do not harm other areas (UNCHE, 1972 - Principle 21); and
- The protection of the climate must encompass the environmental, social and economic impacts of the measures taken and be science-based.

The objective of the Convention (Article 2) is to prevent Climate System alteration by stabilizing GHG to a harmless level in order to avoid ecosystem disruption and economic disturbance. Among the guiding principles (Article 3) set in the UNFCCC, the following may be mentioned:

- The UNFCCC introduces the notion of "common but differentiated responsibilities (CBDR)" and respective capabilities. Based on principle of CBDR, the available capacity and historical contribution is linked to the evolution of a particular problem. Consequently, the Convention defines obligations for all Parties and specific requirements for developed countries which are listed in the Annex I & II (These are referred to Annex I and Annex II countries).
- The precautionary principle is highlighted by recalling that the lack of scientific data should not inhibit action.
- Sustainable development remains a guiding principle.
- The open international economic system should be promoted, and measures implemented to combat climate change should not justify restrictions on international trade.

Despite these declarations, the commitment does not require imperative GHG release reduction. The requirements imposed on States are limited to commitments (Article 4) and communication regarding implementation (Article 12). In short, all Parties have to:

- Develop and communicate to the Conference of Parties a "national inventory of anthropogenic emissions by sources and removals by sinks".
- Commit to develop and communicate the measures related to GHG control.
- Promote "technology transfer and the sustainable management, conservation, and enhancement of greenhouse gas sinks and reservoirs (such as forests and oceans)." (UNEP/UNFCCC, 2002)

- Consider climate change in social, economic and environmental policy development.
- Cooperate in sciences, techniques and education as well as exchange information related to climate change.
- Promote public awareness and education.
- Following the CBDR principle, the developed countries have to commit to additional requirements:
- They must play a leading role and demonstrate their commitment by developing measures and creating adequate strategies to reduce GHG emission.
- Their policies should aim at returning to their 1990's GHG emission level.
- Several countries may join to pursue a common target.
- The countries in transition to market economy benefit from certain flexibility in the implementation.
- The richest nations shall provide additional funding and facilitate technology transfer.

The UNFCCC "supreme body" is the Conference of the Parties (COP) which meets every year. The COP is a large forum for debates and information exchange, beneficial for all participants. The COP plays an important role in promoting, reviewing and supporting the Convention and its members that need support to implement regulations. In addition to the normal discussion, the COP may develop and adopt a protocol, like in 1997 during the 3rd COP in Kyoto for mandatory reduction of GHG emissions; this is known as Kyoto Protocol.

1.3.5. The Kyoto Protocol

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its Parties by setting internationally binding emission reduction targets.

The Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005. The detailed rules for the implementation of the Protocol were adopted at COP 7 in Marrakesh, Morocco, in 2001, and are referred to as the "Marrakesh Accords." Its first commitment period started in 2008 and ended in 2012.

Recognising that developed countries are principally responsible for the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity, the Protocol places a heavier burden on developed nations under the principle of "common but differentiated responsibilities."

In Doha, Qatar, on 8 December 2012, the "Doha Amendment to the Kyoto Protocol" was adopted. The amendment includes:

- New commitments for Annex I Parties to the Kyoto Protocol who agreed to take on commitments in a second commitment period from 1 January 2013 to 31 December 2020.
- A revised list of greenhouse gases (GHG) to be reported on by Parties in the second commitment period; and

- Amendments to several articles of the Kyoto Protocol which specifically referenced issues pertaining to the first commitment period and which needed to be updated for the second commitment period.

On 21 December 2012, the amendment was circulated by the Secretary-General of the United Nations, acting in his capacity as Depositary, to all Parties to the Kyoto Protocol in accordance with Articles 20 and 21 of the Protocol.

During the first commitment period, 37 industrialised countries and the European Community committed to reduce GHG emissions to an average of five percent against 1990 levels. During the second commitment period, Parties committed to reduce GHG emissions by at least 18 percent below 1990 levels in the eight-year period from 2013 to 2020; however, the composition of Parties in the second commitment period is different from the first.

The mechanisms help to stimulate green investment and help Parties meet their emission targets in a cost-effective way.

Monitoring emission targets

Under the Protocol, countries' actual emissions have to be monitored, and precise records have to be kept of the trades carried out.

Registry systems track and record transactions by Parties under the mechanisms. The UN Climate Change Secretariat, based in Bonn, Germany, keeps an international transaction log to verify that transactions are consistent with the rules of the Protocol.

Reporting is done by Parties by submitting annual emission inventories and national reports under the Protocol at regular intervals.

A compliance system ensures that Parties are meeting their commitments and helps them to meet their commitments if they have problems doing so.

Adaptation
The Kyoto Protocol, like the Convention, is also designed to assist countries in adapting to the adverse effects of climate change. It facilitates the development and deployment of technologies that can help increase resilience to the impacts of climate change.

The Adaptation Fund was established to finance adaptation projects and programmes in developing countries that are Parties to the Kyoto Protocol. In the first commitment period, the Fund was financed mainly with a share of proceeds from CDM project activities. In Doha, in 2012, it was decided that for the second commitment period, international emissions trading and joint implementation would also provide the Adaptation Fund with a 2 percent share of proceeds.

The road ahead

The Kyoto Protocol is seen as an important first step towards a truly global emission reduction regime that will stabilize GHG emissions, and can provide the architecture for the future international agreement on climate change.

In Durban, the Ad Hoc Working Group on the Durban Platform for Enhanced Action (ADP) was established to develop a protocol, another legal instrument or an agreed outcome with legal force under the Convention, applicable to all Parties. The ADP is to complete its work as early as possible, but no later than 2015, in order to adopt this protocol, legal instrument or agreed outcome with legal force at the twenty-first session of the Conference of the Parties and for it to come into effect and be implemented from 2020.

The Kyoto Protocol set binding emission targets for the developed countries in Annex I in order to pursue the ultimate objective of the UNFCCC: "with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012." (Article 3)

In addition, the Annex B of the Kyoto Protocol under the "quantified emission limitation or reduction commitment" contains the targets to be reached by individual countries. The GHG emissions are categorised as six main item including CO2, CH4, N2O, HFCs, PFCs and SF6.

To reach their targets, countries can reduce their emission and/or offset their emissions by investing in carbon sinks which generates removal units. To facilitate this, the Kyoto Protocol introduces three innovative mechanisms:

- Joint Implementation (JI)
- Clean Development Mechanism (CDM)
- International Emissions Trading

These mechanisms were designed to limit the cost of mitigation measures by permitting the investment in other countries (both Annex I and non-Annex I) in which emission reduction can be achieved at cheaper costs. However, such offset strategies of emission reduction in other countries must supplement domestic actions and not being the main objective of the country.

International transportation (shipping and aviation) and Kyoto Protocol

The existence of specialized agencies in charge of air and sea transportation avoided the UNFCCC and the Kyoto Protocol to establish specific rules or targets for these sectors. Instead, the Kyoto Protocol clearly identifies the responsibility of relevant special agencies in dealing with the issue in its Article 2.2 by stating:

"2. The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively." (Kyoto Protocol, Article 2.2)

Accordingly, the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) are required to pursue the objectives and intentions defined by the UNFCCC. Both ICAO and IMO have been heavily involved on issues relating to control of climate change and GHG emissions from aviation and maritime respectively.

Reference

United Nations Framework Convention on Climate Change, [Viewed 28th October 2016]. Available from: http://unfccc.int/kyoto_protocol/items/2830.php

Chapter 2: Ship-Board Operations and Energy Efficiency and references to Crew Responsibilities

2.1.Shipping Operations

2.1.1. 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 (CO_2) emissions.
- Adopt efficient voyage planning techniques to reduce distance sailed, minimise exposure to adverse weather 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 CO_2 reductions are then further discussed in other sections of this module.

2.1.2. 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 below.

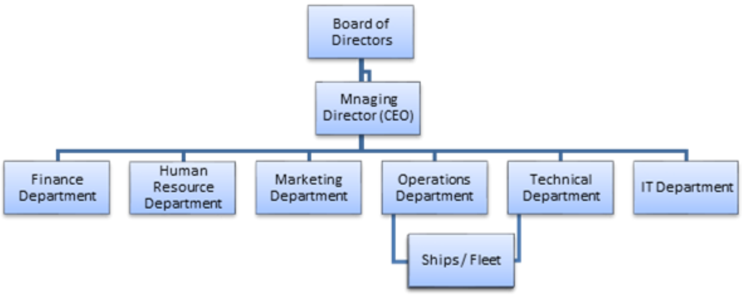

Figure 2.1: Typical organisation of a shipping company

Of the departments shown in figure 2.1., 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, dry dock, etc.

2.1.3. 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 usually around -162 ºC.

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, fruit, eggs, flowers, 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.

2.1.4. 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.

2.1.5. 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 containerised. 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.

Port operations involve a great many players, both at management level and at operational level. The management of ports also varies from one country to the other. The port as a physical entity is managed by a port authority in which the public authorities may or may not be a stakeholder. In addition, depending on the size of the port, any number of enterprises may be located within its perimeter. Figure below offers an overview of the various market players within a port, indicating who provides services to whom. The diagram confirms that shipping companies rely on services provided by third parties (e.g. pilots, towage services, ship repairers, provisioning, waste reception facilities, and bunkering companies) that are somehow but not fully associated with a port.

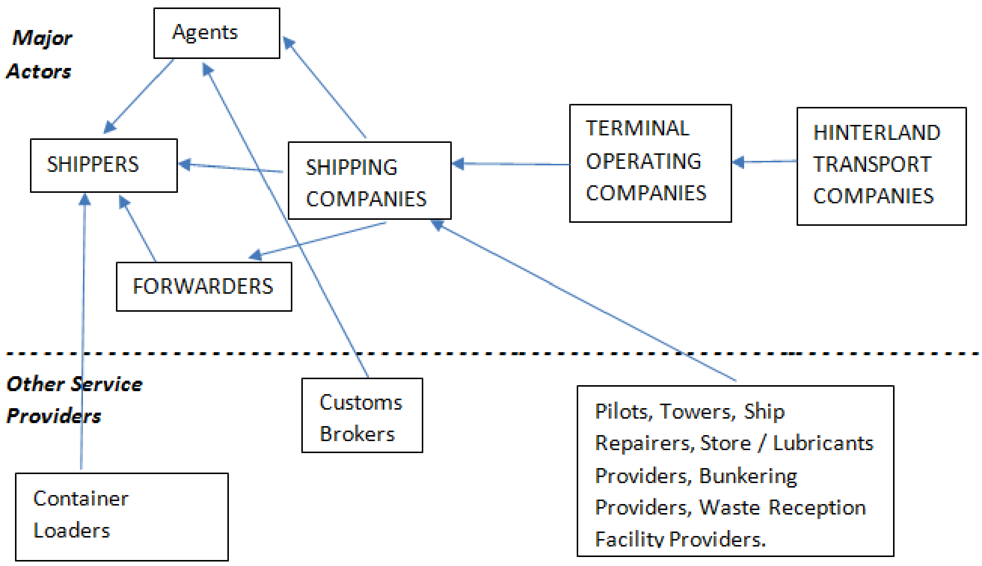

Figure 2.2: Schematic of major players in port-related activities [Meersman, Van de Voorde and Vanelslander]

The large number of parties involved in port activities, each of which pursues its own objectives, gives rise to a considerable degree of diversity, both within the port and between ports. Hence, a generalised comparison between ports may not be fully possible. Moreover, the situation is further complicated by the fact that different ports often work under different economic, legal, social and tax regimes just because they are regarded as part of national entities in each country. Thus, ports are to a large extent different from international shipping that is mostly regulated by IMO rather than by national-specific regulations that applies to ports [Hilde Meersman, et al].

The issues of governance, control and ownership are critical to any discussion of environmental management in ports. The vast majority of harbours are characterized by privately owned dock facilities and in these instances, control of property and operations lie with each private property owner.

Ports and air emissions

On the environmental side, one of the main issues that ports are facing is local air quality. This is caused due to air pollutants; rather the CO_2 emission that is the main topic of this training course. As most of activities relating to reduction of air pollutants have impacts on CO_2 emissions, in this module, the emphasis will be on all air emissions rather than simply CO_2.

In port areas, air emissions and energy consumptions are primarily due to ships. However, there are other equipment and facilities that use energy or contribute to air emissions to port areas. These are for example:

- Cargo loading and unloading devices.
- Trucks and other land-based transportation units such as locomotives.
- Buildings and energy needed for these building.
- Harbour crafts that provide additional services to port and shipping companies.

Emissions in port areas are mainly those due to diesel engines and boilers. These air emissions include:

- Nitrogen Oxides (NO_x): The main sources of NO_x are diesel engines both for ships and other land-based trucks.
- Particulate Matters (PM): Again, diesel engines are the main source of such emissions.
- Sulphur Oxides (SO_x): These are due to burning of sulphur content of fuel.
- Some carbon monoxide and unburned hydrocarbons could also be emitted from ship engines if they are not properly tuned.

The amount and level of such emissions will depend on not only technologies used but also operational aspects of ships, the time they stay in port and other energy using machinery and facilities in port itself.

Emission reductions in the port area are typically focused on PM, SO_x and NO_x due to air quality health impacts. Controlling NO_x, PM and SO_x is the central focus for most national and regional regulatory agencies and therefore the same applies for ports as does to the shipping industry. GHGs emissions have recently been seriously addressed by regulatory agencies such as IMO, although in the port area, health effects and thus pollutants typically take the priority over GHG emissions.

In a discussion paper by International Transport Forum [Olaf Merk], it is claimed that shipping emissions in ports are substantial, accounting for 18 million tonnes of CO2 emissions (this is equivalent to burning of about 6 million tonnes of fuel oil), 0.4 million tonnes of NO_x, 0.2 million tonnes of SO_x and 0.03 million tonnes of PM10 (PM with size of less than 10 microns) in 2011. Around 85% of emissions come from containerships and tankers. Containerships have short port stays, but high emissions during these stays.

The same paper states that most of CO2 emissions in ports from shipping are in Asia and Europe (58%), but this share is low compared to their share of port calls (70%). European ports have much less emissions of SO_x (5%) and PM (7%) than their share of port calls (22%), which can be explained by the EU regulation to use low sulphur fuels at berth. Future forecasts indicate that most of shipping emissions in ports are estimated to grow fourfold up to 2050. This would bring CO2-emissions from ships in ports to approximately 70 million tonnes in 2050 and NO_x -

emissions up to 1.3 million tonnes. Asia and Africa will see the sharpest increases in emissions, due to strong port traffic growth and limited mitigation measures.

The above indicates that various initiatives are needed to combat air pollution in ports. These will be discussed in this module with specific reference on CO2 emissions. Various ports have developed infrastructure, regulation and incentives that mitigate shipping emissions in ports. These instruments would need wider application in order for ship emissions in ports to be significantly reduced. It is important to note that the most contaminants ships in ports are the cruise ships.

2.1.6. 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.

2.1.6.1.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 trans-shipments to/from ocean-going vessels or to move cargoes between inland ports.

2.1.6.2.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.

2.1.7. Ship/Fleet Planning

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

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

2.1.7.1.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, which 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.

2.1.7.2.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 CO_2 emissions becomes an important decision-making aspect at this level.

2.1.7.3.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.

2.1.7.4.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 steerage 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.

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.

2.1.8. 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, the circle of maintenance and continuous survey of the ship is of 5 years, each year the Classification Society survey the ship on float and each 2,5 year the Classification Society survey the ship in dry dock. 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 caterers. 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.

Ship maintenance operations and management are fundamental for energy efficient operation of its machineries and systems. Deterioration of ship systems' condition takes place due to normal wear and tear, fouling, miss-adjustments, long periods of operation outside design envelopes, etc. As a consequence, equipment downtime, quality problems, energy losses, safety hazards or environmental pollution may result. The end outcome is a negative impact on the operating cost, profitability, customer satisfaction and probable negative environmental impacts. Thus good maintenance is in line with good performance and energy efficiency.

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 shoe-based staff.

The planned maintenance is organised based on makers prescribed maintenance frequency and a set amount of spares is supplied to vessel prior to the scheduled maintenance date. A computer operated maintenance database is maintained on board and in the shore office synchronised to upkeep all the maintenance info and spare parts availability etc. including maintenance procedure.

The breakdown maintenance is performed upon failure of a component or machinery. Though this procedure is cost saving but in the long run it may pose the vessel to undue delays and uncertainty of the schedule.

The Condition monitoring is another kind of diagnosis system of the machineries by which a decision may be made if a maintenance should be carried out by feeling its' running condition e.g. Vibration, load current, operation temperature etc. This is a cost saving procedure in respect to planned maintenance, and a maintenance requirement is assumed prior to a breakdown, however, the condition monitoring requires very highly skilled engineers to diagnose a fault.

2.1.9. Bunker Procurement

A ship may consume hundreds 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.

Due to the increasing fuel price shipping businesses normally use Heavy Fuel Oil (HFO) that is of lowest quality and the cheapest in price amongst marine fuels and could be of poor quality if care is not exercised during procurement and use. Control of quality and quantity of fuels purchased and also on-board fuel treatment can provide significant benefits for safeguarding the machinery from damage but also in terms of energy efficiency.

For the optimum energy gain from a certain grade of fuel it has to be treated with appropriate chemical compound to improve its' combustion quality. For appropriate atomisation of the fuel, it needs proper viscosity prior to injection to the combustion chamber. The viscosity is directly related to fuel temperature, therefore, it is of utmost importance to determine the injection temperature for that grade of fuel. This can be achieved either from the bunker delivery note or by lab test of the fuel.

2.2. Introduction to Shipboard Roles and Responsibilities

2.2.1. Shipboard Organisational Structure

The ship's crews are the personnel who sail on board a ship and are responsible for its operation and maintenance when the ship is at sea and at port. For the purpose of ship operation and traditionally, the crew of a commercial ship is divided into three departments:

- Deck department
- Engine department
- Catering (steward's) department.
- Radio Department

Figure below shows some typical ship-board management organizational charts. A brief description of the important roles is given below.

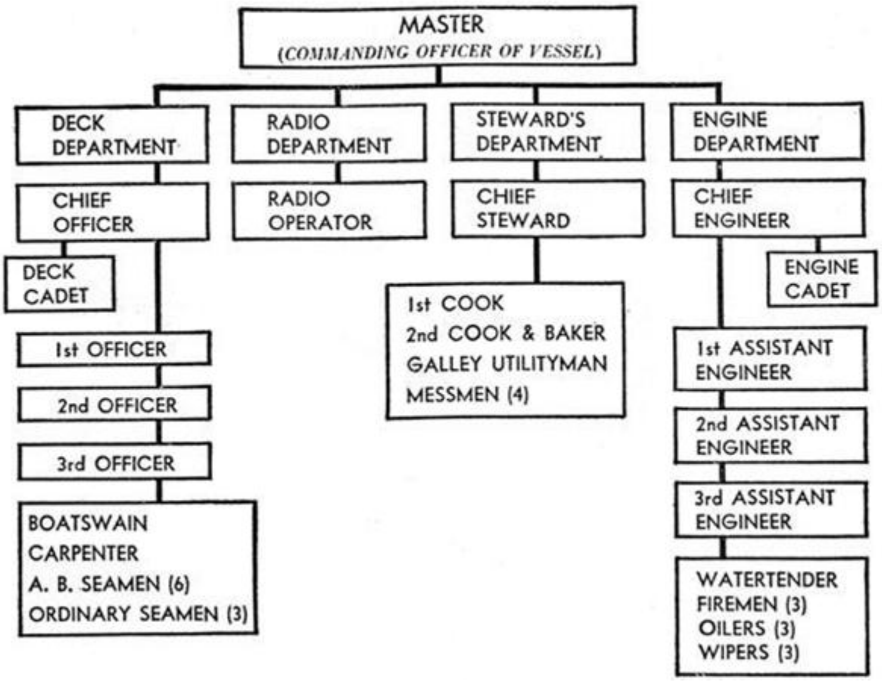

Figure 2.3: Typical Shipboard Organogram with three main departments. The Radio Department is obsolete as a result of the implementation of GMDSS certificates to the Deck Officers

The Master or more commonly the Captain is the ship's highest responsible officer, known as the supreme authority of the vessel acting on behalf of the ship's owner / operator or the manager. The Captain is legally responsible for the day-to-day management of the ship. His responsibility is to ensure that all the departments on board perform legally to the requirements of the ships' owner /operator or manager. Also, each shipboard department has a designated head who reports to the master. The deck department is headed by a Chief Officer. The engine department is headed by a Chief Engineer. He has other licensed engineers to assist him with engine room watch and the performance of maintenance and repair activities in the engine room. The Chief Steward is the head of the catering department.

2.2.2. Deck Department

Chief Officer: The Chief Officer is the head of the deck department. He is second-in-command after the ship's master. The Chief Officer's primary responsibilities are the vessel's cargo operations, its stability and supervising the deck crew. The Chief Officer is responsible for the safety and security of the ship, as well as the welfare of the crew on board. The Chief Officer typically stands the 16:00 to 20:00 hours and from 04:00 to 08:00 hours of navigation watch. Additional duties include ensuring good maintenance of the ship's hull, cargo gears, accommodations, the lifesaving and firefighting appliances. The Chief Officer also trains the crew and cadets on various aspects like safety, firefighting, search and rescue and various other contingencies.

Second Officer: The Second Officer is usually in charge of ship navigation with a position below Chief Officer and above Third Officer. He/she is the third-in-command, after the Master and Chief Officer. The second officer typically stands watch from 12:00 to 16:00 at noon and again from 00:00 to 04:00 in the nights.

Third Officer: The third officer primarily charged with the safety of the ship and crew. The Third officer generally serves as the ship's chief safety officer. The Third Officer is the next licensed position on board the vessel, as fourth-in-command. The third officer typically stands watch from 08:00 to 12:00 at noon and again from 20:00 to 24:00 in the nights.

2.2.3. Engine Department

The engineers on board ships are also called technical officers. They are responsible for keeping the machinery maintained and operational. Today, ships are complex systems that combine a lot of technology within a small space. This includes not only the engines and the propulsion system, but also for example, the electrical power supply, devices for loading and discharging, garbage incineration and freshwater generators. Additionally, more and more environmental protection technologies, fuel treatment systems and cargo conditioning devices are used on board ships. The upkeep of all these are in the hands of engine department staff. The ship is like a city that needs all kind of services like electricity, fresh water, sewage treatment, etc. and all of them must be produced under the knowledge and responsibility of the officers of the engine department.

Chief Engineer: The Chief Engineer on a commercial vessel is the official title of an Engineer qualified to manage and oversee the technical department of the vessel. The qualification for this position is the Marine Engineer Class 1. The Chief Engineer is responsible for all operations and maintenance of all engineering equipment throughout the ship. He reports directly to the Captain on all issues related to technical dept.

Second Engineer: The Second Engineer is the officer responsible for supervising the daily maintenance and operation of the engineering systems. He or she reports directly to the Chief Engineer. The Second Engineer is second in command in the engine department after the ship's Chief Engineer. The person holding this position is typically the busiest engineer on-board the ship, due to the supervisory role this engineer plays, and the operations duties performed. Operational duties include responsibility for the refrigeration systems, main engines and any other equipment not assigned to the third or fourth engineers. The second Engineer typically stands watch from 16:00 to 20:00 at noon and again from 04:00 to 08:00 in the nights.

Third Engineer: The Third Engineer is junior to the second engineer in the engine department and is usually in charge of boilers, fuel, auxiliary engines, condensate, and feed systems. This engineer is typically in charge of bunkering, if the officer holds a valid certificate for fuel transfer operations. The third Engineer typically stands watch from 08:00 to 12:00 at noon and again from 20:00 to 24:00 in the nights.

Fourth Engineer: The Fourth Engineer is junior to the third engineer in the engine department. The most junior certificated marine engineer of the ship, he or she is usually responsible for electrical, sewage treatment, lube oil, bilge, and oily water separation systems. Depending on usage, this person usually stands a watch. Moreover, in some companies the fourth engineer may assist the third officer in maintaining proper operation of the lifeboats. The fourth Engineer typically stands watch from 08:00 to 12:00 at noon and again from 20:00 to 24:00 in the nights.

2.2.4. Steward's Department

Chief Steward: The Chief Steward directs and assigns personnel that do functions such as preparing meals, cleaning and maintaining officers' quarter, and managing the stores. The Chief Steward also does other activities such as overtime and cost control records and may requisition or purchase stores and equipment. Other additional duties may include taking part in cooking activities. The Chief Steward is assisted by a chief cook and his/her assistant cooks, mess men and assistant stewards.

2.2.5. Shipboard Activities for Energy Efficiency

Considering the above description, all ship crews have certain degree of roles to play on ship energy efficiency. Each crewmember's role is different to achieve the same goal. For example:

The Master, being overall in charge, has a significant impact on all aspects of ship operation including planning, execution, controls and evaluations. The Master in particular could influence significantly all ship operational issues. Without Master's full awareness and drive, ship energy management is unlikely to succeed on-board ships. Areas that Master could significantly impact are those related to ship operational aspects such as voyage management, weather routing, just in time arrival and so on. The Master has the authority to reroute the vessel at more convenient and cost saving way as well as he has the decision-making capacity to reduce the vessel speed to complete a voyage at much lower fuel consumption but without making significant delays. The master's management skill has significant implications for ship energy efficiency. So, a ship's Master could have the highest influence for an energy efficient ship operation than any other ship-board staff.

The Chief Officer plays significant roles on the cargo and loading/unloading operations, ballast management operations, trim optimisation and aspects of hull and propeller condition and maintenance, etc. In this regard, all detailed operational issues are handled by Chief Officer and in this way he/she exerts a lot of influence on various ship activities including energy and environmental management. Good communications between Chief Officer and Chief Engineer would provide a more optimised operation between deck department requirements and engine department efficiency and maintenance requirements. Based on this, the Chief Officer is the second most important person on deck department that could influence the overall ship energy efficiency.

The Chief Engineer being in overall charge of technical aspects of ship engineering systems and machinery operations where the fuel is consumed and energy transformed, could play a major role on technical issues including the condition and performance of engines and various machinery and the way they are utilised. The Chief Engineer normally carries out most of the machinery condition assessment activities, engine record logs and reporting and communications with Master and Chief Officer. The Chief Engineer is the competent person to calculate the optimum output of an engine with the minimum fuel consumption and he has the expertise to control air emission at the same time. By virtue of having the full picture of all engineering system, Chief Engineer is the most important person on-board in terms of energy efficiency implementation and execution.

The Second Engineer, by virtue of being the most engaged person in the engine department on day to day operation and maintenance of various systems, has the second most important role in engine department in ensuring that all machinery are in optimal working condition and performance as well as their usage are limited to requirements.

The other officers and crew members also play vital roles to maintain energy efficiency on board. The watch keepers keep the bare minimum machineries in operation to save energy. They can monitor the auxiliary engine loads and can decide if parallel running of multiple engines is good for economy at all. They can monitor the main engine load and inform the Chief Engineer for necessary action. Similarly, the deck officers can monitor the vessel trim, weather condition etc. to manipulate the best energy efficient option.

2.2.6. Importance of Communications between Departments

One of the issues observed most of the time is the lack of optimal organisational communications between various departments that lead to waste of energy. For example, communication between deck and engine departments is essential for machinery use optimisation. In an effective ship-board energy efficiency programme, the collaboration and communications between all departments need to be enhanced. This may be achieved via consideration of energy efficiency at daily meetings and relevant ship-board work planning for reduction of electricity and steam consumption, for compress air, produce fresh water, etc.

The Engine and Deck department can jointly make an electricity consumption plan in the morning meeting where they can exchange information as how many cargo cranes will be operating throughout the day and at what rate the ballasting operation is required. The Engineers would then decide on load demand if a parallel operation of two generators is essential. For ballast operation a variable motor speed devise may be put into operation if the full capacity of the ballast pump is not required. Similarly, catering department can inform engine department in advance the usage of hot plates in order for the engineers to make an energy demand plan.

It is always a very good energy saving method to run one generator at full load rather than running two at half load. Therefore, it is essential to maintain a very good communication between the departments to know how much would be the load demand for the day and number of generators to run in order to optimise the energy efficiency.

2.3.Ship-Board Energy Efficiency Measures

2.3.1. Introduction

The energy efficiency measures relating to ship's operation/commercial management have been widely argued and shown that these kinds of measures are not fully under the control of ship staff, thus the issue of communication and coordination between ship, shore office, charterer, shipper, etc. are under consideration to manage the ship's operation energy efficiently.

For a complete success in energy efficiency management, measures have to be taken to a large extend and primarily to the hands and under the control of the ship-board staff (although not all of them by 100%). They could be the subject of ship's in-passage activities for energy efficiency. An overview of major aspects of shipboard activities that impacts the ship's fuel consumption coming under this category are briefly introduced first and then fully described in other sections of this chapter.

2.3.2. Optimized Ship Handling

Optimum trim: Most ships are designed to carry a designated amount of cargo at a certain speed for certain fuel consumption. The same applies to ballast operations. Whether loaded and unloaded, for such conditions, normally there exists a ship trim that minimises the propulsion power, thus main engines' fuel consumption. In fact, for any given draft there is one optimum trim that gives minimum ship resistances. In some ships, it is possible to assess optimum trim conditions for fuel efficiency continuously throughout the voyage. Setting the ship trim is to a large extent in the hand of shipboard staff although loading, operational and navigational constraints may limit the full extent of proper use of this energy efficiency measure.

Optimum ballast: Ships normally carry ballast water to ensure ship's stability and safety. Normally, ballast levels should be adjusted taking into account the requirements to meet ship stability, steering aspects of the ship and optimum trim. This does not necessarily mean carrying lots of ballast water all the time. This unnecessarily increases the ship displacement that directly increases fuel consumption. Thus there is an optimum ballast condition that needs to be achieved through good cargo planning as well as voyage planning. Therefore optimising the ballast levels for energy efficiency within the framework of ship stability, safety, steerability and optimum trim can be regarded as an energy efficiency measure.

Optimum use of rudder and autopilot: There have been large improvements in automated heading and steering control systems technologies. Whilst originally developed to make the bridge team more effective, modern autopilots can achieve much more. An integrated navigation system can achieve significant fuel savings by simply reducing the distance sailed "off track". The principle is simple; better course control through less frequent and smaller corrections will minimize losses due to rudder resistance. In some cases, retrofitting of a more efficient autopilot to existing ships could be considered.

2.3.3. Optimized Propulsion Condition

Hull maintenance: Hull fouling always happens in ships. The rate of hull fouling will depend on a number of factors such as quality of paint, ship service speed, periods of idle /waiting and ship geographical area of operation. Hull resistance can be optimized by new advanced coating systems, possibly in combination with hull cleaning at certain intervals. Regular in-water inspection of the condition of the hull is recommended. Consideration may be given to the possibility of timely full removal and replacement of underwater paint systems to avoid the increased hull roughness caused by repeated spot blasting and repairs over multiple dry dockings.

Propeller cleaning: Propeller cleaning and polishing or even appropriate coating may significantly increase fuel efficiency. The need for ships to maintain efficiency through in-water hull and propeller cleaning should be recognized and facilitated by port States.

Main engine maintenance: Marine diesel engines have a very high thermal efficiency (~50%). This is the best efficiently currently available on the market and is the main reason why diesel engines are unrivalled in shipping. The high efficiency is due to the systematic minimisation of heat and mechanical loss of such engines and improved performance parameters that has taken place over many decades. In particular, the new breed of electronic controlled engines can provide efficiency gains with wider flexibility for example for slow steaming. To keep these engines in optimal condition and performance, they need to continuously undergo on-board condition and performance monitoring. Maintenance in accordance with manufacturers' instructions in the company's planned maintenance schedule will also maintain efficiency. The use of engine's condition monitoring can be a useful tool to maintain high efficiency.

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Chapter 3: Trim, Hull and Propeller Design and Optimisation

3.1. Trim Optimization Introduction

Most ships are designed to carry a certain amount of cargo at a designated speed, consuming a certain amount of fuel under a specified trim condition. Loaded or ballast, trim has a significant influence on the resistance of the ship through water. Therefore, optimizing the trim can deliver significant savings. For any given draft and speed, there is a trim condition that gives minimum resistance. Therefore, the vessel optimum trim is a function of draft and speed. A ship's optimum trim may be established as part of routine operations or through tank testing or use of computational methods. Nowadays, Computational Fluid Dynamics (CFD) methods are extensively used to estimate optimal trim settings for energy efficiency. However, these may require information from ship model tests and /or full-scale measurements. Operationally, design or safety factors may preclude the full use of trim optimization. The possibility of trimming a ship should be seen in relation to stability, manoeuvrability and other safety and operational aspects. It is the master or chief officer of the vessel that will ultimately ensure all situations are considered. To ensure best practice, the concern of masters with regard to loading and ballasting aspects needs to be taken into account.

3.1.1. Economic Benefits

Trim optimisation has significant economic benefits in terms of fuel savings. These economic benefits will vary from one ship size and type to others. It should be emphasised that even small trim changes can have a large impact on vessel performance. A 2% to 4% reduction potential in fuel consumption is generally referred to in most literatures. However, depending on ship type and operation draft, this number may be higher or lower. Therefore, for energy saving, all possible measures should be tried to help with ensuring that this potential is realised. Sailing just 5-10 centimetres off optimal trim might cause ships to operate at higher fuel consumption levels than normal [Tero Illus, 2012]. There is a bulk of evidence on significant fuel saving potentials due to trim. Ship resistance is altered due to the trim of a vessel through viscous resistance which is a function of the wetted hull surface area. When trim changes, wetted surface area and thereby hull resistance will be affected. By definition, if resistance increases, fuel consumption and emissions also increase. Thus, to reduce fuel consumption and emissions, trim needs to be optimised before and during a ship's voyage through a proper loading of the ship or use of ballast water in order to achieve a floating position that consumes the least propulsion power. Ships normally record their trim before the voyage by directly reading the draft marks. So, considering that the weight distributions on the ship allow trim adjustment, finding the appropriate and optimal floating position before voyage becomes possible (this is referred to as "static trim" when ship is not sailing). However, knowing the exact trim and draught during a ship's voyage is important. The trim under operational condition is normally referred to as "dynamic trim" and is different from "static trim" due to the impact of ship motion. Its measurement requires real-time readings through sensors and relevant on-board data systems.

A vessel with high trim and draught fluctuations (more changes of dynamic trim) during its voyage might benefit more from trim adjustments than the one with small fluctuations. The following are two real examples of proven savings by trim optimisation:

- **Containership Example [Tero Illus, 2012]:** This case is for a 5,500 TEU container ship over 136 sea days crossing. It was found that the average percentage of propulsion power loss due to non-optimal trimming was 5%, whilst the vessel was on long, trans-oceanic legs, although lower on shorter and more coastal routes. The trim-related saving potential was calculated at 350 tons of HFO for the crossing. Even if operational constraints meant that the ship was only able to follow an optimum trim 80% of the time, 280 tonnes of fuel would still have been saved. Such a saving translates into more than US$ 100,000 reduction in bunker costs for the vessel operator in less than five months.
- **VLCC Example [Melvin Mathew, 2012]:** The results of a study on the impact of trimming on a VLCC showed that VLCCs can benefit significantly from trim optimisation due to their size and rate of daily consumption. The saving is dependent on the rate of use of the suggested optimum trim by the crew. This can be influenced by external conditions, such as extreme weather, as well as the crew's commitment to apply the trim guidance given to them. This study showed that proper use of trim adjustments, translates into propulsion energy savings of 1.8%, which equates to about 505 tonnes of fuel consumption reduction with saving levels of more than US$ 200,000 annually.

3.1.2. Definitions

Trim: Trim is normally defined as the difference between the aft draft and the forward draft:

Trim = dA - dF

Where: dA Aft draft (m) dF Forward draft (m)

When the trim is positive, it means that the stern of the vessel is more inside the water than forward. Accordingly, positive trim means trim to aft and negative values of trim means trim to forward. The concept of trim is shown in figure below.

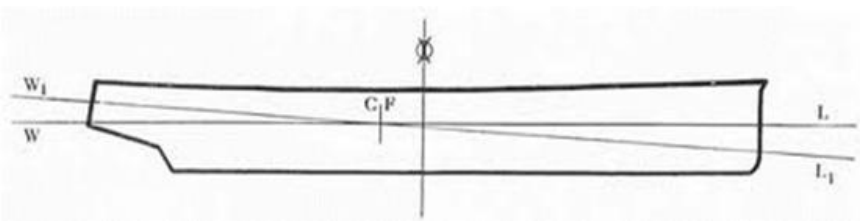


Figure 3.1: Concept and definition of trim

Optimum trim: Optimum trim refers to a ship's trim under which the required propulsive power is minimal for the specific operational speed and draft of the vessel.

Load planning: The ship loading plan specifies the loading levels and how the loads should be distributed in different cargo spaces. The load planning should be done by consideration of corresponding regulations (e.g. load line convention) but above all the ship stability. The process of loading of a ship is with port's staff and loading superintendents but the master or chief officer is ultimately responsible for all the loading and unloading operations.

Loading computer: A loading computer system is a computer-based system for the calculation and control of ship loading conditions for compliance with the applicable stability requirements and longitudinal and local strength requirements. The ship-board loading computer system consists of software (calculation program) and an appropriate computer (hardware).

Lodicator: The Lodicator is an approved instrument on board which can facilitate the following calculations:

1. Cargo stow plan, underdeck & on deck of all types of cargo.

2. Weights distribution to check deck load not exceeded.

3. Draft, Trim, Stability and Strength calculations.

The pre-stowage plan of the container weights are fed in through a disc supplied by the shore planner, which is a great convenience over manual feeding of thousands of containers, their numbers, weights, ports of loading and destination, and type of cargo, if dangerous, reefer, etc.

Even keel: This refers to ship condition when the draft of a ship fore and aft is the same. In other words, even keel refers to zero trim.

Static trim: This refers to a ship's trim when the ship is in still water (not moving). In this case, it is the difference between aft and forward drafts; mainly dictated by the ship's cargo, ballast, fuel on board, etc. distributions.

Dynamic trim: This refers to a ship's trim when the ship is underway and moving. It is different from static trim due to the ship sinkage phenomena. The ship sinks down relative to the still water level when it is underway, due to its forward movement and environmental effects. The level of sinkage is characterised by a dynamic sinkage at the forward and a dynamic sinkage at the aft of the ship. Normally, the forward sinkage is more than the aft sinkage and is a function of ship speed as well. Dynamic trim thus is static trim plus trim changes due to ship sinkage while underway.

3.1.3. Physics of Trim

A ship's resistances and its trim are closely related to each other. This is due to the fact that trim could change parameters that impact the hydrodynamic performance of a ship. The high impact of trim on ship performance is well known in particular for container ships and Ro-Ro vessels. Large fuel savings are claimed due to changes to the ship trim.

The possible explanations for the relatively large dependencies of ship performance on the trim could be attributed to the following impacts of trim [Force Technology 2011]:

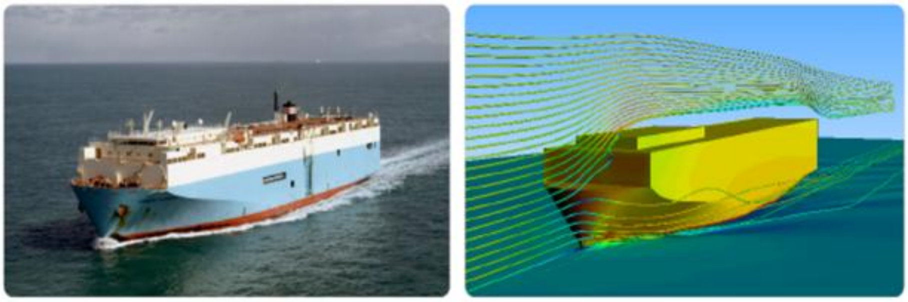
- Changes to wave resistance
- Changes to wetted surfaces and thereby the frictional resistance.

- Changes to form resistance due to transom submergence
- Changes to various propulsion coefficients including:
- Resistance coefficients
- Thrust deduction.
- Wake fraction
- Changes to propulsive efficiencies including:
- Relative rotative efficiency.
- Propeller efficiency

On fast container ships and Ro-Ro vessels, there is much to be gained by introducing the correct (optimum) trim. However, a reduction in fuel consumption due to changes to trim might be achieved even on tankers and bulk carriers [Force Technology 2011].

Impact of trim on powering requirement

There are different methods of determining a ship's optimum trim. The best results are obtained from self-propulsion tests using a scale model (model tank testing). In self-propulsion tests, not only the changes in hull resistance are investigated and the choice of propeller is examined but also the propulsion coefficients are normally measured. These tests, if performed over a sufficient range of speed and draft, could provide input in identifying optimum trim. Figure below shows the parameters that are normally measured under self-propulsion tests.



When you choose trim optimisation from Lloyd's Register we create a computer model of your ship, enabling us to perform a rapid and cost-effective analysis.

Speed		14 – 15.9 knots						16 – 17.9 knots					
Trim (metres)		-2 – -1.51	-1.5 – -1.01	-1 – -0.51	-0.5 – -0.01	0.01 – 0.5	0.51 – 1	-2 – -1.51	-1.5 – -1.01	-1 – -0.51	-0.5 – -0.01	0.01 – 0.5	0.51 – 1
Draught (metres)	7.9 – 8.5	Avoid 6.4%	Fair 2.5%	Good 1.6%	Optimal 0.0%	Fair 2.2%	Avoid 8.5%	Avoid 4.5%	Fair 2.1%	Good 6.4%	Optimal 0.0%	Fair 3.2%	Avoid 7.2%
	7.2 – 7.85	Fair 2.0%	Good 0.6%	Optimal 0.0%	Good 0.3%	Good 0.9%	Fair 2.8%	Good 1.2%	Good 0.6%	Good 0.0%	Optimal 0.0%	Good 0.4%	Avoid 3.3%
	6.5 – 7.15	Good 0.6%	Good 0.2%	Optimal 0.0%	Good 0.6%	Fair 2.0%	Avoid 3.0%	Good 0.1%	Optimal 0.0%	Good 0.1%	Good 0.5%	2.0% Fair	Fair 2.8%

An example section of the trim optimisation table you will receive for your ship. This contains a set of optimal trims according to draught and speed, and is specific to your vessel.

Source: Lloyd's Register

Figure 3.3: Trim Optimisation Guidance Table

Alternatively, with today's accuracy, trim tables based on use of CFD software tool calculations can be comparable to resistance model tests. However, both resistance tests and CFD methods tend to ignore the impact of the propeller; this may have a significant impact on evaluations of vessels with light drafts. To determine the optimum trim, the vessel's loading conditions need to be investigated in order to find the extreme operational speeds and drafts. A test matrix is then set up; with drafts evenly divided in the test matrix. Typically, the ship is tested at both forward and aft trims depending on the feasibility of the vessel to undergo those trims. Normally, forward trim is often not possible for the lighter drafts due to restrictions in the propeller's submergence. Also, a simple resistance test under light drafts with aft trim, will not give the correct trim indication as the effects of the propeller inflow and submergence that makes a positive contribution to performance are not present. Figure above by Lloyd's Register shows an example of such trim guidance table developed using CFD. As indicated, the ship is converted into a digital model with consideration of both ship hydrodynamics and aerodynamics. This digital model that resembles the full-scale ship model is then trimmed at a variety of ship speeds and drafts and corresponding fuel consumption is estimated. The fuel consumption is then normalised relative to optimum values to show trims that would lead to high fuel consumption.

3.1.4. Operation Guidance

The current industry practice points to the fact that in the great majority of cases, even keel operation (zero trim) is the normal practice. This generally may represent the optimal trim for ships with high block coefficients and non-pronounced bulbous bow (e.g. bulkers and tankers). These ships are not normally operating at very high speeds; thus, having a relatively lower wave making resistance. In ships with a slimmer body and higher speed, the impact of trim on performance could be significant. In particular, the trim may have impact on performance of the bulbous bow, and thereby wave making resistance. This will signify that these types of ships are more sensitive to trim and therefore greater care should be exercised with trim optimization. With the recent development in energy efficiency regulations, more companies have opted out to establish their ships' optimum trims; with the extensive use of CFD capabilities for this purpose. The issue, however, is that all the saving levels given are based on analytical forecasts and it is extremely difficult to do actual in-operation measurements to confirm the level of fuel savings. Based on the above facts and for best practice, it is not sufficient to develop a trim matrix and then assume that the specified trim guidance is going to lead to energy efficiency. Practical tests and trials will be required to refine the trim tables. The best way is to use these trim guidance tables but also at the same time gather feedback from masters on their judgement of trim table and its impact on ship powering requirements. The feedback by masters on best trim for ship handling and powering requirements can help to refine the company best practice in this important area. In using trim optimization, the following ship types would be given greater consideration:

- Container ships
- RoRo cargo and passenger ships
- RoRo car carriers

As indicated above, in addition to identifying and documenting the optimum trim as a function of ship speed and draft, it is proposed that the experience gained by ship staff on the impact of trim on a vessel's fuel consumption should be gathered in order to improve the ship's "trim matrix". Also, the effective use of the loading computer's capabilities is important to ensure safe trimming of the vessel with an optimal level of ballast water.

3.1.5. Tools for Support

There is a number of tools that could be used for this purpose:

CFD methods for trim matrix: The effect of trim on fuel consumption can be measured at the model scale in a towing tank or simulated at full scale using CFD. Many different speed and draft combinations can be simulated in a time efficient manner using fully viscous flow description analytical techniques. As a result, a trim matrix or map similar to that shown previously can be specified, where the optimum trim as a function of ship speed and draft are specified. The ship master or deck officer would normally follow this as a guide for setting the trim.

Dynamic trimming systems: These systems rely on a number of signals that are recorded whilst the ship is underway. The signals provide an indication of the ship's actual trim and some performance aspects of the vessel. Then the system uses analytical or artificial intelligence methods to forecast an optimum trim. Similar to "trim matrix" as explained above, this makes a good deal of theoretical sense, but the actual effectiveness has yet to be established. Dynamic trim optimization includes collecting and monitoring real-time data of propeller thrust and manoeuvring rudder angles, weather conditions and sea-state. These data are then analysed constantly, and the optimal trim value is calculated and displayed on a real time basis to give advice to the crew on-board.

Loading computers: The change in ship trim is achieved via cargo load planning and a ballasting plan when in port. When underway, the shift of ballast water and fuel between their relevant tanks may be used to adjust trim. During loading, occasionally there are limitations for achieving optimum trim due to the level of cargo and loading limitations that may not allow additional ballast for a proper trim. Nowadays, loading computers provide additional functionality for the representation of trim, optimal trim and also loading options to achieve the optimal trim. Trim linked to a loading computer helps the deck officers to achieve a better loading plan and optimal trim.

There is a direct method that consists in measurement the power developed for the main engine and to change the trim to get the best trim with the minimum power and minimum fuel consumption.

3.1.6. Barriers to Trim Optimisation

The good application of trim optimisation can be affected by the following constraints:

Ship loading: The weight distribution on board must be determined in order to allow trim optimization. Therefore, adequate communication between ship and port is paramount. As stated above, the loading computers may be effectively used for safe loading as well as for setting the optimal trim.

Operational risk challenges: This includes the oversight of bending moments and shear forces when practicing trim optimization. In this respect, it should be noted that not all vessels have real time stability assessors or calculators on-board. Additionally, danger to cargo in particular for those ships with deck cargos, is also another constraint.

Real-time bunker and water transfers on-board: The officers on the watch might have incomplete knowledge of the bunker and water (grey/fresh water) transfers on-board. Therefore, they may not be aware of the effects of such activities on the trim. Again this highlights the importance of shipboard communications between deck department and engine department.

Watch changeover: Sometimes the information regarding ballast operations is not passed on during the watch changeover between the crew. Removing of the above barriers requires not only good understanding of the subject and training of ship-board crew and their dedication on best practice but also a continuous improvement approach to the problem for long-term sustainable culture of best practices.

3.1.7. Trim Optimisation Frequently Asked Questions

In this section, a number of frequently asked questions are raised and a summary of the discussion in this section is provided.

How much trim impacts fuel consumption?

There is no clear-cut answer to this important question. Whilst the impact of trim is known to be significant under some conditions or for some ship types, there are no hard facts from ships' actual operations on the exact level of savings that may be made using perceived optimal trim. This is due to the fact that the measurement of savings under real operational conditions is quite difficult to assess. There is ample evidence from model tank tests and CFD analytical methods that show trim has a significant impact on ship fuel efficiency performance.

How does the optimal trim change with ship speed?

The change in optimal trim with ship speed and draft is through its impact on various types of ship resistances. It is quite reasonable to find that the optimal trim varies with ship speed and ship draft, but this relationship will vary from ship type to ship type.

Is in-passage ship trim different from the trim set when in port?

It is well known that when the ship trim is set to zero during loading (even keel), the ship will give trim by bow due to the impact of ship speed (due to the ship sinkage phenomena). This means that the trim of the vessel while underway is different from its trim while at berth or waiting.

How in practice is trimming done while a ship is underway?

This is done via a shift of ballast water, and in some cases bunker fuel, between alternative tanks and possibly shift of water.

Is optimum trim different for loaded versus ballast conditions?

A ship's hydrodynamic performance under loaded and ballast conditions could be significantly different due to changes in draft and wetted surface area and performance of the bulbous bow. The same is true for trim under loaded and ballast conditions. Therefore, there is a need to have the optimal trim established for various draft levels. Also, for ships operating in a variety of loading, and therefore variety of draft conditions, the optimal trim needs to be established for all the working drafts.

How is the trim set / changed?

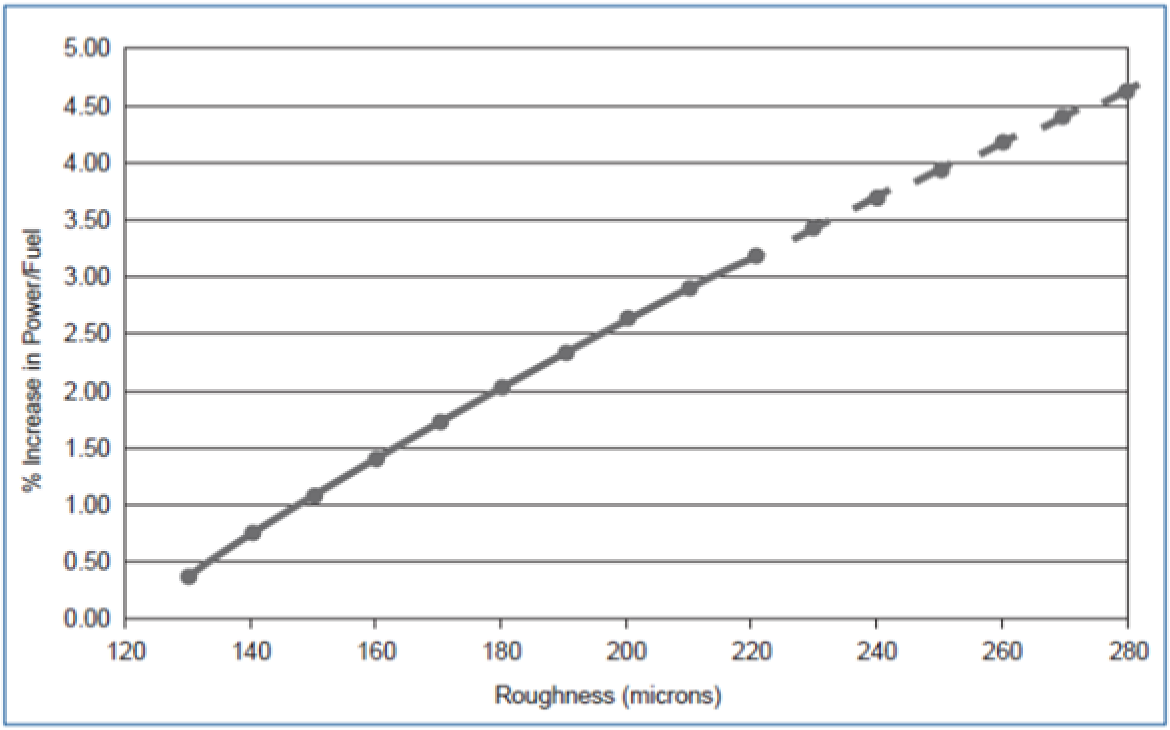
The change in ship trim is achieved via the proper cargo load planning and ship ballasting plan. The combination is used to achieve the desirable trim. After the loading is complete, ballast water shifting and to some extent bunker fuel shifting between tanks can be used to aid trimming. In any case, it is better that load planning is done by considering the optimal trim as otherwise it may not be possible to trim the ship properly with the use of ballast water only. Based on what has been described in this section, the following may be stated:

- Trim could influence ship fuel consumption significantly, with the evidence showing up to 4% of savings.
- Trim impact is the result of changes to ship hydrodynamics and thereby ship resistances.
- For every ship, there is an optimal trim that will give minimal ship resistances and maximise fuel efficiency.
- The optimum trim is a function of ship speed and draft.
- For certain ship types, in particular those with higher design speed, slimmer body, pronounced bulbous bow and flat stern design, trim will provide more impact.
- Optimal trims are established either through extensive model testing or CFD analytical methods.
- To achieve optimal trim, due consideration should be given to ship loading and its load planning.
- Ballast water, and to some extent bunker fuel, may be used to trim the vessel.
- Most loading computers on-board provide functionalities and trim tables to achieve the desirable ship trim.
- It is difficult to measure the actual saving levels due to trim while the ship is underway due to impact of other operational conditions (speed, draft, weather and sea impacts).

3.2. Hull and Propeller Condition

7.2.1 Ship Resistance and Hull Roughness

As discussed earlier, the ship resistances due to wetted surface areas are composed of frictional and wave making resistance. Frictional resistance, in particular for slower speed ships, is the primary component of total resistance. A tanker at its design speed will use the majority of its fuel overcoming frictional resistance when sailing in calm water. When the hull moves through the water, water will be dragged along, creating a body of water following the ship and forming what is referred to as a “boundary layer”. In the forward part of the ship this boundary layer will be comparatively thin, but it grows in thickness along the sides of the hull. A boundary layer will form even on completely smooth hull surfaces. Increasing the roughness of the hull surface tends to increase the boundary layer, consequently increasing the frictional drag of the hull. In ship resistance, another major player is the ship speed relative to water close to hull surface. The effect of surface roughness on the resistance depends on the effective speed of the water relative to the hull, and this varies over the hull surface. For example, increased surface roughness in the bow area will cause greater resistance than in the aft areas or under the hull bottom because the effective speed of the water will be less. So, in reducing the roughness, different part of the ship will have different level of impacts even if their original roughness is the same. The smother the hull, the less resistance the ship will have and thus the faster it will go for the same power output, saving fuel and reducing GHG emissions. Fouling will reduce the smoothness (increase roughness) of the hull and even may add weight to the vessel reducing the cargo carrying capacity. These impacts make the hull roughness and fouling a major issue of control for energy efficiency. Figure below shows this relationship between increase in required propulsion power or fuel consumption and hull roughness. It has been suggested that each 10 µm to 30 µm of additional roughness can increase total hull resistance by about 1 percent for full form ships (of course the increase in resistance will be influenced by ship speed as well).



Source: International Paint 2004

Figure 3.4: Typical increase in power/fuel required to maintain vessel speed of a fast fine ship vs increasing hull roughness [International Paint 2004]

3.3.References

Trim Optimisation 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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Chapter 4: E-Navigation and Weather Routing

4.1.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. IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities) 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 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 below) to describe the overall concepts and outline the basic elements of the system.

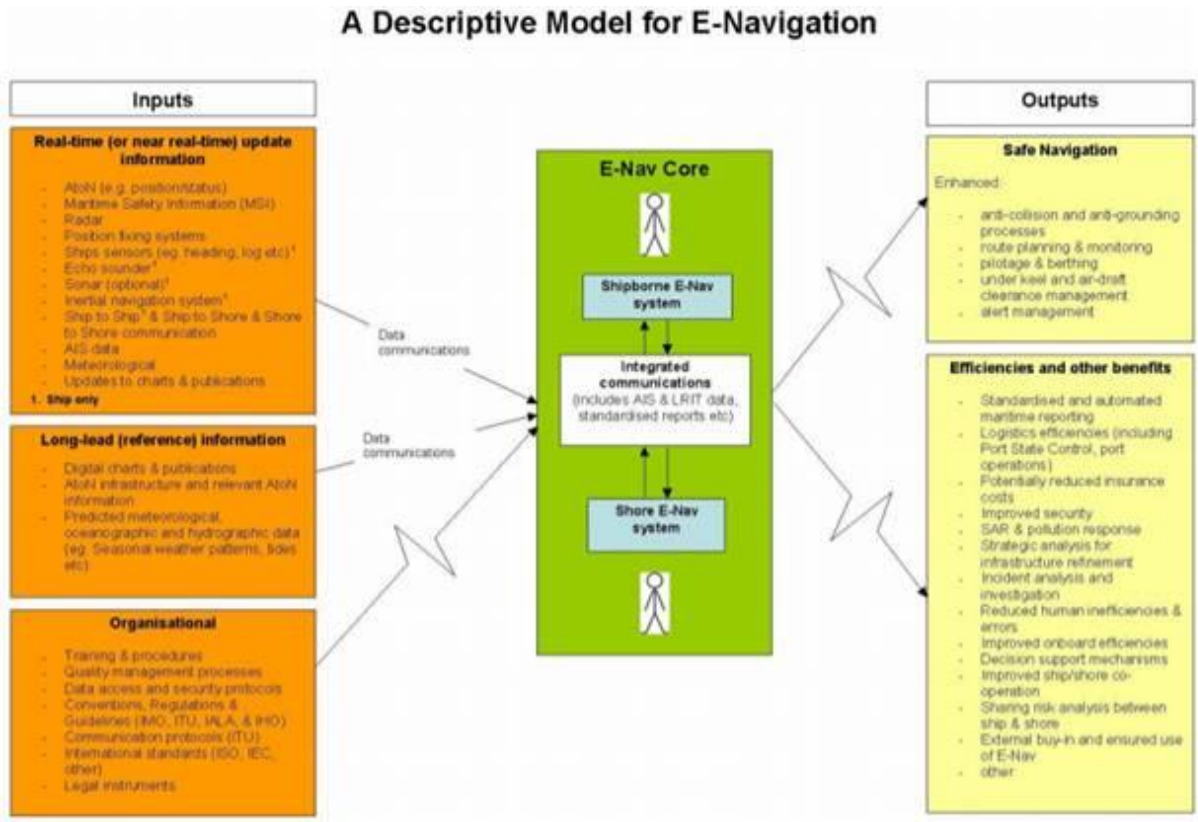

Figure 4.1: The IMO model of the principle outline and basic elements of the e-Navigation concept

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 analysed 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.

4.2.E-navigation Tools and GHG Emissions

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. 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 auto pilot will be put in precision mode providing for the better accuracy and ensuring safe navigation.
- **Manoeuvring 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 manoeuvres in harbour 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 manoeuvres 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.
- **Computerised manoeuvring 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.

4.3.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 in not mandatory. Figure below shows a concept of how ECDIS as linked to other ship-board systems. 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-programs 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.

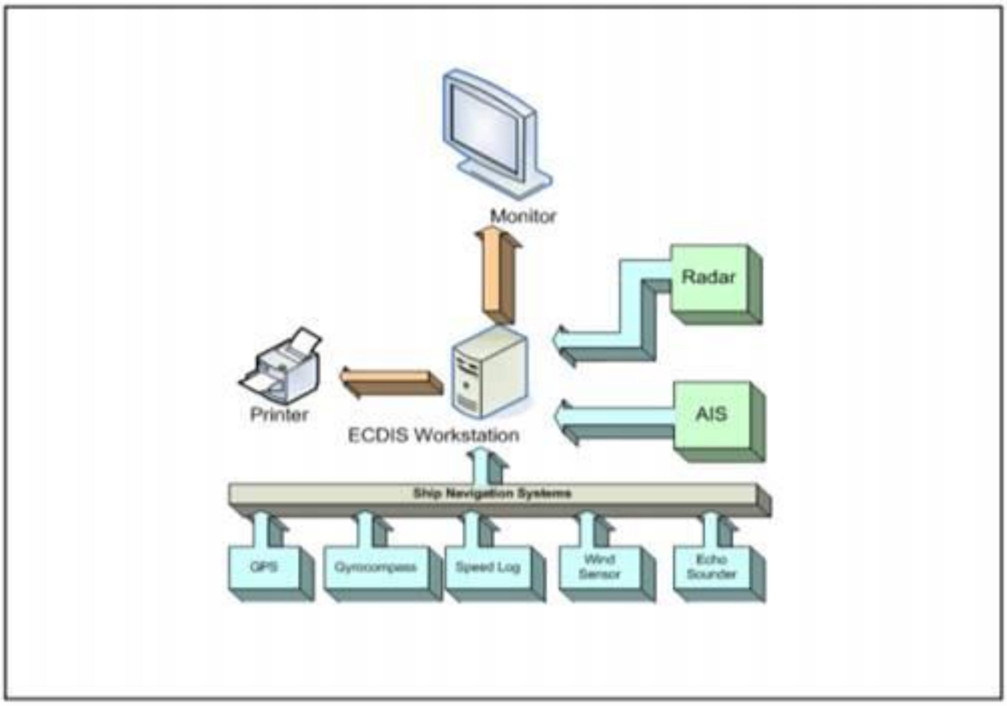

Figure 4.2: Concept of ECDS and its' integration with other system [Fredrik Larsson]

4.4.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.

4.5.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 ISF / ICS (International Shipping Federation / International Chamber of Shipping) 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.

4.6.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 CO_2 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.

4.7.Shallow Water 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 below shows the fuel consumption increase (%) for different water depths D in meter and speeds X in knots.

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 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" (*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)* 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.

4.8.Weather Routing

4.8.1. 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 below 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 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 modelling 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.

4.8.2. 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 pounding 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 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.

4.8.3. 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 rout 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 he 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 constrains 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 charter 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.

4.8.4. 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-modelling 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.

4.9.References

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 http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Air%20pollution/M3%20from%20management%20to%20operation%20final.pdf

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.mcga.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.

Chapter 5: Engines and Machinery Load and Utilisation Management

5.1.Engines and Machinery Load and Utilization Management Introduction

Ship operation involves a variety of activities and tasks. Some aspects are listed below:

- Loading
- Unloading
- Ballasting and de-ballasting
- Inner gas generation and top ups for crude oil and product tankers
- Bunkering
- Manoeuvring
- Stand-by
- Normal passage operation
- Waiting and anchorage
- Fresh water generation
- Potable water generation
- electricity
- steam generation
- Air condition and climatization
- Sewage treatment plant
- Etc.

Observation: It is important to reflect that the ship is like a city and needs the same services that a city does.

The nature of the above operations will vary from one ship type to the other. Also, they may vary with area of operations and ports of calls. To improve fuel consumption, the requirements of various operations need to be carefully examined, and ship machinery/resources are then used accordingly. Planning of the above require good coordination between deck and engine departments. In this section, examples of ship-board planning activities are examined with main reference to engine load management, electrical load reduction and minimisation of use of auxiliary boilers. These activities are advocated under “system planning” as improvements require significant level of ship-board systems-use planning, good communication between staff and in particular between deck and engine departments as stated above and also the awareness of the staff of the deck and engine.

5.2. Engine load Management

5.2.1. Rational

It is well known that the efficiency of a diesel engine is a function of its load level or its load factor. Figure below shows the engine Specific Fuel Consumption (SFC) as a function of the load factor.

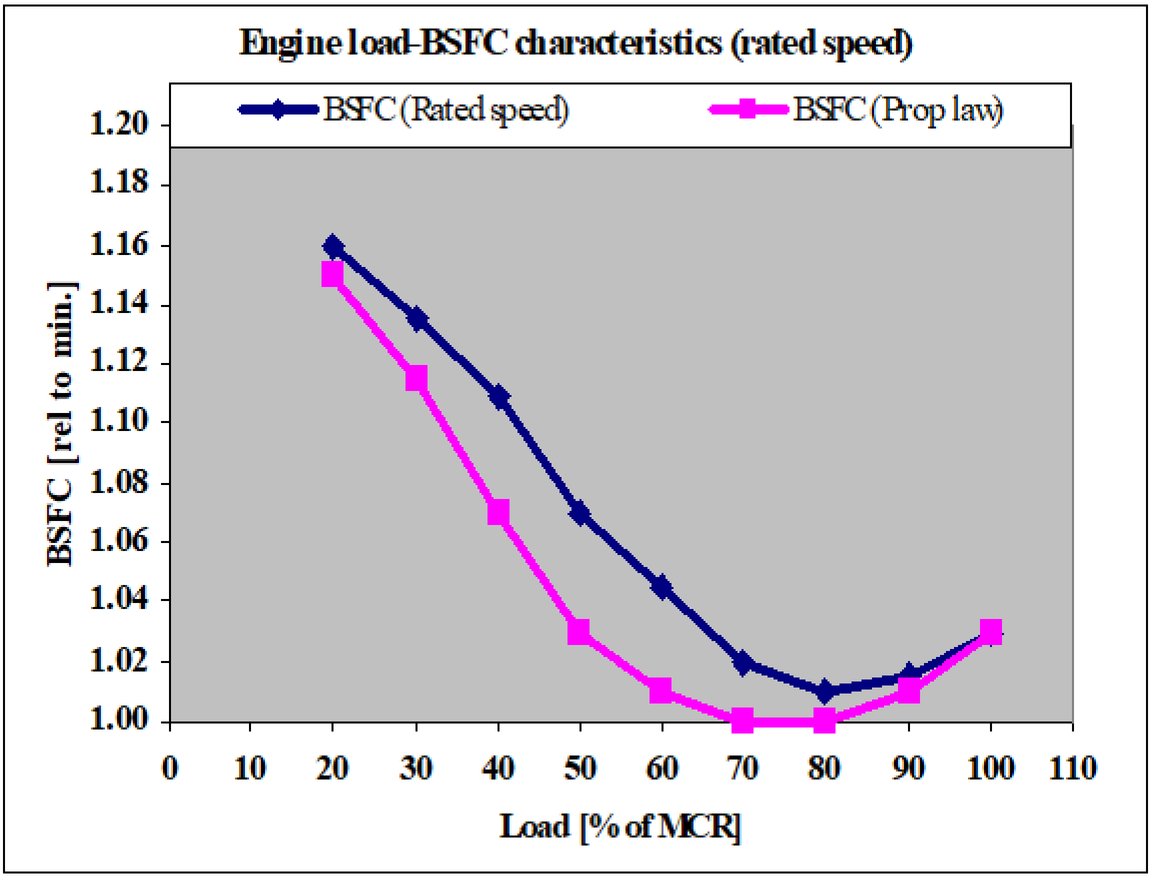

Figure 5.1: Engine SFC as a function of load factor

Load factor: The engine load factor is defined as the actual power output of the engine relative to its Maximum Continuous Rating (MCR). The Load factor is normally specified in percent. An engine working at 50% of its maximum load has a load factor equal to 50%.

In figure above, the curve for constant engine speed operation (rated speed) represents operation of electric generation engines (such as auxiliary engines, e.g. diesel generators) and the curve for propeller law shows the main engine operation characteristics. As can be seen there is no significant difference and for both types of application, the engine's SFC (Specific Fuel Consumption g/kWh) varies with the engine load. SFC is a minimum (i.e. efficiency is a maximum) for a certain load level; typically for engines it is in the range of 70 to 90% of an engine's Maximum Continuous Rating (MCR). The above diagram also shows that under low load conditions, the SFC of the engine will increase (engine efficiency will reduce). Although the load on the main engine is primarily dictated by ship speed, the load on the auxiliary engines depends on the ship-board electrical loads that are a function of the number of machines, machinery and equipment being used at each point in time plus the number of engines used to satisfy the requirements. In this Section, it is argued that engine loads should be managed, where possible, so that the engine fuel consumption is minimised. This will effectively mean operating the engines at 70 to 90% load range as discusses above with reference to figure above. The lower consumption of fuel by each kW per hour output by the engine is when this, is running with a load between 70-90%.

5.2.2. Load Management for Main Engine

For the main engines in a direct-drive or gear-drive configurations (mechanically linked to propeller), there is not much that can be done as far as load management is concerned as normally ships have one main engine and load management normally applies to cases with more than one engine. It should be noted that it is easy to show that the slow steaming leads to the main engine's operation at low loads at a less efficient load factor. Overall, this low-efficiency operation of main engine has been accepted by industry since the impact of reductions in ship resistances on a ship's fuel consumption is much more effective than increases in the main engine's SFC for slow steaming cases. Therefore, in main engines, non-optimal operation may be allowed due to slow steaming because of slow steaming greater benefits from much lower fuel consumption. However, in such conditions and if slow steaming is going to continue for long term, changes to engines performance characteristics are recommended via changes to turbochargers, injection system and other engine settings (engine adjustments for slow steaming optimised operation). No matter what load the main engine is operating under, it is mostly recommended that the main engine load should be kept at a reasonably steady level under normal operation. This is achieved by keeping the engine speed (RPM) constant. Frequent changes to the shaft rpm, thus engine load, are not efficient and must be avoided. When we need to reduce the output power of the main engine to reduce the consumption of the fuel and we apply the slow steaming, in this case the reduction of the output power is proportional to the consumption of fuel per hour, but at the same time, we are consumption more amount fuel per kW per hour output by the main engine.

To the above indicated, it is necessary to have in account the problems of damage and maintenance that the slow steaming produce in the engines.

Fuel Coefficient and Fuel Consumption in Relation to the Load Management

The fuel consumption of a ship depends upon the power developed. Indeed, the overall efficiency of power plant is often measured in terms of the *Specific Fuel Consumption,* which is the consumption per unit of power, expressed in kg/kWh. Efficient diesel engines may have a SFC of about 0.180 kg/kW h. The specific fuel consumption of a ship at different speeds follows the form shown in figure below.

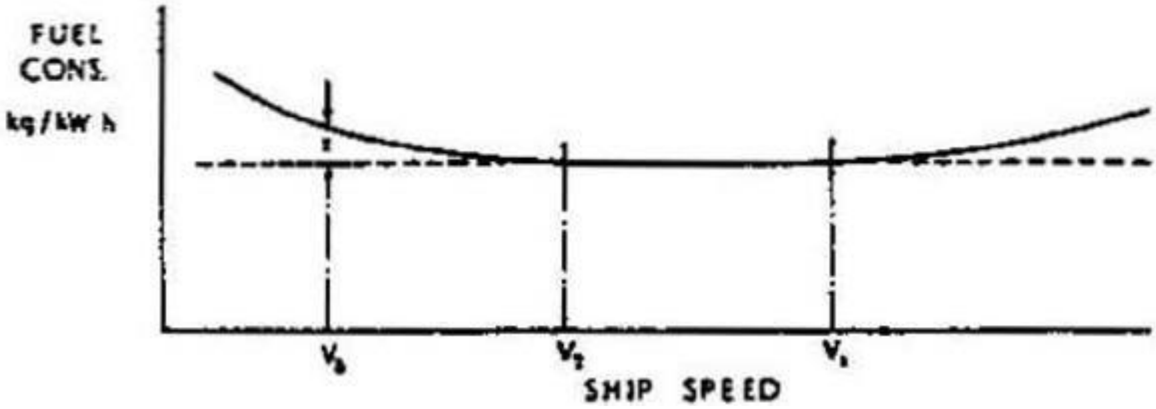

Figure 5.2: SFC VS Speed

Between V1 and *V2* the specific consumption may be regarded as constant for practical purposes, and if the ship speed varies only between these limits, then:

Fuel consumption/unit time $\propto$ power developed.

Power developed is known as Shaft Power (SP)

Then, the SFC $\propto$ SP

And since SP $\propto \Delta^{2/3} V^3$ while Δ is the displacement of the vessel in tonne and V is the speed.

Then SFC $\propto \Delta^{2/3} V^3$

Or fuel consumption /day = $\Delta^{2/3} V^3$ / (Fuel Coefficient)

We would keep the Fuel Coefficient and displacement constant for a given ship and compare the fuel consumption at different speed only:

Then, Fuel consumption/unit time $\propto$ speed^3

Hence $cons_1 / cons_2 = (V_1 / V_2)^3$

For example, we can take a ship that uses 20 tonnes of fuel /day at 13 knots. If we keep the displacement constant for that vessel and reduce the speed to 11 knots then,

New daily consumption = 20 X $(11/13)^3$

= 12.11 tonne

Therefore, we can see that reducing speed by 2 knots saves quite a huge amount of fuel.

Similarly, we can compare the total voyage consumptions at different speeds keeping the displacement same for a given ship.

If D is the distance travelled at V knots then:

Number of days $\propto$ D/V

But daily consumption $\propto V^3$

Therefore, total voyage consumption $\propto V^3 X D/V$

Or $\propto V^2D$

i.e. voy. $Cons_1$ / voy. $Cons_2$ = $(V_1 / V_2)^2 X (D_1 / D_2)$

Hence for any given distance travelled the voyage consumption varies as the ***speed squared***.

For example, we consider a ship that uses 125 tonnes of fuel on a voyage travelling at 16 knots.

If the speed of the ship reduced to 15 knots keeping the displacement, weather condition etc. steady, we can calculate the new voyage consumption.

$= 125(15/16)^2 = 110$ tonne

Therefore, saving in fuel = 125 – 110 = 15 tonne.

A general expression can be derived for voyage consumption as:

(New voy.cos / old voy. cons) = $(\text{new displ / old displ})^{2/3}$ X $(\text{new speed / old speed})^2$ X (new distance / old distance)

Outside the range of speed between V_1 and V_2 the SFC is much higher where, if we operate the vessel will incur a heavy fuel cost which will increase tremendously for a slight speed increment.

(Ref: Stoke EA, 2013, Naval Architecture for Marine Engineers (Reed's Marine Engineering Series Vol 4, 4th edition, London, Adlard Coles Nautical.)

5.2.3. Load Management for Auxiliary Engines

There is ample evidence that shows that load management for auxiliary engines is an effective way of reducing the engines' fuel consumption as well as their maintenance costs. Each ship normally has three or more auxiliary engines; each connected to one electric generator. The engine and generator as a combined system are normally referred to as diesel-generator (DG). On-board ships, and often in order to assure against black out, two DGs are operated for long periods at less than 50% load factor. The periods for which these conditions are sustained can include all discharge ports, standby periods, tank cleaning periods, movement in restricted waters and ballast exchange periods. This often leads to unnecessary simultaneous usage of multiple engines, at low load factors and beyond requirements. As a result, low load factor leads to poor energy efficiency performance. Additionally, the operation of diesel engines at low loads causes poor piston ring seal, sub-optimum turbocharger performance, low specific fuel consumption, elevated thermal stresses and increased specific lube oil consumption. In short, it leads to more maintenance and higher fuel consumption.

5.3. Electrical Load Reduction

It is often possible to reduce energy consumption on board by working towards more conscious and optimal operation of ship machinery and systems. These could be achieved more effectively if planned for each mode of operation. Examples of measures that can be considered include:

- Avoidance of unnecessary energy use via switching off the machinery when not needed. All non-essential and not-required machinery and equipment that do not affecting the ship and personnel safety should be stopped whilst in port and at sea to reduce the load on diesel generators. Such items should be identified first and then procedures for the execution of tasks to be developed and implemented.
- Avoidance of parallel operation of electrical generators, when one is sufficient for the purpose. This aspect is covered and fully discussed under "engine load management".
- Optimized HVAC (Heating, Ventilation and Air Conditioning) operation on board. The HVAC system operation should be aligned to outside weather conditions either via automatic settings or manual operations (more important for cruise ships).
- A proper coordination should be maintained on board between deck and engine departments especially for use of machinery/equipment items such as steering gear motors, bilge and fire pumps, winches and mooring equipment, deck cranes and service and deck compressed air usage, etc. so that to reduce loads on generators.

The above activities will lead to reduced electrical power demand. Moreover, jobs could be co-ordinated and bundled together so that two generators could be run more effectively and for a shorter period of time. This could be achieved via system planning and more coordinated actions

5.4.Auxiliary Machinery Use Reduction via System Planning

There is a significant number of redundant machinery on board ships; this allows ship operation when one fails as well as for safety-critical situations where two machinery needs to simultaneously operate. In practice, redundant machinery is normally used more than necessary. This could include any type of machinery in particular fans and pumps. Any reduction in use of such machinery can lead to energy efficiency.

Proper planning of the use of number of machinery versus operation mode is an effective way of achieving this objective. Use of simultaneous use of multi machinery in parallel could be reduced via advanced planning and decision making on the number of machines to be used; taking into account the actual operational requirements. For example, when ship is in port, the plan should include switching off one or two engine room ventilation fans as main engine is not operating any more. Another example is the mooring equipment. When mooring equipment is not needed, the related pumps and machinery could be switched off.

To ensure safe operation, all these need to be proactively planned and executed. Without daily planning and establishment of relevant processes, the task of reduction in energy use cannot be accomplished. As emphasized before, coordination between deck and engine departments are of paramount importance for an effective and at the same time safe action to avoid mis-understanding or unexpected consequences.

5.5.Auxiliary Fluid Machinery

This refers to pumps, fans, compressors, etc. that are extensively used on-board ships. There are a number of opportunities to save energy with these machineries that are briefly discussed. The main areas of evaluation include:

Sizing: The sizing of machinery against the actual operation requirements needs to be checked in order to identify cases of over sizing. This can be carried out by monitoring of the machinery operational performance against manufacturer’s specification. In addition, the following may be indicative of oversized machinery:

- Continuous throttling of flow in order to match supply with demand (e.g. permanently fixed valve or damper positions).
- Short periods of operation when the machinery is used in on-off mode. For example, in a compressed air system, an oversize compressor will supply air to tank in a shorter period of time than a rightly sized compressor.

For each machinery, a “capacity factor” can be defined that is indicative of over-sizing or under-sizing. Capacity factor may be defined as the “operational capacity” divided by “design nominal capacity”. A capacity factor significantly below or above unity is indicative of poor sizing or system’s operational anomalies.

Operation profile: The operation profile of machinery represents the machinery’s load versus time. Continuously operated machinery at a certain load will represent a steady operation profile.

Machinery with highly variable load will represent a non-steady load profile. Load and operation profiles are normally presented in histogram format, an example of which is shown in figure below.

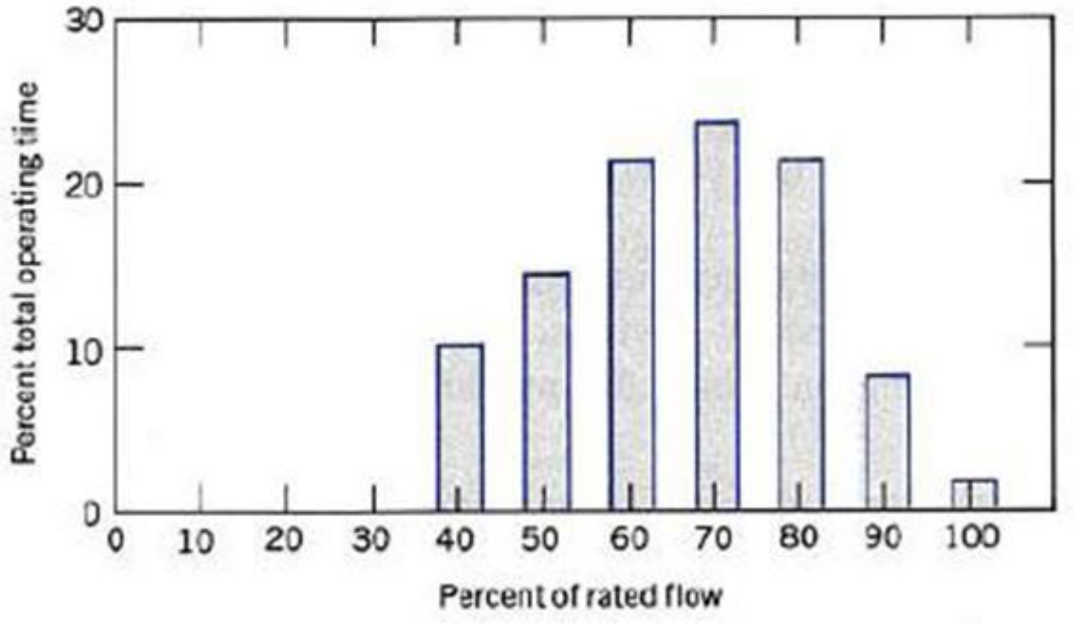

Figure 5.3: Load profile for a typical pump

From operation profile, operation management strategy of the machinery could be decided. In particular, method of control and choice of on-off or Variable Speed Drive (VSD) modes can be established. For variation of flow, two methods of flow control could be used (see figure below):

- Valve system modulation (changes to valve open area) is the traditional way of flow control. This method of control is energy inefficient.

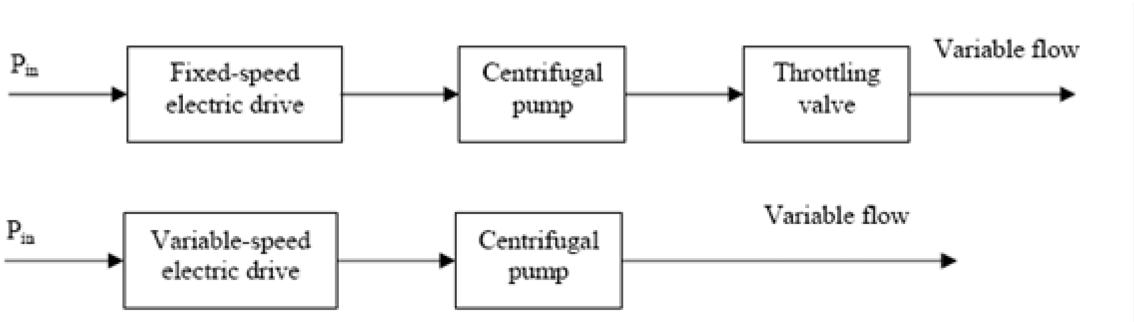

Figure 5.4: Main types of flow control

- Variable Speed Drive (VSD) is used to control flow without throttling. This is the most efficient way of flow control for fluid rotating machinery (see figure below).

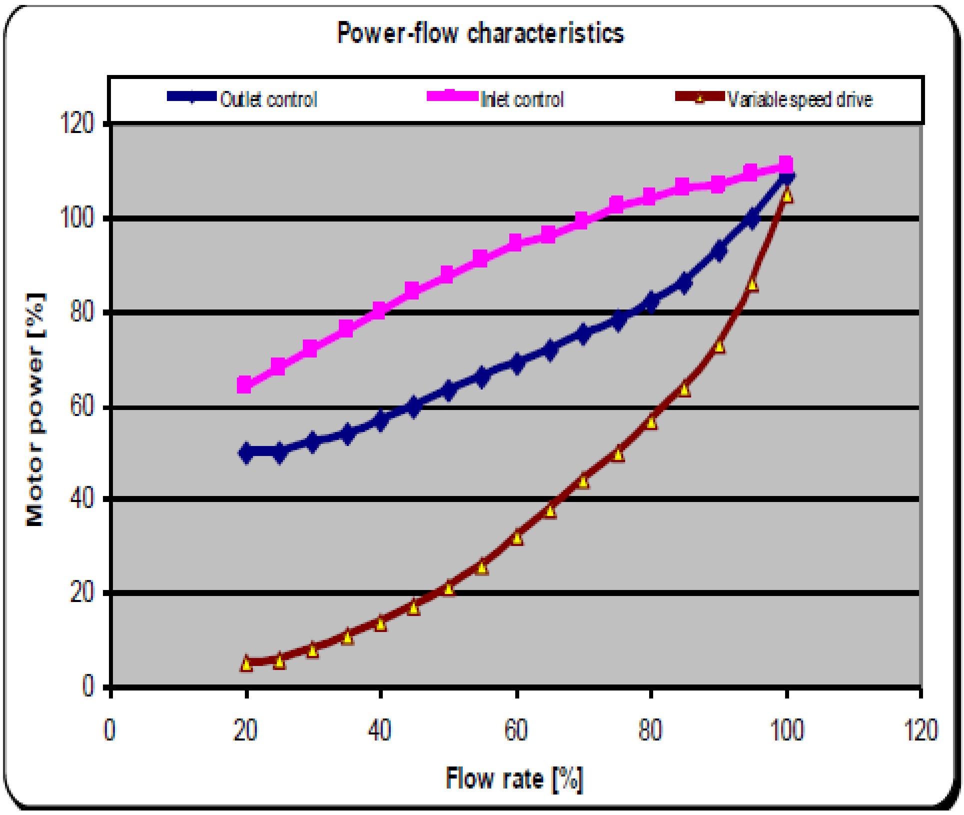

Figure 5.5: Impact of Variable Speed Drive method of flow control on power demand

The load profile for a multi-machinery setup could provide valuable information on method of load sharing strategy and management between machinery.

Operational aspects

Based on the above evaluation and basic characteristics of fluid machinery, the main opportunities for energy saving are:

Fouling reduction: Fouling in fluid machinery is a common cause of performance deterioration. Fouling can be controlled via best-practice maintenance activities. For examples, fans are very sensitive to inlet fouling.

Multi-machinery management: In general, in a multi-machinery configuration (e.g. chiller plant compressors), the minimum number of machinery running for a particular duty represents the best machinery management strategy and ensures minimum overall machinery energy consumption.

Reducing idling mode of operation: In addition to operation of the machinery at optimal efficiency, it is prudent to reduce the none-productive operating hours of all machinery especially during port stays and also change over from on to off modes and vice a versa. In general, the following policies should be implemented:

- Each machinery should be operated at its optimum efficiency.
- The none-productive hours of operation must be minimised by on-off controls. In particular, late turn-off and early turn-on of machinery should be avoided.
- **Flow control and management:** As discussed earlier, control of flow is an area where significant savings may be made:
- **Throttle flow control:** A pump with variable flow requirements that is controlled by throttling could save energy by:
- Replace the constant speed drive to variable speed drive (level of saving depends on the pump duty cycle).
- Replace throttle control with on-off control, if feasible (switch on and off according to demand), especially if some storage capacity can be added to the system.
- **Excessive flow:** For example, pump flow rates in excess of system requirements, lead to increased energy losses. To avoid:
- Ensure that pump flow is controlled according to process requirements.
- Review and adjust control settings.
- **Demand control and demand reduction:** The need for flow should be investigated at the demand side. Every effort should be made to reduce demand by:
- Preventing all leakages.
- Conservation policies in compressed air, water, conditioned air, etc. lead to reduced energy consumption by corresponding systems.

5.6.Electric Motors

Electric motors provide the drive system for the majority of ship auxiliary and hotel systems. In electric propulsion, electric motors are used for driving the propellers. There are a number of ship auxiliary systems that support the operation of main power plant or required hotel services. Some of these are:

- Engine cooling system.

- Engine fuel system.
- Engines lub oil system.
- Compressed air system.
- Chiller plant for hotel HVAC system.
- Chiller plant for provision area.
- Steam system for hotel services and freshwater generation.
- Fresh water generation systems.
- Sewage
- Steering gear
- Etc.

The main components of all the above systems are a number of rotating machineries, all driven by electric motors. Electric motors, excluding propulsion motors, consume the majority of the ship auxiliary electrical loads. Their efficient operation, therefore, is an important element of the overall ship energy management.

Basic characteristic

Electric motors used in ships are invariably of AC (alternative current) type. The typical characteristics of the electric motors are shown in figure below.

According to figure below and other relevant information on electric motors, the followings are applicable:

- Electric motor efficiency is highest at its rated power. However, the efficiency does not reduce significantly up to about 40%. Below 40% of rated power, efficiency reduces significantly. This threshold of 40% is lower for larger motors.
- Electric motor efficiencies are usually below 80-90% depending on its size, denoting that there are losses associated with such motors. The loss is dissipated in the form of heat.

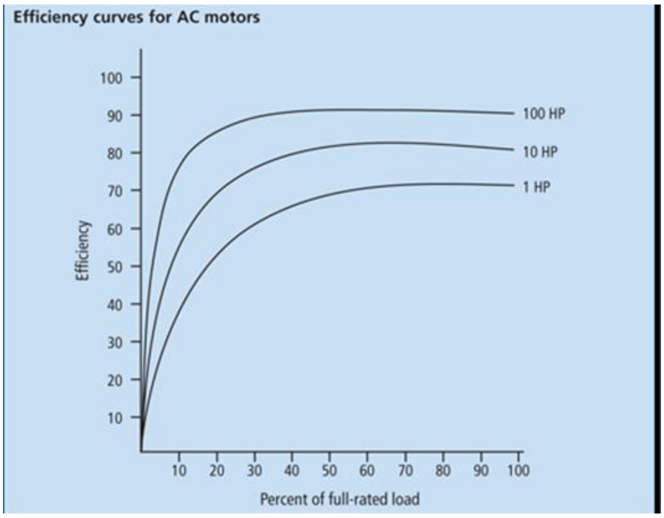

Figure 5.6: Typical characteristic of electric motors

Main energy efficiency aspects associated with electric motors are as follows:

Sizing: The sizing of electric motors against actual performance needs to be checked in order to identify cases of over sizing. This can be identified via monitoring the performance data against the manufacturer's specification.

Operation profile: The operation profile of machinery is indicative of its load versus time. Continuously operated machinery at nominal load will represent a steady operation profile. Machinery with highly variable load will demonstrate a non-steady load profile.

Power factor: In electric motors, power factor is defined as the ratio of the actual power in kW divided by power directly derived using current and voltage of machinery in KVAR. A low power factor means added electric network losses.

In dealing with ship-board electric motors, the above needs to be analysed to find out about their relative efficiency and if there is a need for changing any motors during technical upgrades in order to improve efficiencies. Technical upgrades should be normally considered within the ships' machinery maintenance programmes.

References

Engines and Machinery Load and Utilisation Management 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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2. OCIMF "Example of a Ship Energy Efficiency Management Plan", Submission to IMO, MEPC 62/INF.10, 8 April 2011.

3. ABS 2013 "Ship Energy Efficiency Measures, Status and Guidance", http://www.eagle.org/content/dam/eagle/publications/2013/Energy%20Efficiency.pdf, viewed on 7th Nov 2016.

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Chapter 6: Fuel Management

6.1. Fuel Management Introduction

Fuel quality has significant impact on engines' and boilers reliability and performance. When ordering a fuel, qualities in terms of grade of fuel, its specification, calorific value and suitability for engines and boilers need to be considered. It is well known that higher density fuels and higher water and sulphur contents all reduced calorific value that represents the energy content of fuel. Also, high sulphur contributes to undesirable air emissions of SO_x and high metallic impurities put the engines and boilers at risk.

The limits for fuel quality parameter as set out in International marine fuel standard, ISO 8217, are based on the understanding that the fuel will be treated on-board the vessel to meet specific requirements for particulars of engines and boilers fitted on-board the vessel. On-board treatment systems are therefore vital in ensuring that fuel is purified effectively in order to ensure it complies with the necessary specifications of the relevant combustion system.

This section covers aspects of fuel management which includes bunkering, fuel quality analysis, storage and treatment. It starts at bunkering point and ends at the point where fuel is supplied to various combustion systems including engines, boilers, etc.

6.2. Fuel Oil Procurement and Bunkering

The first major step in fuel management is to ensure that the right quality of fuel is ordered for the vessel. While requesting bunkers for a specific vessel, any limitations of ship's machinery capabilities, limitations on storage, operation profile, trading area for environmental compliance and giving enough time to get analysis before the fuel is put into use, should be considered.

The on-board fuel management starts first with the bunkering operation. During the bunker operation, safe handling and pollution prevention controls measures, correct measurements before, during and after bunker operations, loading in empty tanks (to avoid mixing of incompatible fuels) and collection of representative samples are the most critical issues. Quantity (by weight) of fuel bunkered should be established and recorded along with the on-board storage locations and tracked to ensure selection of good subsequent heating or purification characteristics.

Quantity calculations aside, taking representative sample(s) of the fuel delivered to the vessel is a regulatory requirement as well as of paramount technical and commercial importance for safety of engines and boilers. Without adherence to correct sampling procedures, which give real insight into the quality of fuel loaded by the vessel, the analysis results provided may be flawed. Analysis of fully representative samples of each bunker batch serves as first line of defence against poor quality fuels. Such an analysis should be performed in order to assure the quality of fuel supplied and to identify potential problems at the earliest opportunity which helps to identify mitigating actions/claims that may arise due to the supply of poor-quality fuels.

6.3.Fuel Quality and Quantity Assurance

Bunkers come in a wide variety of quality levels and to meet the international quality standards (ISO 8217) and statutory requirements (mainly sulphur), the marine residual fuels are generally blended by manufacturers or suppliers with different components. Using better quality fuel and /or a higher grade of fuel can lead to an improvement in engine efficiency, safety of combustion systems and / or prevent degradation. On the other hand, to meet the regulatory requirement to reduce the sulphur level in bunker fuel, more and more refinery processes and also blend components are being used which could results in an increase in the levels of highly abrasive particles of Aluminium and Silicon (also called catalytic fines) or fuel's chemical stability over the long term. This has also raised concerns about the ignition and combustion quality of fuels along with the issues related to the stability and compatibility of the fuels.

Thus, analysis of the representative sample(s) of the bunkered fuels should be carried out to ensure:

- Appropriate storage, handling and treatment actions are taken beyond bunkering up to consumption.
- The use of fuel in a most safe and efficient way.
- Compliance to environmental legislation.
- Maximise combustion performance.
- Appropriate actions are taken to avoid any adverse effects and mitigating disputes.
- Reduce commercial, technical and operational risks associated with using varying quality fuels.

The same applies to quantity measurement as discussed in section Bunker Measurements.

6.4.Fuel Storage and Transfer

It is important that all precautions to be made to try to avoid co-mingling (i.e. loading on top of each other) of different batches of fuels. Incompatible fuels are the most common problem with the bunker fuel mixing that leads to clogged filters and in the worst-case scenarios, complete paralysis of the fuel system lines as shown in figure below. This also helps in case the fuel supplied is of undesired quality then co-mingling makes it difficult to de-bunker the fuel if such situation arises.

Figure 6.1: Clogged fuel pipes due to very poor-quality fuels

If due to bunker planning and/or operational reasons mixing of the fuels is unavoidable then this should be done after performing the compatibility test between the fuels to be mixed that would indicate their stability after mixing. Ideally such a test should be carried out under lab conditions however this test can be carried out on-board the vessel as illustrated in figure below.

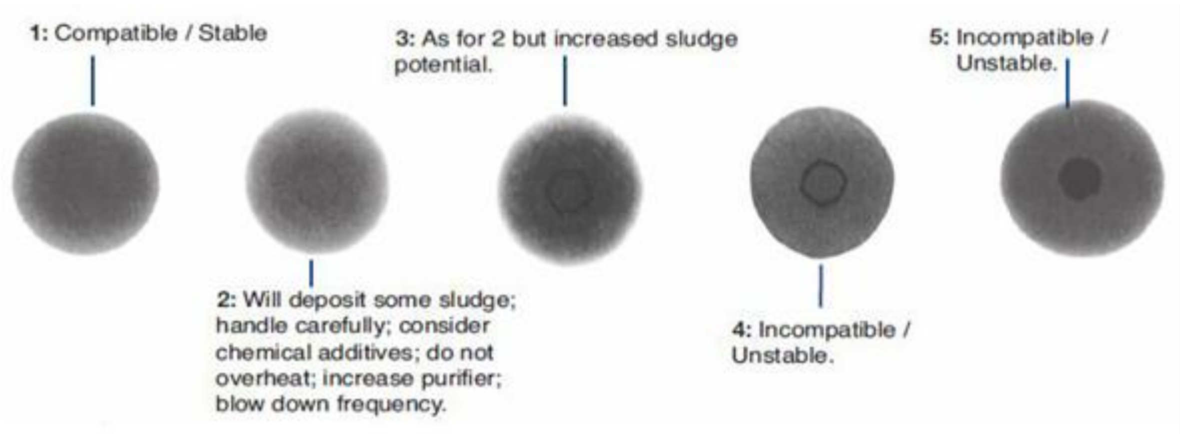

Figure 6.2: Compatibility test procedure [ExxonMobil]

Fuel should be consumed in a first in, first out fashion. Avoid carrying or use fuels that are over a few months old. The longer a fuel is kept on-board, the chances of sediments in the fuel to drop out and stratification of the fuels increase. This then leads to more potential for filter clogging and other fuel issues and problems. Fuel that cannot be used for any reasons should be de-bunkered off the ship as soon as possible in consultation with vessel's technical superintendent.

6.5.Bunker Measurements

Bunker measurement is normally carried out before and after bunkering by the chief engineer or his/her representative to ensure that the actual quantity of lifted bunkers is accurate. The method of measurements includes:

- **Manual gauging of all the fuel tanks before and after bunkers:** This together with making corrections for the trim/heel of the vessel gives the volume of the fuel in the tanks which is then subtracted from the pre-bunker readings. Using the fuel volume, temperature and the density of the fuel as provided by the fuel supplier and by applying correction factor for the observed temperature, the weight of the fuel is calculated. This calculation is based on the understanding that the density of the fuel given by the supplier is correct and that there is no excess water in the fuel. This weight is adjusted accordingly upon receipt of the analysis of the bunker drip sample if density of the fuel varies considerably from the reported values or the amount of water in the fuel is excessive.
- **Use of the mass flow meters:** Based on the performance of the available technologies, Coriolis mass flow meters are advocated to be a good choice for mass flow metering of the fuel during bunkering because of the direct mass measurement by this device. Manufacturers claim that such measurements are not affected by fuel temperature, pressure, and composition. Meter size and location of the meter plays an important role therefore proper installation and operation practices are critical for these meters.

Of the above methods, the use of Coriolis flow meters are still being investigated and tested in the field to ensure optimal performance and benefit these types of flow meters. Currently, option 1 above that involves fuel inventory check is the common practice in industry.

6.6.Fuel Consumption Measurement and Reporting

Fuel consumption of main engines, auxiliary engines and boilers is normally measured and recorded on a daily basis. These are recorded in the engine logbook and reported to the company through noon reports and voyage reports. Method of daily fuel consumption measurement is done as follows:

- By the use of mass flow meters fitted for main engines, auxiliary engines and for the boilers.
- By manual gauging of the tanks and measuring the amount of fuels transferred to the specific machinery type.

Accuracy of fuel flow meters is of great importance. For energy efficiency monitoring, the vessel should be able to accurately measure the amount of fuel consumed on-board by the main consumers. This includes a thorough understanding of the fuel system and the placement of accurate fuel flow meters on the system, which must have a reasonable accuracy. Furthermore, the fuel oil temperature at the flow meters should be measured and related correction made from normally measured volumetric flow rate to mass flow rate. It is best if the accuracy of the fuel flow meters is regularly verified.

6.7. Fuel Oil Treatment – Settling and Purification

6.7.1. Settling Tank(s)

The role of settling tank is to separate heavy residues and water from the fuel through the natural settling process. In this way, these items are expected to settle gradually at the bottom of the settling tank. To provide best performance:

- Settling tank temperature should normally be maintained between 60-70ºC for HFO to reduce the density and viscosity of the fuel to facilitate gravitational separation.
- Transfer of fuel to the settling tank to be controlled automatically to top up in small quantities at frequent intervals. This is to help minimise the temperature drop and quantity of dirty/unsettled fuel in the tank immediately after the transfer.
- It is important to drain off water and sludge at the settling tank bottom drains at regular intervals. Frequent / low volume – “flash blowing” is the most effective way of removing settled contaminants.
- Some settling tanks are fitted with high and low outlets. In normal service conditions, it is always preferable to use the lower outlet to minimise the space available for sludge accumulation and give early warning of contamination issues. The high outlet should only be used when there are major issues such as when the tank is subject to a significant water contamination.

6.7.2. Fuel Purification

Purifiers are almost invariably used in ships. The main task of purifiers is to separate water and other impurities from fuel. The purification process is based on centrifugal motion principle and the fact that materials with different densities will be subject to different centrifugal forces and thereby will separate from each other. Figure below shows the typical arrangement of fuel oil purifiers on board ships.

Figure 6.3: Typical purifier systems on-board

The efficiency of a centrifugal separator is affected by several factors such as composition of the fuel (nature, quantity and size of undesired components), unstable process fluid dynamics (homogenisation of the fuel before the separators, turbulence within the fuel, poor temperature stability of the process fluid), cleanliness of the separator (the gap between individual discs in the disc stack, fouling of the clean fuel centripetal pump, fouling of the control water system or sliding bowl parts) and general operation (separator throughput, incorrect discharge interval).

For good purifier performance, the following operating controls should be observed:

- Operate purifiers / clarifiers in an optimum manner with purification level dependent on contaminant levels.
- Where applicable, ensure correct gravity disc fitted to purifiers. Manual de-sludge cycle time should be set with regard to fuel contaminant levels.
- In order to optimise the volume available within the bowl the interface line should be as close to the edge of the separating disc as possible.

Sludge (oil residue) is considered to be the residual waste oil products generated during the normal operation of a ship, such as those resulting from the purification of fuel or lubricating oil for main or auxiliary machinery, separated waste from oil filtering equipment, waste oil collected in drip trays and waste hydraulic and lubricating oils.

Excessive sludge from the fuel oil system such as purifiers is a parameter that reduces the fuel efficiency of the ship via increased fuel waste. As a result, the monitoring of the fleet's sludge production in relation to the fuel consumption, with the aim of promptly identifying cases where corrective actions are needed is quite important. Some ships will benefit from use of fuel homogenisers to reduce sludge.

6.8. Fuel Viscosity Control

For use of fuels in engines it is very important to ensure that the fuel is heated to the correct temperature to maintain the required injection viscosity at the engine inlet. Incorrect injection viscosity results in poor atomisation which affects the efficiency by which the fuel is burnt.

The first figure below shows the fuel oil steam heater for control of fuel oil temperature. The arrangement of viscosity controller and fuel filters are shown in the second figure below.

Figure 6.4: Typical fuel oil heaters

Figure 6.5: Viscosity controller and fine filter units

It is best to put the viscosity controller on auto viscosity control mode than on the fixed temperature control mode. The correct function of the viscosity controller should be ascertained specifically when changing over from high viscosity fuels to low viscosity fuels and vice versa.

Due to the complex nature of marine residual fuels, it is difficult to predict the ignition and combustion performance of two fuels even if their standard quality parameters are the same. Poor quality fuels may lead to significant damages to the engine (see figure below). In view of this, it is good practice to monitor the engine's cylinder combustion performance through available diagnostic tools on-board, particularly at the start of the use of a new bunker. In case of any issues with the ignition / combustion of the fuels, appropriate actions should be taken to keep the engine parameters within the specified limits. Engines fitted with VIT (Variable Injection Timing), or similar arrangements can be adjusted accordingly to enhance the ignition / combustion efficiency.

View of damaged cylinder liner with piston fitted.

Figure 6.6: Damage to engine piston and cylinder liner [Gard 2014]

6.9.Fuel Oil Additives

Fuel additives are chemical compounds formulated to enhance the quality and efficiency of the fuels used. Environmental legislation to reduce emissions and improve fuel economy is having a significant impact on fuel formulations and engine system design. As a result of low sulphur regulations, the composition, long term stability, lubricity, combustion quality, etc. of fuels are evolving due to either de-sulphurisation of heavy fuel oil or blending. Fuel contaminations with bio-related products mixed with fuels adds a new dimension to fuel's long-term stability.

Typical types of additives are metal deactivators, corrosion inhibitors, oxygenates and antioxidants. Fuel additive suppliers advocate them as delivering flexible and advanced solutions to the ever-changing fuel market environment and fuel quality issues. Over many years, additive products have demonstrated benefits in some specific areas of marine applications.

The fuel additive technology could provide benefits for marine fuels mainly in areas of enhancing the fuel combustion and preventing the formation of particulates (combustion enhancing additives). Same additives also help prevent fouling of exhaust systems and economisers as well as provide a cleaner combustion system altogether. Therefore, it may be stated that additives have proven records with regard to:

- Improvement of fuel combustion and reduction of particulate matter and visible smoke.
- Overcoming soot build-up in the exhaust system, thus ensuring the efficiency of exhaust system including economiser via keeping them clean, foul free with a reduction in risk of fire.
- Reduction and inhibition of deposit build-up on piston rings, injector nozzles and valves.
- Reduction and prevention of cylinder liner lacquering build-up.
- Protection against fuel pump and injector needle seizures commonly associated with ultra-low sulphur fuels.
- Extension of engine maintenance intervals and less engine downtime; saving both time and money.

The impact of fuel additives on engine fuel efficiency has not been proven despite some significant claims made by some suppliers. However, and in view of the better combustion efficiency and cleaner engine and exhaust system, some improvement in engine thermal efficiency is expected; but not significant.

Various fuel oil additives are available on the market. Use of additives, being chemicals, should take place with care and after full testing and consultation with engine manufacturers. Also, right dosage at well-defined periods should be observed. Also, treatment of fuel oil should be carried out in accordance with manufacturer's advice so as to ensure optimum performance from the combustion of fuel.

6.10. Energy Efficiency Measures

There is a number of energy efficiency measures directly related to fuel management aspect. These measures include:

- Vessels should carry the most economical amount of bunker in inventory. Carrying too much bunker fuel is not energy efficient as they have weight, and any transport of extra weight will cause extra fuel consumption.
- Energy is also used for temperature control of fuel and its transfer. To ensure energy efficient storage and transfer, fuel temperature in storage tanks needs to be controlled to lowest temperature feasible in order to retain it in a fluid condition and also suitable for transfer. In the latter case it is only the fuel to be transferred which is to be heated. Steam heating and trace heating should only be applied as required and not be left running unnecessarily.
- Ensure tank fittings (manhole covers, vent pipes, etc.) do not allow water, cargo or other material to get into the fuel. Ensure heating coils are tight.

- Ensure that tank wall condition is in good order thus avoiding corrosion or other material being entrained with the fuel which then has to be removed.

Maintain settling tanks at a temperature which will enable the purifier heaters to achieve the required treatment temperature.

- When a service tank is not in use it is not necessary to maintain usual high temperatures.
- Heater controls should be checked to ensure correct operation. Accumulations on heater elements should be minimised.
- Periodically verify that the viscosity controller is working correctly.
- Monitor fuel oil sludge levels and ensure that sludge levels are not high due to poor maintenance of the purifiers. As advocated, homogenisers can be used to reduce the sludge levels.
- Fuel measurement and metering is the first step for subsequent performance analysis of various engines and boilers. The more accurately fuel consumption is measured and reported, the more will be the chances for identifying inefficiencies and making improvements.

Although all aspects of fuel management have a close association with energy efficiency, most of the ship-board activities are done to safeguard the engines and boilers from damage. Therefore, fuel management for safety of assets marries well with its aspects of energy saving and there is no conflict between the two objectives.

References

Fuel Management References and further reading.

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Chapter 7: Technical Upgrade and Retrofit

7.1.Technical Upgrade and Retrofit Introduction

One effective way of improving the energy efficiency of a ship is to upgrade ship-board technologies to more energy efficient ones. Upgrading of technologies is not a ship-board activity but nevertheless, the ship-board staff could always engage in proposing such technologies. For this reason, this topic is covered under this module.

A number of technology upgrades can be considered for energy efficiency. It should be noted that applicability of such technologies will depend on ship type, ship size, operation profile and other factors. Thus, the decision making for each technology will need to go through the normal process of technical feasibility aspects and economic cost-effectiveness analysis for the specific ship that is under consideration. The technologies described here only shows a good sample, but the list is not comprehensive as there are other potential technologies that may be included.

7.2.Devices forward of Propeller

7.2.1. Mewis Duct

The Mewis Duct developed by Becker Marine System and other similar devices are designed for installation forward of the propeller as appendages. They have successfully been adapted for the larger scale commercial vessel. Figure below shows such devices.

Figure 7.1: Mewis Duct [Becker Marine Systems]

Since its introduction to the market in 2010, the Mewis Duct has gained acceptance by both ship owners and ship builders. A large number of vessels of the order of few hundreds are currently fitted with this sort of duct. They are mainly used on tankers and high block coefficient ships.

It is claimed that the Mewis Duct produces energy saving through three major impacts:

- Wake field equalisation: The installed duct straightens and accelerates the hull's wake into the propeller and also produces a net forward thrust.

- Reduction of propeller hub vortex: An improved flow behind the duct significantly reduces the propeller hub vortex with corresponding thrust deduction, leading to improved thrust and better inflow to the rudder.
- Contra-rotating swirl: Due to individually placed fins, a pre-swirl in counter direction could be generated, reducing the rotational flow losses of the propeller.

The way it improves the propeller efficiency is via a better streamlined and directed flow into the propeller thus reduces the propeller losses. The level of energy saving is claimed to be about up to 8%; however this maximum potential may be applicable to certain ship types and designs. The potential saving for each vessel will depend on a number of factors and thus any decision should be made on a ship-specific basis after performing a good deal of ship hydrodynamic analysis and model tests.

7.2.2. Wake-Equalizing Duct

The wake-equalizing duct consists of one half-ring duct with foil-type sections attached on each side of the after body forward of the propeller (see figure below). The half-ring duct accelerates the flow into the propeller in the upper quadrant on each side and retards the flow in the lower quadrants. This results in a more homogeneous wake field in front of the propeller, while the average wake is almost unaltered. The improved power consumption that is obtained from well-designed wake-equalizing ducts can be attributed to the following:

a. Improved efficiency because of more axial flow and a more homogeneous wake field.

b. Reduced resistance because of reduced flow separation at the after body.

c. Orientation of duct axes so that the inflow to the propeller is given a small pre-rotation.

d. Improved steering, due to straightened flow over the rudder and more lateral area aft.

Similar to Mewis Duct, it is placed to the fore of the propeller with the aim of accelerating water in-flows. This device is ideally suited to vessels with full hull forms (such as tankers) and containers operating at lower speeds (under 19 knots).

Figure 7.2: Typical wake equalising duct [Scheneekluth]

7.2.3. Pre-Swirl Stator

These are stators located at the fore of propellers as shown in figure below, acting like guide vanes for the flow into the propeller. The aim of guide vanes is to eliminate or reduce the crossflow that is often observed in front of the propeller. These vanes are fitted in front of the propeller on both sides of the sternpost. The vanes straighten the flow in the boundary layer in front of the propeller, thereby improving its efficiency. Crossflow appears mostly in ships with stern bulbs and full hull forms that operate at relatively low speed. The benefit is therefore largest for tankers and bulk carriers. The improvement decreases with decreasing fullness of the hull form.

Thus, pre-swirl stators (guide vanes) aim to provide a favourable pre-rotation of the water flow into the propeller. They are alternatives to ducts as explained above.

[Fathom] DSME system [SPPA]

Figure 7.3: Pre-swirl stator

As shown in figure above, in general:

- This arrangement enhances propeller efficiency via fitting of the bladed stators on the hull immediately forward of the propeller.
- The stator improves propeller efficiency via better adjusting the flow into propeller as the same happens in in normal pumps with guide vanes.
- A gain of 4% in propulsion power is claimed by proper tuning of stator blade angle.
- Better cavitation performance and supress of cavitation generated pressure pulses on the propeller is the other advantage.

As with the ducts, the device is especially suitable for the larger ships and hull forms. Its first installation on a 320,000 DWT VLCC has resulted in a 4% reduction in fuel consumption with more installations afterwards.

7.3.Devices Aft of Propeller

The propeller operation involves flow losses that appear at the rear of the propeller in the form of axial flows and rotational flows. The typical levels of such losses are shown in figure below these flow losses mostly appear in the slipstream at the back of the propeller.

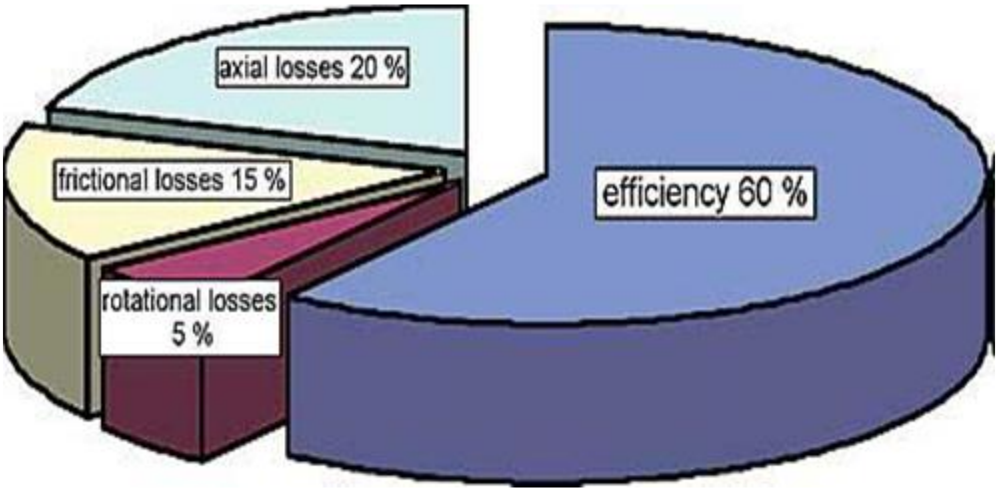


Figure 7.4: Typical propeller efficiency and losses

There are devices that can be placed at the aft of the propeller to recover some of the lost energy thus increase the overall efficiency of the propeller. These devices are normally cost effective as a retrofit option with a short payback period, provided they can be fit correctly. A number of devices belong to this category. Some of them involve modifications to the rudder. The most important among these devices are described below:

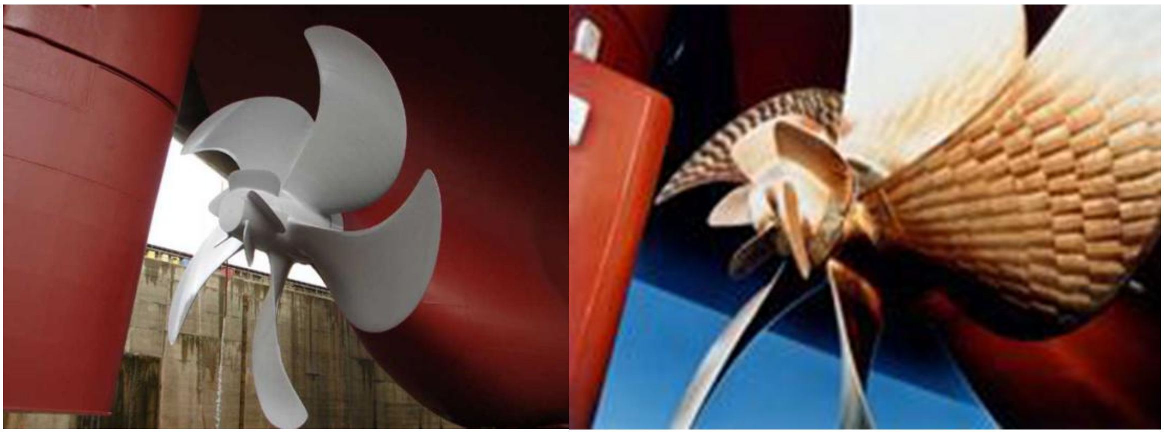
7.3.1. Propeller Boss Cap Fin (PBCF)

One of such devices is the Propeller Boss Cap Fin (PBCF) (see figure below) that can be added to the propeller's rear in place of the normal boss cap. This performs the function of recapturing some of the rotational energy lost by the propeller.

PBCF consists of small fins attached to the propeller cap. It was first developed and manufactured at the end of 1980s and so far has had some few thousands installed on ships worldwide. Therefore, there is significant experience with this device. The PBCF is relatively low-cost and non-complicated additions to a propulsion system. The return on investment of one year or so has been claimed and with installation time of only few days without the need to dry-dock.

The following are to a large extend the agreed benefits of using such a device:

- PBCF eliminates or reduces the hub vortices generated. As a result, PBCF can play an important role in reducing propeller generated noise and vibration.
- It is suitable for slow speed vessel.
- PBCF boost propulsive efficiency by about 5% and ship fuel efficiency by about 2%.
- PBCF can be retrofit easily to an existing ship.

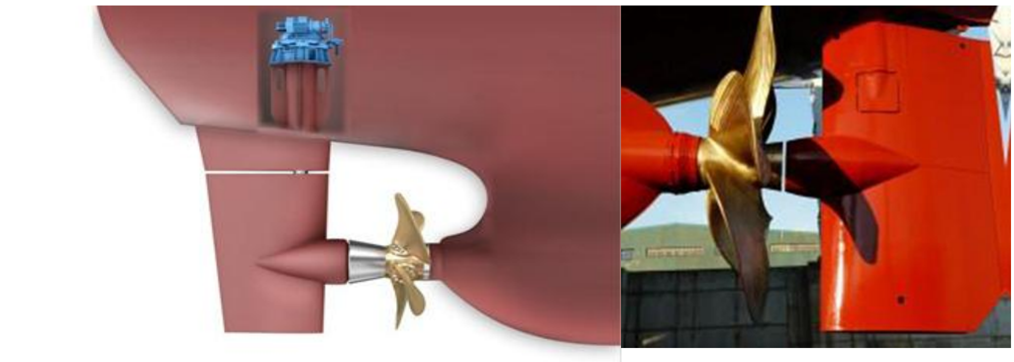


[Fathom] ***[MOL Techno-Trade]***

Figure 7.5: PBCF at the back of propeller

7.3.2. Integrated Propeller and Rudder Units

As the name implies, the propeller and rudder are designed as an integral unit. Part of the design is a bulb behind the propeller that is fitted to match similar configuration on the rudder. There are a few patented designs for such an arrangement (see figure below as main examples). The effect of these units has been reasonably well documented in tests on models and in full-scale trials. A reduction of about of 5% in required power of the vessel for design speed can by typical savings. The units are applicable to general cargo vessels, RoPax vessels and container vessels operating at relatively high speed. As with all other devices that impact ship hydrodynamic and resistances, the choice must be done after significant flow analysis and testing as the claimed savings are not universal. However, the potential for such a savings always exists for certain ship types and sizes.

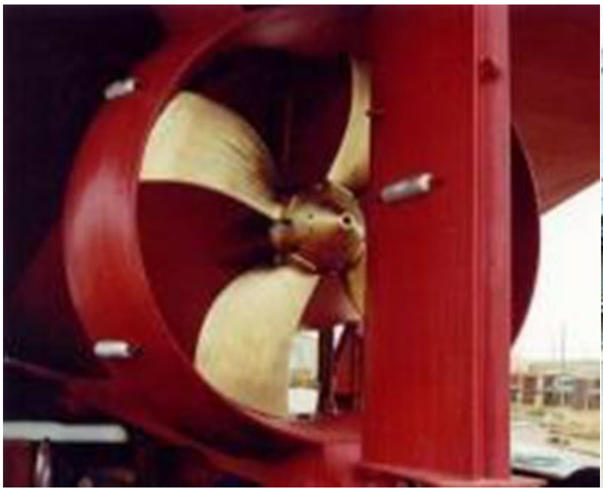


Promas efficiency rudder [Ship Technology] ***[VICUSdt 2015]***

Figure 7.6: Integrate propeller rudder

7.4.Ducted Propeller

The ducted propellers, as the name implies, refer to a two-component propulsor consisting of a propeller located inside a nozzle (duct) as shown in figure below.



[Chatterjee 2012] *Kort Nozzle [FathomShipping 2012]*

Figure 7.7: Ducted propeller

Compared to the conventional propeller of the same diameter and thrust, the ducted propeller arrangement allows a larger mass of water to be supplied to the propeller, improving the operating conditions around the propeller, thus its improved efficiency leads to corresponding potential for reduced power and fuel used by the ship propulsion.

Although, the reported benefits claim of the range of 5–20% is generally high, similar to Mewis Duct, it may have significant positive impact on certain ship types and designs. On the negative side, use of additional appendix in the form of a duct will increase the skin frictions thus flow resistances. Additionally, ducted propellers are prone to fouling of the system that may lose some of the advantages. As a result, there may be more need for propeller and duct underwater cleaning. This is regarded as one of their main weaknesses.

Ducted propellers are suited for ships operating at high propeller loadings, such as tankers, bulk carriers, tugs and different offshore supply and service vessels. The advantages of the ducted propellers in addition to fuel efficiency, could also include aspects such as reduction of propeller cavitation, vibrations and noise, better manoeuvrability if used with azimuthing thrusters and more safety for the propeller for example in ice operation or while grounding.

7.5. Fore-Body Optimisation and Bulbous Bow

Fore-body optimization includes consideration of the bulb design, waterline entrance and so on. The reason is that when a ship sails, the fore-body generates waves. These waves then hit the front side and increase the ship resistance and thus required power. The faster the ship sails, the more is the wave making resistance and the more energy it needs to overcome the waves.

A properly designed bulbous bow thus reduces wave resistance by producing its own wave system that is out of phase with the bow wave from the hull, creating a cancelling effect and overall reduction in wave making resistance (the concept is shown in figure below). A bulbous bow works best at a certain speed range and is sensitive to ship draft as well. If the ship sails at a different speed and draft ranges than the ones the bulbous bow is designed for, the bulbous bow has no, or in the worst cases even a negative effect.

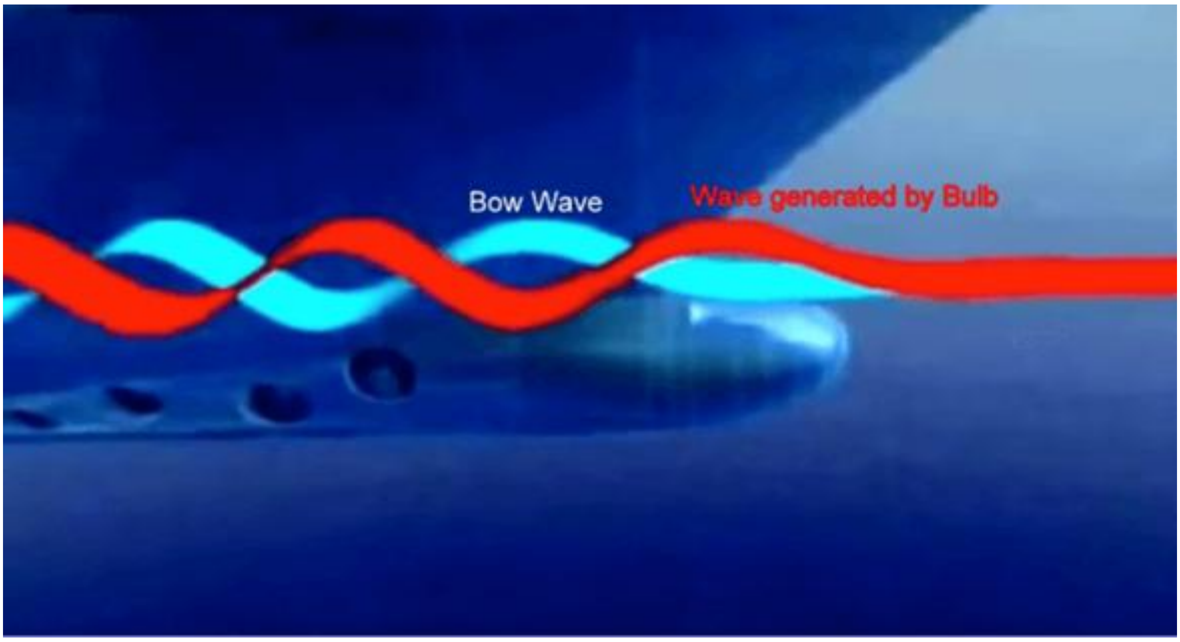


Figure 7.8: Concept of bow waves and bulb waves that cancel each other [http://www.marineinsight.com/naval-architecture/why-do-ships-have-bulbous-bow/]

Design of the bulbous bow involves significant level of flow and hydrodynamic analysis. A bulb with a reverse pear-shaped section is primarily effective at the design condition; pear-shaped bulbs work best for drafts below the design draft (i.e. ballast draft or partial load draft) and cylindrical shaped bulbs offer a compromise solution [ABS 2013].

A V-shape may be introduced at the base of the bulb to mitigate slamming impact loads. Faster and more slender vessels favour larger volume and forward extension of the bulb (more pronounced bulbs). Fuller ships such as tankers and bulk carriers are often arranged with bulbs having a large section area and V-shaped entrance, such that it behaves as a traditional bulb at loaded draft and acts to extend the waterline length at ballast draft [ABS 2013].

Commercial vessels normally do not operate solely at the design draft, thus, compromises in the bulb design are needed to provide good performance over the expected range of operating drafts and speeds. Depending on operation profile of a ship, retrofitting a new bulbous bow could be quite attractive from energy efficiency point of view. Maersk Lines has reported fuel savings of over 5% by modifying the bulbous bow from the original shipyard design that was optimized to the design draft [Jonathan Wichmann]. This change took place because of the reduction in operating speed of the vessels relative to their design speed for slow steaming. This provided more favourable performance over the anticipated actual operating profile compared to design assumptions.

Retrofit of bulbous bow simply involves the cutting off of the old one and replacing it with the new design. This takes place in shipyard and during dry dock (see figure below). As mentioned, this has practiced by major liner operators due to the need for changes to ship operation profile.

Figure 7.9: Bulbous bulb retrofit on Maersk ships [Jonathan Wichmann]

7.6.Waste Heat Recovery

Waste heat recovery can be carried out to produce hot water, steam or electricity from the hot exhaust gases or hot water from engines cooling system. The main candidate areas of waste heat recovery are from exhaust of the engines where the temperature is high. Also, low grade heat recovery from engine cooling system is possible and need to be considered for specific ship applications.

Exhaust gas economisers are the usual waste heat recovery system currently used on many ships. This is a shipbuilding issue and not subject to retrofit. It has been covered as part of discussion on "steam system" in Boilers and Steam System. Also, more sophisticated exhaust gas steam system with steam turbine is used in larger ships; this is not normally a subject of retrofit but mostly applicable to new buildings. For ships in operation, the scope for extra heat recovery needs to be reviewed, and generally if lower grade heat is needed on-board, then waste heat recovery system could be used.

7.7.Auxiliary Machinery and Systems

7.7.1. High Efficiency Electric Motors

Electric motors are not 100% energy efficient but generally have energy efficiency that could be anything from 75% to 95%. Thus choice of energy efficient electric motors for a ship will make energy saving over the long term. These days, there are standards for energy rating of electric motor and efforts are made to make these motors more energy efficient. Figure below shows an example of rating practiced by Europe.

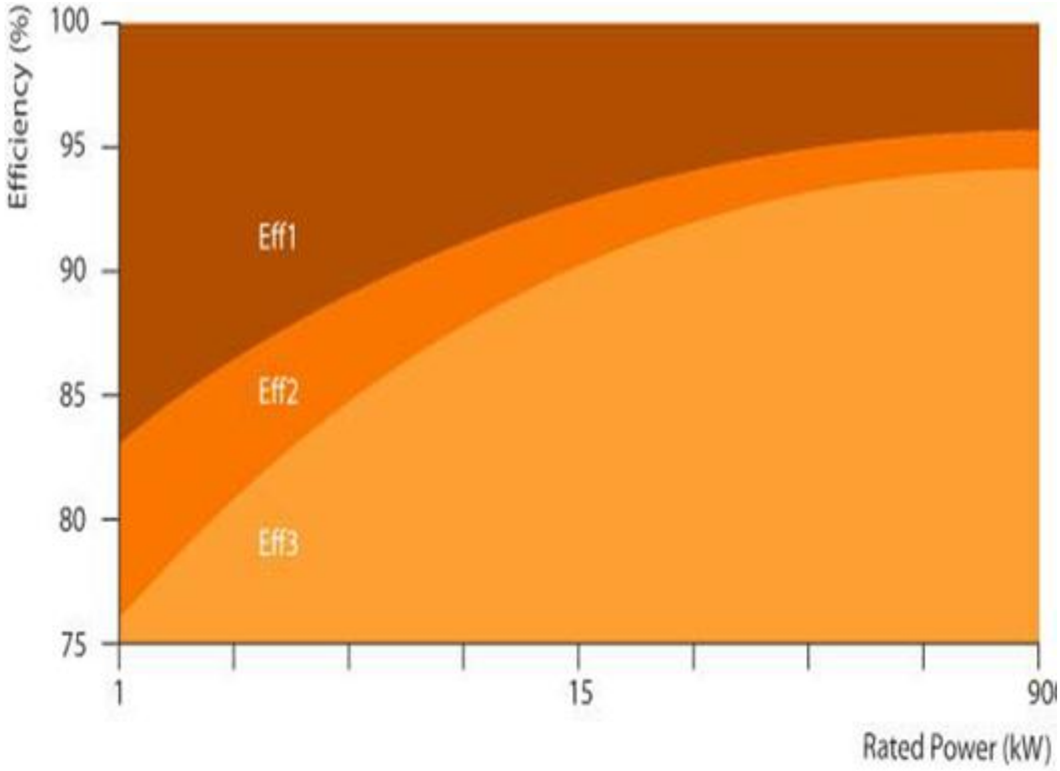


Figure 7.10: Example of energy efficiency rating of electric motors

In choice of electric motors for ship, the idea of energy efficiency needs to be taken into account early and during the shipbuilding stage. For existing ships, when an electric motor needs to be replaced due to maintenance requirement, procurement of an energy efficient electric motor should be considered.

7.7.2. Fuel Oil Homogenisers

Fuel sludge may constitute up to 1% of fuel used on board. The sludge disposal is normally done either via burning on board (incinerator) or transfer ashore. The whole process is waste of energy and money. Finding ways of reducing sludge thus could be desirable.

A homogenizer assists the process of fuel homogenizing and thereby a reduction is sludge level. It also helps with the supply of more uniform fuel to combustion systems. The main job of a homogenizer is to create a uniform structure of all solid and non-solid materials present in heavy fuel oil. A homogenizer also breaks down large water elements into small homogenous structure, resulting in an emulsion consisting of water molecules spread evenly throughout the whole fuel.

A homogenizer mainly works by agitating and milling of the fuel. Agitation can be done by using a mechanical arrangement which pumps the liquid through an orifice plate. Such a system is shown in figure below. Agitation can also be done by an acoustic medium which uses ultrasonic frequency to agitate a surface over which the liquid is pumped.

Figure 7.11: Typical homogeniser

A conventional homogenizer is like a milling machine which churns the liquid as it passes through it. The design consists of fixed stator housing with a rotor which is generally driven by a motor. The mating surface of stator and rotor has specially designed channels. Both rotor and stator are conical in shape and have a specific clearance between them through which the fuel is passed.

Moreover, the design is made in such a way that the liquid accelerates as it moves through the channel, making the dissolved components uniform in nature. It should be noted that although the unit looks like a pump, it doesn't have a pumping unit. A separate pump needs to be installed to pump the fuel through the system.

The operation of a homogeniser has the following advantageous effects:

- Reduction in sludge production (up to 75% has been claimed but a number of 40% is more realistic). This causes an increased amount of burnable fuel, thereby fuel saving and fuel cost. Also, this reduces the cost of disposing of the sludge.
- Influence on purifier efficiency.
- Less wear and tear of engine components.

In case, a homogeniser is used for some water emulsification into fuel, it could positively impact exhaust pollutants as well. Both NO_x and smoke reduction can be achieved if the system is used for water-fuel emulsification.

7.7.3. Other Technologies

There are other technologies that may be used for upgrade and retrofit that include:

- Energy saving lamps.
- Card controlled or occupancy sensors lighting system for accommodation.
- Variable speed drives for pumps, fans and compressors.
- HVAC system control upgrade and also pre-cooling of incoming air using outgoing cold air.
- Engine de-rating: This is a significant area and only applies for extreme slow steaming.

References

Technical Upgrade and Retrofit 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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8. Jonathan Wichmann, "The nose job: Why 10 of our ships are getting a new bulbous bow", http://maersklinesocial.com/nose-job/, access August 2015

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Chapter 8: Boilers and Steam System

8.1.Boilers and Steam System Introduction

The steam system plays a major role in energy efficiency of certain ship types (such as steam driven LNG ships) and a medium role in ships such as oil tankers carrying liquid cargo that require cargo heating or there is a need for cargo transfer using steam driven pumps but also need to generate Inert Gas for cargo tank cleaning, purging or tank top ups. **Figure below** shows typical level of fuel use in boilers as compared to main and auxiliary engines for a VLCC vessel.

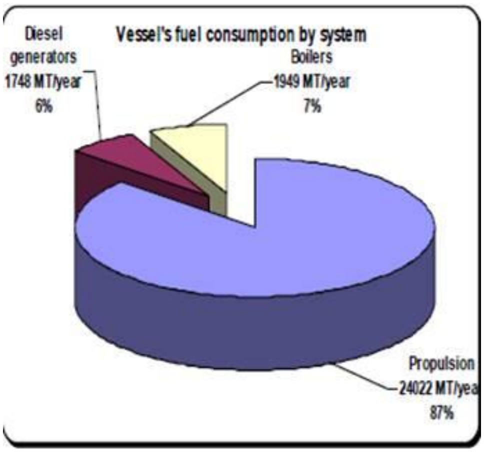


Figure 8.1: Overall annual fuel consumption and boiler share [Bazari 2012]

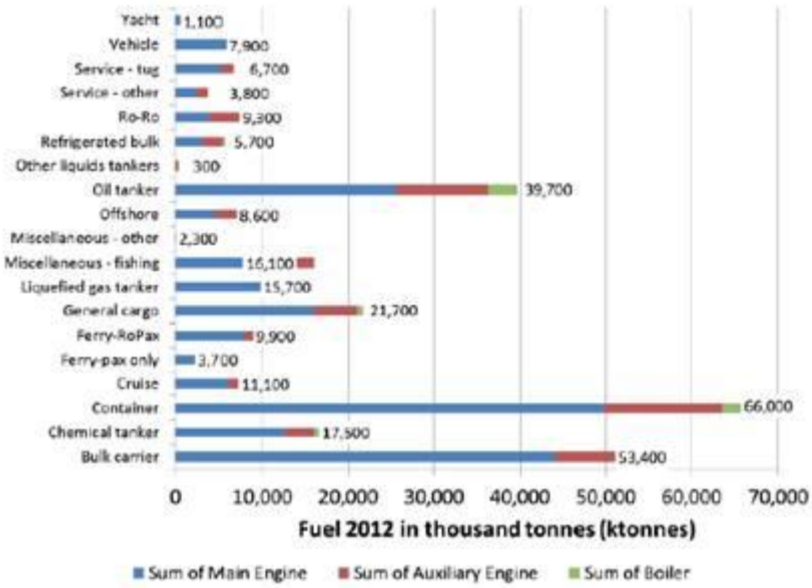


Figure 8.2: Annual shipping fuel consumption per ship type and combustion system [Third IMO GHG Study 2014]

It can generally be stated that an overall average number of up to a maximum of 7% of shipping fuel consumption could be attributed to the use of boilers. As stated, for steam turbine propulsion ships such as steam LNG ships, more than 80% of energy use is due to boilers.

8.2.Overview of A Ship's Steam Auxiliary System

In commercial ships, the steam system normally includes the following equipment:

- Auxiliary boilers
- Exhaust gas economisers

As the names imply, the exhaust gas economiser is a waste heat recovery system that recovers heat from exhaust of main or auxiliary engines and thus generally does not use fuel. The more the second system is used, the less will be a need for use of the auxiliary boilers, thus good maintenance and operating conditions of exhaust gas economiser should always be regarded as part of energy saving in the steam system. **Figure below** shows a typical steam system for a ship.

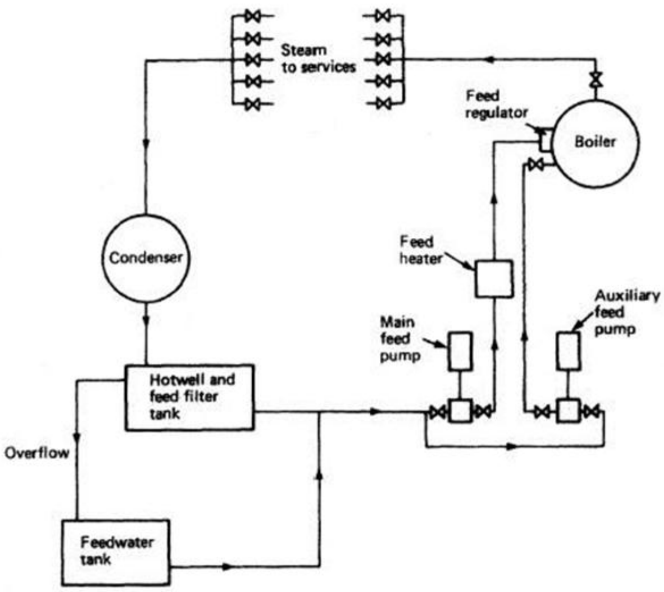


Figure 8.1: A typical auxiliary boiler steam system configuration [Machinery Spaces.com]

For the sake of presenting the energy efficiency case, the ship-board steam system will be divided into the following parts:

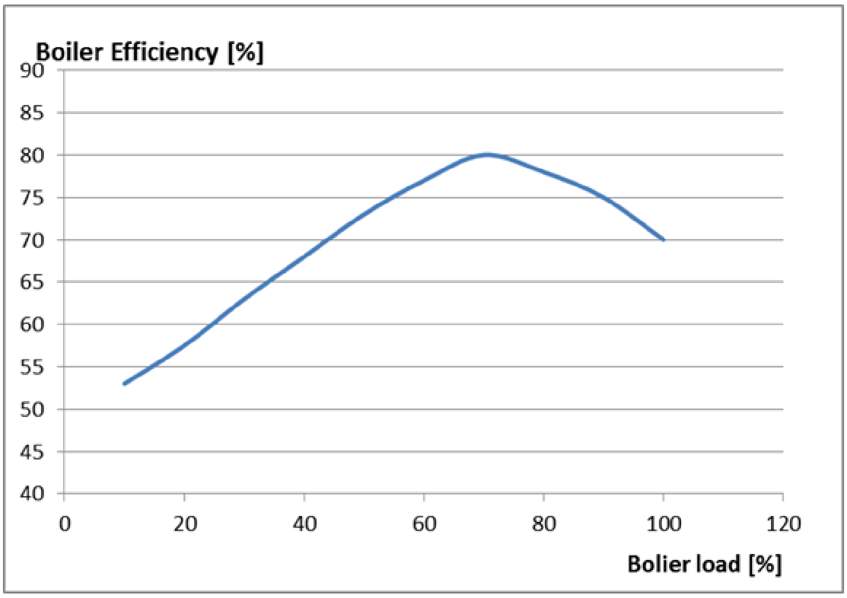
- The auxiliary boilers: This is where the steam is produced using fuel.
- The exhaust gas economiser: This is where the steam is produced via waste heat recovery.
- The steam distribution system: This refers to steam piping system and relevant instruments and devices used for steam controls.

- Steam end-use: This refers to all the steam consuming systems such as steam turbines, freshwater generators, steam heaters, etc.

8.3. Boiler energy efficiency measures

8.3.1. Boiler Efficiency Characteristics

Figure below shows typical energy efficiency characteristics of a boiler that is normally specified by boiler manufacturer. As can be seen, the boiler efficiency is a factor of its load.



In operation, the efficiency tends to be lower than the above design values. There are a number of major areas that need to be managed in order to keep the auxiliary boiler at its highest energy efficiency levels as signified by figure above.

8.3.2. Fouling of surface:

The boiler main function is to generate steam at correct pressure and temperature and with best energy efficiency. Optimal energy efficiency means optimal transfer of fuel energy to boiling water via various boiler pipes and heating surfaces. Aspects that could lead to a reduced rate of this heat transfer include:

- Fouling of boiler tubes and heat transfer surfaces on the gas side
- Fouling or scaling of boiler tubes on the water side.

The above will normally translate into a less heat transfer from gas and more heat retention by the exhaust gases as they leave the boiler. Thus, high boiler outlet exhaust gas temperature could be a good indication of such fouled conditions. To remedy the case, maintenance practices should include boiler's soot blowing, de-scaling, good water, combustion adjustments (to reduce soot formation) and son on. For this purpose, the heat transfer areas of the boiler must be monitored. The soot blowing of the boiler must be done regularly as build-up of soot acts like an insulator and reduces the heat transfer rate. The same goes for the build-up of scale in the water tubes. The stack temperature must be monitored regularly and any increase in it means that heat recovery is not optimum. High increases of exhaust gas temperature beyond those experienced after the last cleaning would indicating build-up of fouling and would require another cleaning action.

8.3.3. Optimum hot well temperature and blow-down levels:

There is a hot well that collects all the condensates from steam system end-users plus where water treatment and cleaning may take place. It is from hot-well that the feed water is supplied to the boiler. Hot well temperature must be maintained at temperature specified by manufacturers. A low temperature (e.g. below 80-85 C) will cause colder feed water to enter the boiler thus increasing the fuel cost due to the need for more heating for steam generation. An overheated hot well may cause evaporation of water at the suction of feed pump (e.g. cavitation) and cause vapour lock in the feed pump and loss of suction. For heat retention in the hot well to keep temperature higher, heat losses due to poor insulation can be reduced. Also, control of make-up water is important as excessive need for make-up water will be indicative of leak in the steam system as well as more heating for make-up water that is normally at low temperature. The blow down of the boiler is required for controlling the number of dissolved solids as a result of evaporation and impurity of make-up water or addition of other chemical. Blow down must be calculated and done after measuring the level of dissolved water. In some cases, the engineers blow down the boiler excessively, thus not only loose hot water, but also increase the need for make-up water and make-up water generation.

8.3.4. Excessive combustion air:

In order to burn the fuel, air needs to be supplied to the boiler. The excess air unused in the combustion gets heated and then discharged through the chimney. This is waste of energy. Thus, any excess air that is not needed for combustion will cause energy loss as it will take away heat from boiler and discharge to the atmosphere, thus normally should be avoided. Boilers normally have certain amount of optimal excess air, and the air input must be adjusted to this level. It signifies a balance between combustion efficiency and amount of air supplied. Excessive “excess air” is identified in the form of either high O_2 concentration or low concentration of CO_2 in the boiler exhaust gas. These two parameters thus need to be monitored as part of controlling boiler excess air thus its energy efficiency. Figure below shows the boiler efficiency as a function of CO_2 concentration. As can be seen, it is desirable to maximise the CO_2 concentration in the exhaust gas for best efficiency. As indicated, the optimum level would normally be specified by the manufacturer.

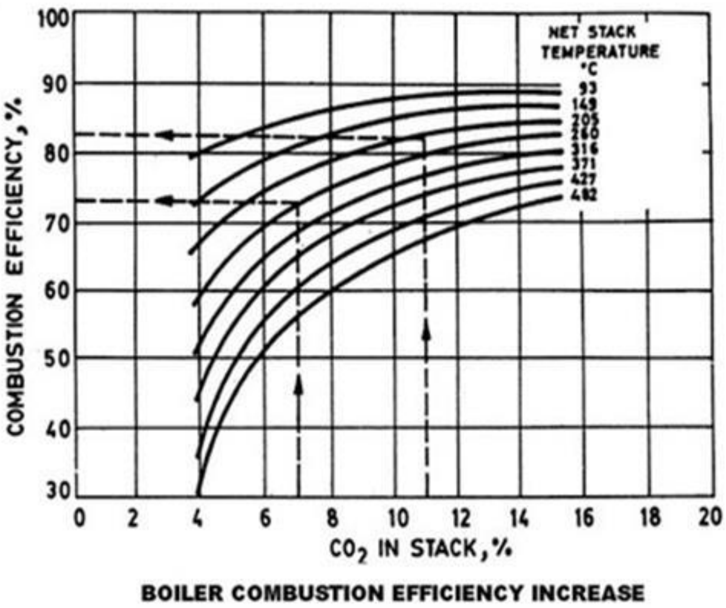


Figure 8.2: Boiler efficiency as a function of CO2 level in the exhaust gas [Mohit Sanguri]

8.3.5. Exhaust gas economiser efficiency:

The Exhaust gas economiser in a ship is like a huge heat exchanger that exchanges heat between exhaust gas from engines to water and produces steam for the same purpose that auxiliary boilers produce steam. The revered energy and amount of steam generate by exhaust gas economiser is normally sufficient for routine ship-board steam requirements, thus normally a ship with exhaust gas economiser does not need to fire the boiler while in passage. As far as improving efficiency by avoiding the fouling on the gas side and water side, the same principles discussed under boiler applies. The efficiency of an exhaust gas economiser can be improved by increased soot blowing frequency (once or twice a day while at sea). Recording the exhaust gas temperature difference and pressure drop can provide an indication of economiser cleanliness. Water washing should be scheduled into major repair periods. The exhaust gas economiser maintenance will not only improve energy efficiency but also reduce maintenance overall costs and reduce safety risks associated with soot fires. Occasionally use of fuel additives may improve the cleanliness of the economiser. As for ship design, the maximum waste heat recovery is desirable. For exhaust gas economisers, the funnel stack temperature must be as low as possible but with sufficient margin to be above the dew point to avoid sulphur corrosion. Generally, a funnel temperature of 165° to 195°C when using fuel oil is considered optimum.

8.3.6. Boiler efficiency and load factor:

Like any other devices, the boiler energy efficiency is a factor of its load factor. First figure shows typical such efficiencies.

Accordingly, for this boiler the efficiency is highest at certain point and then drop off with changes in load. Thus boiler load management could be considered as one aspect of energy efficiency. First figure shows that at 70% load, the efficiency is 80% and at 30% load, the efficiency is 63%: a significant drop. Operating the boiler at low load is thus inefficient.

Avoiding low load boiler operation will depend on ship type, number of boilers and where the steam is used. Generally, if there are two auxiliary boilers on a ship, they must not run in parallel if one can supply the whole steam demand, unless safety issues dictate the need for such a parallel operation case.

8.4.Steam Distribution System Energy Efficiency Measures

The steam distribution system maintenance makes a significant contribution to energy efficiency in steam system. Measures to consider include:

- Steam loss through open bypass valves.
- Steam loss through failed open steam traps.
- Heat loss through un-insulated or improperly insulated piping and equipment.

To determine if your ship could benefit from a steam distribution system maintenance program, normally steam lines and steam traps surveys need to be done at regular intervals. The inspection activities will include steam pipes, insulation, traps, steam supply/discharge on or around heat exchange devices etc. Fundamental to such inspections is the collection of good data. Aspects to consider include:

- Reduce steam leakage: As part of day routines, checks should be made for steam leaks. The steam leaks should be rectified as soon as observed.
- Heat loss due to inadequate insulation: The boiler and steam lines along with condensate return to the hot well must be well insulated. Over a period of time insulation is damaged or worn out. Any analysis by thermography or any other thermal measurement system could identify the hot spots. Improvement of damaged insulation due to repair work must be done. All these will reduce the heat losses from the system thus improve energy efficiency.
- Steam trap losses: Steam traps are used to discharge condensate once it is formed, thus the main function is to prevent live steam from escaping and to remove air and non-condensable gases from the line. However, it is a largely neglected part of the steam distribution system. Steam traps that are stuck open allow live steam to escape thus resulting in loss of heat and also increasing the load of the condenser. Steam trap that is stuck shut results in reduced capacity of the equipment it is being supplied to. Overall, steam traps must be checked at planned intervals to show their good working conditions.

8.5.Steam End-Use Energy Efficiency Measures

Steam end-use could vary according to ship types. The main users of steam include:

- Steam-driven cargo pumps in tankers.
- Steam driven ballast pumps.
- Cargo heating
- Fuel storage, treatment and condition system.
- Fresh water generation especially in cruise ships
- HVAC system in particular in cruise ships

Every effort should be made to economies on steam-end use as this would eliminate the need for extra steam generation thus very effective in energy saving.

8.5.1. Cargo Heating Planning and Optimisation

In some ships, the cargo requires cooling to maintain quality, e.g., refrigerated or frozen cargo. With other cargoes such as special oil products, special crude oils, heavy fuel oils, etc. may require heating in particular in winter and cold climate regions. Some of this heat required can be supplied by exhaust gas economiser. However, in many cases an additional auxiliary boiler is needed to supply sufficient steam. Steam from exhaust gas is generally sufficient to heat the heavy fuel oil that is used on most ships; in port, however, steam from an auxiliary boiler may be needed.

For cargo heating purposes and in order to reduce fuel consumption and the heating costs, a voyage specific cargo heating plan should be developed by the shipboard team with support from operation department at head office. For a proper plan, the following should be considered:

- Vessel tank configuration.
- Whether deck heater or tank heating coils are provided.
- Number of heating coils and surface areas.
- Cargo details including specific heat, pour point, cloud point, viscosity, and wax content.
- Weather enroute including ambient air and sea water temperatures.
- Estimated heat loss and drop in temperatures.
- Recommended return condensate temperatures.
- Estimated daily heating hours and consumption.

Various parameters such as daily air/sea temperatures, weather, cargo temperatures at three levels, steam pressures, return condensate temperature, actual against estimated consumptions and temperatures are discussed between shipboard team and head office. The heating plan should be reviewed and revised appropriately throughout the voyage.

The optimum temperature to which cargo should be heated for carriage and discharge largely depends on the following factors:

- Pour point: It is the lowest temperature at which the liquid will pour or flow under prescribed conditions. It is a rough indication of the lowest temperature at which cargo is readily pump-able. General principle is to carry cargo at 10^{o} C above pour point temperature.
- Cloud point: It is the temperature at which dissolved solids are no longer completely soluble, precipitating as second phase and is synonymous with wax appearance temperature. Once separated, it requires temperature over 80 0 C to dissolve the wax. Cargo temperature should not be allowed to fall below the cloud point.
- Wax content: High wax crude tends to deposit sludge, and therefore require to be maintained at a higher temperature to prevent wax fall out.

- Viscosity: High viscosity oils do not necessarily deposit sludge and may be carried at lower than the discharge temperatures. However, for discharge purposes, the heating will be done to reduce the viscosity to acceptable levels for cargo pumps.
- Ambient weather and sea conditions: This will also influence the cargo carriage and discharge temperatures as these impacts the level of heat transfer from cargo tanks or fuel tanks.

The cargo heating plan would need to take into account the above parameter. As part of cargo heating planning, relevant instructions will be developed. Heating instructions should be reviewed after loading cargo, based on charterer requirement. Permission to carry and discharge the cargo at optimum temperatures should be requested from charterer or cargo owner. The heating plan should be made soon after loading cargo and reviewed/updated on daily basis considering the various factors that affect the heating and customer requirements.

A review of the heating log abstract with the following will help with better future planning and identifying the gaps:

- Actual vs. planned temperature
- Actual vs. planned fuel oil consumption
- Actual vs. planned heating hours.

Vessels should complete the heating abstract (daily basis) after completion of each voyage and send it ashore along with the Cargo Heating Log, also identifying any gaps. Figure 10.8 shows a typical cargo heating patterns graph. Figure 10.8 - Example of a cargo heating process [OCIMF 2011] Operational control and best practice For best practice cargo heating planning, the following should be noted:

- Vessels should have a greater understanding of the voyage manager/charterer's heating instructions.
- Seek the receiver/charterer's permission for allowable range of cargo temperatures.
- Avoid heating during adverse weather period.
- Create and follow the proper cargo heating plan to verify the effectiveness of actual heating progress.
- Closely monitor and analyse cargo heating reports. Monitor heating daily to address deviations from the heating plan.
- Do not heat for short frequent periods and running boiler at low loads.
- Follow the recommended condensate temperature and optimum boiler settings for efficient cargo heating. Heating instructions, accompanying the heating plan, should further highlight these points.
- Maintain efficient and good communication between the vessel and the voyage manager/charterer about the plan and execution. Cargo heating may also benefit from the use of effective insulation. For example, using lagging on heating coil water / condensate return pipes as well as steam, thermal oil and hot-water lines on deck area. This could be significant energy saving option as it has been observed that some ships lack insulation of branch lines and cargo tanks. It is important that the insulation material

is of good quality. A poor quality of insulation material is likely to rot or lose its effectiveness.

8.5.2. Steam for Cargo Discharge or Ballast Water Operation

Certain ships such as large crude oil and product tankers as well as ships for the need for large ballast pump may use steam-driven turbines to drive the cargo and ballast pumps. In these ships, extra boilers are operated to drive the cargo pump steam turbines as well as for inert gas generation. Cargo pump driven steam turbines are highly inefficient (with an overall efficiency of about 10-15%) and care should be exercised in their usage level. During cargo discharging operations, vacuum should be maintained properly in the vacuum condenser. This will ensure better work transfer across the steam turbine thereby increasing output at the same boiler load. During cargo discharging operation, better coordination and planning must be maintained with the terminal personnel (loading master, terminal representative(s)) as also on board with deck and engine department so as to reduce idle firing period of main boilers; reducing unnecessary / prolonged cargo oil pumps' warm up period, idle running of inert gas plant etc.

8.5.3. Inert Gas Generation (IGG)

In various type of crude oil and product tankers, IG is needed for cleaning, purging and top of the cargo tanks for safety reasons. The IGG (Inert Gas Generation) system produces exhaust gas with minimal O2 concentration for this purpose. The IGG operation resemble that of boilers and consumes fuel thus its management is required for saving energy. The IGG usage needs to be monitored to ensure that it is not used excessively. Also, optimising of the cargo tank cleaning, gas freeing and inspection intervals will reduce the usage of IGG system. When IGG system is used, the level of discharge to atmosphere (blow off of not needed IG) should be minimised via optimal operation of the system.

8.6. Shipboard Best Practice Guide

The need to maintain clean surfaces on all exhaust gas economiser and auxiliary boilers is emphasised. The differential pressure across the economiser and its gas inlet and exhaust temperatures should be constantly monitored and appropriate action taken if measurements are out of optimum range. Additionally, steam traps are to be checked regularly for functionality and steam leaks are to be identified and stopped. Boiler control settings such as burner start/stop and water level setting for feed pump start/stop shall be chosen in a way to reduce energy consumption. Cargo tank heating (if applicable) shall be carried out according to the specification of the cargo and control temperatures shall be set as low as possible. Also, fuel oil temperature in various storage tanks must be monitored and kept within acceptable limits. For evaluation of insulation and steam traps, thermal imaging may be used as a tool. To demonstrate compliance to the above guidelines, the following need to be carried out:

- Steam pipes insulation should be kept in good condition.
- Boiler insulation should be kept in good condition.
- Steam traps are to be checked regularly for functionality.

- Steam leaks are to be identified and stopped.
- Boiler pressure setting for burner start/stop is to be as wide as practicable.
- Cargo tank heating (if applicable) shall be carried out according to the specification of cargo and control temperatures shall be set as low as practicable.
- Fuel temperature in storage, settling ad supply tanks shall be monitored and kept at acceptable lower limits.

Other activities will include:

- Steam trap maintenance should be carried out regularly. Steam traps which are not working correctly may lead to the loss of an excessive amount of additional energy.
- All steam leakages to be minimised.
- Auxiliary boiler is to be used during anchorages and other relevant opportunities.
- Starting of auxiliary boilers too far in advance of intended use is to be avoided.
- Steam dumping when possible is to be avoided.
- Pipe/ valve lagging is to be maintained in good order to minimize heat loss.
- Steam tracing is to be used judiciously.
- Bunker tank heating is to be optimised.

References

Boilers and Steam System 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. Mohit Sanguri, "Energy Conservation in Boilers and Making an Audit Report" http://www.marineinsight.com/marine/marine-news/headline/energy-conservation-in-boilers-and-making-an-audit-report/ accessed August 2015.

2. Bazari Z, 2012, "Ship Energy Efficiency – Developments and Lessons Learnt", Lloyd's Register, LRTA publication, November 2012.

3. Machinery Spaces.com "Feed systems for auxiliary boilers and steam turbines - operating principle", http://www.machineryspaces.com/feed-system.html, accessed August 2015.

4. Carbon Trust, 2012, "Steam and high temperature hot water boilers", Carbon Trust UK publication, 2012.

5. Alfa Laval, "Efficiency in boilers and beyond", http://www.alfalaval.com/globalassets/documents/industries/marine-and-transportation/marine/whr.pdf, Alfa Laval document, accessed August 2015.

6. "IMO train the trainer course material", developed by WMU, 2013.

7. OCIMF 2011, "Example of a Ship Energy Efficiency Management Plan", submitted to IMO by Oil Companies International Marine Forum (OCIMF), MEPC 62/INF.10, April 2011.

Chapter 9: Port Operations, Air Emissions, and Efficiency Measures

9.1.Ports and Port Area Emissions Introduction

9.1.1. Port Role and Functions

Ports are part of a wider international and national network of transport and logistics. They significantly contribute to the cargo logistic network. The success of ports in the logistics chain depends on their strengths as well as the strength of other players in that chain including shipping. A similar reasoning applies to the other maritime transport players including ship owners, port operators and the land-based transport service providers. Accordingly, the function of a port like other major maritime stakeholders (e.g. ship owner) does not depend exclusively on its own facilities and management processes but also affected by a variety of other stakeholders. Figure below shows a simple view of the basics of a logistic chain.

Figure 9.1: A simplified schematic of a logistic chain [Voorde & Elsander]

As figure above indicates, the maritime logistics chain consists of three large sections:

- The purely maritime aspects (at the centre above) that mainly relates to ship operation.
- The cargo handling and storage in the port; and
- The land-based (hinterland) transport services.

Depending on the cargo category concerned and the type of chain management applied, this structure may become more complex and possibly involve different players as well as other ports of call. Considering only the port-related activities in the above overview, one of the core and most important function of ports relate to the ships' cargo loading and unloading. Specifically focussing on ports, figure below shows the main activities of a marine port in a schematic form.

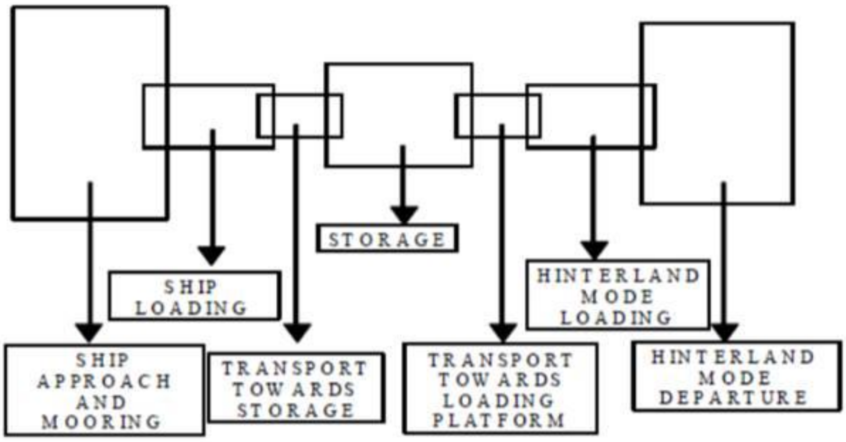


Figure 9.2: The main activities of a marine port [Voorde & Elsander]

Over the time, ports have engaged in a large number of so-called value-added services in addition to cargo loading and unloading plus other core services. These could include a variety of marine services such as bunkering, to repair and real estate activities in ports as shown in figure below. This evolution of port activities is indicative of the increasingly complex nature of ports of modern times.

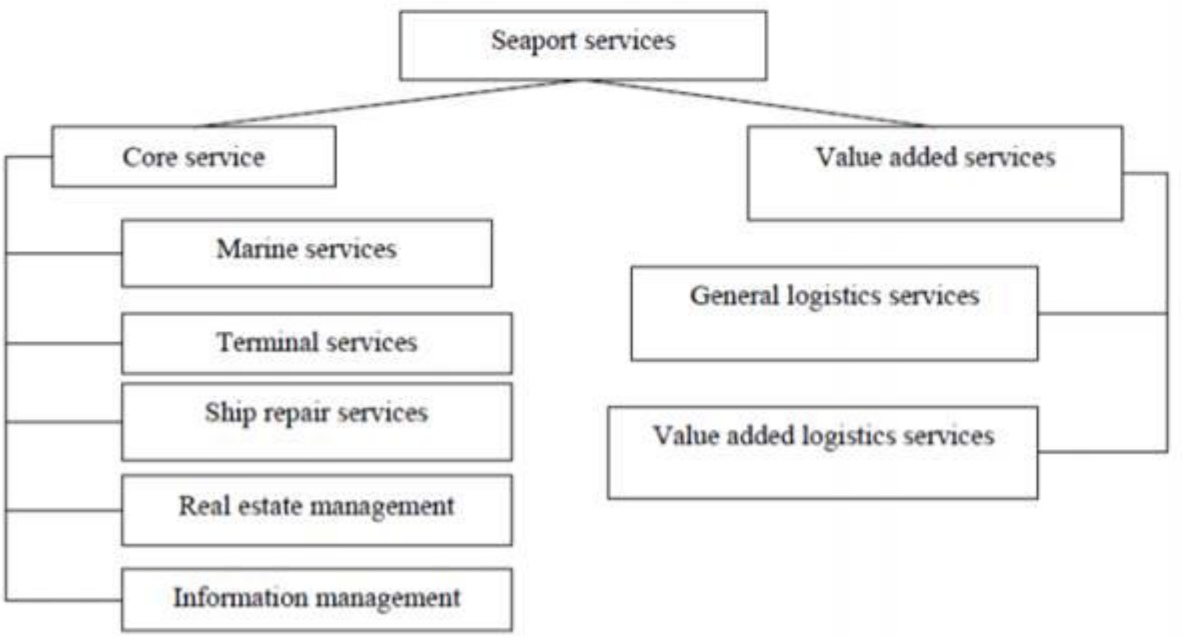


Figure 9.3: Principal port activities [Voorde & Elsander]

9.1.2. Complexity of Port Operation

A port encompasses more than the port authority as the top governing body but also other players such as shipping companies as its principal customer and terminal operating companies as the main suppliers of services. There are numerous other, often smaller players to take into account and typical examples of such players are fuel trading and dredging. The former plays a big role in ship operations, whereas the latter has its role in the construction of shipping and port facilities. The availability of efficient fuel provision can convince a shipping company to call at the port and even make a longer stay, in both cases resulting in more cargo loading and unloading capacity. Dredging activities are an important element of capacity creation and maintenance.

From a different perspective, port management is a complex process as this is normally made up of a variety of links. Often different parts of the chain are controlled or managed by different players, but some activities are also integrated across links. So, ports could have a relatively complex management and decision making structure.

No two ports are physically and economically the same. Therefore, their operations will depend on the port as a physical entity, taking into account the various activities such as facilitating the loading/unloading of vessels, freight handling and storage and access to land-based transportation. Clearly these are quite diverse activities, which combine to make port services quite diverse and complex.

Port operations involve a great many players, both at management level and at operational level. The management of ports also varies from one country to the other. The port as a physical entity is managed by a port authority in which the public authorities may or may not be a stakeholder. In addition, depending on the size of the port, any number of enterprises may be located within its perimeter. Figure A simplified schematic of a logistic chain [Voorde & Elsander] offers an overview of the various market players within a port, indicating who provides services to whom. The diagram confirms that shipping companies rely on services provided by third parties (e.g. pilots, towage services, ship repairers, provisioning, waste reception facilities, and bunkering companies) that are somehow but not fully associated with a port.

The large number of parties involved in port activities, each of which pursues its own objectives, gives rise to a considerable degree of diversity, both within the port and between ports. Hence, a generalised comparison between ports may not be fully possible. Moreover, the situation is further complicated by the fact that different ports often work under different economic, legal, social and tax regimes just because they are regarded as part of national entities in each country. Thus ports are to a large extent different from international shipping that is mostly regulated by IMO rather than by national-specific regulations that applies to ports [Hilde Meersman, et al].

The issues of governance, control and ownership are critical to any discussion of environmental management in ports. The vast majority of harbours are characterized by privately owned dock facilities and in these instances, control of property and operations lie with each private property owner.

9.1.3. Ports and Air Emissions

On the environmental side, one of the main issues that ports are facing is local air quality. This is caused due to air pollutants; rather the CO_2 emission that is the main topic of this training course. As most of activities relating to reduction of air pollutants have impacts on CO_2 emissions, in this module, the emphasis will be on all air emissions rather than simply CO_2.

In port areas, air emissions and energy consumptions are primarily due to ships. However, there are other equipment and facilities that use energy or contribute to air emissions to port areas. These are for example:

- Cargo loading and unloading devices.
- Trucks and other land-based transportation units such as locomotives.
- Buildings and energy needed for these building.
- Harbour crafts that provide additional services to port and shipping companies.

Emissions in port areas are mainly those due to diesel engines and boilers. These air emissions include:

- Nitrogen Oxides (NO_x): The main sources of NO_x are diesel engines both for ships and other land-based trucks.
- Particulate Matters (PM): Again, diesel engines are the main source of such emissions.
- Sulphur Oxides (SO_x): These are due to burning of sulphur content of fuel.
- Some carbon monoxide and unburned hydrocarbons could also be emitted from ship engines if they are not properly tuned.

The amount and level of such emissions will depend on not only technologies used but also operational aspects of ships, the time they stay in port and other energy using machinery and facilities in port itself. Emission reductions in the port area are typically focused on PM, SO_x and NO_x due to air quality health impacts. Controlling NO_x, PM and SO_x is the central focus for most national and regional regulatory agencies and therefore the same applies for ports as does to the shipping industry. GHGs emissions have recently been seriously addressed by regulatory agencies such as IMO, although in the port area, health effects and thus pollutants typically take the priority over GHG emissions.

In a discussion paper by International Transport Forum [Olaf Merk], it is claimed that shipping emissions in ports are substantial, accounting for 18 million tonnes of CO2 emissions (this is equivalent to burning of about 6 million tonnes of fuel oil), 0.4 million tonnes of NO_x, 0.2 million tonnes of SO_x and 0.03 million tonnes of PM10 (PM with size of less than 10 microns) in 2011. Around 85% of emissions come from containerships and tankers. Containerships have short port stays, but high emissions during these stays.

The same paper states that most of CO_2 emissions in ports from shipping are in Asia and Europe (58%), but this share is low compared to their share of port calls (70%). European ports have much less emissions of SO_x (5%) and PM (7%) than their share of port calls (22%), which can be explained by the EU regulation to use low sulphur fuels at berth. Future forecasts indicate that most of shipping emissions in ports are estimated to grow fourfold up to 2050. This would bring CO_2- emissions from ships in ports to approximately 70 million tonnes in 2050 and NO_x-emissions up to 1.3 million tonnes. Asia and Africa will see the sharpest increases in emissions, due to strong port traffic growth and limited mitigation measures.

The above indicates that various initiatives are needed to combat air pollution in ports. These will be discussed in this module with specific reference on CO_2 emissions. Various ports have developed infrastructure, regulation and incentives that mitigate shipping emissions in ports. These instruments would need wider application in order for ship emissions in ports to be significantly reduced.

9.1.4. Method of Reduction of Port Area Emissions

Numerous and diverse measures and strategies are available to effectively reduce emissions and improve energy efficiency for ships in the port area. Experience with addressing ship emissions and implementing measures in the port area dates back to the late 1990's and is becoming more prevalent over the past decade There are initiatives underway by various stakeholders to evaluate and demonstrate emerging and innovative measures that could be effective both at-sea and in the port area.

Although the direct control of ports/terminals on ships' emissions is limited, they can have an impact on the reduction of ship emissions in the port area in a number of ways [MEPC 68/INF.16]:

- Ports/terminals can facilitate the just in time ship operations in ports that substantially reduces the ship's port time, thus emissions.
- Ports/terminals can directly or indirectly provide incentives for the ship owners to implement emission abatement measures on-board.
- Ports/terminals can facilitate port area ship emissions reductions by providing certain infrastructure themselves, like OPS facilities.

To deal with the above, one could deal with port related emissions for ship sources and non-ship sources.

9.1.5. Port Non-Ship Related Emissions Reduction

9.1.5.1.Port-land based side

If the land-based side of marine transport operations is taken into account, it would include cargo handling equipment, stationary power sources, locomotives and heavy-duty trucks operating within the port area. These are non-vessel related emissions from ports. To reduce emissions in such cases, the following may be considered [Corson et al]:

- **Clean Fuel:** Change to advanced clean diesel fuel, such as low or ultra-low sulphur diesel (LSD) (), emulsified diesel, biodiesel, compressed natural gas, liquefied natural gas, liquefied petroleum gas (propane, which requires a dedicated engine) and so on. All of these will provide direct benefit to port air quality and at the same time some reduction in GHG emissions.
- **Technology Retrofit:** Installation of "after treatment" devices on existing diesel engines such as diesel particulate filters, oxidation catalysts, closed crankcase ventilation, selective catalytic reduction, lean NO_x catalyst, exhaust gas recirculation and so on. Trucks could be retrofitted with some of these technologies.
- **New technologies:** Use of hybrid-electric technologies as replacements for pure diesel engine vehicles and equipment.
- **Operation management:** This could include a large number of measures that helps to reduce fuel consumption and emissions including:

- Implementation of policies that would reduce the idle operation of vehicles such as reduction of port congestion and start-stop technologies.
- Include incentives for emissions reduction in leases and contracts with tenants, contractors and transportation service providers.
- Expand operating hours to reduce truck queuing, idling and traffic congestion.
- Promote other aspects that would reduce port area traffic congestion and emissions.

The above include a summary of the important pollution reducing measures. For reduction of energy consumptions, port need to follow energy management system and develop energy management plan that could be applied to all aspects of port operation. ISO 50001 (see Fuel Management) can be used for this purpose and energy review and audit will form a part of energy planning for the port.

9.1.5.2.Port Harbour crafts

Apart from ships calling a port, there are a significant number of harbour crafts that provide support services to ships and port. Although not directly related to international shipping emissions, such crafts contribute to port air quality as they are mostly powered by diesel engines.

For harbour crafts and in order to save fuel and reduce pollutants to port, similar general measures as larger ships are applicable. Measures that can be applied to address emissions from harbour crafts are often adapted from those developed for on-road and non-road equipment. These measures include. Some of the measures that may apply for harbour crafts are:

- **Engine Replacement:** Replacement of a harbour craft engine is not an easy option as it normally will require all sort of different auxiliary machinery, space and fuel requirements. However, retrofit of engine can be an important consideration for harbour crafts in view of changing technologies, move to hybrid electric options as well alternative fuels. Replacing main-propulsion engines with cleaner engines will provide great emission benefits that compound over the remaining life of the equipment. For harbour craft, this can be significant because the total operating life can be up to 30-40 years. Cleaner engines are, however, costly and capital costs may be a major barrier [ICCT June 2012].
- **Clean Fuels:** The second option that may require less capital cost but will have implications on operating costs is the use of cleaner alternative fuels. The most obvious one is the use of low sulphur fuel in a similar fashion as road transport that uses ultra-low sulphur fuels these days. Additionally, other options could include emulsified diesel fuels and biodiesel. The more promising alternative fuel is natural gas in the form of LNG as LNG fuelling infrastructure is being developed. Move to LNG will require capital investments but the longer term the return could be via cheaper fuels, and a reduction of all types of air emissions. Use of biofuels, CNG or LNG would benefit the climate change as they would reduce overall discharge of CO_2 to atmosphere.
- **Technology upgrade:** This option relates to retaining the engines but opting for more advanced available engine controls, fuel additives and after-treatment emission control

technologies such as diesel oxidation catalyst, diesel particulate filter and selective catalytic reduction (SCR).

- **Hybrid electric systems:** The harbour crafts are good candidates for use of more advanced technologies such as hybrid technologies to include batteries and electric motor / generators in the same way that land-based vehicles are moving into hybrids domain. Also, these vessels can be connected to onshore power when at berth for on-board electrical generation for hoteling functions. Hybridization is best for harbour crafts when they are away from the berth and have fluctuating energy demands. Hybridizing for harbour crafts has become much more feasible in the past several years as several demonstration projects have illustrated the feasibility and benefits of the technology. In Long Beach, Foss tugboats retrofitted an existing tug with lithium-ion batteries and advanced drives for a total project cost of $2.1 million [ICCT June 2012].

The above discussion about port-side emissions including those from cargo handling equipment, buildings, ground transportation services, etc. plus those coming from harbour craft will not be further discussed in the following sections. Instead, the full attention will be on ship-port interface and ship-related emissions from now on.

9.1.6. Port Ship-Related Emission Sources

The emission sources directly associated with ship operations in port include those due to propulsion engines, auxiliary engines and auxiliary boilers plus Volatile Organic Compound (VOC) that is associated with bulk liquid cargos and various Ozone Depleting Substances (ODS) due to refrigeration system. From an air pollutant perspective, vessels can produce significant amount of NO_x, SO_x and PM from burning fuel in the propulsion engines, auxiliary engines and auxiliary boilers/steam plants. Depending on the geographical configuration of the port area and type of vessels, these three combustion systems can have varied level of emissions. It is important to know for the vessel in question, which of these plays a more important role in ports when it comes to emissions and energy efficiency reduction measures [MEPC 68/INF.16]. Most emissions from ships in ports are the result of diesel engines burning heavy fuel oil. Compared to land-based transport, the marine engines are not as strictly regulated as their land-based counterparts. National and regional regulatory authorities have limited control over international ships other than on their own flagged ships and to some extent ships visiting their ports. Reducing emissions from ship-board diesel engines is therefore one of the significant challenges and opportunities related to improving air quality in port areas. The unique challenge associated with the port area, with regard to reducing ship emissions, is how the emission sources listed above associated with various modes of ship operation in the port area. Generally, a ship in port area has two general modes of operation [MEPC 68/INF.16]:

Transit and manoeuvring: During this mode, a ship is typically operating within confined channels and within the harbour approaching or departing its assigned berth. The distance associated with this mode is unique for each port and varies depending on geographical configuration of the port. During this mode of operation:

- The ship is moving at its lowest speeds, thus propulsion engines are operating at low loads.
- Auxiliary engine loads are normally at their highest compared to other modes because of the need for running additional machinery on-board, such as thrusters (for manoeuvring), air scavengers/blowers (due to low main engine load), etc.
- An additional auxiliary engine (diesel generator) is online for safety reasons in case one auxiliary engine's trip/failure does not lead to dangerous situations or blackouts.
- Auxiliary boilers are on because the economizers are not producing enough steam due to low propulsion engine loads and resultant lower engines' exhaust temperatures (this does not apply to large diesel-electric ships with central electric power generation).

In such a mode, still most of fuel consumption will happen in main propulsion engines but boilers and auxiliary engines will consume fuel more than the normal sea going levels. The other aspect is that all the above combustion systems are working off-design at part loads. This is not good as such systems tend to be less efficient and more polluting under such low-load operating conditions.

At berth or anchored: During this mode, a ship is secured and not moving. Typically, under this condition:

- Propulsion engines are off.
- Auxiliary engine loads can be high if the ship is self-discharging its cargo, as with general cargo vessels, auto carriers and roll-on roll-off (Ro-Ro) vessels and oil tankers.
- Auxiliary boilers are operated to keep the propulsion engine and fuel systems warm in case the ship is ordered to leave port on short notice and also for other purposes. In some tankers, steam is used for discharge of cargo through the use of steam turbine driven pumps.

Vessel fuel consumption can be low, medium or high for auxiliary engines and can be low, medium to very high for boilers (for example for tankers when discharging), depending on ship types and if it uses energy for cargo operations. Again, both auxiliary engines and boilers will be operating at part load with low efficiency and high specific levels of emissions.

The majority of ship owners, operators and engine manufacturers as well as the regulators to some extent focus their efforts in reducing emissions and increasing energy efficiency for normal at-sea conditions as opposed to the port area. Typically, most ships move from one port area to another and for these ships, a majority of the ship's energy consumption over the life of the ship occurs at sea. Ship emissions estimation studies show total ship carbon dioxide (CO_2) emissions in the port area range from 2% at the Port of Los Angles [Starcrest Consulting] as compared to the entire voyage of the ship, to 6% at the Port of Rotterdam [MEPC 68/INF.16] as compared to greater North Sea area. Figure below emphasizes this point by illustrating the magnitude of time and energy spent at sea versus time and energy spent during the modes.

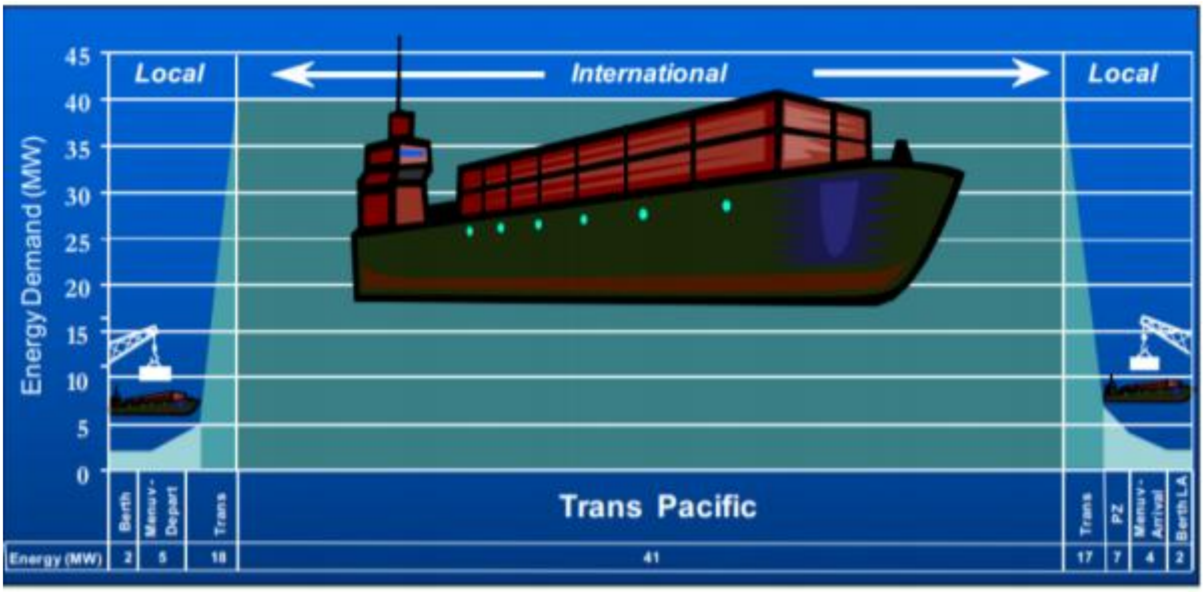


Figure 9.4: Energy demand example: Trans Pacific transit from Shanghai to Los Angeles [Starcrest Consulting Group]

It is not uncommon for most vessels to be operating at propulsion loads below 50% in the port area and even at loads below 25% for significant portions of the time in the port area. In the transit and manoeuvring modes, the propulsion engine is operating with variable loads and is even turned off/on depending on the specific area the ship is manoeuvring through. The emission factors *(Emissions factor refers to emission produced per unit of energy produced or fuel used and for engines it is specified as g/kWh or g per kg of fuel)* of an engine will vary according to engine load and generally becomes worse (higher) at lower loads as both pollutants and CO_2 emissions factors will increase at lower loads per unit of power production. Thus, in port and harbour areas, it can be stated that:

- Ship engines are operating with lower and varying loads.
- Propulsion and auxiliary engines are operating below their optimal performance loads.
- Auxiliary boilers are also for most of the time below their normal operating loads
- Various emissions factors for engines and boilers are higher than design values due to low load factor.

The main question is that whether one could avoid the above situations via use of alternative technologies, fuels and operational processes. These questions will be answered in various sections of this module.

9.1.7. How to deal with Ship-Port Interface

Based on discussion about the ship-related and non-ship related emissions in port, it is clear that the emissions in port areas can be dealt with by measures to be implemented at ship level and port level via analysis of the following:

- Non-ship related air emissions
- Ship-related air emissions.

The “non-ship related air emissions from port’s infrastructure, facilities, its land-based transport, and harbour crafts” and main aspects of dealing with them was introduced and summarily covered in Section 17.5. As this is not the main focus area of this course, no further discussion will be provided. The readers could refer to list of references for further information on this subject in particular the ICCT reports.

The ship-related emissions to port as indicated above can be divided to those related to ship manoeuvring and transit in port area plus those when ship is at berth. To reduce them, a number of main measures could be followed:

- **Reducing the time of ship stay / operation in port:** No matter how low or high a ship emits, the absolute total amount of exhaust emissions to the port area will be a function of total time of ship manoeuvring and stay in port area. Thus staying in ports for an extra 50% of the time is expected to increase the ship emissions to port area by approximately an extra 50%. For this reason, reducing a ship’s time in port could be regarded as one major strategy for improving air quality in ports. This at the same time would help the ship save fuel significantly by running slower due to extra time in passage. This strategy can be achieved via a policy of operating just in time in port.
- **Use of alternative ship technologies and fuels:** As discussed, current diesel engines burn heavy fuel oil that is not a clean and low carbon fuel. Additionally, the conventional diesel engines technology on-board ships can be improved to more efficient engines with lower fuel consumption and pollutants. There are options to move away from these technologies and fuels to more energy efficient and clean technologies and fuels. This strategy, in particular new and alternative technologies, may be more applicable to new ships rather than existing ships.
- **Ship in-port technical operation management:** When a ship in port at berth or at anchor, various engines, boilers and machinery still need to be operating and thereby will use energy. Off course, the way these operations take place would impact a ship’s in-port fuel consumption and exhaust emissions.
- **Switching off the engines in port via shore connection:** The next strategy could be to switch of the ship-board engines when in port. This is subject to availability and supply of power from port to ship and the ship has shore connection with enough power for the hoteling services. This is an important development and requires investment both by port and ship and may result in some extra operational complexities. This policy is achieved via onshore power supply system (cold ironing).
- **Ship loading with due consideration for ship energy efficiency:** The subjects of ship loading, trim optimisation, ballast optimisation were covered in previous modules. Some of these will not be achieved unless the cargo handling aspects of the ship are done properly. Although this may not have impact on port area fuel consumption and emissions, but is an important measure for a ship’s energy efficiency that is impacted by its port operations.
- **Environmental oriented incentives:** To encourage ship-owners and operators to do their best to reduce emissions, regulations and market incentives could be used to encourage use of the above measures. IMO and regional initiatives have already

regulated ships to some extent; for example with switch over to low sulphur fuel in certain areas and ports. There are financial incentives from certain ports to encourage use of environmentally friendly ships and so on. Section 6 on green port initiatives and port environmental program cover some of these aspects. Overall, there are significant opportunities for ship-port interface improvements to reduce air emissions from ships to port area and enhance overall energy efficiency of shipping. Although ports' core attention is on air quality and pollutions, nevertheless, there is a strong link between air pollutants and GHG emissions and this will be the subject of detailed discussion throughout this module.

9.2.Ship Time in Port and Just in Time Operation

9.2.1. Introduction

International shipping is the most energy efficient mode of cargo transport in world trade but unfortunately is also a major producer of NO_x, SO_x and CO_2 emissions. The existing measures being EEDI (Energy Efficiency Design Index) for new ships and SEEMP (Ship Energy Efficiency Management Plan) for all ships. With the current debates on further measures and fuel consumption measurement and reporting, new regulations in this area are forthcoming.

When it comes to ports, there have been limited studies on port operation / management and its contribution to ship energy efficiency. The main reason for this may be the lack of IMO's regulatory authorities on ports because the IMO's main focus is on ships and international shipping rather than ports that are mainly regarded as national entities. Despite this lack of regulatory focus, marine ports are important for shipping energy efficiency and in particular they play a major role in delivering an energy efficient ship operation. Thus, their roles and responsibilities and what they could do need to be understood.

As discussed before, there are few effective ways of reducing a ship's fuel consumption. Two main examples are:

- Operating the ship at a reduced speed during passage via Just-in-Time operation. It was shown earlier that speed reduction can bring about significant energy savings.
- Trim optimisation and ballast water management can contribute to significant energy savings.

Port operation has impacts on both of the above cases. For example, when it comes to the energy efficient ship operations, reduced ship speed at sea is closely related to the minimisation of a ship's time in port. A ship's time in port will be referred to here as ship's "port time". Reduction in port time through the high-quality port operations allows shipping lines to improve the operational efficiency via reduced ship speed and thus fuel consumption. This calls for examination of all aspects of port operation in order to find practical ways to cut down on ship port time.

One possible way is to make a ship to operate Just-in-Time that involves getting rid of the waiting times in port. This will not only help shipping lines to get the maximum notice of berth availability, but also facilitate the use of optimum ship speed at sea. Further, reduction of berth time by improved cargo handling could be another way to reduce ship time in port. Few studies, however, have been done to identify the relationship between ship time in port and efficient ship operation at sea.

The main goal of this section is to investigate the operational issues on how time in port affects the efficient ship operation in terms of operating costs, GHG emissions and other externalities and methodologies for reducing not only the ship-in-port time but also improve other aspects of ship handling that could reduce a ship's fuel consumption.

9.2.2. Activities in Port Operations

As shown in figure below, activities in port operations are largely divided into 2 parts: ship related activities and cargo related ones. In the case of import cargoes, the latter consists of activities that are cargo handling in the apron area, transfer to storage, yard storage and gate processing. This diagram is representative of a container ship terminal; however, similar diagrams could be constructed for other ship types to define the activities in port operations.

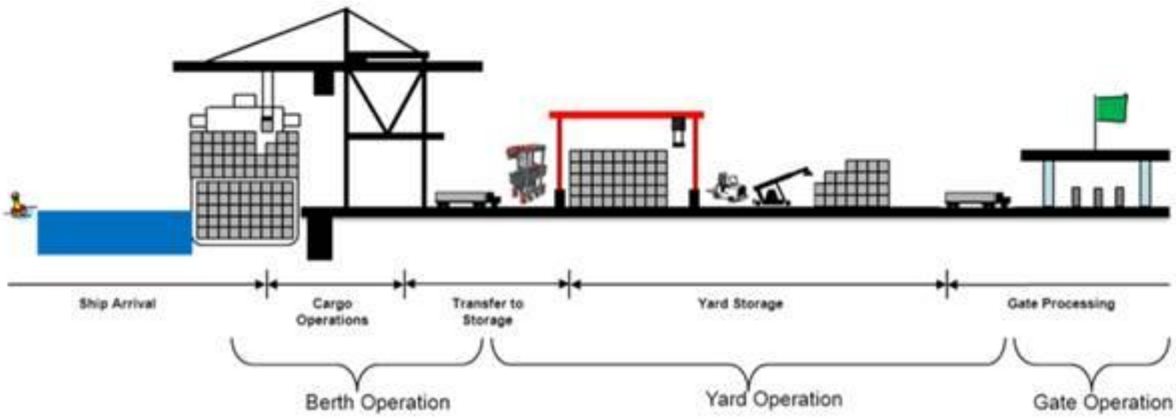


Figure 9.5: Schematic diagram of a container terminal operations

When a ship arrives at the entrance buoy of a port, the pilot comes aboard the ship to help the master in manoeuvres to the designated place. If no berth is available on arrival, the ship is assigned an anchorage area. If the berth is available, the ship is berthed with the help of tug(s), depending on ship size and port's rules and regulations. At this point, line handling services are provided at the berth. In particular, the time when a first line is connected to the pier (or dock) is very important since it is the starting point of the so-called 'berthing time'. The berthing time stops when the last line from the ship let's go of the bollard as it leaves the berth.

When berthed, the Custom, Immigration and Quarantine (CIQ) authorities may board the ship. Usually, cargo handling is not made until the authorities have completed their inspections, with the exception of the container shipping business.

In dedicated container terminals, container boxes are unloaded and loaded usually using a gantry crane at the apron where containers are moved to or from storage by In-terminal Movement Vehicles (IMV). Once the container cargoes are unloaded, they are transferred to an assigned slot; this is a space in the yard where storage operations occur. The containers are stored until they are inspected and claimed by the consignee (importers). The containers, then, are moved from the yard onto trucks (or railcars) for their final destinations through the gate operation.

Gate processing includes weighing the container, reviewing paperwork, and conducting a security check. All the above are shown in figure above.

9.2.3. Impact of Ship's Port Time on Efficient Ship Operation

9.2.3.1.Ship's (voyage) time

Time at sea and time in port Tough competition in the last couple of decades has caused container shipping, in particular, to be able to achieve profit only through economies of scale. This has led to larger ships and ever shorter cargo handling times and demurrage. Today, new potential for economisation can only be achieved by reducing operating and fuel costs. Two ways out of this predicament are either to use "slow steaming", meaning a ship's speed is reduced to save fuel, or to deploy even bigger ships, allowing the higher fuel costs to be spread over the additional tonnage. However, increasingly strict environmental requirements in harbours and enroute limit the engine size and thus the size of the ships. When it comes to the operation of container shipping lines, the timetables of the routes are normally fixed. If the ships are delayed in port at some points, they are forced to make up for the lost time by increasing their speeds at sea. As illustrated in figure below, a ship's (voyage) time is composed of 'time at sea' and 'time in port'.

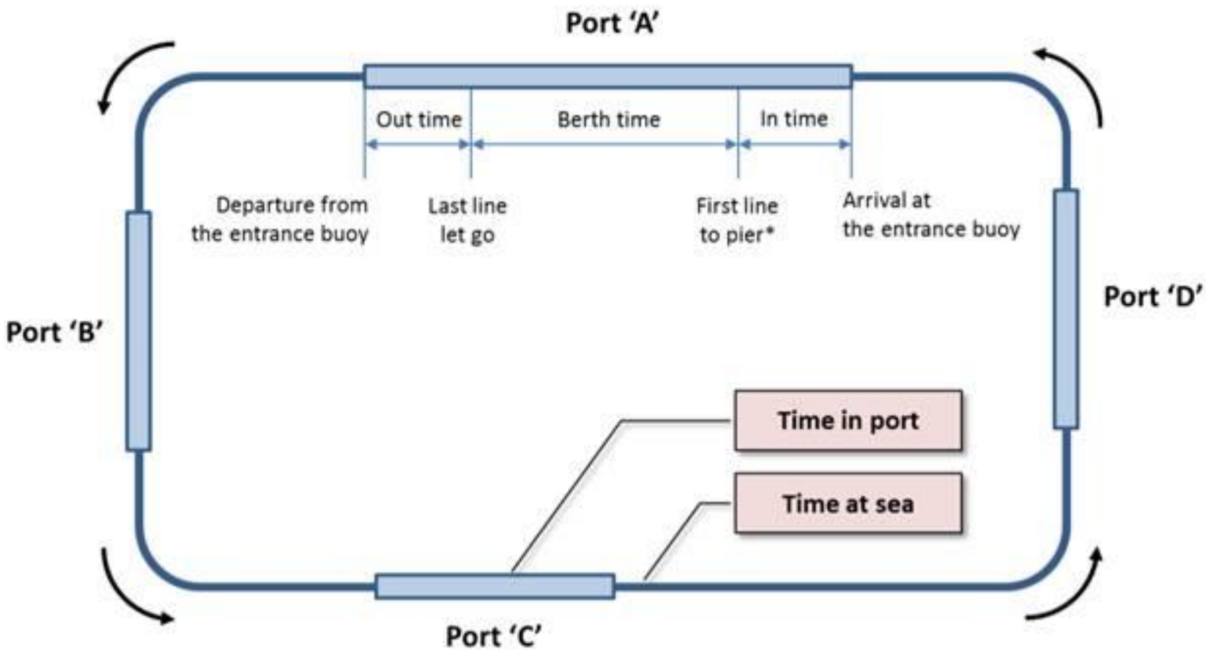


Figure 9.6: Composition of ship's voyage time in container shipping line

9.2.3.2.Time in Port

Ports are essentially providers of service activities, in particular for vessels, cargo and inland transport. The degree of satisfaction that is obtained on the basis of pre-set standards will indicate the level of port performance achieved. It is obvious that port performance levels will be different depending on the ships, cargoes or inland transport vehicles that are used or served. Port performance cannot be assessed on the basis of a single value or measure. In fact, a meaningful evaluation of a port's performance will require sets of measures; one of which will be the ships' time in port.

Figure below shows the times at which each step of ship's port operation starts and stops as documented in the port, allowing for the calculation of a variety of parameters (or indicators) that the shipping industry uses to calculate performance.

The ship's time in port of a given vessel on a given call is an important concern in an efficient ship operation for shipping lines. The shorter it is, the better it is economically. Port time (or a ship's time in port or ship turnaround time) is the time duration between a ship's arrival at the entrance buoy and ship's departure from the same buoy (see figure below). It can be categorised as the following times:

- **Waiting Time:** The period the ship waits for berth availability.
- **Manoeuvring Time:** periods of manoeuvring in port either to reach anchorage or to reach berth or to leave the port.
- **Berthing Time:** Actual time at berth. Berthing time normally consists of two parts: productive time and idle times (preparation time and arrangement time). The preparation time is the time before starting cargo handling after the ship is berthed, while the arrangement time is the time after finishing cargo handling until the ship is un-berthed. To increase the productivity at the berth, these non-production times must be minimised. Further, to make productive time more efficient, there should be no stoppage time that is related to breakdown, maintenance, etc.
- **Productive Time:** Actual time from start of cargo handling operation to end of cargo handling operation.
- **Idle Time:** Times in berth where there are no cargo handling operations.

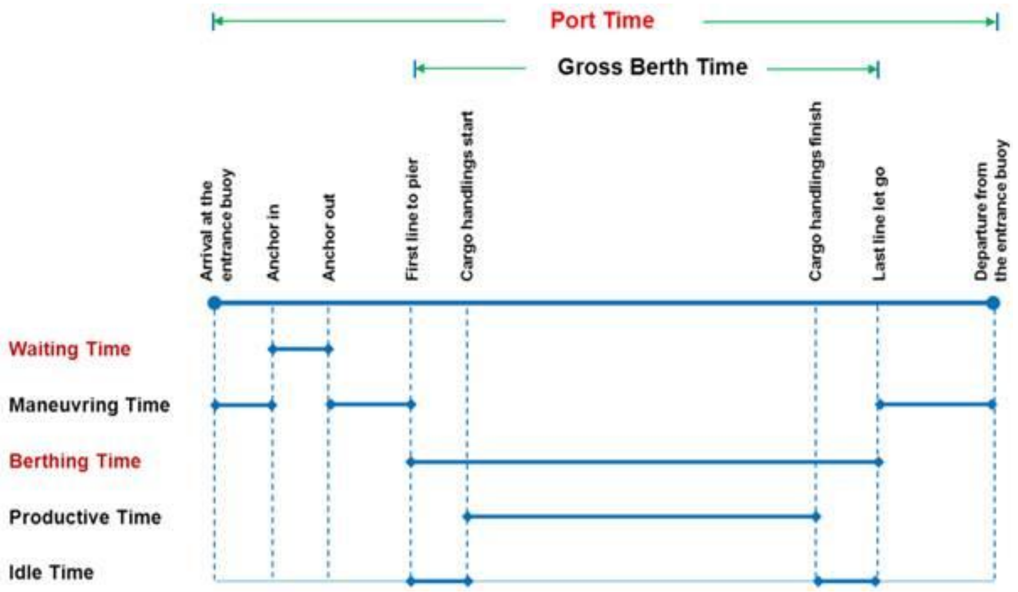


Figure 9.7: Breakdown of ship's time in port

A reduction of any of "these times" will improve the overall productivity of the ship in port. Among these times, in particular 'waiting time' and 'berthing time' must be emphasised since they are crucial criteria in ports facing latent or acute port congestion.

In a nutshell, measures of the duration of a 'ship's stay in port' are key indicators of the service quality that is offered by ports to shipping lines.

9.2.4. Just in Time Arrival/Departure and Improved Cargo Handling

The search for efficiency across the entire transport chain takes responsibility beyond what can be delivered by the owner/operator alone. A list of all the possible stakeholders in the efficiency of a single voyage is long; obvious parties are designers, shipyards and engine manufacturers for the characteristics of the ship, and operators, charterers, ports and vessel traffic management services, etc., for the specific voyage. All the involved parties should consider the inclusion of efficiency measures in their operations both individually and collectively. When it comes to efficient port operations that aim to reduce ship's time in port, as discussed and shown in figure Breakdown of ship's time in port, 'waiting time' and 'berthing time' are two key components to consider in more detail.

If the ship involved gets a berth on-arrival, there will be no waiting time. In this regard, just-in-time arrival and departure is very important for shipping lines to operate their fleet efficiently. According to "2012 Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP)", good early communication with the next port of call should be an aim in order to give maximum notice of berth availability and facilitate the use of optimum speed where port operational procedures support this approach. Optimised port operation could involve a change in procedures that are engaged in different handling arrangements in ports. Port authorities should be encouraged to maximise efficiency and minimise delay.

Regarding the just-in-time arrival/departure of ships, from the viewpoint of ship operators, the reliability of the berthing window is another issue to be looked at. In another words, on-arrival services for ships have to be guaranteed between port authorities and shipping lines. Otherwise, even though ships are already in port, they might have to wait until the berths are available. This will definitely make the time at sea shorter than anticipated, thus increased ship speed in passage will be used to counter act the lost time. This will be counterproductive in terms of efficiency of total voyage time or fuel consumption.

In this sense, the relationships between ship operators and ports must be kept close and their operations harmonised in order to enhance reliability for securing on-arrival services in port. Having a contract for a dedicated (exclusive) terminal with shipping companies on a long-term basis is an exemplary case of resolving this kind of reliability issue.

Just-in-time arrival and departure

Figure below shows that the main activities of the whole container terminal operation can be divided into three operations:

- Berth operation,

- Yard operation
- Gate operation.

This diagram lists specific operations/activities that take place in each phase.

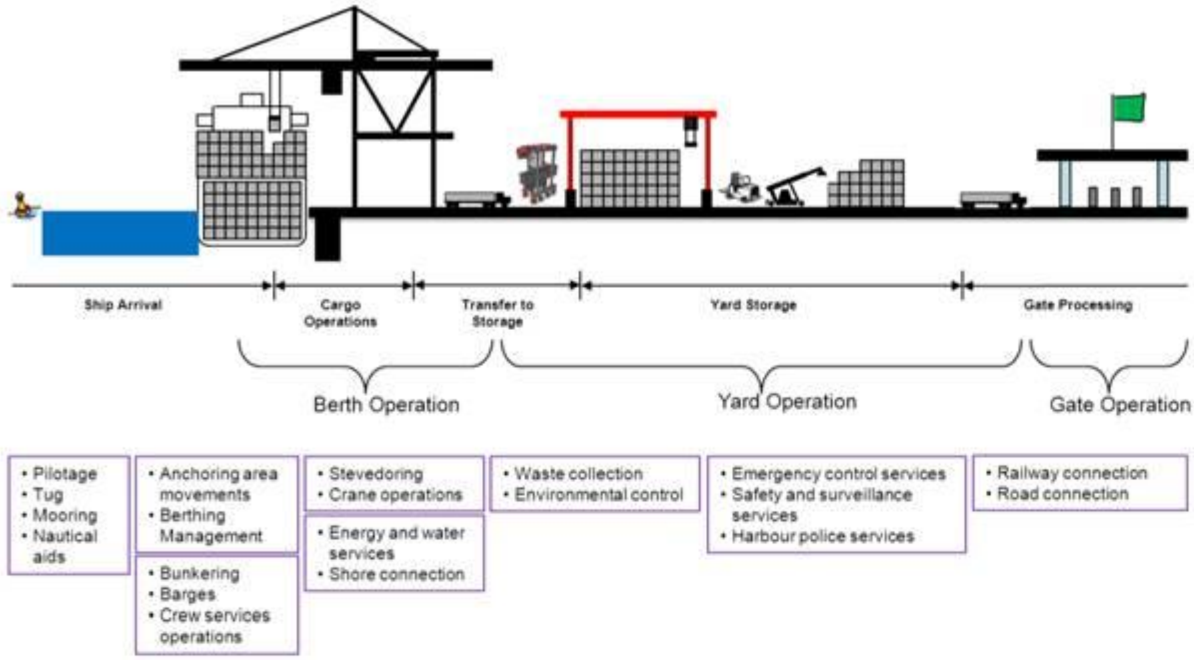


Figure 9.8: Schematic diagram of container terminal operations with activities

The berth operation mainly concerns the schedules of arriving vessels and the allocation of berth space and quay crane resources to serve the vessels. The key concern of the berthing operation is the turn-around time of vessels. It also involves the unloading and loading of containers on-board the vessel that is handled by gantry cranes. To achieve high crane rates (number of containers moved per hour), the planner has to optimise the crane working sequence (a detailed list of crane moves). The yard operation is perhaps the busiest of all the activities in the terminal. The operation involves the unloading of containers from the ships, the loading of containers onto vessels, the shuffling of containers that are out of sequence in the yard block, the redistribution of containers to other blocks (yard shifting) for more efficient loading onto the second vessels and the inter-terminal haulage where containers are moved to other yards in another terminal. The gate operation deals with external freight forwarders. Two activities are involved, namely export delivery where the freight forwarders bring in export containers to the yard or wharf to be loaded onto the vessels, and import receiving, where the freight forwarders receive containers from the yard or wharf to bring into the country.

9.2.5. Port Operation Management

Each port or terminal has its own port management system for the efficient and effective operation of port, which will be referred to as Maritime and Port Operation System (MPOS) as an example to be explained here. This is a customized management tool that focuses and optimizes the work of “agents”, “entities” and “port services on ships” by coordinating the actions, controlling them and allowing them to analyse how best to reduce the cost/time. All the parties concerned, including the ships, must participate in the MPOS from prior to the ship's arrival in the port to the ship's departure from the port. Whenever the ship wishes to enter a port, 'the Request for Berth' is made through Communication Services (normally internet) well before arrival and is confirmed by the MPOS, against the ISPS (International Ship and Port Facility Security) and Dangerous Goods Codes, before issuing the Preliminary Authorization to Berthing. See figure below.

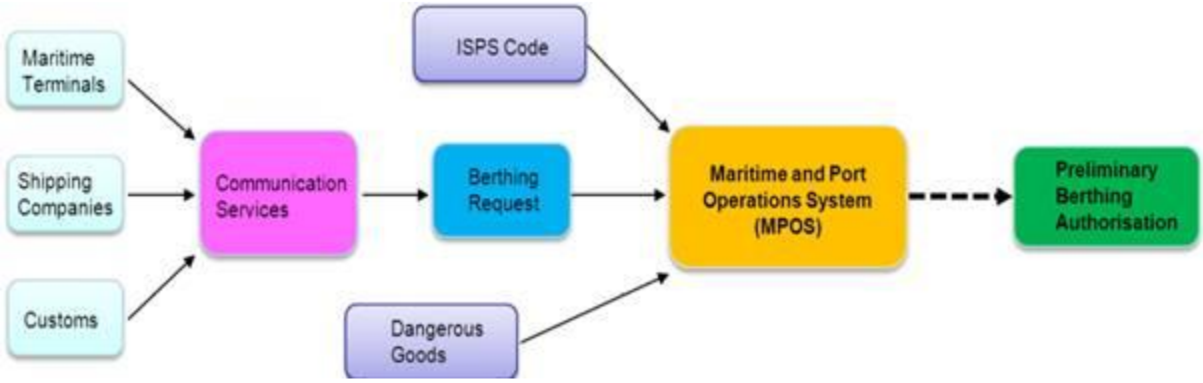


Figure 9.9: Application of berthing request in a typical port management system

After issuing the Preliminary Berthing Authorization, the MPOS compares it with information from the anchoring area and with activities of any anchored or berthed ships, nautical activities inside the harbour, status of maritime signals, maintenance status of berths, and informs the berthing operation to the ship and to the pilot service. It supervises at all times compliance with the Operating Procedures.

The MPOS informs and coordinates all Port Services regarding berthing manoeuvres, informing also the other agents. Furthermore, throughout this phase, the MPOS is capable of performing the control actions and coordination tasks with other agents as shown in figure below.

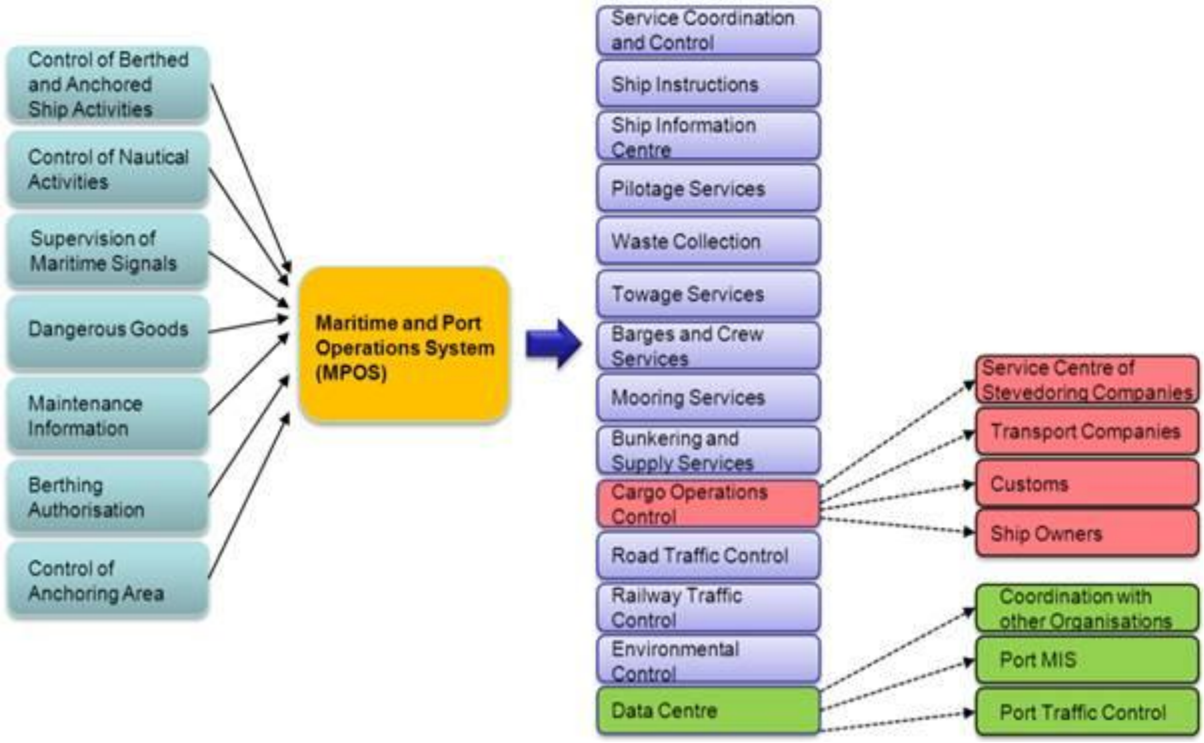


Figure 9.10: MPOS and port services coordination

Generally, the MPOS controls port activities relating to maritime safety and the protection of the marine environment. Typically, the MPOS is part of the port authority organisation and is responsible for ensuring the efficient flow of traffic through port and coastal waters (including allocation of vessels to berths) and—on behalf of the government or port authority—for coordinating all marine services. Major port services that are related to MPOS can be as follows:

- Pilotage services: These are services given by maritime pilots that provide an essential and unique service to the shipping industry. Their principal role is to provide critical independent local knowledge and navigational information to vessels and to bring the highest level of ship-handling skills to manoeuvre vessels within their port. The prime obligation of pilots is to provide a critical public safety service by ensuring the careful management and free flow of all traffic within their pilotage area, thus protecting the environment.
- Towage services: These are services provided by a small, strongly built powerful tugboat that is used to guide large ships into and out of port and to tow barges, dredging and salvage equipment, and disabled vessels. Tugboat operations are typically carried out by private firms. If the volume of vessel traffic is not sufficient to support a tugboat service on a commercial basis, a port authority may be obliged to provide such a service itself.
- Line handling services by line boats: These are the services given by line boats that help the ship to be berthed. When berthing, once the lines from the ship are given to line boats, they approach a berth and try to throw a line to someone on land who ties off the lines at the dock.
- Mooring services: These are the services that secure a ship to the designated place, i.e. a berth or a dock or a buoy, or anchoring with two anchors. Mooring services in

smaller ports can be provided by the local stevedore. In larger ports, a mooring service is usually performed by a specialised private firm. Especially in a complicated nautical situation (for example, single point mooring buoys, specialised piers for chemicals or gases, or ports with large tidal differences), mooring activities require expert skills and equipment. A port authority may choose to regulate this activity when only one specialised firm exists.

- Vessel traffic services (VTS) and aids to navigation: This is a marine traffic monitoring system established by port authorities. VTS is a service designed to improve vessel traffic safety and efficiency and to protect the environment; it offers the potential to respond appropriately to traffic situations emerging in an area. VTS is usually part of a port or a maritime authority. Such services are provided in port areas and in densely used maritime straits or along a national coastline. VTS should be regulated by the competent authority. Responsibility for aids to navigation usually rests with the national maritime authority in port approaches and in coastal areas, and with the port authority in port areas. Often, provision and maintenance of buoys and beacons are contracted out. Because aids to navigation are generally part of an integrated maritime infrastructure, the costs of providing these services are included in the general port dues.
- The control of dangerous goods: This is usually performed by a specialised branch of the port authority. The same goes for the handling of dangerous goods in port terminals. The oversight and regulation of the land transport of dangerous goods is normally the responsibility of government.
- Waste management services: These are privatised under the strict control of a port authority or another competent body. Proper waste management can be expensive for shipping lines. With high costs, ship masters might be tempted to dump waste into the sea or into port waters. The control of such dumping practices is extremely difficult, especially for chemical cargoes. To spread waste management costs, ports can include all or part of the waste management costs in the general port dues. The transport of waste from the ship to a reception facility also poses a challenge, especially in larger port areas. Port authorities should directly provide or organize the provision of transport barges or trucks for this purpose. The entire waste management system, including personnel and facilities, should be closely controlled by the competent authority. When private firms are engaged in waste handling, the authority should employ experts from its organisation to ensure compliance with all relevant laws, rules, and regulations.
- Emergency response services: These are carried out by a variety of public organisations such as the port authority, fire brigade, health services, and police. Some ports have sophisticated tools available to aid in crisis management, such as prediction models for gas clouds. Such tools are often integrated in a traffic centre of the local vessel traffic management system (VTMS). Private firms (for example, tugboat companies) may play a subsidiary role in crisis management in the event that they are equipped with fire-fighting equipment. Larger ports use patrol vessels and vehicles for a variety of public control functions. In some ports, such patrol vessels also have fire-fighting equipment on board. When a port does not have patrol vessels available, a contract with a tugboat

company should be arranged to guarantee the availability of floating fire-fighting capability.

- Control of dredging operations: These are normally given by a port authority. Often, the port authority or the competent maritime administration does not have enough expertise to exercise sufficient control over both maintenance and capital dredging. Port authorities with large water areas under their control should employ sufficient competent personnel to prepare dredging contracts and oversee dredging operations. Sounding is an activity that should preferably be carried out (or contracted out) by the port authority itself. Dredging is usually carried out by private firms. It might be cost effective for some ports to use their own dredgers, especially when continuous and important maintenance dredging is required.

As the above list of services, ships may need to use the above services in addition to cargo handling service. This then may have impacts on port time of the ships.

9.2.6. Measures for Avoiding Ship's Waiting Time in Port

9.2.6.1. Virtual Arrival

Virtual Arrival is a concept for a ship's just in time operation. The main focus is to avoid early arrival and resultant waiting.

9.2.6.2. Improved cargo handling

Cargo handling is, in most cases, under the control of the port and the optimum solutions matched to the ship and port requirements should be explored. Whatever solutions that might be thought of, they should contribute to increasing the gross berth productivity, meaning faster cargo handling that can lead to reduce the berthing time.

When it comes to container terminal optimization, for example, the integrated planning and scheduling of all the activities of a terminal could be suggested to increase moves per hour and reduce costs. To improve cargo handling, the following planning needs to be improved:

- Berth planning
- Quay crane scheduling
- Prime mover scheduling
- RTG (Robber Tyre Gantry) /RMG (Rail Mounted Gantry) cranes scheduling
- Operational planning, typically day(s) ahead

These activities are closely connected to cargo handling in port where efficient operations can bring about the reduction of ship's time in port as well as giving environmental benefits. Efficient cargo handling in port can definitely be helpful for the environment. A well-planned cargo operation, both in port and on board can reduce the level of emissions from the ship's machinery that leads to reduced energy consumption per transported unit. Ways to improve cargo handling resulting in environmental benefits include:

- The use of an internal movement vehicle that has less fuel consumption per cargo unit
- The introduction of high capacity loading and unloading operations with lower emissions to reduce the ship's time in port
- Safer and easier cargo operations and monitoring
- The application of new technology with advanced software tools
- The use of eco-friendly and user-friendly cargo handling products
- Well trained shore-staff and ship- staff who are keen on safety and environment matters

Quick ship turnaround time in port will ensure slow steaming at sea and this will again contribute to reduce emissions.

9.2.7. Implication of Just in Time

It is not difficult to make an economic analysis of just in time in relation to various ship costs including fuel costs as well as ship air emissions during passage and in port. Numerous analyses including the one carried out by INTERTANKO and OCIMF on virtual arrival shows the benefits. Based on this study [INTERTANKO and OCIMF (2010)] for a typical ship, Virtual Arrival gives a 43% reduction in the ship's voyage fuel consumption. Of course, this number will depend on ship type, size, voyage characteristics and current port times. Nevertheless, all indications are that if just in time is realized, the saving levels will be in double digit numbers. Firstly, the fuel consumption and the amount of CO_2 emissions are sensitive to the changes of port time. As port time decreases, the fuel consumption and the amount of CO_2 emissions are sharply reduced (assuming total voyage time is fixed). This result means that port time has a big impact on efficient ship operations. The reduction of port time, or minimization of waiting time through just-in-time arrival and departure, improvement of berth productivity and simplification of the administration process, lead not only to the reduction of the operating cost but also to the improvement of the environmental performance of the shipping industry. In particular, this result tells us why port selection (or choice) is important to shipping lines. In other words, when a shipping line establishes and/or improves their service loop based on the calling ports that have high productivity and efficiency, they can improve their ship operational efficiency by minimizing their operating cost and the amount of CO_2 emissions. Secondly, as vessel size increases, the impacts of the changes of port time on the operating cost and the amount of CO_2 emissions also increase. This result implies why port time is more important to a shipping line that operates larger vessels. Moreover, this result tells us why shipping lines have been focusing on the development of their own container terminals on the major routes. Namely, the larger vessel is more sensitive to unstable port operations and non-production times in port, and this leads to an increase in operating costs and acceleration in the amount of CO_2 emissions. In summary, terminal operators have to improve their operational efficiency. This is because the improvement of operational efficiency leads not only to strengthen their own competitiveness but also to contribute to the reduction of costs and the amount of CO_2 emissions in the liner shipping industry. A simple exercise is provided in the next section to demonstrate the benefits of port operation improvements.

A simple estimated level of fuel saving and CO_2 reductions.

Figure below show the actual operation times for a specific ship, denoting that 23.3% of her time is spent in ports (combined berth and anchorage).

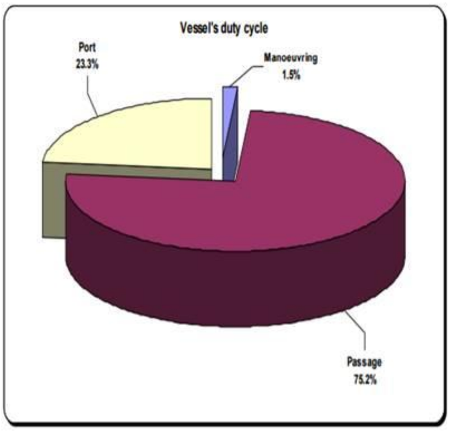


Figure 9.11: Ship's times in passage, port and manoeuvring

The same ship was analysed for number of port calls and just-in-time operations and the required time for just in time operation was estimated. If operated according to port just-in-time, the ship time in port will reduce from 23.3% to 16% (a reduction of about 30% of port time). For calculation purposes, it is assumed that the ship would in practice get partial just-in-time operations and thus port time could be reduced from 23.3% to 20.3% in a real feasible scenario. It is further assumed that the extra time gained from better port operation will be used in passage, thus increasing the in-passage periods from 75.2% to 78.2%. This extra time will then be used to proportionally reduce the in-passage ship speed, assuming that the total annual number of port calls will remain the same. The reduced ship speed is then converted to fuel consumption reduction using the well-known cubic relationship between ship speed and required propulsion power. CO_2 Emissions reduction is estimated using fuel consumption reduction and relevant emissions factors. Table below shows the result of this simple calculation in terms of ship fuel consumption reduction, denoting a reduction of more than 1,000 tonnes of fuel consumption per year. This exercise shows how effective the port times could be on overall energy efficiency of a ship and how large gains could be achieved via better port related operations.

Passage operation time in passage, current	75.2% of annual
Passage operation time with less port time (see above)	78.2% of annual
Fuel consumption reduction for same distance (estimated)	7.5%
Fuel consumption and emissions reduction	
Main engine fuel consumption reduction	1,065 MT/year
Boilers and auxiliary engines fuel consumption reduction	Assumed negligible
Net fuel consumption reduction	1,065 MT/year
Net CO_2 reduction	3,400 MT/year

Table: Estimated ship fuel consumption and emissions reductions

9.3.Technologies for Port Air Quality and GHG Emissions Reduction Introduction

Port operations involves not only ship operation but a lot of other activities such as cargo loading and unloading, ground-level port related transportations and activities of harbour crafts for provision of various services to ports or ships (e.g. dredging, tugs, bunkering, etc.). The main prime mover for most of these vessels, vehicles, cargo handling equipment are diesel engines although move to electrification and use of other technologies are underway. In this section, technological solutions for port area emissions reduction and GHG emissions reductions are discussed. A number of studies has been carried out in the past, the most prominent ones are those by ICCT20 and the IMO. These studies are used as the basis of material in this section and the main outcomes of these studies are highlighted.

9.3.1. ICCT Study on Port Air Quality

Most of the studies performed on port related emissions concentrate on port air quality and not energy efficiency. One of these is reported by ICCT in December 2012. In this report, the ICCT highlights the technologies that could be used in diesel engines as the prime mover for ships and port-side trucks. The main focus is on pollutants including PM (Particulate Matters), carbon monoxide, SO_x, NO_x and VOC.

The types of technologies identified for reduction of emissions are:

- **Diesel oxidation catalysts:** This is a device installed at the back of the engine on the exhaust gases path to oxidize such pollutants as CO, PM and HC.
- **Diesel particulate filter:** This is the devise used at the back of diesel engines on the exhaust gases path to trap the particulates and prevent them from leaving the engines.
- **SCR (Selective Catalytic Reduction):** This is a very well know technology for significant reduction of NO_x emissions. As the name implies, it works via use of agents at the presence of a catalyst to covert NO_x beck to N_2 and O_2.
- **Exhaust Gas Scrubbers:** Again, this is a very well-known technology for the back of engines on the exhaust gases path to capture the SO_x and prevent them from leaving the engine exhaust.
- **Exhaust Gas Recirculation (EGR):** This is a well-known technology that aims to reduce the engine's combustion temperature and thus reduce NO_x via circulating part of the exhaust gas back into cylinder.
- **Shore power:** This refers to ship connection to port electricity so that the ship-board engines could be completely switched off.
- **Clean fuels:** These include a variety of options such as ultra-low sulphur fuel, LNG, CNG, water-emulsified fuels, biofuels and so on. Most of these options not only reduce SO_x but also NO_x as well.

Figure below summarises various options, itemises potential applications for use at ports, provides estimates for the reduction potential for various pollutants and provides basic cost estimations of each option. This shows a significant potential for alleviating air quality issues from ports but they mostly are considered as options for CO_2 reduction directly. In fact, most of these options may lead to a small increase in overall fuel consumption as for example NO_x control methods most of the time makes engines less efficient.

Type	Technology Name	Application	Potential Emissions Reduction	Cost (US$)
General Emissions Control Technologies	Diesel Oxidative Catalysts (DOC)		PM 20-30% HC 50-90% CO 70-90%	$1,000-2,000 (Truck, CHE) $3,000-4,000 (Marine) Variable Cost (Locomotive)
	Closed Crankcase Ventilation (CCV)		PM 15-20%	$700 ($48-50 filter replacement)
	Diesel Particulate Filters (DPF)		PM up to 90% HC, CO 60-90%	$6-18K (Truck) up to $40K (Marine, Locomotive)
	Selective Catalytic Reduction (SCR)		NO_X 70-90%	$36K (Truck & CHE) $60K-120K (Marine)
	Lean NO_X Catalyst (LNC)		Moderate NO_X Reductions	$14K (On-road) $40K (Off-road (limited))
	Exhaust Gas Scrubbers		SO_X 90-99% PM 60-80%	$5M (Marine)
	Shore Power		Net emissions reductions	$1-15M
On-Engine Modification	Exhaust Gas Recirculation (EGR)		NO_X 40-50% PM 70% (with DPF)	$12K (Truck) $10M (Marine)
	Engine Replacement, Repower, Rebuild, Refuel		NO_X up to 90% PM up to 90%	$0.5-1.5M
	Slide Valves		PM 10-50% NO_X 10-25%	$1.5-16K (Marine)
Alternative Fuels	Ultra Low Sulphur Diesel (ULSD)		PM 5-15% SO_X 99%	Surcharge: $0.05-0.15/gal
	Biodiesel Fuel (BXX)		PM 15-70% HC 10-40% CO 10-50%	Surcharge $0.25-0.40/gal
	Emulsified Diesel Fuel (EDF)		NO_X 10-20% PM 15-60%	Surcharge $0.25-0.40/gal
Operational Strategies	Vessel Speed Reduction (VSR)		Net reductions in NO_X, PM, and other air pollutants	Net negative cost over time (balance fuel savings and travel time increase)
	Landside Operational Improvements		Net emissions reductions	Multi-million/billion dollar improvements

Notes: – Trucks, – Cargo Handling Equipment, – Marine, and – Locomotive. 1 icon= Low or uncertain deployment, 2 icons= Emerging, 3 icons= More Widespread. The technology and operational emission reduction options are diverse, and the per cent emission reduction estimates represent the potential reduction from best practices in each area. The associated cost ranges are illustrative, based on the most common such alternatives; "K" = 1,000 USD, "M" = 1,000,000 USD. Cost estimates are based on Starcrest (2012) estimates from the *Developing Port Clean Air Programs*.

Figure 9.12: Port air emissions reduction measures according to ICCT December 2012 report

9.3.2. IMO Ship-Port Interface Study

The MEPC 68/INF.16 document presents the results of an IMO commissioned study that deals with a broad range of topics on ship-port interface including a large number of existing and future innovative technologies that ship owners and operators, ports, and other stakeholders can consider and evaluate for reducing emissions in the port area. A number of technology classification has been done in this study including for example “existing technologies” that are considered to be readily implement-able to reduce emissions from various operational modes of ships associated with the port area. This IMO commissioned study’s focus is ship-port interface thus is not dealing with portside measures.

9.3.2.1.Measures categories:

Existing measures are grouped into three major categories:

- Equipment measures
- Energy measures
- Operational measures

Equipment measures:

Equipment measures consist of the following groups that are applicable mainly to diesel engines and boilers:

- Engine technologies
- Boiler technologies
- After-treatment technologies

Energy measures:

The “energy” measures relate to energy sources used by a ship, whether they are physically located on board or on land (e.g., shore power). Energy measures include the following groups:

- Alternative fuels
- Alternative power supply

Operational measures:

The operational measures refer to those that primarily affect and focus on the operation of the ship, terminal, or port and can be implemented for reduction of emissions of ships in the port area. This can take the form of operational efficiency improvement on board, at the terminal, and/or at the port. Operational measures include the following groups:

- Ship operational efficiencies
- Port/terminal operational efficiencies
- VOC working losses

9.3.2.2.Symbols used

The IMO commissioned report then provides a brief description of each measure including summary information about the measure, followed by discussion on how these considerations relate directly to the port area. The report then, in systematic way, summaries the findings using the following symbols as shown in brackets below:

- Applicable emission sources – describes which emission sources can be affected by the “measure” and include:
- Propulsion engines (P)
- Auxiliary engines (A)
- Auxiliary boilers (B)
- Applicable to propulsion engines, auxiliary engines, and auxiliary boilers (all)
- Working VOC cargo tanks (Tank).
- **Retrofit-able:** This provides information if the measure can be retrofitted on existing ships with three options; (Yes – Y) or limited to only new builds (No – N), and not applicable (na).
- **Terminal/vessel:** The port/terminal operational efficiencies measures are sub-categorised as below:
  - Terminal (T)
  - Vessel (V)
- **Applicable operational modes:** This specifies the ship operational mode category in which the measure is effective. These operational modes are sub-categorised as:
  - Open water or sea conditions (S)
  - Transition (T) o Manoeuvring (M)
  - At-berth (B) o At-anchorage (A)
  - All modes (all)
- **Emissions and energy efficiency:** This lists the pollutant specific emission changes anticipated by the measure and provides a relative potential reduction. The IMO commissioned report highlights that emission reduction impacts are based on public data and published values, which do not necessarily represent verification by appropriate authority. For case where information has been available, the following symbols on impact of measure on emissions are used:
  - ↑ for increases in emissions
  - ↓ for decreases in emissions
  - | for either increase or decrease depending on various factors

If a percentage value is provided it represents the potential maximum value. If published levels or limited data are such that the reductions cannot be quantified at this time, then the symbol “to be determined” (TBD) denotes this case.

It should be noted that emission reduction levels are dependent on applicable modes, engine loads, ship power configuration, fuels, operational parameters, equipment parameters, and other factors. Typically, each application of a measure needs to be evaluated on a case-by-case (CBC) basis such that specific parameters and conditions are considered to determine the most appropriate reduction level. Energy consumption is included as an indicator for energy efficiency.

9.3.2.3.Study outcomes on existing technology measures.

For each category, the IMO commissioned study presents a summary table within which the list of measures (first column) is given together with the applicability, retrofit-ability, applicable modes, and emission reduction potential for NO_x, PM, SO_x and HC and last but not least the "energy consumption" that denotes energy efficiency of some form. In the following, a brief description of findings on various categories and measures are given. Engine technologies (figure below) show the engine related technologies that are to a large extent comparable to items covered under ICCT report (see figure below).

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
Engine Technologies								
Repower	P/A	Y	All	≤80%↓	↓ cbc	–	–	↕ cbc
Remanufacture Kits	P/A	Y	All	↕ cbc	↓ cbc	–	↕ cbc	↕ cbc
Propulsion Engine Derating	P	Y	STM	↑ cbc	↕ cbc	–	tbd	↕ cbc
Common Rail	P/A	Y	All	≤25%↓	↓ cbc	–	–	≤5%
Exhaust Gas Recirculation	P/A	Y	All	≤60%↓	tbd	–	tbd	tbd
Rotating Fuel Injector Controls	P	N	STM	≤25%↓	≤40%↓	cbc	cbc	cbc
Electronically Controlled Lubrication Systems	P	Y	STM	–	≤30%↓	–	≤30%↓	–
Automated Engine Monitoring/Control Systems	P/A	N	ALL	≤20%↓	tbd	≤3%↓	–	≤5%↓
Valve, Nozzle, & Engine Timing NOx Optimization	P	Y	STM	↓ cbc	↕ cbc	–	↓ cbc	↑ cbc
Slide Valves	P	Y	STM	↓ cbc	↓ cbc	–	↓ cbc	↕ cbc
Continuous Water Injection	P/A	Y	All	≤30%↓	≤18%↓	–	–	–
Direct Water Injection	P/A	Y	All	≤60%↓	↕ cbc	–	↕ cbc	–
Scavenging Air Moistening/Humid Air Motor	P/A	Y	All	≤65%↓	↑ cbc	↑ cbc	–	↑ cbc
High Efficiency Turbochargers	P/A	Y	All	↓ cbc	↓ cbc	–	↕ cbc	↓ cbc
Two Stage Turbochargers	P/A	Y	All	≤40%↓	tbd	–	–	↓ cbc
Turbocharger Cut Off	P	Y	STM	≤40%↓	tbd	–	tbd	↓ cbc
Crank Case VOC Leakage	P	Y	STM	–	tbd	–	≤100%↓	–

Figure 9.13: Summary of engine technologies [MEPC 68 INF.16]

As can be seen, many technologies are judged to be retrofit-able, they apply mostly to both propulsion and auxiliary engines, and their impacts on energy consumption and GHG emissions could not be quantified. Some of the measures could have negative impacts on energy efficiency.

After-treatment technologies

Figure below shows the after-treatment technologies that are mainly related to diesel engines exhaust gas after treatment systems. These technologies include scrubbers, SCR etc. and the main aim for their use is to reduce exhaust pollutants rather than CO_2 emissions.

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
After-Treatment Technologies								
Selective Catalytic Reduction (SCR)	All	Y	All	≤95%↓	–	–	–	↑ cbc
Exhaust Gas Scrubbers - Wet	All	Y	All	≤5%↓	≤80%↓	≤98%↓	–	↑ cbc
Exhaust Gas Scrubbers - Dry	All	Y	All	≤5%↓	≤80%↓	≤98%↓	–	↑ cbc
Barge-Based Systems	AB	na	B	≤95%↓	≤95%↓	≤95%↓	tbd	↑ cbc

***Figure 9.14:** [Summary](#) of engine exhaust gas scrubbing systems [MEPC 68 INF.16]*

As can be seen, many technologies are judged to be retrofit-able, and they could significantly reduce ship exhaust pollutants. Unfortunately, these technologies will generally increase the ship's energy consumption, thus the level of GHG emissions. The level of increase of energy consumption could not be quantified and will also depend on case by case.

Alternative fuels options

Figure below shows the alternative fuels that includes a large list of options such as natural gas, low sulphur fuel, biofuels, methanol and so on.

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
Fuels								
Low Sulfur Fuels	All	NA	All	↓ cbc	↓ cbc	↓ cbc	–	↓ cbc
Liquefied Natural Gas - gas only	All	N	All	≤88%↓	≤98%↓	100%↓	↑ cbc	↕ cbc
Liquefied Natural Gas - dual-fuel	All	Y	All	↕ cbc	≤78%↓	97%↓	↕ cbc	↕ cbc
Water in Fuel	All	Y	All	≤30%↓	–	–	–	–
Methanol	All	Y	All	↓ tbd	tbd	100%↓	tbd	↓ cbc
Biofuels	All	Y	All	↑	tbd	↓ cbc	tbd	tbd

***Figure 9.15:** [Summary](#) of alternative fuel options [MEPC 68 INF.16]*

As can be seen, many of alternative fuels are judged to be useable with current technologies (retrofit-able). Some demonstrates significantly reduction potential for exhaust gas pollutants. They may lead to reduced energy use or GHG emissions depending on a case-by-case analysis. The case for alternative fuel is well known to industry, regulations on ECA (Emissions Control Area) forces industry to use low sulphur fuel or other relevant alternatives in designated areas and the move to natural gas in the form of LNG is underway in some parts of the world.

Alternative power system technologies

Figure below shows the alternative power technology options where onshore power, barge power supply and solar power systems are highlighted.

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
Alternative Power Systems								
On-Shore Power Supply	A	Y	B	≤95%↓	≤95%↓	≤95%↓	≤95%↓	≤95%↓
Barge Power Supply	A	Y	B	↕ cbc	↓ cbc	↓ cbc	↑ cbc	↕ cbc
Solar Power	A	Y	B	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc

Figure 9.16: Summary of alternative power systems [MEPC 68 INF.16]

As can be seen, the onshore power system is the most effective system for reducing ship air pollutants. On other technologies, the level of reductions is not clear and will be case by case dependent. Also, on energy consumption and GHG emissions, the impact is not clear cut and the number for onshore power only refers to ship-board fuel consumption reduction since same amount of energy will be used but this time in the form of electricity from onshore.

9.3.2.4.Future innovative technologies, fuels and operation processes

The measures included are those innovative technologies, fuels and operation methods that:

- Possess a clear theoretical potential for emission reductions or efficiency improvements that is either not yet tested in real-world application or exists primarily in a prototype phase of development.
- Are available and ready to deployed and is in limited or niche use, but with a substantial potential for expansion if certain key barriers like cost can be overcome.
- Are being used at land-side facilities or in other applications from which it can be adapted and re-engineered for application in the maritime sector.

Figure below shows a large number of alternatives in this area, some relating to existing technologies, but some are purely new measures.

	System Applicability	Retrofitable	Market Maturity	NOx	PM	Efficiency Improvement	Cost
Measures from Existing List							
Engine Optimization Technologies	P	Y	M/E	↓	↓	↑	↕
Engine Automation and Data Collection	P/A	Y	M/E	↓	↓	↑	↓
Turbocharger technologies	P	Y	M/E	↓	↕	↑	↕
Combustion Water Technologies	P	Y	M/E	↓	↕	↕	↑
Shore-based exhaust treatment systems	P/A	Y	L/E	↓	↓	↕	↑
Automated Berthing	O	Y	M	↓	↓	↑	↓
Alternative Fuels	P/A	Y	M/E	↕	↕	↕	↕
Solar Power	E	Y	M	↓	↓	↑	↓
"New" Measures							
Variable camshaft timing	P	Y	L/E	↓	↓	↕	↓
Selective non-catalytic reduction (SnCR)	P	Y	L/E	↓	↕	↕	↑
Low-Temperature SCR	P	Y	L/E	↓	↕	↕	↑
Low NOx Burners	B	Y	L/E	↓	↕	↕	↑
Eletrical System Improvements	E	Y	M	↓	↓	↑	↓
Low energy lighting	E	Y	M	↓	↓	↑	↓
Multi-mode propulsion	P	N	M/E	↓	↓	↑	↕
Battery Hybrids	P/E	Y	L/E	↓	↓	↑	↓
Fuel Cells	P/E	N	L/E	↓	↓	↑	↓
Vessel size increase	O	N	M	↓	↓	↑	↓
Megaboxes	O	N	T	↓	↓	↑	↓
Alternative cargo Loading	O	N	T	↓	↓	↑	↓
Mid-stream operations	O	Y	L/T	↓	↓	↑	↓
Virtual Arrival and Alternative Berth Policies	O	Y	M/E	↓	↓	↑	↓

Figure 9.17: Summary of innovative and emerging technologies [MEPC 68 INF.16]

As can be seen, many of these measures are judged to reduce not only air pollutants (NOx and PM) but also improve (increase) the energy efficiency of the ship and reduce costs.

9.3.2.5.Study key findings.

From the above technical and operational measures identified and studies, the following key findings relevant to this section are reported by the MEPC 68/INF16 report:

- Numerous technical measures are available to effectively reduce emissions and increase energy efficiency, and experience with some of the measures implemented in the port area goes back over ten years and is growing. The range of available technical measures is quite extensive including engine and boiler technologies, after treatment technologies, fuel options, alternative power systems, operational efficiencies, and cargo vapour recovery.
- There are no "one size fit all" technical measure solution for ships and ports. Due to numerous variables such as pollutant(s) targeted, port configuration, cargos handled, drivers, barriers, vessels servicing the port area, vessel configurations, operational conditions and the nature of technical measures, each measure needs to be analysed on a case-by-case basis in advance of implementation.

- Several emerging and innovative technologies and measures potentially could provide additional options to reduce emissions from ships in the port area. There are initiatives underway from various stakeholders that are focused on the demonstration of emerging technologies and measures, with the ultimate goal of bringing them to the market in an expedited fashion.

9.4.Ship In-Port Operational Energy Efficiency Measures

9.4.1. Introduction

When the ship arrives at a port, there are some limited scopes for the ship to reduce its fuel consumption while at anchor or at berth. Despite the fact that such reduction in fuel consumption may not have significant impact on a ship's overall annual fuel consumption; the impact on port air quality could be significant. Therefore, the question "if ship-board staff could do anything to support a more efficient ship-in-port operation" is main topic of this section.

A number of measures could be identified that if implemented would reduce fuel consumption for the benefit of ship's energy efficiency and port air quality. These measures are analysed by assuming that ship will not be connected to shore power or a major switch in terms of fuel type will not take place as these changes may make some of the arguments put forward herein redundant.

The aspects covered in this section are simple day to day ship-board operational measures that can be undertaken by all ships. In fact, some of them could be implemented also by harbour and port support vessels. The main ship-board systems working when ship is at anchor or at berth include:

- Auxiliary machinery and equipment
- Diesel generators,
- Boilers

Additionally, and on some ships, cargo handling equipment may be in operation that would provide extra opportunities and further measures for energy saving. However, in this section, the above three items are only investigated.

9.4.2. Operation of Auxiliary Machinery

The ship's diesel generators operate in port in order to produce electricity for operation of a large number of machinery and systems in engine room, deck and accommodation areas. Amongst them are the engine room auxiliary machinery like fans, pumps and other devices. On the accommodation side, the need for lighting, HVAC and galleys exists in port. In order to save energy and reduce emissions, auxiliary machinery utilisation in port should be minimised with consideration for safety.

There are practical evidences showing that such machinery are normally over-utilised in ports. Ship staff may follow the same processes as sea-going condition and keep the machinery running in the same way as during sea going conditions. This could also be considered as a way of avoiding additional processes, remain ready to leave the port without the need to re-start some of the machinery and for simple reasons that the company may not have plans and procedures on how the port operations with regard to machinery utilisation need to be handled.

This should not be the case and it can be changed via specific planning for the engine room machinery operations for at-berth/at-anchor operation to ensure energy efficiency while safety is taken into account. The main aim of the plan will be to save energy via switching off the unnecessary machinery. As examples, the following may be undertaken:

- Minimising the number of running auxiliary machinery based on port operation requirements. There are a large number of pumps on board such as sea water cooling pumps, steering pumps, engine water circulating pumps, engine lubricating oil pumps, etc. All these need to be investigated and a plan for their port-operation should be devised based on port requirements.
- Minimising the number of A/C units operated or switch them off when conditions permit. The mean temperature on board does not need to be lower than 24 ºC degrees.
- The number of engine ventilation fans should be reduced in port or brought to slower speed. Since main engine(s) is not working in ports, there is no need to run all the engine room ventilation fans.
- The fuel treatment machinery needs to be reviewed if they all needed to run in the same way as sea-going condition in view of the significant reduction of ship fuel consumption because of main engine being switched off.
- Minimisation of use of compressed air and its use where required. Compressed air is an expensive commodity and for example should not be used for ventilation purposes.

As indicated, these measures will provide less demand for electric generation and thus will lead to reduced fuel consumption. Additionally, the machinery run hours will reduce and this will be beneficial from maintenance point of view.

There are opportunities for reduction of energy needed in the accommodation area when in port. Although these measures are applicable to sea going conditions as well, it will be more effective under port condition. Some aspects include:

- Lighting system: The lights in spaces when not in use can be switched off and deck lighting during day hours can be avoided.
- Galleys: The galley area also provides some opportunities. For example, lighting and electric equipment can be switched off after use.
- Deck lighting: No need for lighting during daytime.

These measures also help to reduce demand for electric power.

9.4.3. Use of Auxiliary Engines

In ports, many ship staff run two auxiliary engines (diesel generators) in parallel to safeguard security of electric power supply. This is not needed for most of normal berth activities or when at anchor. When two engines operate in parallel, each run at very low loads thus give higher pollutant levels, consume more energy (they operate less efficiently) and the operation mode not good for engine components and maintenance.

Therefore, it is best practice if unnecessary cases of operation of two diesel generators can be minimised. This would equally reduce air pollutants to port as well.

To do this safely, the communication between deck department and engine department is crucial. If such communications are effective, then the engine room control engineers could pre-plan diesel generator operations in ports.

9.4.4. Operation of Boilers in Port

Boilers form a major part of ship-board energy consumption in ports in particular for certain types of ships such as oil tankers. Although boilers emit less harmful emissions than diesel engines (e.g. less NO_x), nevertheless the control of their energy use will be beneficial for the port area emissions. This is the case as the ship auxiliary boilers mostly operate at low loads while in port. At low loads, the energy efficiency reduces and emissions factors increase that is not helpful.

The following ship board measures could potentially reduce the usage of boilers in ports:

Use of parallel operation of two boilers should be avoided. This not only improves the efficiency of the working boiler but also gets rid of electrical requirements for the second auxiliary boiler.

- Planning and optimisation of cargo discharge operation is another area if it relies on steam driven cargo pumps, the steam condenser of cargo pumps should be worked under vacuum pressure (e.g. larger oil tankers). In some of the ships, there may be provisions for a mix of electric and steam driven pumps. Proper planning could be done to avoid excessive use of boilers.
- Plan and optimise ballast operation if it relies on steam driven ballast pumps. In many ships, the ballast pumps are now electric driven, or a mix of steam and electric drives are used for this purpose.
- All aspects covered in relation to steam system maintenance on reducing the ship-board steam demand will also help the port operation. In other words, steam users need to be investigated, and their operations decided based on port requirements.

In some ships such as oil tankers, auxiliary boilers may be used for inert gas generation (IGG). The whole process of generating inert gas and its use can be part of optimisation; as for inner gas generation, the boiler would normally run at very low load (normally a dedicated IGG system is used to avoid use of large boilers).

9.4.5. Ship Operational Efficiency Measures

The IMO commissioned study on ship-port interface [MEPC 68/INF.16] was discussed in detail in Technologies for Port Air Quality and GHG Emissions Reduction, also provide a list of operational measures as shown in figure below.

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
Ship Operational Efficencies								
Vessel Speed Reduction/Slow Steaming	All	Y	STM	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc
Optimization of Ship Reefer Systems	All	Y	All	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc
Optimization of Ship Systems	A	Y	All	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc
Optimization of Fleet Sizing to Maximize Vessel Efficienc	All	Y	All	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc

Figure 9.18: Summary of ship operational measures [MEPC 68/INF.16]

Of the measures listed above, the optimisation of ship reefer system and other cargo conditioning systems need to be also considered as a case-by-case basis.

9.5. Onshore Power Supply (OPS)

9.5.1. Introduction

During the ship's port operations and at berth, auxiliary engines are run in order to generate electricity for supply to ship-board systems as well as to the cargo loading or loading/unloading machinery, where applicable. Today, this power is generally provided by auxiliary engines that emit carbon dioxide (CO_2) and air pollutants, affecting local air quality and ultimately the health of both port workers and nearby residents.

As an alternative to on-board power generation, vessels can be hooked up to an onshore power supply, i.e. connected to the local electricity grid. In this way ships' operations can proceed uninterrupted, while eliminating negative side-effects. The amount of power generated, and fuel consumed is dependent on type of ships and could be anything from a few hundred kW to several MW of electric power. The operation of auxiliary engines is a major source of SO_x, NO_x and Particulate Matters (PM) emissions to ports. The amount of emissions is generally proportional to the amount of fuel used. The longer the ship stays at berth or at anchor, the higher the ship fuel consumption will be and thereby the more the exhaust pollutants emitted to the port.

Concern over air quality in ports has led to growing pressure on port operators to reduce exhaust emissions; in particular pollutants of SO_x, NO_x and PM. The supply of power from onshore (port) to ship is one system that has been advocated for this purpose. Use of this system allows ships to turn off their auxiliary engines when in port and plug into a shore-side electricity supply. As a result, not only air emissions to port are reduced but also it helps positively with other aspects of the ship and port operations. It is claimed that this system, in addition to the environmental and social benefits, could provide economical savings to all stakeholders. However, this last point has yet to be validated.

Onshore Power Supply (OPS), as defined above, has been known for a long time in particular for naval ships, where the ship normally stays at berth for a long period of time. Under such conditions, it is cost effective to run the vessel via a supply of electricity from shore. This was used by the US Navy originally and the term "cold ironing" originates from this naval application. Over the years, other terms have also been used for OPS; some of which are listed below:

- Alternative Maritime Power (AMP)
- Shore side electricity
- Shore power

In this section, the term Onshore Power Supply (OPS) will be used throughout. Figure below shows a typical OPS system.

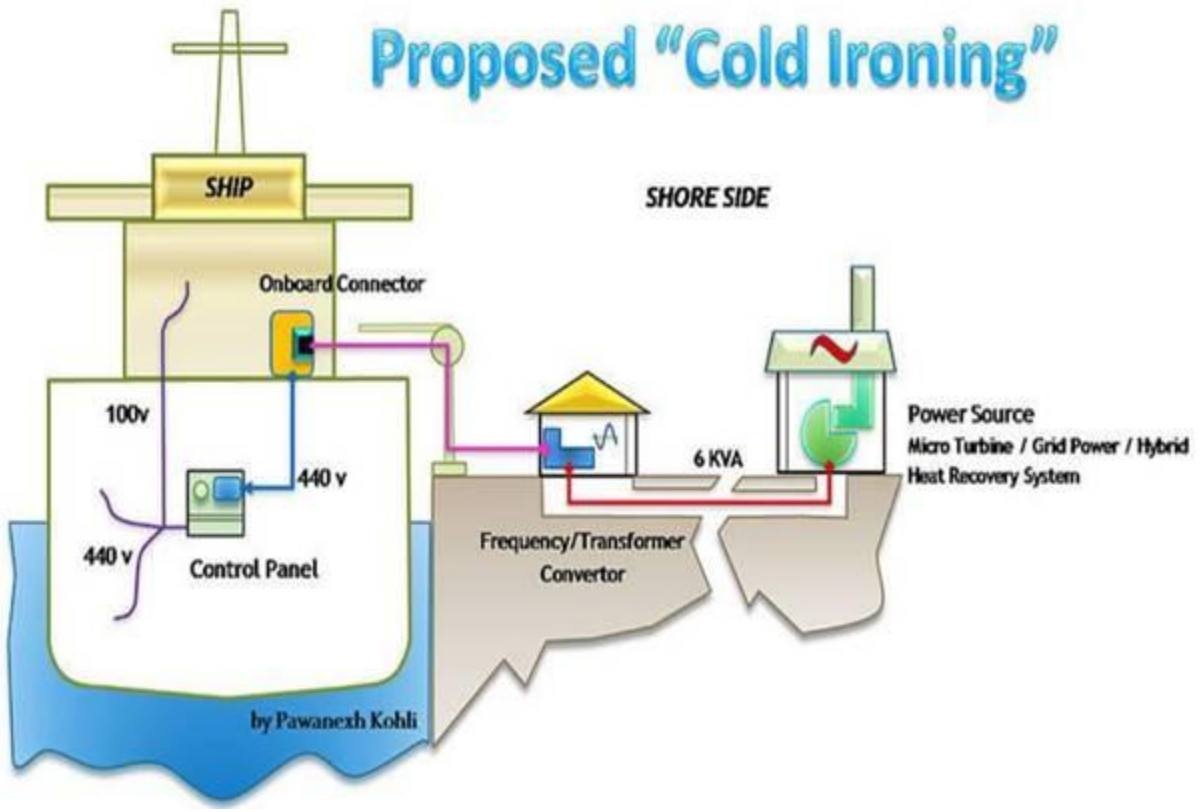


Figure 9.19: Typical OPS arrangement [Wikipedia]

9.5.2. The Case for OPS

Ships normally use some base-load electricity levels for essential services all the time, including while at berth. For a case of a typical mid-size tanker, this could be about 400 kW (excluding the electricity needed for cargo operations and ballast operations). For such a tanker staying at port for 30 hours, it would require 12 MWh of electricity; the longer the vessel stays at berth, the larger this figure will be. For an average cruise ship, the electrical requirement could be about 8 MW. For such a cruise vessel, staying at berth for 12 hours will require 96 MWh of electric power. Generating this power on-board generates NO_x, SOx, PM and CO_2 emissions that could be significant if the number of ships at berth, and/or their duration of stay, or number of calls increase. The environmental profile of electricity generated by power plants on land versus ships' diesel electric generators running on bunker fuels, is one of the main advantages of OPS technology. In land-based power plants, electricity can be generated at high energy efficiency in large efficient power plants with the use of either clean fuel or exhaust gas cleaning systems. Also, electricity is generally generated in remote areas beyond population centres with minimal air quality impact on population centres. On the contrary, ship-board generation is not as energy efficient as land-based plants and also any exhaust emissions from engines directly pollutes the port and surrounding areas. The reason that shipboard generation is less efficient is due to smaller engines used (with an MCR of up to 2,000 kW) as well as part-load operation (engine load factors at berth barely go beyond 50% for most of the time). OPS will substantially but not completely reduce SO_X emissions as the steam generated by the on-board boiler is still needed for some ship's operation at berth. Nevertheless, OPS have been widely used as a viable way to reduce ship-based local polluting emissions. The California Air Resource Board, for example, requires a fleet operator to reduce at-berth emissions from its vessels' auxiliary engines at each California port by approximately 80 percent by 2020 either through connecting the vessel to shore power or through alternative control technique(s) that achieve equivalent emission reductions. Major ports in Europe, such as Antwerp and Gothenburg, are also engaged in provision of shore power to ships. Shore power is also being developed in some ports in China, such as Shanghai and Lianyungang. It is expected that lowered cost resulting from the economy of scale and standardization will make the OPS more attractive in the future [ICCT December 2012]. The use of OPS thus could be seen primarily as a green port initiative in order to improve the port air quality. For ports, the ability to supply power to ships at berth enables them to establish a more efficient overall electrical supply and also act as a utility; i.e. as an organisation that sells electricity to ships. For the port and ship staff closely linked to ships while at berth, there is an additional benefit of reduced noise and vibration in harbour areas. For ship staff, when the system is fully operational, more time will be available to deal with maintenance and other aspects of port-related activities. OPS are best for ships that make multiple calls at a particular terminal for multiple years. The best candidates for OPS are container ships, reefer ships, ferries, Ro-Ro and cruise ships because they tend to operate in these types of regular services and require substantial electricity while at berth.

9.5.3. Infrastructure requirements

Installing new shore power systems requires shore-side infrastructure and can be expensive but can also result in major reductions in port emissions. The infrastructure is typically constituted of power connection to utility, power transformation, conditioning and switching equipment, and land for these facilities, cabling, synchronization equipment, and berth side infrastructure. Shipside infrastructure is also expensive, but the cost has been declining with more streamlined and standardized designs. The cost difference between the grid power, especially the high demand charges, and price of bunker are key factors in business case for OPS. Low price differential of electricity over HFO can provide a strong incentive to the use of the shore power.

To use OPS, there will be a need for extra investment both at shore-side (port) and ship side. As the responsibility for supply of electricity to ship is with port, the capital investment of ports will be more significant. Additional investments stem from construction and installation of electricity supply conditioning/safety systems at the quay and potential needs related to strengthening the port's electricity grid.

9.5.4. Standardisation

In order for OPS to become widespread among various ports and ship-owners, the nature and arrangement of power connections must be standardized. Neither a port owner nor a ship-owner can justify investment in expensive equipment to enable a shore connection system without assurance that such a system will be functional across many countries with alternative electrical characteristics in terms of voltage, frequency and other aspects. Work on a common standard for OPS for ships at berth began early in 2005. Major players in this effort have included technology suppliers, governments, port authorities, ship-owners (particularly cruise line, tanker and container ship companies), classification societies and others. The IEC, ISO and IEEE have joined forces and developed the international standard " ISO/IEC/IEEE 80005-1:2012 ISO/IEC/IEEE 80005-1 Utility Connections in Ports - Part 1: High Voltage Shore Connection (HVSC) Systems -- General requirements". This standard revised the "IEC/PAS 60092-510:2009 Electrical installations in ships -- Special features – High Voltage Shore Connection Systems (HVSC-Systems)" and addresses the connection between ship and shore and the procedures for safe operation.

9.5.5. Port Related Initiatives

The International Association of Ports and Harbours has provided information to IMO on the World Ports Climate Initiative and also established a website (http://wpci.iaphworldports.org/onshore-power-supply/environment-and-health/climate.html) to provide practical information about OPS for seagoing vessels and shore installations. The website provides information on numerous issues connected with OPS such as power generation, voltage and frequency, safety and health, costs, implementation, ports utilizing OPS, etc. The latest list of ports with some degree of OPS capability is given in the table below.

Port	Country	High Voltage	Low voltage	Frequency
Antwerp	Belgium	6.6 kV		50 Hz/60 Hz
Goteborg	Sweden	6.6 kV/10 kV	400 V	50 Hz
Helsingborg	Sweden		400 V/440 V	50 HzV
Stockholm	Sweden		400 V/690 V	50 Hz
Piteå	Sweden	6 kV		50 Hz
Kemi	Finland	6.6 kV		50 Hz
Oulu	Finland	6.6 kV		50 Hz
Kotka	Finland	6.6 kV		50 Hz
Lübeck	Germany	6.6 kV		50 Hz
Zeebrugge	Belgium	6.6kV		50 Hz
Los Angeles	U.S.A	6.6 kV/11 kV		60 Hz
Long Beach	U.S.A	6.6 kV	480 V	60 Hz
San Francisco	U.S.A	6.6 kV/11 kV		60 Hz
San Diego	U.S.A	6.6 kV/11 kV		60 Hz
Seattle	U.S.A	6.6 kV/11 kV		60 Hz
Juneau	U.S.A	6.6 kV/11 kV		60 Hz
Pittsburgh	U.S.A		440 V	60 Hz
Vancouver	Canada			
Oslo	Norway	6.6 kV		50 Hz
Rotterdam	Netherlands	6.6 kV		50 HZ

Table: Ports with OPS at 9 October 2012 [IMO MEPC.1/Circ.794]

9.5.6. IMO Regulations

Currently and at the time of writing this document, there is no IMO regulation on OPS. In fact, IMO has developed minimal regulations on ports development/operation other than those that may directly be required for ship operation (such as reception facilities). Thus, there have been proposals to add some new regulations to MARPOL Annex VI on introducing some ships' requirements for the future wider use of OPS. For example, it is proposed that ships should undertake an assessment of the environmental benefits as well as cost-benefit of addressing emissions from ships at berth. As part of this, it should be taken into account how the supplied electrical power is generated, and if similar environmental benefits could be achieved by other more cost-effective means.

As part of the proposed draft regulation (http://www.sjofartsverket.se/pages/9333/55-4-13.pdf), submitted by Seden to MEPC 55 in 2006, it is suggested:

- Ships that can document that their on-board power production has lower total emissions than the supplied shore side electricity should, if no other local circumstances dictate otherwise, be exempted from the requirement to connect to shore-side electrical power.
- No ship should be required to connect to OPS when the planned port stay at the actual berth is less than a couple of hours (e.g. 2 hours).
- The port or terminal shall provide sufficient electrical power to sustain all normal operations during the port call, including calculated peak consumption.
- The costs for the ship to connect to shore power at berth should not exceed the average comparable costs of port services in general and the cost of supplied electricity to shore based consumers within the vicinity of the port or terminal.

The apparent aim of the above proposals seems to be to protect ship owners from undue pressures by ports to force them to use OPS without good and reasonable business or environmental justifications.

Subsequently, IMO reviewed the situation in MEPC 64 meeting in 2012 and while considering various views including the above proposal concluded that:

"The majority was of the view that ports equipped with on-shore power supply are limited and mandatory requirements for the on-shore power supply should not be developed at this stage. The MEPC agreed to request the IMO Secretariat to disseminate the information relating to the on-shore power supply, e.g. lists of relevant standards and ports providing onshore power supply as MEPC.1/Circ.794" *IMO MEPC 64/23].

9.5.7. OPS Effectiveness

There is no doubt that OPS leads to significant reduction in air pollutants in ports and areas at their vicinity. However, the case for overall energy efficiency of the OPS in terms of power used while including all the transmissions losses and overall CO emissions to atmosphere is not clear. Although both have been advocated by OPS enthusiast as justification for OPS and reduction of ship-owners' energy cost, this topic is not certain and most likely will vary case by case.

9.5.7.1.Energy efficiency

The energy efficiency of OPS relative to ship-board generation needs to take into account all the various forms of energy transfer and transformation losses along the transfer route. In addition, the thermal efficiency of a land-based power plant versus ship-board systems needs to be taken into account.

In general, it is estimated that transmission losses from a land-based power plant to the ship will be around 10 to 25% depending on the supply transmission network (i.e. an average value of about 17.5%). This means that from the energy efficiency and CO_2 reduction points of view, the land-based power plant needs to be generating less CO_2 by at least 10 to 25% compared to ship-board generation. As indicated above, this will vary from case to case and needs specific studies for various ports.

On the other hand, the case in favour of OPS is the operating condition of auxiliary diesel engines while at berth. This should be borne in mind while at berth, since the auxiliary engines normally work at a part load of about 40 to 50%. Under this loading condition, the engine efficiency is lower than the optimum value and the emissions are higher.

There is occasionally discussion on future low-carbon electricity that could be supplied to ports (or generated by a port itself) for supply to ships. There are a number of solutions, such as the use of greener energy in ports. As an example, there have been cases where LNG-based power plants are advocated for port-side power generation. Such cases yield a significant reduction in both CO_2 and pollutants and get rid of transmission losses over the grid. The drawback is port self-generation that is not the core expertise of shipping ports.

For ports deciding on self-generation, there is a case to help the grid when they have excess electricity and thereby impose less overall load on the grid.

9.6.Energy cost

The issue of energy cost is important for ship-owners. There is evidence that the overall cost of OPS electricity may be higher than the on-board generation for the following reasons:

- A tax on electricity will normally be applied if it comes from OPS. The tax level may change from case to case and country to country.
- The base cost of electricity as supplied to ports may be high.
- The port charges which are intended to cover the investment and running costs will be added to electricity price.

All the above require detailed studies for each port. To reduce the cost of pollutants on society and port areas, there may be a need to transfer the burden of cost to ships as they represent the main source of pollutant. However, since this may vary from port to port, it will have an impact on port business as well.

9.7.Port Clean Air Program

A port clean air program is a comprehensive initiative used by some ports to address air emissions from shipping and port operations. Such a program is generally established and implemented by a port authority with input from other stakeholders. Such a program normally sets specific emission reduction targets for a port and develops a roadmap to achieve those targets. To ensure success, the management would follow continuous improvement cycle and success is measured and monitored and target revised periodically based a Plan – Do – Check – Act (PDCA) process cycle [ICCT December 2012]. As any other management continuous improvement cycle, the port clean air program will be successful where the management and staff of port authorities and regulatory agencies are committed to the improvement of air quality in the region. In addition, the participation from other stakeholders and port related organisations gives the clean air team more influence and authority over the air quality improvement in the port. A successful port clean air program is dependent on the identification, evaluation, and use of appropriate technologies and operational strategies. During the “Plan” stage, it is required to determine emission mitigation measures and coordinate with different stakeholders to implement these measures. After choosing the right measures and during other parts of the cycle, the measures need to be executed, and their effectiveness monitored. Finally, the overall achievements need to be reviewed and assessed against the initial targets and objectives. So far, a number of ports have been developing and implementing the “port clean air programme” as documented in ICCT reports given in the references.

9.8. Just in Time (JIT) and Virtual Arrival (VA)

9.8.1. Definitions

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.

9.8.2. 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 timetables.
- 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 nontechnical 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.

9.8.3. 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 fewer waiting times and more passage time; thereby scope for speed reduction and thereby fuel efficiency.

9.8.3.1.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.

9.8.3.2.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 on e-navigation) and systems such as weather routing and voyage monitoring systems.

9.8.4. Virtual Arrival (VA)

9.8.4.1. 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.

9.8.4.2.Virtual Arrival process

Figure below 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.

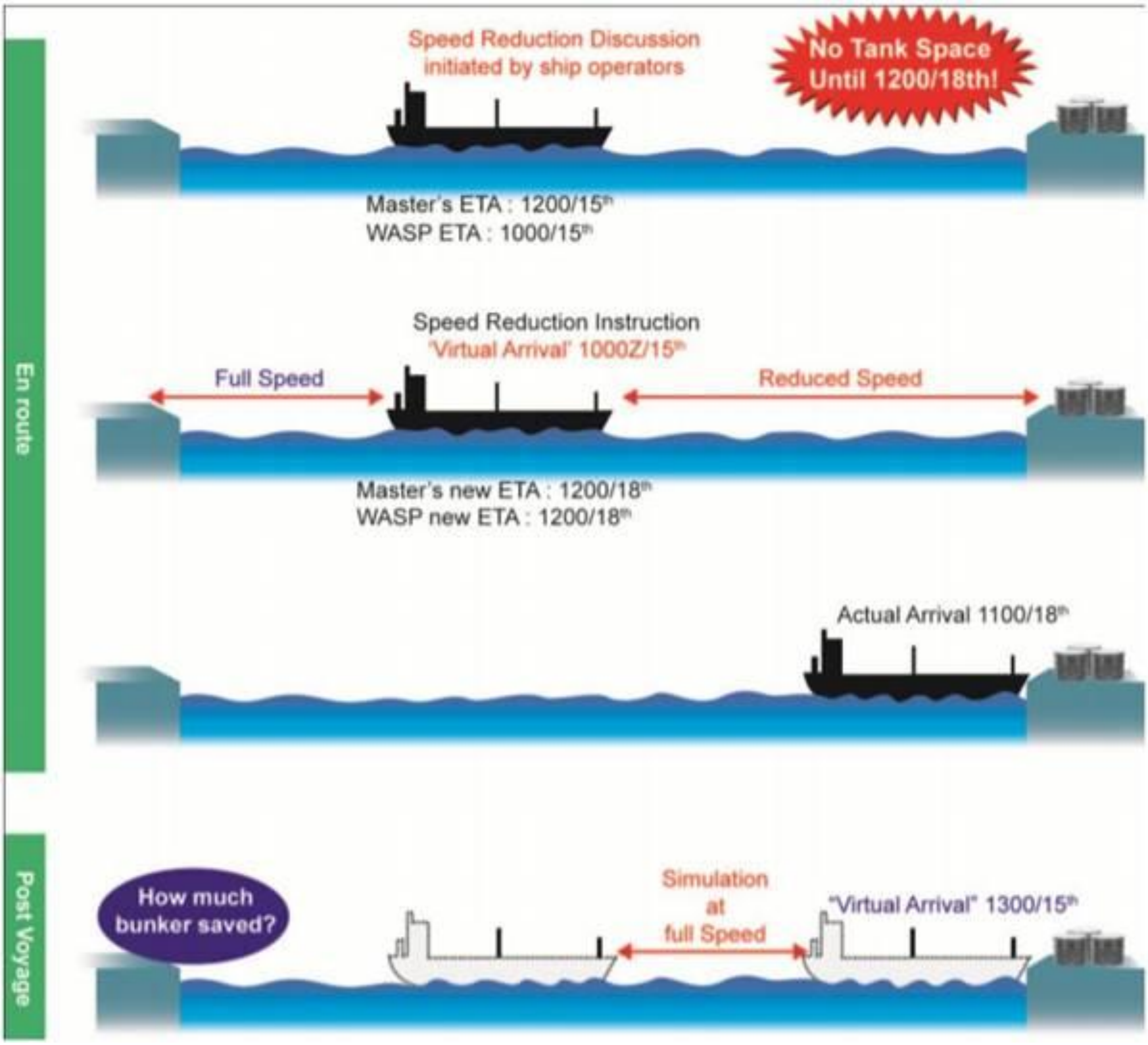


Figure 9.20: Virtual Arrival processes [INTERTANKO and OCIMF 2010]

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 time, 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.
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.

9.8.4.3.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 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.

9.8.4.4.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 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.

9.8.5. Potential for Saving Energy

For a review of the current ship operational profiles and their analysis, refer to Reference [Charlotte Banks et. al.] that presents 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 below 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 Handy size tanker ships which only spend around 40% of the year under loaded conditions.

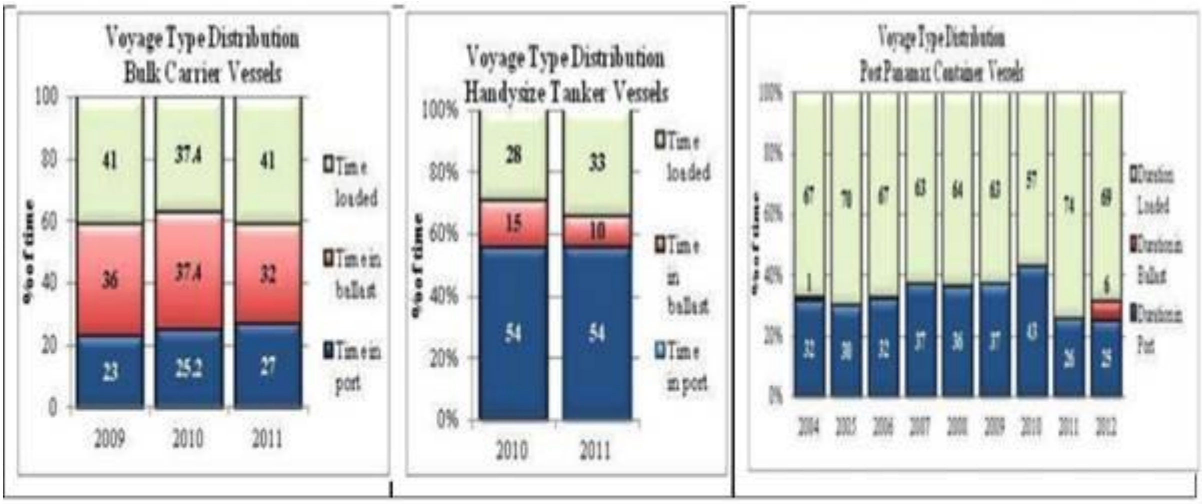


Figure 9.21: Voyage profiles for typical bulk carriers, tankers and containerships [Charlotte Banks et. al.]

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 costal 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.

9.9. Green Port Initiatives and Port Environmental Programs

9.9.1. Introduction

Apart from Onshore Power Supply (OPS) that could lead to improved air quality in port areas and likely reduction of GHG emissions, various ports are promoting green initiatives that aim to reduce air emissions from ships. Green port initiatives are in place in particular in USA, Europe and to some extent Asia. In the majority of cases, reduction of air pollution and improving the port area air quality are at the core of the green port initiatives.

Green port initiatives could take many forms and shapes, but the main purpose as indicated to reduce port-area emissions. Example activities could be reduced port dues for clean ships, investment in port infrastructure to improve port operations, providing OPS facilities, reducing or exemption from taxation for clean ships, etc.

In this section, a number of port related green activities that relate to air emissions are presented and discussed.

9.9.2. Port Related VOC Management

Volatile Organic Compounds (VOCs) are the lighter parts of crude oil, or their products. They normally vaporise during the ship loading process in the loading tanks. This is then normally vented to the atmosphere causing air pollution in port areas.

IMO MARPOL Annex VI regulations allow the Flag state to designate ports that intend to control and reduce VOC from tankers. This is embodied in Annex VI Regulation 15 on VOC. The regulation enables ports and terminals to implement VOC controls.

For compliance purposes, these ports should be able to receive such gases and collect and safely dispose of them. Tankers that visit such ports should also have a Vapour Emissions Control

System (VECS) to be compliant with IMO MSC/Circ. 585 on Standards for VECS system. Figure below shows a schematic of such a shipboard VECS. Further information on technical information on systems and operation to assist development of VOC management plans can be found in the relevant IMO MEPC Circular (MEPC.1/Circ.680, 27 July 2009).

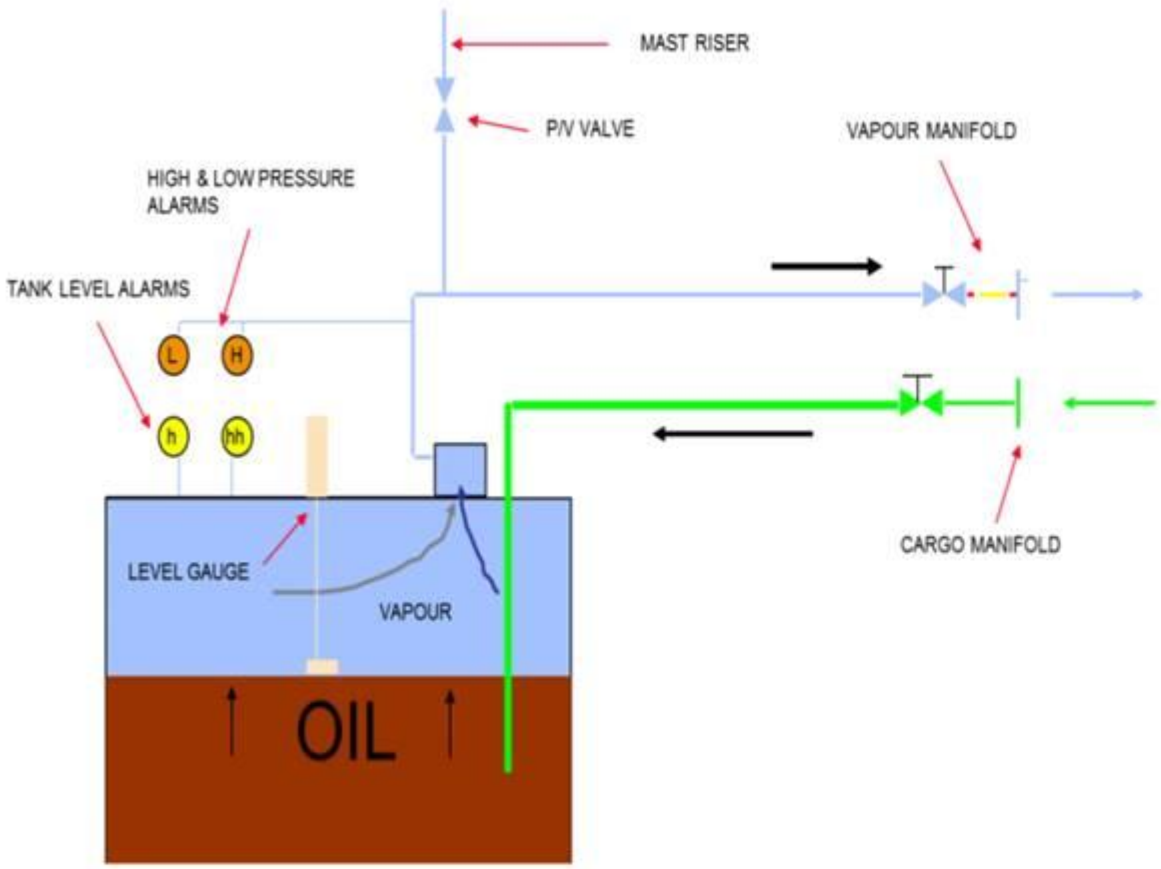


Figure 9.22: Schematic of an oil tanker's VOC emissions control system

Additionally, crude oil tankers are required to have an approved VOC manual. This should contain procedures for minimizing VOC emissions during loading, sea passage and discharge and additional VOC during washing. Currently, a number of ports have been assigned as VOC control ports; see the table below.

DESIGNATED PORTS AT WHICH VOC EMISSIONS ARE REGULATED

NAME OF PORTS, TERMINAL/FACILITY		SIZE OF TANKERS	CARGOES REQUIRING VAPOUR EMISSION CONTROL SYSTEMS	EFFECTIVE DATE
The Netherlands				
Amsterdam	All terminals	All sizes	Cargoes with VOC, with the exception of methane, with a vapour pressure of 1 kPa (10 mbar) or more at a temperature of 293.15 K (20°C) or such cargoes with an equal volatility of 10 mbar	9 November 2011
Rotterdam	Botlek Tank Terminal, Rubis, ETT, Argos	All sizes	Cargoes with VOC, with a vapour pressure of 1 kPa (10 mbar) or more at a temperature of 293.15 K (20°C). For Rubis only, substances under class LT2 are to be controlled	9 November 2011
Moerdijk	Afval Stoffen Terminal Moerdijk ATM, Shell Chemie Moerdijk, Den Hartoch Moerdijk bv	All sizes	Cargoes with VOC, smelling products and ADR Class 3 and 6	9 November 2011
Terneuzen	Dow Benelux BV Terneuzen, Oiltanking Terneuzen BV.	100,000 GT and less	Cargoes with VOC	9 November 2011
Groningen	VOPAK	All sizes	Cargoes with VOC, with the exception of methane, with a vapour pressure of 1 kPa (10 mbar) or more at a temperature of 293.15 K (20°C) or such cargoes with an equal volatility of 10 mbar	1 July 2012
Vlissingen	Zeeland refinery	9,000 GT and above	Cargoes with VOC	9 November 2011
The Republic of Korea				
Busan Incheon Pyeongtaek/Dangjin Ulsan Yeosu Kwangyang		400 GT and above	Crude oil Gasoline Naphtha	20 May 2009
Daesan		400 GT and above	Crude oil Gasoline Naphtha	20 May 2015

Table: Designated ports with VOC emissions control

9.9.3. Differentiated Port Dues

If ports/terminals give ship owners and operators of relatively clean ships a port due advantage, they give a direct incentive for reducing ship port emissions. Thus, port dues advantages for relatively clean ships can be put into practice by two options:

- Reducing port dues for relative clean ships while keeping port dues for the other ships unchanged and thus reducing a port's income.
- To apply the 'polluter pays principle', raising the port dues for those ships that have relatively high port emissions.

In the first case, where discounts are given, the funding of the incentive scheme could turn out to be a problem for a port. In the second case, where port dues are raised based on ship emission level, the port runs the risk of losing business to competing ports, which have not introduced such a penalty-based scheme. Another potential barrier in this context is the presence of privately owned quays in the port area that may hamper the introduction of the polluter pays principle, as this also may affect the level playing field within the port [MEPC 68 INF.16].

Some of the existing ports provide incentives for efficient and clean shipping via reduced port dues based on their regulated emissions levels. Examples are the Swedish ports that currently provide differentiated port dues based on environmental criteria. About 20-25 of the bigger ports in Sweden have differentiated port dues on the basis of the sulphur content of the fuel used and the NO_x emissions from the engines on-board. For example, in Gothenburg, Sweden the port dues used to increase if the sulphur content of the fuel exceeded 0.2% (currently, the regulatory limits for Swedish ports are 0.1% due to the IMO Emissions Control Area regulations, thus the above is irrelevant).

For ships with a NO_x emission level lower than 10 g/kWh, a discount is applied that increases progressively as shown in below table.

Emission level in grams of NOx/kWh	Reduction in SEK per unit of the ship's gross tonnage (GT)
6.0-9.9	0.05 SEK/GT
2.0-5.9	0.10 SEK/GT
0-1.9	0.20 SEK/GT

Table: NOx reduction incentives in port of Gothenburg

9.9.4. Differentiated Ship Registration Fees

The EEDI (Energy Efficiency Design Index) is part of the energy efficiency regulations under MARPOL Annex VI that aims to improve shipping CO_2 emissions via enforcing future targets for ship designs that will provide major reductions to EEDI. Some administrations have taken, or are evaluating, to use this index for differentiated registration fee or tonnage taxation. An example of such an initiative is the one by Singapore MPA (Maritime Port Authority) in 2011 that was undertaken under the Singapore Green Ship Programme.

The Green Ship Programme targets Singapore-flagged ships. The MPA provides incentives to ship owners who adopt energy efficient ship designs that will reduce fuel consumption and carbon dioxide emissions. Accordingly, Singapore-flagged ships registered on or after 1 July 2011, which go beyond the requirements of the International Maritime Organization's EEDI, will enjoy a 50% reduction on the Initial Registration Fees under both the normal registration and the Block Transfer Scheme during the registration of the ship. They will also enjoy a 20% rebate on Annual Tonnage Tax payable every year for a number of years based on a scheme that uses EEDI.

Existing ships which utilise energy efficient ship designs that meet the requirements for the Green Ship Programme can also take part in this programme but will only enjoy the 20% rebate on Annual Tonnage Tax payable every year until the ship ceases to exceed the requirements of IMO EEDI reference lines.

9.9.5. Environmental Ship Index (ESI)

A large number of the world's key ports have committed themselves to reducing the port-related GHG. This commitment is called the World Port Climate Initiative (WPCI). One aspect of this initiative is to give incentives to ships that visit such ports as a way of reducing port-related emissions.

One of the projects within WPCI is the development of an Environmental Ship Index (ESI). The ESI identifies seagoing ships that perform better in reducing air emissions than the levels required by the IMO MARPOL Annex VI. The ESI evaluates the amount of nitrogen oxide (NO_x), sulphur oxide (SO_x) that is released by a ship and includes a reporting scheme on the GHG emission of the ship.

The ESI aims to identify cleaner ships in a general way. The index is intended to be used by ports to reward ships when they participate in the scheme for promoting clean shipping. Also, WPCI encourages the shippers and ship owners to use the index as their own promotional instrument. ESI is a voluntary scheme designed to improve the environmental performance of sea going vessels. It can be applied to all types of seagoing ships. It is easy to calculate and simple in its approach.

ESI relies on various formulas for the calculation of various parts for NO_x, SO_x and CO_2. It additionally awards a bonus for the presence of OPS. The ESI Score ranges from 0 for a ship that meets the IMO environmental regulations that is already in force and 100 for a ship that emits no SO_x and no NO_x and reports or monitors its energy efficiency. In other words, a ship with a score of 0 point is actually in full compliance with the applicable regulations while a ship with 100 points has zero air emissions. In reality, the best performing ships currently score at around 40 points.

For further information on ESI and current ship ranking, refer to Environmental Ship Index website. For the ESI calculation formula, refer to ES web site.

9.9.6. Norway Nox Tax and Nox Fund

This is a NO_x tax applicable mainly to national industries including shipping. The NO_x tax is collected from participating industries and is fed into a NO_x fund. The participating companies could include oil and gas producers, fishing and offshore supply vessels, ferries, airlines, cargo, railways, land-based industry, etc. The NO_x fund then provides financial incentives for those participating organisations that want to implement NO_x reduction measures including shipping industry.

This incentive system in Norway is only applicable to domestic shipping around Norway. It is an example of an effective local program that tries to create a finical scheme and business case for NO_x reduction from shipping. These funds are generated by gathering revenue from companies that emit NOx emissions by making them subject to a NO_x tax. On the basis of the scheme, a large number of ships have so far been equipped with NO_x reduction technologies.

As for shipping, this started from 1st January 2007 and tax level is 1.9 €per kg NO_x. It is applicable to propulsions engines exceeding 750 kW. This fund has so far widely funded major Norwegian initiatives such as the move to LNG as fuel for ships operating in Norwegian water.

9.9.7. General Discussion

IMO commissioned a study on ship-port interface in 2014 [MEPC 68/INF.16] that is widely looking at many aspects of ship-port interface including the green initiatives. Based on this study a survey of stakeholder was conducted. These stakeholders included representatives from port authorities and terminals, ship owners and operators, equipment manufacturers as well as governmental and regulatory authorities. This section mainly taken from this study discussed some the issues raised.

All stakeholders indicated that air pollution is a major environmental challenge. On international or regional regulations, these have specific and high impacts on ship owners and operators but not necessarily ports. When it comes to port-ship interface green initiatives, the lack of a sound business case was widely reported by the stakeholders as the largest barrier to the implementation of various initiatives. This lack of business case issue is closely related to the reason that regulation is reported in the survey as the most effective driver.

On the other hand, voluntary and financial instruments leave room for individual decisions and evaluations regarding the use of advanced technologies or other measures, but also require a business case to be driven by factors beyond direct return on investment.

The availability of energy infrastructure, for example with LNG bunkering or connection to OPS, was also reported as a barrier, and is closely connected to the problem of having an insufficient business case. Subsidies may be needed to address this barrier, followed by fine-tuned regulation that considers local circumstances and cost effectiveness of the measures on the basis of clear criteria.

In addition to regulations, it is cited that the number of voluntary and financial incentive schemes has grown significantly in recent years. Various schemes have been implemented in Asian ports (Hong Kong, Shenzhen, Singapore), providing discounted port dues to visiting ships using low sulphur fuel. The ESI as explained is the most widely implemented and is still growing from its current participation involving over 3,000 ships and 24 ports. However, compared to the overall number of cargo ships in operation worldwide, the share of ships joining such voluntary schemes is estimated to be around 5%. As a consequence, the effectiveness of voluntary schemes is limited on the worldwide level. It can however be effective at smaller scale, such as the port level, where a smaller portion of the overall fleet can be targeted, and incentives can be tailored in a way that incrementally enhances (without entirely satisfying) the business case for adoption of measures.

Maintaining a level playing field among ports when implementing financial incentives schemes or regulations is a challenge. Partnering with other regional stakeholders by harmonizing the requirements for ships may increase the effectiveness of instruments, while the regional level playing field is maintained. There are ship owners implementing voluntary measures and participating in voluntary and incentive-based programs set up mainly by port authorities.

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Chapter 10: Cargo and Ballast Management

10.1. Ship Loading and Cargo Management

10.1.1. 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.

10.1.2. Load Lines

10.1.2.1. Origins of the Load Line Convention

It was Samuel Plimsoll who first came up with the concept of a load line mark hence the load line mark is often called the Plimsoll line. Plimsoll's work on the load line was inspired by several major accidents at sea. In 1867, Plimsoll as a member of UK parliament endeavoured 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.

10.1.2.2. The Plimsoll line

The Plimsoll 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 logbook 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 kg/m^3. 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 kg/m^3 and 1000 kg/m^3, 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 Plimsoll line and will allow the ship to load to greater draft so that when it reaches salt water the ship will be fully loaded.

10.1.2.3. The International Load Line Convention

The requirements for an international load line certificate are 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 passengers 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 Landline certificate every 5 years. The ship must also have an intermediate survey every 30 months with a 3-month windows 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.

10.1.2.4. 1966 Load Lines Convention

Cargo capacity is normally decided on most ships by it load-lines which are placed on each side of a ship to show the ships 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 ships 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 opening which are allowed a reduced freeboard and 'type B' with covers all other ships.

10.1.2.5. 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 is why a ship would want to have a reduced maximum true mean draft and a reduced measured gross tonnage, and the answers are in the 1969 Tonnage Convention.

10.1.3. Ship Capacity Utilisation

10.1.3.1. 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 or 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 factor 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 gCO_2/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.

10.1.3.2. '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-owners 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.

10.1.4. Energy Efficient Technologies and Ship Capacity

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

10.1.5. Loading Aspects, Trim and Ballasting

10.1.5.1. 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 freshwater 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 minimised.

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 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 build-up 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 build-up 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.

10.1.5.2. 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. 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 weighs such as ballast water, cargo and fuel in the vessel. The centre of floatation of the hull is not normally at the centre 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.

10.1.5.3. 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 loll.

10.1.5.4. 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.

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.

10.1.6. 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)

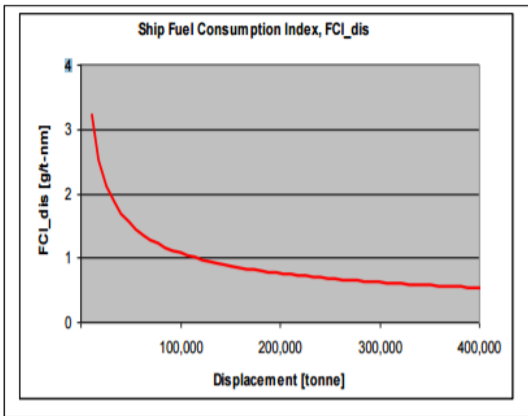
- Water cooled reefer plant with lower energy consumption
- Insulation of heating pipes (tankers)
- Optimisation of reefer container stowage
- Use VOCs to power engine or process and send ashore (Norway shuttle tankers).

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.

10.1.7. 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 CO_2 generated (see figure below).

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



NOTES:
From the figure, the ship fuel consumption index based on displacement indicates the following values for two types of tankers:

VLCC: ~ 0.65 g fuel/t-nm

Aframax: ~ 1 g fuel/t-nm

Thus, carrying crude oil with a VLCC could be about 35% more energy efficient is the business requirement is ready to deploy the larger (VLCC) ship.

Figure 10.1: Ship energy efficiency as a function of ship size [Bazari 2006]

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.

10.2. Ballast Water Management (BWM) and Energy Efficiency

10.2.1. Introduction

Ballast water (BW) is essential to control trim, list, draught, stability and stresses of a ship. Ballast water activities are largely regulated not only because of the above ship's safety implications but also since they have been recognized to be a pathway for the movement of undesirable and alien bio-species from their natural habitat to other ecosystems (figure below).

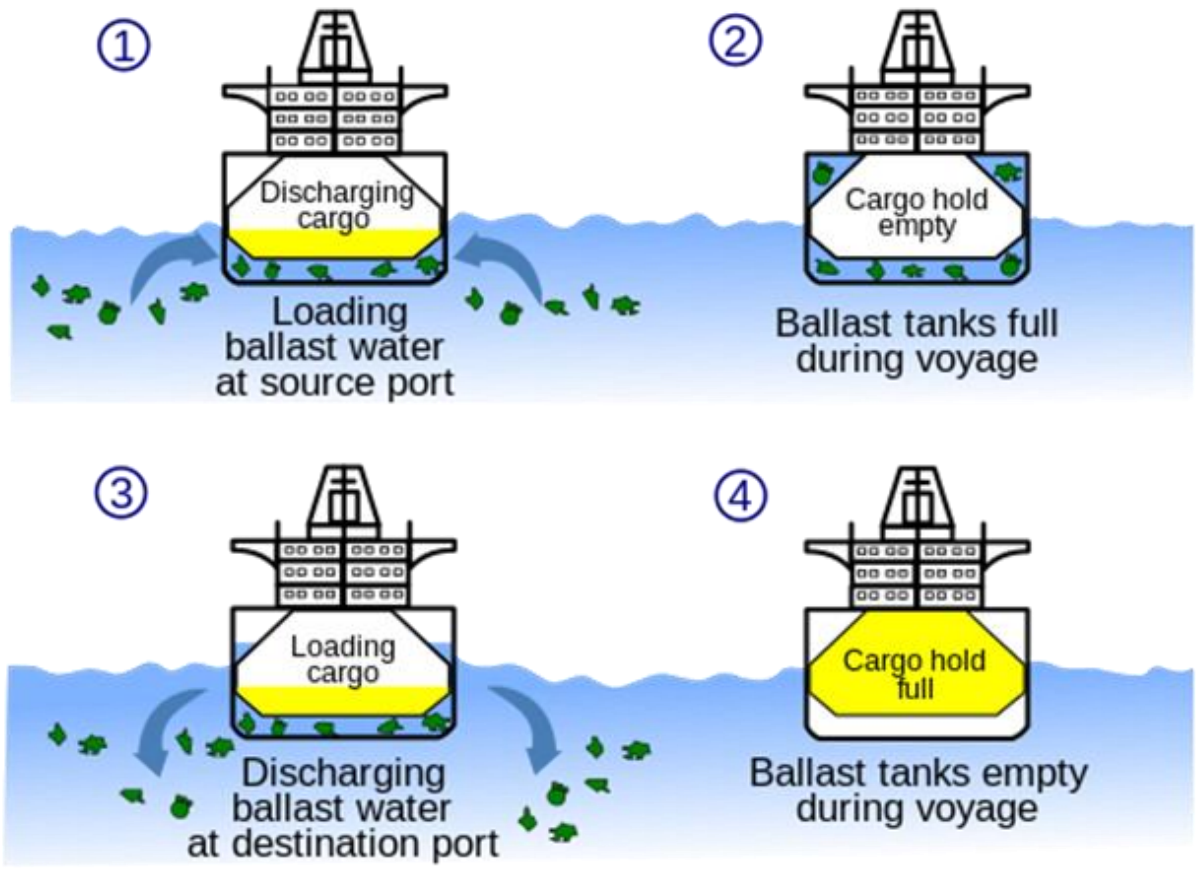


Figure 10.2: Transfer of bio-species due to ballast operations [Wikipedia]

Today, a full IMO Convention is devoted to ballast water management. In this Convention, two main methods are highlighted: ballast water exchange (Regulation D-1) and achievement of ballast water standards (Regulation D-2). The impact of Ballast Water Management (BWM) on a ship's fuel consumptions is not normally considered despite the evidence that, regardless of the management method established, the overall energy efficiency of a ship is affected by ballast water because:

- The ballast exchange requires the additional use of the ballast water handling equipment and in particular pumps.
- Treatment systems developed to reach D-2 standards require the installation of additional energy consuming equipment on board ships.

In addition to the increased use of ship-board power due to additional ballast treatment equipment, ballast water impacts the ship's energy efficiency in two additional ways:

- The change in ship displacement; thus, wetted surfaces and ship resistance. Generally, the more ballast water or ballast sediments are carried around, the bigger the ship displacement will be, and the higher ship's energy consumption is expected.
- The change in ship trim: Trim optimisation via the effective use of ballast water could lead to gains in energy efficiency as has been discussed in the previous section.

In ballast water operations and management, one should use considerable foresight in choice of regulatory compliance methods due to the fact that many variables such as type and size of ship, ballast tank configurations and associated pumping systems, trading routes and associated weather conditions, Port State requirements and manning would impact the choice of the system.

10.2.2. Port and Voyage Planning Aspects

The amount of ballast water discharge/uptake in a port depends on type of vessel, amount cargo loaded/un-loaded and ship loading planning. The need to counterbalance the detrimental effects of weight distribution during and after loading/unloading must be addressed in ports. The cargo distribution should be considered as having an impact on the quantity of ballast as well as on the ability to optimize the trim without jeopardizing the ship's strength and stability. Therefore, the port and ship responsible persons must develop plans and procedures to optimize the ballast water intake through the establishment of the cargo loading/unloading process and the final cargo plan. In addition to the anticipated ballast plan, the dynamics of the voyage should be taken into account especially when ballast water exchange has to be carried out. Ballast water and trim optimisation and adjustments while in passage should be pre-planned relative to the port operations that normally give and even-keel no trim. Sediment uptake and removal should be controlled as part of voyage planning to ensure the minimal level of sediments. As part of voyage and daily activity planning, the case for these two should be included and discussed. The voyage should be planned taking into account when ballast water exchange or adjustments are to be carried out. Also, trim optimisation and adjustments, while in passage, should be pre-planned relative to the port even keel operation.

10.2.3. Typical Ballast Water Systems without Treatment

Figure below shows a typical ship's ballast water engineering system. It is comprised of ballast pumps, relevant piping system and flow control methods. This system is normally installed according to IMO guidelines and is operated in accordance with the system design criteria and the manufacture's operational and maintenance instructions.

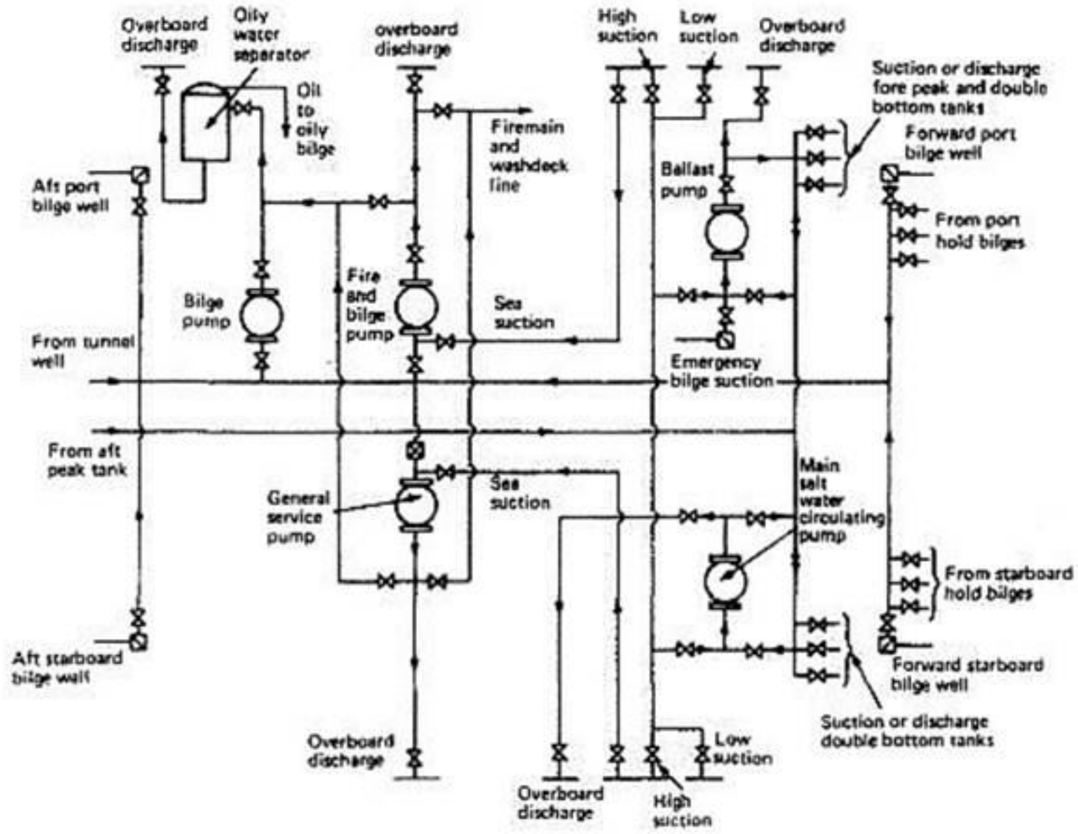


Figure 10.3: Typical ballast and bilge pump arrangement [Machinery Spaces.com]

The ship-board use and operation of such a system is normally described in the ship's Ballast Water Management Plan (BWMP). All failures and malfunctions of the system are recorded in the Ballast Water Record Book (BWRB) according to IMO requirements.

10.2.4. Ballast Water Management Plan (BWMP)

As soon as the Ballast Water Management Convention enters into force, the 8th of September 2017, it will be a requirement for each applicable ship to have a BWMP that specifies requirements for this purpose (most ships currently have such a BWMP in different formats).

The following are normally included in the BWMP:

- Acceptable methods for ballast exchange and relevant procedures.
- Details of the procedures for the disposal of sediments at sea and to shore. Method of the use of port reception facilities for sediments.
- Designation of the on-board officer-in-charge of the implementation of BWMP. The identification of a responsible person should enhance the planning of BWM operations. In this respect, adequate training of such crew members should encompass awareness

on the energy efficient operation of the BWM equipment and optimization for deadweight management and trim optimization.

- Method of the sediment removal or reduction at sea, and when cleaning of the ballast tanks takes place.

Principle of sediment management:

- To reduce the sediment levels, the following general advice is provided by the IMO:
- All practical steps should be taken during ballast uptake to avoid sediment accumulation.
- When sediment has accumulated, consideration should be given to flushing tank bottoms and other surfaces when in suitable areas.
- The volume of sediment in each ballast tank should be monitored on a regular basis.
- The frequency and timing of removal will depend on factors such as sediment build up, ship's trading pattern, availability of reception facilities, workload of the ship's personnel and safety considerations.
- Removal of sediment from ballast tanks should preferably be undertaken under controlled conditions in port, at a repair facility or in dry dock.
- The removed sediment should preferably be disposed of in a sediment reception facility if available, reasonable and practicable. Disposal should take place in areas outside 200 nm from land and in water depths of over 200 m.

Officer-in-charge: Basic tasks and responsibilities held by the officer-in-charge according to IMO guidelines include:

- An officer should be made responsible to ensure the maintenance of appropriate records and to ensure that ballast water management procedures are followed and recorded.
- When carrying out any ballast water operation, the details need to be recorded in the Ballast Water Record Book.

The officer-in-charge of ballast water management should perform the following duties:

- Ensuring that the ballast water operations follow the procedures in the BWMP.
- Ensuring that the Ballast Water Record Book and any other necessary documentation are maintained.
- Being available to assist the inspection officers authorized by a Party8 for any sampling that may need to be undertaken.

Since the Ballast Water Management Convention has not yet entered into force, the management of BW is not a worldwide obligation. However, an increasing number of countries require proper BWM before arriving in their waters. Currently, a small amount of the world's fleet carries BW treatment systems. Thus, the present dominant technique to manage BW is through the "ballast water exchange".

10.2.5. Methods of Ballast Exchange

There are three methods of ballast water exchange which have been evaluated and accepted by the IMO. The three methods are the sequential method, the flow-through method and the dilution method.

- Sequential method – A process by which a ballast tank is first emptied and then refilled with replacement ballast water to achieve at least a 95 per cent volumetric exchange.
- Flow-through method – A process by which replacement ballast water is pumped into a ballast tank, allowing existing ballast water to overflow from the tank (see figure below). For effective ballast exchange, the volume of flow through water should be at least 3 times the volume of the water in the tanks.
- Dilution method – A process by which replacement ballast water is supplied through the top of the ballast tank with simultaneous discharge from the bottom at the same flow rate and maintaining a constant level in the tank throughout the ballast exchange operation.

Figure 10.4: Ballast water exchange using flow-through method [Wikipedia]

For ballast water exchange, particular care should be taken of the following:

- Stability, which is to be maintained at all times as regulated by the IMO or flag or port authorities.
- Longitudinal stress and torsional stress values, not to exceed permitted values with regard to prevailing sea conditions, where applicable.

- Sloshing (Sloshing in ships refers to the movement of liquid inside a tank due to ship motion. Strictly speaking, the liquid must have a free surface to create a slosh dynamics problem) impact reduction due to water movement should be considered in order to minimise the risk of structural damage, in particular at non-favourable sea and swell conditions.
- Wave-induced hull vibrations when carrying out ballast water exchange.
- Limitations of the available methods of ballast water exchange in respect of sea and weather conditions.
- Forward and aft draughts and trim adjustment, with particular reference to bridge visibility, slamming, propeller immersion and minimum forward draft; and energy efficiency (optimum draft).
- Additional workloads on the master and crew.

As explained, the ballast water exchange process has implications for both safety and energy use. Also, it is shown that trim optimisation has a significant impact on ship energy efficiency.

10.2.6. Energy Efficiency Aspects

In general, observing the following will lead to energy efficiency:

- **Carrying less ballast water:** The displacement of a vessel is a function of lightweight, fuel, cargo and ballast weights. As such, less ballast water means lower displacement and lower resistances (or more cargo). Therefore, it is generally desirable to have less ballast from an energy efficiency point of view. Of course, this should not contravene any of the regulations nor compromise ship safety.
- **Optimizing use of the equipment**: This item relates to the use of ballast water equipment via management of the amount of ballast water to uptake, discharge, correct method of uptake/discharge and so on. The aim would be to reduce or optimise the usage of relevant ship-board equipment.
- **Efficient ballast management operations:** This means performing ballast exchange or ballasting and de-ballasting in a way that is more energy efficient.

For example:

- Gravity assisted ballast exchange is preferred to simple pumping in/out processes. When the gravity-assisted method is used, there is less need to run the ballast pumps.
- Sequential ballast exchange method, where tanks are first de-ballasted and then ballasted again is more energy efficient than the “flow-through ballast exchange” method, where the thanks are allowed to overflow. Again, this is for reasons of the amount of water that needs to be displaced; thus, the number of hours for ballast pumps to operate.
- Trim optimisation: Ballast water is used to adjust the ship trim as discussed before. Trim optimisation using ballast water leads to significant energy savings on some ships.
- Steam driven ballast pumps: In some ships, ballast pumps are steam driven. The use of a boiler for this purpose is extremely inefficient. Therefore, minimisation of the use of

steam-driven ballast pumps by better planning of the ballast water operations can lead to energy savings.

- Sediment removal: It is usual to take in sediments as part of ballast water operations. These sediments could be heavy and thus causes higher ship fuel consumptions when they are carried around. Thus, sediment removal leads to better cargo capacity and better energy efficiency.

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Ship Loading and Cargo Management References and further reading.

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Chapter 11: Ship Maintenance and Energy Efficiency

11.1. Requirements, Rules and Regulations

International Safety Management Code (ISM) specifies the rules and regulations for maintenance management that influence the shipping industry. The ISM Code stipulates that each ship operator is responsible for the safe and pollution free operation of the ship and that the ship's hull, machinery and equipment should be maintained and operated in accordance with applicable rules and regulations.

The part of the ISM Code on "maintenance of the ship and its equipment" describes in general how ships should be maintained, inspected, non-conformities be reported and corrective actions are taken. Accordingly, the ISM Code states that the shipping company should establish procedures to ensure that the ship is maintained in conformity with the provisions of the relevant rules and regulations and with any additional requirements which may be established by the company. Based on ISM Code, it is a requirement that "the company should identify equipment and technical systems that through sudden operational failure might result in hazardous situations".

When implementing a maintenance management system on-board a vessel as part of the shipping company's safety management system, it is imperative to define the critical systems and equipment. Maintenance instructions according to manufacturers or other policies should be issued to ensure the uninterrupted and safe operation of them at all times.

On the same issue of ship safety, the classification societies are a big player within their classification rules. The major classification societies gradually support more advanced routines for non-intrusive inspections such as condition-based maintenance where equipment and machinery systems can receive a specific class certificate of alternative survey arrangement, if maintained according this alternative method. This approach simplifies classification routines for certain specific ship-board equipment and systems and thus leads to more flexible operation and reduced inspection costs.

11.2. Maritime Maintenance Management

Like any other continuous improvement activity, the senior management has to be committed to provide required resources, competent crew and a well designed and implemented maintenance management system in order to achieve the above objectives on-board.

The fundamental part of the maintenance management system is normally a database that contains a register of all equipment on-board that need to be maintained. This database then populated with maintenance plans, maintenance activities carried out, etc. thus providing not only the requirements and plans for maintenance but also the fully history of maintenance activities performed.

Effective maintenance planning is essential for ship operation due to its complexity and the obligations on shipping organisations to comply with certain regulations and requirements including ISM. Poor maintenance management could reduce the ship‘s availability, which may in turn, be reflected in the revenue of the company. Another issue that requires attention is the impact of maintenance on ship’s fuel consumption that is highlighted in this section. It is argued and shown that good maintenance leads more energy efficient ship operation, thus the requirement for maintenance and energy efficient operation fully overlaps with each other.

11.3. Type of Maintenance

Maintenance has different forms, and its practice may vary from one company to other depending on their different requirements. The shipping company usually chooses the most appropriate maintenance type for various ship’s equipment based on its maintenance policy or strategy.

Figure below indicates different maintenance types and policy options with an outline description that follows.

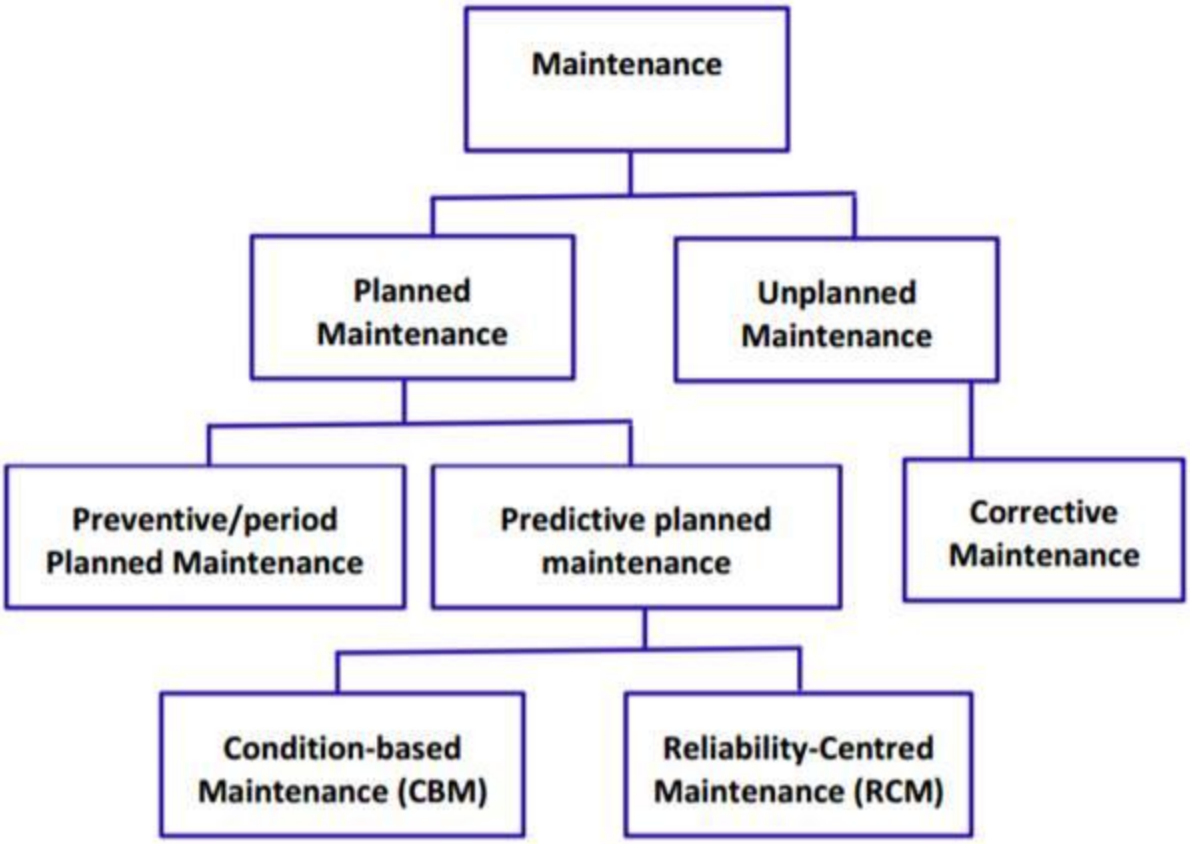

Figure 11.1: Types of maintenance policy

Unplanned Maintenance: This type of maintenance is basic and simple as it is defined as breakdown maintenance. In this maintenance policy, the repair or replacement is performed only when failure occurs. In this type of maintenance policy, however, basic preventive maintenance routines such as lubrication and machine adjustment are applied to the system at regular intervals.

Planned Maintenance: Maintenance scheduling or planning embraces all activities necessary to plan, control, and record all maintenance activities. Planned maintenance is based on a defined schedule of equipment maintenance. This maintenance policy is normal practice today in the majority of shipping companies. The planned maintenance schedule is decided based on manufacturers' recommendation or use of analytical techniques such as analysis of mean time between failures (MTBF) and reliability analysis. This approach is based on a model of the time that elapses between maintenance periods that takes into account the mechanisms of failures. Therefore, planned maintenance schedule is not necessarily based on fixed-time schedules but could be based on an analysis method that takes into account a number of factors such as reliability characteristics of the equipment.

Preventive Maintenance: This is a subset of planned maintenance (see figure above). Preventive maintenance usually depends on the manufacturer's recommendations and past experience for scheduling repair or replacement time. In this policy, the maintenance is performed on a planned basis within normally fixed scheduled intervals. Preventive maintenance is thus time-driven in that maintenance is performed based on elapsed time or hours of operation. The preventive planned maintenance is still the main strategy for shipboard maintenance. The intervals were based upon the manufacturers' recommendations in addition to past company's or ship-board experience. Predictive Maintenance: This is a subset of planned maintenance (see figure above). This is generally based on what is referred to as condition-based maintenance (CBM) or reliability-based maintenance (RCM). The maintenance decision is based on the current condition or reliability of the system or equipment. This policy stipulates the monitoring of the machinery and acting upon its condition. Usually, engineers record the system parameters, do condition/performance analysis and use their senses or equipment to hear, sight, and smell the equipment in order to assess the condition of the system. Different techniques are used in condition monitoring, such as visual inspection, performance monitoring, trend monitoring, vibration monitoring, lubricant monitoring, thermograph monitoring, and acoustic monitoring. The advantages of such a policy are that unnecessary maintenance work can be avoided. In this way, the loss of production during scheduled machine downtime can be reduced and components can remain in service if the machine is in good working condition. The industry is gradually moving from preventive maintenance to predictive maintenance.

Reliability Centred Maintenance (RCM): This could be regarded as a subset of predictive maintenance. RCM is a structured way to determine the maintenance requirements of complex systems and assets. It was first developed in the late 1960s, and the approach was derived from the aircraft industry. RCM focuses on the effect of failure with the consequences of a failure being more important than its technical characteristics. The main objective of RCM is to reduce the maintenance costs by focusing on the most important functions of the system and avoiding or removing maintenance actions that are not strictly necessary.

Corrective maintenance: The corrective maintenance may be defined as maintenance which is carried out after failure detection. Corrective maintenance can be subdivided into "immediate corrective maintenance" (in which work starts immediately after a failure) and "deferred corrective maintenance" (in which work is delayed in conformance to a given set of maintenance rules). Corrective maintenance is thus a subset of the unplanned maintenance policy.

The ship maintenance and repair activities can be completed in two different ways.

• They can be undertaken in the ship repair yard when the ship is due for dry docking for regulatory or class surveys. Certain types of maintenance activities are carried out at shipyard when the ship is at berth.

• Maintenance can be conducted during the ship's day-to-day operations of the ship, either while at sea or when in port.

Figure below shows this way of dividing the maintenance and repair activities.

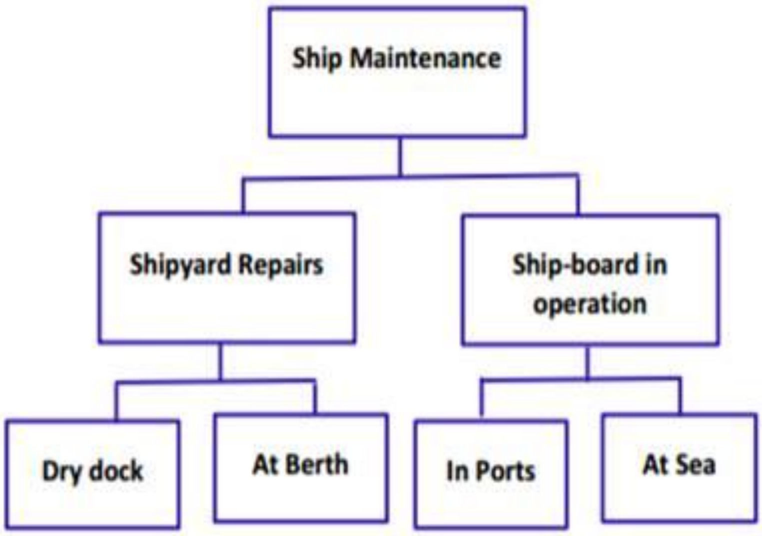

Figure 11.2: Ship maintenance by location

11.4. Maintenance and Energy Efficiency

Maintenance operations are fundamental for energy efficient operation of machineries and systems. Deterioration of ship systems' condition takes place due to normal wear and tear, fouling, maladjustments, long periods of operation outside design envelopes, etc. As a result, equipment downtime, quality problems, energy losses, safety hazards or environmental pollution. The end result is a negative impact on the operating cost, profitability, customer satisfaction and probable environmental impacts if maintenance is not properly done.

The major challenge of maintenance optimization is to implement a maintenance policy which maximizes availability and efficiency of the equipment, controls the rate of equipment deterioration, ensures the safe and environmentally friendly operation and minimizes the total cost of the operation which includes energy cost. Fortunately, most of the machinery maintenance activities are simple adjustments, cleaning, part replacement, or elimination of adverse conditions which means preventive maintenance.

Studies by a variety of industries and companies have shown that a company can cut energy consumption at its facility by about 5% to 10% by focusing on its preventive maintenance effort [Terry Wireman 2011]. As indicated earlier, the main strategic aim of a maintenance programme is to safeguard the safety of ship and its assets and increase the ship's availability for highest operational returns. Luckily, the good maintenance of a ship generally leads to improved performance of the hull, propeller and machinery, thus provides a more energy efficient operation as well.

In this section, various aspects of benefits of good maintenance for energy efficiency are further demonstrated.

Hull and propeller cleaning

Keeping hull and propeller in clean good condition can lead to major energy saving. Engines are the subject of frequent maintenance actions for a variety of reasons; one of the main reasons being the impact of burning low quality fuel and its impact on engines. Engine condition monitoring is normal practice on-board ship and engine adjustments and tuning could lead to energy saving.

On board ships, a variety of mechanical transmissions systems are used. The most complex and important one is the propulsion shafting and the simpler ones include all the mechanical linkages between drives / motors and the machinery. The energy savings in mechanical transmission systems would be influenced by the type of maintenance performed and adjustments made.

For example, the following would influence the energy efficiency of the mechanical transmissions systems depending on the type:

- **Shaft and couplings alignment:** Any shaft misalignment will not be good for machinery maintenance as well as for transmission energy efficiency. This would lead to extra losses in the system in the form of heat.
- **V-belt slippage:** Improved tension in belt-driven transmissions would prevent slippage during loading on the belt as well as during high loading. This would reduce frictional losses due to slippage.
- **Chain and gear misalignment:** In chain-driven systems, any misalignment will lead to loss of energy and at the same time will not be good for upkeep and maintenance of the system.
- **Proper bearing lubrication:** Over-lubrication and under-lubrication are not good for energy efficiency. If bearings have excessive lubrication, it may need to churn more of the lubricant, increasing the fluid friction in the lubricant and thus energy losses. The opposite is definitely not desirable as the lack of enough lubrication not only will increase energy use but also will lead more maintenance due to extra wear and tear due to metal-to-metal contact. Electrical systems Similar to mechanical systems, the energy losses in electrical systems can also be influenced by state of maintenance of the system. Typical energy losses occur in poor operating conditions for electric motors. For example, when a motor is fouled with dirt and moisture, this would inhibit the thermal heat transfer process. This condition results in increased resistance of the wiring which

further increases the temperature of the motor and subsequently its energy consumption. This could lead also to early failures as compared to a better maintained electric motor. For electric motors, improper or insufficient maintenance on mechanical transmission system (as explained above) will also increase the amount of energy required by the motor to drive the system. Steam system Steam generation systems (boilers) have long been recognised as having potential to produce substantial energy savings for most plants. There are a number of EEMs (energy efficiency measures) in this area. Most of the relevant EEMs are directly influenced by state of the steam system maintenance. Examples of such cases are:

- Steam trap maintenance and inspection programs
- Reduced fouling of boilers with direct improvement in its energy efficiency.
- Adjustment of combustion air in relation to fuel flow in boilers (so called control of excess air). This is part of the performance-related maintenance activities that could yield significant energy saving.
- Leak detection programs for hot water and steam. All leak reductions directly will support the energy efficiency aspects as well.
- Insulation inspection programmes to reduce heat losses from the system due to loss of insulation.
- End-use steam optimisation via improved cleaning of the heat transfer surfaces, etc.

All the above measures can be only achieved by an effective maintenance programme.

Compressed air system

Compressed air systems can experience similar problems as steam system such as air leaks, excessive end-use air consumption and air compressor conditions. Maintenance not only will look at compressed air production (air compressors) but also the compressed air distribution and end-use areas. Aspects to cover include:

- **Compressors:** Poor maintenance of compressors or incorrect pressure settings would lead to extra running hours and thus more energy use.
- **Air leaks:** Any air leakage in the system would require the compressors to run more than necessary. This would lead to additional energy use by the need for compressors to operate for longer periods.
- **End use devices maintenance:** The compressed air is used for end-use devices that may have a poor state of maintained. This will lead to extra need for compressed air generation.

The above examples are part of a longer list where proper maintenance could support energy efficiency. All of the above require planned or condition-based approaches to maintenance of the compressed air system.

References

Ship Maintenance and Energy Efficiency 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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Chapter 12: Energy Efficiency Management and Operational Measures

12.1. Chapter 4 of MARPOL Annex VI

12.1.1. Overview

As a result of energy efficiency debate at the IMO and subsequent agreements, a new Chapter 4 was added to MARPOL Annex VI. table below shows (in red) the list of added new regulations.

Resolution MEPC.176(58)	Resolution MEPC.203(62)
Chapter III Reg. 12 Ozone Depleting Substances Reg. 13 Nitrogen Oxides(NOx) Reg. 14 Sulphur Oxides(SOx) and Particular Matter Reg. 15 Volatile Organic Compounds (VOCs) Reg. 16 Shipboard Incineration Reg. 17 Reception Facilities Reg. 18 Fuel Oil Availability and Quality	Chapter III Reg. 12 Ozone Depleting Substances Reg. 13 Nitrogen Oxides(NOx) Reg. 14 Sulphur Oxides(SOx) and Particular Matter Reg. 15 Volatile Organic Compounds(VOCs) Reg. 16 Shipboard Incineration Reg. 17 Reception Facilities Reg. 18 Fuel Oil Availability and Quality
	Chapter IV **Reg. 19 Application** **Reg. 20 Attained EEDI** **Reg. 21 Required EEDI** **Reg. 22 SEEMP** **Reg. 23 Promotion of technical co-operation and transfer of technology relating to the improvement of energy efficiency of ships**
Appendix I ~VI	Appendix I ~VI **Appendix VII Form of International Energy Efficiency(IEE) Certificate**

Table: Newly added regulations (marked red) for energy efficiency of ships

In this section, a short description of the main aspects of these regulations is provided. Further details on the subject can be found in relevant publications by IMO in particular the IMO book on MARPOL Annex VI [IMO MARPOL Annex VI, 2013].

12.1.2. Regulation 19 – Application

This regulation specifies the domain of application of the energy efficiency regulations. Accordingly, Chapter 4 of MARPOL Annex VI applies to all ships of 400 gross tonnage and above that are engaged in international waters. It gives limited power to Administrations to waive the requirements for EEDI for a new ship up to a delivery date of 1 July 2019; subject to informing the IMO and other Parties to MARPOL Annex VI of this decision.

The "waiver" clause came about due to significant discussions at MEPC and stressing that some ships may not be able to comply with IMO requirements whilst considered as good design ships. It is important that waiver applied to specific ships and not the whole of flag State fleet. So far, there has been no need for Administrations to use this option.

12.1.3. Regulation 20 – Attained EEDI

This regulation deals with the Attained EEDI and specifies the need for its calculation and verification. Attained EEDI is the actual EEDI of a ship as calculated using EEDI formula.

According to this regulation:

- The Attained EEDI must be calculated for each new ship, each new ship when undergoes a major conversion, or existing ships that undergo so many changes as according to judgment by Administration can be considered as a new ship.
- The Attained EEDI is only applicable to a large number of ship types but not all ships. For example, fishing vessels are not required to have an Attain EEDI.
- The Attained EEDI must be calculated taking into account relevant IMO guidelines.
- The Attained EEDI must be accompanied by an "EEDI Technical File" that contains the information necessary for the calculation of the attained EEDI and that shows the process of calculation.
- The Attained EEDI must be verified, based on the EEDI Technical File, either by the Administration or by any organisation duly authorized by it.

As indicated, some ship types (e.g. fishing vessels) are not yet part of the EEDI regulations. Specifically, the following list provides the ship types that are currently required to comply with Attained EEDI regulation.

- Bulk carrier
- Gas carrier (none LNG carriers)
- Tanker
- Container ship
- General cargo ship
- Refrigerated cargo ship
- Combination carrier
- Ro-Ro cargo ships (vehicle carrier)
- Ro-Ro cargo ships
- Ro-Ro Passenger ship
- LNG carrier
- Cruise passenger ships (having non-conventional propulsion)

Also, specific ship types such as those with turbine propulsion (with the exception of LNG ships) are also excluded.

12.1.4. Regulation 21 – Required EEDI

This regulation specifies the methodology for calculation of the Required EEDI and all relevant details. The Required EEDI is the regulatory limit for EEDI, and its calculation involves use of "reference lines" and "reduction factors".

The basic concepts included in this regulation are:

- Reference line: A baseline EEDI for each ship type, representing reference EEDI as a function of ship size.
- Reduction factor: This represents the percentage points for EEDI reduction relative to the reference line, as mandated by regulation for future years. This factor is used to tighten the EEDI regulations in phases over time by increasing its value.
- Cut-off levels: Smaller size vessels are excluded from having a Required EEDI for some technical reasons. Thus, the regulatory text specifies the size limits. This size limit is referred to as cut off levels.
- Implementation phases: the EEDI will be implemented in phases. Currently, it is in phase 1 that runs from year 2015 to 2019. Phase 2 will run from year 2020 to 2024 and phase 3 is from year 2025 onwards.

Figure below shows the above concepts in diagrammatic format:

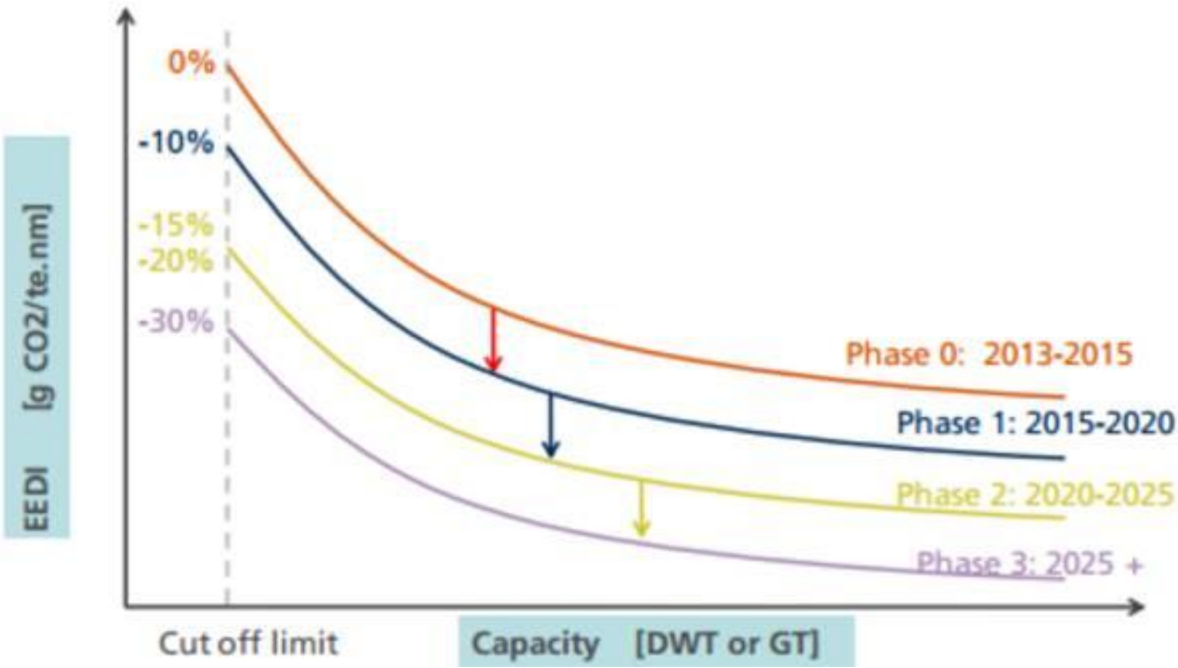


Figure 12.1: Concept of Required EEDI, reduction factor, cut off limits and EEDI phases

12.1.4.1. EEDI Reference Line

This is a baseline EEDI for each ship type, representing reference EEDI as a function of ship size (see graph for Phase 0 in figure below). The reference lines are developed by the IMO using data from a large number of existing ships and analysing these data as is shown in figure below.

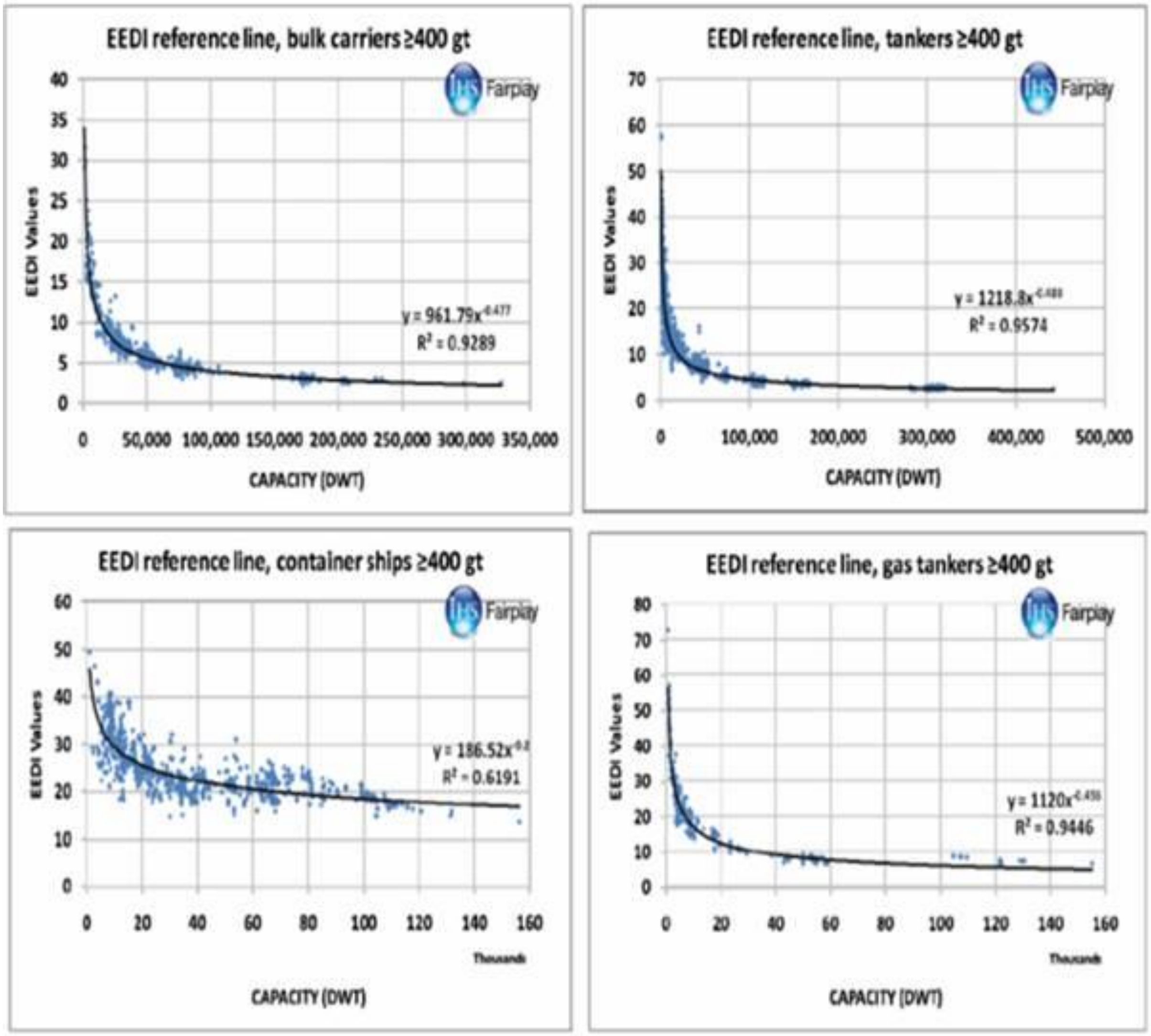


Figure 12.2: EEDI Reference Lines as developed by the IMO using techniques in Resolution MEPC.231 (65)

Full details of how reference lines are developed including sources of data, data quality checks, number of ships selected and year of build, ship sizes, etc. are fully described in relevant IMO guidelines [see Resolution MEPC.231 (65) and Resolution MEPC.233 (65)]. As indicated, the above reference lines are produced through regression analysis of a large number of data and the resultant regression equation is shown on each diagram. These regression equations are then embodied in Regulation 21 in the form of a formula:

Reference EEDI = a*b-c

Parameters a, b and c for some of the ship types are given in table below.

Ship type defined in regulation 2		a	b	c
2.25	Bulk carrier	961.79	DWT of the ship	0.477
2.26	Gas carrier	1120.00	DWT of the ship	0.456
2.27	Tanker	1218.80	DWT of the ship	0.488
2.28	Container ship	174.22	DWT of the ship	0.201
2.29	General cargo ship	107.48	DWT of the ship	0.216
2.30	Refrigerated cargo carrier	227.01	DWT of the ship	0.244
2.31	Combination carrier	1219.00	DWT of the ship	0.488
2.33	Ro-ro cargo ship (vehicle carrier)	$(DWT/GT)^{-0.7} \cdot 780.36$ where DWT/GT<0.3; 1812.63 where DWT/GT≥0.3	DWT of the ship	0.471
2.34	Ro-ro cargo ship	1405.15	DWT of the ship	0.498
2.35	Ro-ro passenger ship	752.16	DWT of the ship	0.381
2.38	LNG carrier	2253.7	DWT of the ship	0.474
2.39	Cruise passenger ship having non-conventional propulsion	170.84	GT of the ship	0.214

Table: Parameters for determination of EEDI Reference value [Resolutions MEPC.203(62) and MEPC.251(66)]

12.1.4.2. EEDI Reduction Factor (X)

This represents the percentage points for EEDI reduction relative to reference line, as mandated by regulation for future years. The value of "reduction factor" is decided by the IMO and is recorded in Regulation 21. This is shown in table below.

Ship Type	Size	Phase 0 1 Jan 2013 – 31 Dec 2014	Phase 1 1 Jan 2015 – 31 Dec 2019	Phase 2 1 Jan 2020 – 31 Dec 2024	Phase 3 1 Jan 2025 and onwards
Bulk carrier	20,000 DWT and above	0	10	20	30
	10,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
Gas carrier	10,000 DWT and above	0	10	20	30
	2,000 – 10,000 DWT	n/a	0-10*	0-20*	0-30*
Tanker	20,000 DWT and above	0	10	20	30
	4,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
Container ship	15,000 DWT and above	0	10	20	30
	10,000 – 15,000 DWT	n/a	0-10*	0-20*	0-30*
General Cargo ships	15,000 DWT and above	0	10	15	30
	3,000 – 15,000 DWT	n/a	0-10*	0-15*	0-30*
Refrigerated cargo carrier	5,000 DWT and above	0	10	15	30
	3,000 – 5,000 DWT	n/a	0-10*	0-15*	0-30*
Combination carrier	20,000 DWT and above	0	10	20	30
	4,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
LNG carrier***	10,000 DWT and above	n/a	10**	20	30
Ro-ro cargo ship (vehicle carrier)***	10,000 DWT and above	n/a	5**	15	30
Ro-ro cargo ship***	2,000 DWT and above	n/a	5**	20	30
	1,000 – 2,000 DWT	n/a	0-5*,**	0-20*	0-30*
Ro-ro passenger ship***	1000 DWT and above	n/a	5**	20	30
	250 – 1,000 DWT	n/a	0-5*,**	0-20*	0-30*
Cruise passenger ship*** having non-conventional propulsion	85,000 GT and above	n/a	5**	20	30
	25,000 – 85,000 GT	n/a	0-5*,**	0-20*	0-30*

Note: n/a means that no required EEDI applies.

* Reduction factor to be linearly interpolated between the two values dependent upon ship size.

The lower value of the reduction factor is to be applied to the smaller ship size.

** Phase 1 commences for those ships on 1 September 2015.

*** Reduction factor applies to those ships delivered on or after 1 September 2019, as defined in

paragraph 43 of regulation 2.

Table: EEDI reduction factors, cut off limits and implementation phases [Resolutions MEPC.203 (62) and MEPC.251 (66)]

12.1.4.3. Required EEDI Calculation Formula

Using the above concept, the following equations show the way Required EEDI is calculated for a ship. First, for each ship a “reference EEDI” is calculated using the below equation:

Reference EEDI = a*b-c . . . . . . (1)

Where:

b: Ship capacity

a and c: Constants agreed for each ship type and included in the regulation.

Reference EEDI: Reference value for EEDI.

The next step is to establish the reduction factor (X) for the ship. This is dependent on year of ship built and is specified within the regulation (see Table 23.4.4). Having established the Reference EEDI and X, the Required EEDI is calculated from the following equation:

Required EEDI = (1-X/100)* (Reference EEDI). . . . . . . (2)

Where:

X: Reduction rate; agreed and included in Regulation.

Required EEDI: The regulatory limit of the ship’s EEDI, which the actual EEDI must not exceed.

The Required EEDI applies only to ships named in column 1 and the ship sizes specified in column 2 of Table 23.4.3. For these ships, regulation 22 stipulates that Attained EEDI must always be less than or equal to Required EEDI:

Attained EEDI < Required EEDI. . . . . . (3)

Where:

Attained EEDI: The actual EEDI of the ship, as calculated by the shipyard and verified by a recognized organization.

This regulation additionally stipulates the following:

- "If the design of a ship allows it to fall into more than one of the above ship type definitions, the required EEDI for the ship shall be the most stringent (the lowest) required EEDI".
- "For each ship to which this regulation applies, the installed propulsion power shall not be less than the propulsion power needed to maintain the manoeuvrability of the ship under adverse conditions as defined in the guidelines to be developed by the Organization". "At the beginning of Phase 1 and at the midpoint of Phase 2, the IMO shall review the status of technological developments and, if proven necessary, amend the time periods, the EEDI reference line parameters for relevant ship types and reduction rates set out in this regulation". This review process is currently underway at the IMO.

12.1.5. Regulation 22 – SEEMP

Regulation 22 is on SEEMP and states:

1. Each ship shall keep on board a ship specific Ship Energy Efficiency Management Plan (SEEMP). This may form part of the ship's Safety Management System (SMS).

2. The SEEMP shall be developed taking into account guidelines adopted by the Organization." [MEPC Resolution 203(62)] Accordingly:

- Each ship more than 400 GT that is involved in international voyages should have a SEEMP on board.
- There is no specific reference to a need for review and verification of a SEEMP's content. However, its existence on board must be verified.
- The SEEMP should be developed according to IMO guidelines.

12.1.6. Regulation 23 – Technical Cooperation and Technology Transfer

This regulation was developed at the request of developing countries following a significant debate at IMO MEPC on role of various countries on GHG reduction efforts as well as the technological and financial difficulties that developing countries may face as a result of energy efficiency regulations. This regulation entitled "Promotion of technical co-operation and transfer of technology relating to the improvement of energy efficiency of ships".

It stipulates that:

1. Administrations shall, in co-operation with the Organization and other international bodies, promote and provide, as appropriate, support directly or through the Organization to States, especially developing States, which request technical assistance.

2. The Administration of a Party shall co-operate actively with other Parties, subject to its national laws, regulations and policies, to promote the development and transfer of technology and exchange of information to States which request technical assistance, particularly developing States, in respect of the implementation of measures to fulfil the

requirements of chapter 4 of this annex, in particular regulations 19.4 to 19.6.". [MEPC Resolution 203(62)]

In support of the implementation of the above regulation, IMO MEPC approved a new Resolution MEPC.229 (65). This Resolution provides a framework for the promotion and facilitation of capacity building, technical cooperation, and technology transfer to support the developing countries in the implementation of the EEDI and the SEEMP.

12.2. EEDI Calculation

12.2.1. Concept of EEDI

The Attained EEDI is the actual value of EEDI for a ship and represents the amount of CO2 generated by a ship while doing one tonne-mile of transport work. In simple term, it may be represented by equation (1):

$$EEDI = \frac{CO_2\ emission}{transport\ work} \quad = \quad \mathrm{EEDI} = \frac{\text{Engine power x SFC x } C_F}{\text{DWT x speed}}\ (gCO_2/\text{ton-mile}) \qquad \textbf{(1)}$$

It is argued that EEDI represents the ratio of a ship's "cost to society" in the form of its CO_2 emissions, divided by its "benefit to the society" represented by the transport work done by the ship as shown in (1). The above concept then translated into a more vigorous calculation method as represented by EEDI formula in equation (2) to account for diversity of ship types, ship sizes, alternative propulsion technologies, alternative fuels and future renewable technologies.

12.2.2. EEDI Formula

Attained EEDI is calculated using the "EEDI formula" as shown below:

$$\frac{\left(\prod_{j=1}^{n} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)}\cdot C_{FME(i)}\cdot SFC_{ME(i)}\right)+\left(P_{AE}\cdot C_{FAE}\cdot SFC_{AE}*\right)+\left(\left(\prod_{j=1}^{n} f_j\cdot\sum_{i=1}^{nPTI} P_{PTI(i)}-\sum_{i=1}^{neff} f_{eff(i)}\cdot P_{AEeff(i)}\right)C_{FAE}\cdot SFC_{AE}\right)-\left(\sum_{i=1}^{neff} f_{eff(i)}\cdot P_{eff(i)}\cdot C_{FME}\cdot SFC_{ME}**\right)}{f_i\cdot f_c\cdot Capacity\cdot f_w\cdot V_{ref}} \qquad \textbf{(2)}$$

Figure: Main terms of the formula indicating that all relevant ship technologies will influence the EEDI level.

Main Engine | Aux Engine (s) | Innovative Energy Eff. Power Generation | Innovative Energy Eff. For Prop.

$$\textbf{EEDI} = \frac{\left(\prod_{j=1}^{n} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)}\cdot C_{FME(i)}\cdot SFC_{ME(i)}\right)+\left(P_{AE}\cdot C_{FAE}\cdot SFC_{AE}*\right)+\left(\left(\prod_{j=1}^{n} f_j\cdot\sum_{i=1}^{nPTI} P_{PTI(i)}-\sum_{i=1}^{neff} f_{eff(i)}\cdot P_{AEeff(i)}\right)C_{FAE}\cdot SFC_{AE}\right)-\left(\sum_{i=1}^{neff} f_{eff(i)}\cdot P_{eff(i)}\cdot C_{FME}\cdot SFC_{ME}**\right)}{f_i\cdot f_c\cdot Capacity\cdot f_w\cdot V_{ref}} \qquad \textbf{(2)}$$

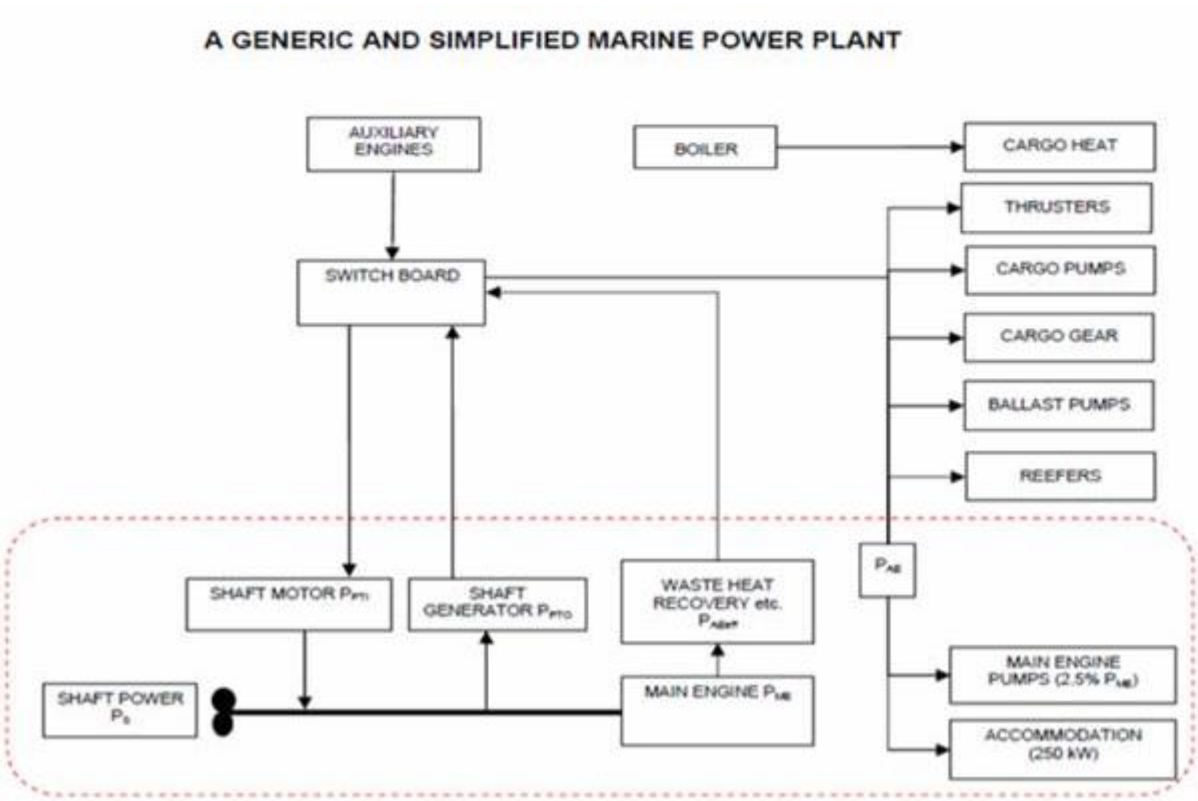
[gCO2/(tonne.nm)]

Figure: Main terms in EEDI formula

The items that primarily influence EEDI are:

- Main engine and energy needed for propulsion; this represented by the first term in the nominator of the formula.
- Auxiliary power requirements of the ship; this is represented by the second term in the nominator.
- Any innovative power (electric) generation devices on board such as electricity from waste heat recovery or solar power. These are represented by the third term in the nominator.
- Innovative technologies that provide mechanical power for ship propulsion such as wind power (sails, kites, etc.). This is the last term in the nominator.
- In the denominator of the formula, ship capacity and ship speed are represented that together gives the value of transport work.

Figure below shows the scope of ship systems that are represented in equation (2). The items contained within the red dashed-line box are included in EEDI formula while everything outside the box is excluded.



Note 1: Mechanical recovered waste energy directly coupled to shafts need not be measured, since the effect of the technology is directly reflected in the V_{ref} .

Note 2: In case of combined PTI/PTO, the normal operational mode at sea will determine which of these to be used in the calculation.

Figure 12.3: Scope of ship systems included in EEDI formula [Resolution MEPC.245 (66)]

As a general rule:

- All the cargo-related energy uses on-board are outside the scope of the EEDI calculations (not included in the formula).
- Auxiliary boilers are also excluded from the formula; assuming that under normal sea-going conditions, boilers will not be operating.

Therefore, electricity needed for cargo pumps, cargo handling equipment, ship thrusters, etc. are out of scope of EEDI calculations.

12.2.3. Terms of the EEDI Formula

Various terms in equation (2) are fully defined in the relevant IMO guidelines [Resolution MEPC.245 (66)], a summary of which is given in table below.

Term	Unit	Brief description
Capacity	[Tonne]	Ship capacity in deadweight or gross tonnage at summer load line draught (for container ships, 70% of deadweight applies).
C_{FAE}	[gCO_2/gfuel]	Carbon factor for fuel for auxiliary engines.
C_{FME}	[gCO_2/gfuel]	Carbon factor for fuel for main engines.
f_{eff}	[-]	Correction factor for availability of innovative technologies.
f_i	[-]	Correction factor for capacity of ships with technical/regulatory elements that influence ship capacity.
f_c	[-]	Correction factor for capacity of ships with alternative cargo types that impact the deadweight-capacity relationship (e.g. LNG ships in gas carrier segment).
f_j	[-]	Correction factor for ship specific design features (e.g. ice-class ships).
f_w	[-]	Correction factor for speed reduction due to representative sea conditions.
n_{eff}	[-]	Number of innovative technologies.
n_{ME}	[-]	Number of main engines.
n_{PTI}	[-]	Number of power take-in systems (e.g. shaft motors).
P_{ME}	[kW]	Ship propulsion power that is 75% of main engine Maximum Continuous Rating (MCR) or shaft motor (where applicable); also taking into account the shaft generator. This will be influenced by alternative propulsion configurations.
P_{AE}	[kW]	Ship auxiliary power requirements at normal sea going conditions.
P_{AEeff}	[kW]	Auxiliary power reduction due to use of innovative electric power generation technologies.
P_{eff}	[kW]	75% of installed power for each innovative technology that contributes to ship propulsion.
P_{PTI}	[kW]	75% of installed power for each power take-in system (e.g. propulsion shaft motors).
SFC_{AE}	[g/kWh]	Specific fuel consumption for auxiliary engines as per NOx certification values.
SFC_{ME}	[g/kWh]	Specific fuel consumption for main engines as per NOx certification values.
V_{ref}	[knots]	Reference ship speed attained at propulsion power equal to P_{ME} and under clam sea and deep water operation at summer load line draught.

Table: Parameters for EEDI formula

More details of the important parameters are given below:

- SFC (Specific Fuel Consumption): The specific fuel consumption (SFC) is for engines and represents their fuel efficiency (fuel used) in g/kWh. The value for SFC is determined from the results recorded in the engine's NO_x Technical File; determined as part of the engine NO_x certification. The SFC for main engine is generally taken at 75% load and for auxiliary engines is generally taken at 50% load.
- CF (Carbon Factor): This factor specifies the amount of CO_2 generated per unit mass of fuel used. Table below provides the standard value for marine fuels. The type of fuel used for the NO_x Certification test (to be taken from NO_x Technical File) should be used to determine the value of the CF conversion factor.

Type of fuel	Reference	Carbon content	C_F (t-CO_2/t-Fuel)
1 Diesel/Gas Oil	ISO 8217 Grades DMX through DMB	0.8744	3.206
2 Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.8594	3.151
3 Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.8493	3.114
4 Liquefied Petroleum Gas (LPG)	Propane	0.8182	3.000
	Butane	0.8264	3.030
5 Liquefied Natural Gas (LNG)		0.7500	2.750
6 Methanol		0.3750	1.375
7 Ethanol		0.5217	1.913

Table: Standard values of CF for marine fuels [Resolution MEPC.245 (66)]

- **Capacity:** The Capacity of the ship is the deadweight or gross tonnage based on summer load line draught. The calculation of the deadweight is based on the lightweight of the ship, and the displacement at the summer load line draught. At the design stage, for EEDI preliminary verification, the lightweight and the displacement may be calculated using the provisional ship's stability documentation. For containerships, capacity is taken as 70% of the capacity at summer load line draught.
- **Power (propulsion – P_{ME})**: The term "P" for power is used in different places in the formula for main engine, auxiliary power (electrical), shaft motor, shaft generator, renewable energy devices, etc. Power for shaft propulsion PME, generally is calculated at 75% MCR (Maximum Continuous Rating) of the main engine. Depending on various options of the propulsion line (shaft generator, shaft motor, limited power, etc.) different formulas are used for this purpose. For details, refer to the IMO guidelines (e.g. Resolution MEPC.245 (66)).
- **Power (auxiliary – P_{AE}):** For auxiliary power (electrical), also different formulation to calculate the auxiliary power applies. PAE generally includes the power consumed by the main engine pumps, navigational systems and equipment as well as accommodation but excludes other power used not for propulsion machinery/systems, e.g. thrusters, cargo pumps, cargo gear, ballast pumps, maintaining cargo, e.g. reefers and cargo hold

fans. In the IMO guidelines [Resolution MEPC.245 (66)], there are specific formulas for calculation of P_{AE}. It should be noted that P_{AE} is not linked to the actual installed power of ship auxiliary engines.

- **Reference Speed (V_{ref}):** The reference speed V_{ref} is the ship speed as measured and verified during sea trials and corrected to the following conditions:
    - Deep water operation
    - Calm weather including no wind and waves
    - Loading condition corresponding to the Capacity
    - Total shaft propulsion power at corresponding value of P_{ME}
- **Weather factor f_w:** f_w is a non-dimensional coefficient indicating the decrease of speed in representative sea conditions of wave height, wave frequency and wind speed (e.g. Beaufort Scale 6), and is taken as 1.0 for the calculation of the Attained EEDI. Efforts are underway to define how this factor can be estimated for various ships, but effort so far has not led to any agreed solution.
- **Ship design related correction factors that influence propulsion power f_j:** There are a host of correction factors that are used to differentiate ships of same type and size if their basic design requirements are different. For example, a tanker with ice-class as against same tanker without ice-class will have a correction factor to cater for their design differences. Design related correction factor f_j for the following ships is specified (see relevant IMO guidelines [Resolution MEPC.245(66)] for calculation process, formula and values); otherwise, it is 1.0:
    - Ice-classed ships o Shuttle tankers with propulsion redundancy (80,000~160,000 DWT)
    - Ro-Ro ships, all types
    - General cargo ships
- **Design factor that impact ship Capacity fi:** These are a set of correction factors that are used to differentiate ships of same type and size if their cargo capacity is influenced by design or type of cargo. For example, a tanker with ice-class as against same tanker without ice-class will have a smaller capacity that needs to be taken into account. Other examples are when an owner decides to voluntarily strengthen the ship structure via use of thicker still plates or when a ship is classed according to Common Structural Rules. Capacity related correction factors are (for details of calculation of each, see Resolution MEPC.245(66) and relevant formulas for each factor below):
    - **Ice-class capacity factor fi:** This is the factor used for ice-class ships.
    - **Voluntary Structural Enhancement f_{iVSE}:** For a ship with voluntary structural enhancement, the f_{iVSE} factor is to be computed according to according to formulation provided in the IMO guidelines.
    - **Common Structural Rules f_{iCSR}:** For bulk carriers and oil tankers built in accordance with the Common Structural Rules and assigned the class notation CSR, the f_{iCSR} factor is to be computed according to formulation provided in the IMO guidelines.

- **Cubic capacity correction factor f_c:** This refers to correction factors that are used to differentiate various types of cargos. Except in the cases listed below, the value of the fc factor is 1.0.
- For a number of chemical tankers as defined under MARPOL Annex II, the f_c factor is to be computed according to formulation provided in the IMO guidelines [Resolution MEPC.245 (66)].
- For gas carriers as defined in certain regulation of IGC Code (*International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk*) having direct diesel driven propulsion. In such cases, the fc factor is computed according to formulation provided in the IMO guidelines [Resolution MEPC.245 (66)].

12.2.4. EEDI Condition

It is important to note that EEDI is calculated for a single ship's operating condition. This single operating condition is referred to as "EEDI Condition". The EEDI Condition is as follows:

- **Draught:** Summer load line draught.
- **Capacity:** Deadweight (or gross tonnage for passenger ships, etc.) for the above draught (container ship will be 70% value).
- **Weather condition:** Calm with no wind and no waves.
- **Propulsion shaft power:** 75% of main engine MCR (conventional ships) with some amendments for shaft motor or shaft generator or shaft-limited power cases, where applicable.
- **Reference speed (V_{ref}):** Is the ship speed when measured/estimated under the above conditions.

To calculate EEDI, all the measurements and data used should be corrected to the above conditions.

12.2.5. EEDI Technical File

Calculation of Attained EEDI involves the determination / measurement / calculation of all the terms as identified in Table 25.3.1 and their verification. Also, determination of Required EEDI is done via formulations provided in Regulation 21 – Required EEDI.

For verification purposes and subsequent implementation and enforcement purposes by flag and port States, it is a requirement that all the relevant terms and their values shall be recorded in an "EEDI Technical File" and then submitted to the verifiers (normally Recognized Organization on behalf of flag State) that will carry out the certification on behalf of flag Administration. Also, the "EEDI Technical File" needs to be kept on board and forms a supplement to International Energy Efficiency Certificate.

IMO in its EEDI survey and verification guidelines [Resolution MEPC.254 (67)] have provided a sample "EEDI Technical File". This sample indicates that all data necessary for verification purposes including all the terms defined in Terms in the EEDI formula need to be recorded in this technical file.

12.3. EEDI Survey and Verification

12.3.1. Overview

EEDI verification is carried out by flag Administration (and most likely on their behalf by the by the Classification Societies or ROs), using corresponding data and documents and observing the ship's model tank tests and ship's commissioning sea trials. Full details of the EEDI verification are described in the relevant IMO Guidelines [Resolution MEPC.254 (67)]. Accordingly, the EEDI verification takes place in two stages:

- Pre-verification
- Final verification

Pre-verification is done at the ship's design stage whereas final verification is carried out after construction and as part of the ship's commissioning sea trials, at the end of ship construction. Relevant ship design data, tank test data and speed trial data will be subject to scrutiny and verification by ROs. The aforementioned IMO guidelines on EEDI verification are developed to ensure consistency of verification, although some important issues such as speed-power scaling methods and unified approach for correction of the measured data has yet to be harmonised as part of industry practices. A document entitled "industry guidelines" has been developed by the main players for this purpose [Industry Guidelines (2015)].

Figure below shows the overall process diagram for EEDI verification.

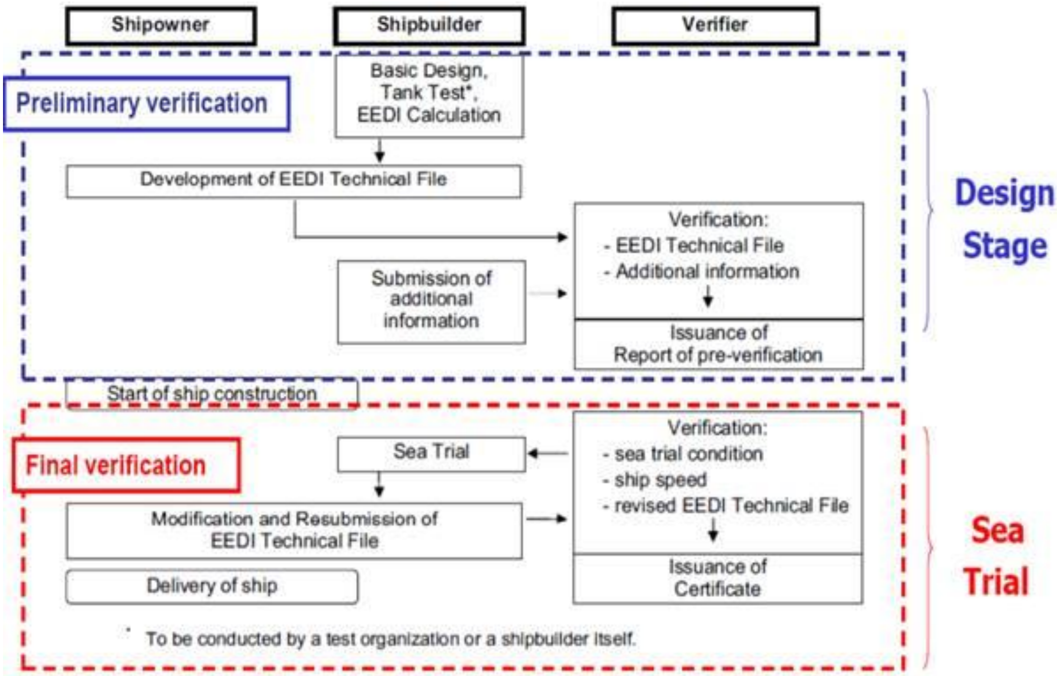


Figure 12.4: EEDI verification process

12.3.2. Preliminary Verification

For the preliminary verification at the design stage, the following should be submitted to the verifier:

- An application for an initial survey.
- An "EEDI Technical File" containing the necessary information.
- Other relevant background documents and information.

The EEDI Technical File should be developed by the submitter (normally ship designer at this stage) inclusive of all the data required. The content of an EEDI Technical File was discussed in EEDI Technical File section and will include all the required data for EEDI calculations. In addition to the EEDI Technical File, the verifier may request additional information. Additional information that the verifier may request includes but not limited to:

- Description of the tank test facility including test equipment and calibrations.
- Lines of the model and the actual ship for the verification of the similarity of model and actual ship.
- Lightweight of the ship and displacement table for the verification of the deadweight. This may require submission of available ship stability data for verification purposes.
- Detailed report of the tank test; this should include at least the tank test results at sea trial condition and extrapolated values to the EEDI condition.
- Calculation process of the ship reference speed.
- Copy of the NO_x Technical File and documented summary of the SFC correction for each type of engine with copy of engines' EIAPP certificate.
- Reasons for exempting a tank test, if applicable.
- Other specific data for specific ships: For example, for ships using gas as primary fuel, the verifier may request data on gas fuel and liquid fuel tank arrangement and capacities for C_F calculation purposes.

The most important element of preliminary verification is the ship's model tank test. According to IMO guidelines [Resolution MEPC.254 (67)]: "The speed power curve used for the preliminary verification at the design stage should be based on reliable results of tank test. A tank test for an individual ship may be omitted based on technical justifications such as availability of the results of tank tests for ships of the same type. In addition, omission of tank tests is acceptable for a ship for which sea trials will be carried under the "EEDI Condition", upon agreement of the ship-owner and shipbuilder and with approval of the verifier. For ensuring the quality of tank tests, ITTC (International Towing Tank Conference) quality system should be taken into account. Model tank test should be witnessed by the verifier."

12.3.3. Verification of the Attained EEDI for Major Conversions

- Documents explaining details of the conversion.
- EEDI parameters changed after the conversion.
- Reasons for other changes made in the EEDI Technical File.

- Calculated value of the attained EEDI, with the calculation summary for each value of the calculation parameters and the calculation process.

The verifier normally will make sure that as a result of the "major conversion", EEDI has not increased. In case of such an increase, the verifier will define the scope for sea trails, if any, and other activities to ensure compliance with regulation.

12.3.4. Verifier Scope of Activities

Based on what described in previous sections, the scope of verification activities may be listed as below.

For preliminary verification, scope of the verifier work includes the following:

- Review the EEDI Technical File, check that all the input parameters are documented and justified and check that the possible omission of a tank test has been properly justified.
- Check that the ITTC procedures and quality system are implemented by the organization conducting the ship model tank tests. The verifier would possibly audit the quality management system of the towing tank if previous experience were insufficiently demonstrated.
- Witness the tank tests according to a test plan initially agreed between the submitter and the verifier.
- Check that the work done by the tank test organisation is consistent with the ITTC recommendations. In particular, the verifier will check that the power speed curves at full scale are determined in a consistent way between test condition and fully loaded conditions.
- Issue a pre-verification report inclusive, possibly in the form of a preliminary statement of compliance.

For final verification, scope of the verifier work includes the following:

- Examine the programme of the sea trial to check that the test procedure and in particular that the number of speed measurement points comply with the requirements of the IMO guidelines.
- Perform a survey to ascertain the ship principle and machinery characteristics to conform with those in the EEDI Technical File.
- Attend the sea trial and notes the main parameters to be used for the final calculation of the EEDI as discussed before.
- Review the sea trial report provided by the submitter and check that the measured power and speed have been corrected according to ITTC Recommended Procedure 7.5-04-01-01.2 Speed and Power Trials Part 2; 2014 or ISO 15016:2015 standard.
- Adjust the reference ship speed Vref according to the simplified method and checks that the difference between the value provided by the submitter and the one computed by the simplified method don't exceed the threshold value. If the threshold is exceeded, request and review a complete justification from the submitter.
- Review the revised EEDI Technical File, if applicable.

- Complete relevant parts of the Record of Construction and endorse.

12.3.5. SEEMP Verification

The verification of SEEMP is only limited to checking if a SEEMP is on board. There is no need for verification of a SEEMP content to establish if it complies with relevant IMO guidelines. It is worth noting that this is the case at this point in time and may change in the future. Upon verification of existence of SEEMP on board, relevant part of the Record of Construction will be completed.

12.3.6. International Energy Efficiency (IEE) Certificate and its Supplements

Upon a successful verification and EEDI and SEEMP, where applicable, the following sets of documents will be issued to the ship by the verifier:

- An IEE Certificate
- A Record of Construction for Energy Efficiency will be attached to the certificate

Additionally, the following two documents that has already been used as part of verification are considered as supplements to the IEE certificate:

- EEDI Technical file
- SEEMP

The “Record of Construction” is a checklist that contains the checkboxes with regard to availability of the following information:

- Particular of ship
- Propulsion system details
- Attained EEDI
- Required EEDI
- SEEMP
- EEDI Technical File
- Endorsement that confirms that data are correct.

The verifier will endorse the “Record of Construction” to confirm that the above details have been checked and verified. For samples of “EEDI Technical File” refer to reference *Resolution MEPC.254(67)] and for format of IEE Certificate and the Record of Construction for Energy Efficiency refer to Annex VIII of MARPOL Annex VI.

According to IMO regulations [MEPC 203(62)]:

“Upon successful verification of EEDI (for new ships) and verification of the existence of a SEEMP on-board for all ships, an IEE Certificate will be issued to the ship. The Certificate shall be issued or endorsed either by the Administration or any organization duly authorized by it. The IEE Certificate shall be drawn up in a form corresponding to the model given in Chapter 4 of MARPOL Annex VI.”

As indicated before, IEE Certification will have the following specifics:

- The IEE Certificate will be valid throughout the life of the ship unless:
- If the ship is withdrawn from service; or
- If a new certificate is issued following major conversion of the ship; or
- Upon transfer of the ship to the flag of another State.
- Any port State inspection shall be limited to verifying, when appropriate, that there is a valid IEE Certificate on board, in accordance with Article 5 of the MARPOL Convention.

12.3.7. Other Related Guidelines

There are a number of additional guidelines that need to be used / consulted while conducting either the EEDI calculations or verification. These Guidelines include the following:

• Resolution MEPC.232 (65): 2013 Interim Guidelines for determining minimum propulsion power to maintain the manoeuvrability (as amended by resolutions MEPC.255 (67) and MEPC.262 (68)).

• MEPC.1/Circ.815: 2013 Guidance on treatment of innovative energy efficiency technologies for calculation and verification of the attained EEDI for ships in adverse conditions.

A short description of the above guidelines follows.

12.3.7.1. Interim Guidelines for Minimum Power

One of the most effective ways of reducing a ship's EEDI is to choose a smaller main engine or main propulsion motor for the ship, thus reduce the ship's design speed. Within IMO a debate took place on how far speed reduction could be used for EEDI reduction? As a result, it was decided that there is a need to limit the use of this method of EEDI reduction so that it does not lead to unsafe and underpowered ships that may lose manoeuvring capability under adverse weather condition. These guidelines effectively define a methodology for estimating the minimum propulsion power for each ship for safe manoeuvring, thus ensuring that choice of the main propulsion engines/motors that satisfies these minimum requirements.

Accordingly, the purpose of the guidelines is to assist Administrations and ROs in verifying those ships, complying with EEDI, have sufficient installed propulsion power to maintain the manoeuvrability in adverse conditions [Resolution MEPC.232(65), as amended by resolutions MEPC.255(67) and MEPC.262(68)]. The guidelines currently apply to:

- Tankers
- Bulk carriers
- Combination carriers

Assessment methods

The methodologies proposed for estimating the minimum power are based on two assessment levels or methods that are briefly described.

Assessment Level 1 – Minimum power lines assessment: This is a simple approach and involves calculation of the minimum power from a specific line as a function of ship deadweight. For this purpose, the verifier should check if the ship has an installed power not less than the minimum power defined by the line represented by the following equation:

Minimum Power Line Value [MCR, kW] = a*(DWT) + b

Where "a" and "b" are constants and vary with ship type and given in the guidelines. As can be seen, this is a very simple approach.

Assessment Level 2 – Simplified assessment: This is a more mathematically involved method of assessment. The assessment procedure consists of two steps:

- Step 1: Definition of the required advance speed in head wind and waves, ensuring course keeping in all wave and wind directions.
- Step 2: Assessment whether the installed power is sufficient to achieve the above required advance speed.

The required ship advance speed through the water in head wind and waves is decided first. Then relevant calculation formulas are used to determine the required power to achieve this advance speed. For details of relevant mathematics and equations, refer to IMO guidelines [Resolution MEPC.232 (65), as amended by resolutions MEPC.255 (67) and MEPC.262 (68)].

12.3.7.2. Draft Guidelines for Innovative Energy Efficiency Technologies

The purpose of this guidance is to assist manufacturers, shipbuilders, ship-owners, verifiers and other interested parties related to Energy Efficiency Design Index (EEDI) of ships to treat innovative energy efficiency technologies for calculation and verification of the attained EEDI [MEPC.1/Circ.815]. As indicated, the guidance document is in its preliminary stage and as such as time progresses:

- The guidance should be reviewed for the inclusion of new innovative technologies not yet covered by the guidance.
- The guidance also should be reviewed, after accumulating the experiences of each innovative technology, in order to make it more robust and effective, using the feedback from actual operating data.

Categorisation of technologies

Innovative energy efficiency technologies are allocated to category (A), (B) and (C), depending on their characteristics and the way they influence the EEDI formula. Furthermore, innovative energy efficiency technologies of category (B) and (C) are categorized to two sub-categories (category (B-1) and (B-2), and (C-1) and (C-2), respectively).

- **Category (A):** Technologies that directly influence and shift the ship speed-power curve, which results in the change of combination of Propulsion Power (PP) and Vref. For example, such technologies at constant V_{ref} can lead to a reduction of PP; or for a constant PP they could lead to an increased V_{ref}. All technologies that directly impact the ship hydrodynamics could have such impacts.
- **Category (B):** Technologies that reduce the PP, at a Vref, but do not generate electricity. The saved energy is counted as P_{eff}.
- **Category (B-1):** Technologies which can be used at all times during the operation (e.g. hull air lubrication) and thus the availability factor (f_{eff}) should be treated as 1.00.
- **Category (B-2):** Technologies which can be used at their full output only under limited conditions and periods (e.g. wind power). The setting of availability factor (f_{eff}) should be less than 1.00.
- **Category (C):** Technologies that generate electricity. The saved energy is counted as P_{AEeff}
- **Category (C-1):** Technologies which can be used at all times during the operation (e.g. waste heat recovery) and thus the availability factor (feff) should be treated as 1.00.
- **Category (C-2):** Technologies which can be used at their full output only under limited condition (e.g. solar power). The setting of availability factor (feff) should be less than 1.00.

Table below shows the current categories of technologies and typical examples.

Innovative Energy Efficiency Technologies				
Reduction of Main Engine Power			Reduction of Auxiliary Power	
Category A	*Category B-1*	*Category B-2*	*Category C-1*	*Category C-2*
Cannot be separated from overall performance of the vessel	Can be treated separately from the overall performance of the vessel		Effective at all time	Depending on ambient environment
	$f_{eff} = 1$	$f_{eff} < 1$	$f_{eff} = 1$	$f_{eff} < 1$
– low friction coating – bare optimization – rudder resistance – propeller design	– hull air lubrication system (air cavity via air injection to reduce ship resistance) (can be switched off)	– wind assistance (sails, Flettner-Rotors, kites)	– waste heat recovery system (exhaust gas heat recovery and conversion to electric power)	– photovoltaic cells

Table: Innovative energy efficiency technologies categories [MEPC.1/Circ.815]

The way each category influences the EEDI is schematically shown in figure above. For example, "solar power" and "waste heat recovery" for power generation are category C and influence via the term shown by arrow as shown. Wind power is a category B and is influencing the last term in the nominator. Category A mainly influences the speed power curve thus P_{ME} and V_{ref}.

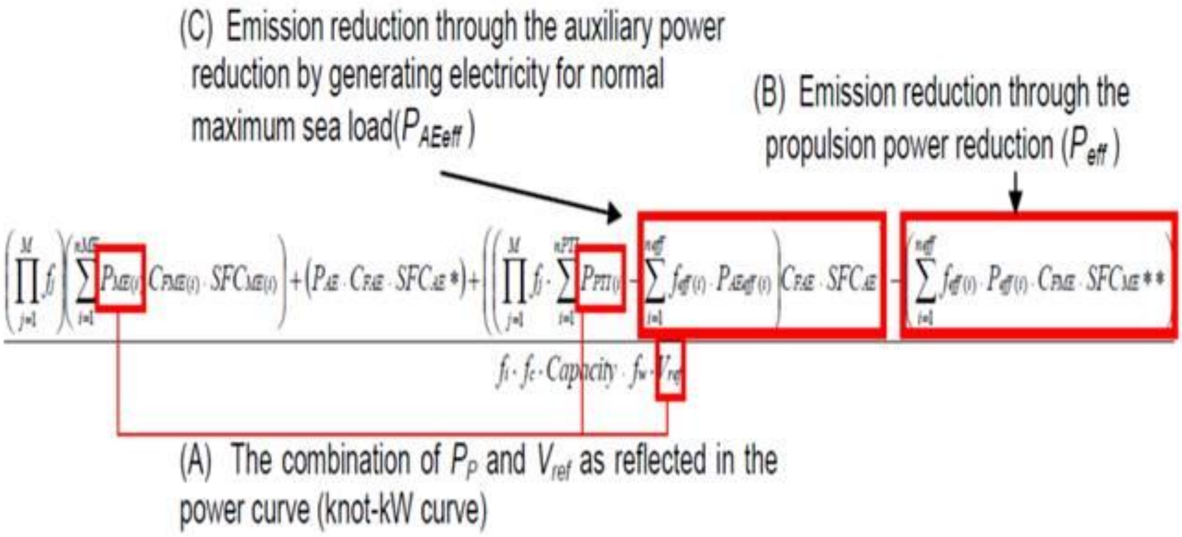


Figure 12.5: The way various categories influence the EEDI [MEPC.1/Circ.815]

The technologies that are currently covered in the guidelines are shown schematically in figure below:

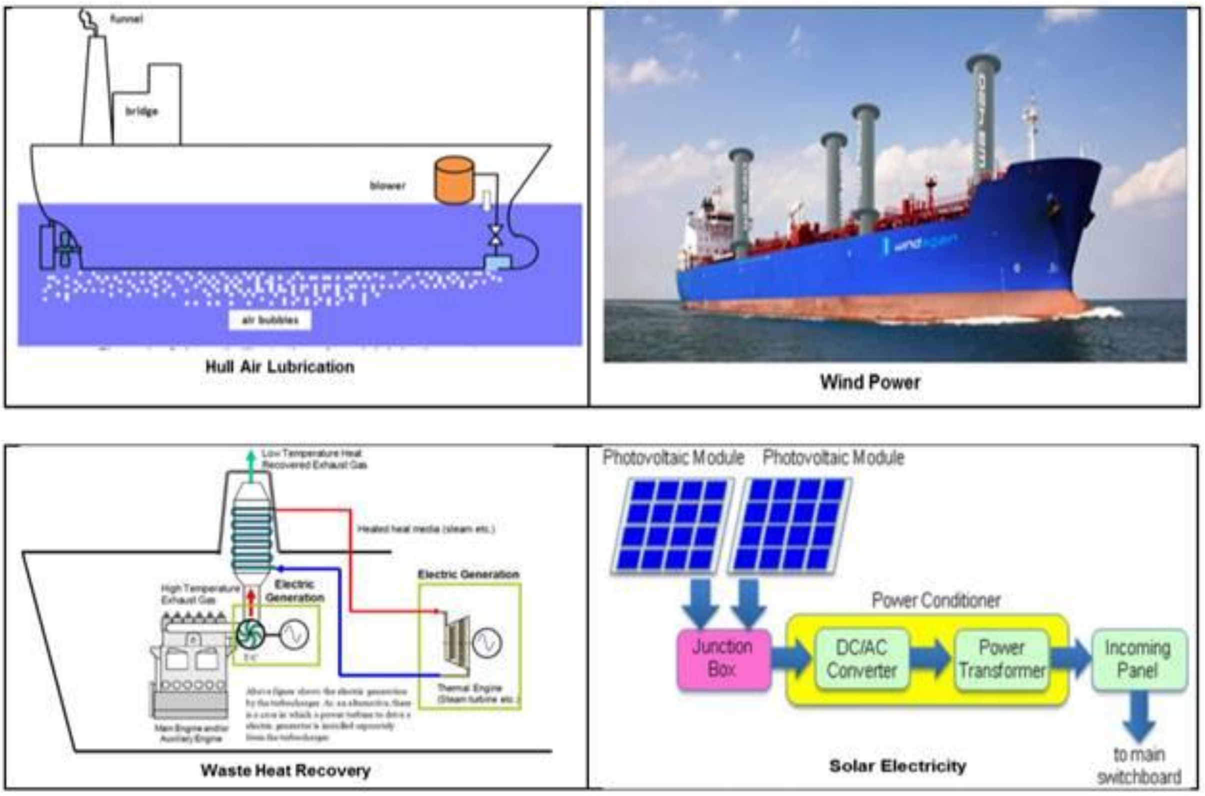


Figure 12.6: Technologies currently covered under the innovative technology guidelines

Calculation and verification of innovative technologies

The evaluation of the benefit of innovative technologies on EEDI is to be carried out in conjunction with the hull form and propulsion system with which it is intended to be used. Results of model tests or sea trials of the innovative technology in conjunction with different hull forms or propulsion systems may or may not be applicable. An outline of calculation and verification aspects is given here. Full details can be found in the relevant guidelines [MEPC.1/Circ.815].

Category A: Innovative energy efficiency technologies in category (A) affect PP and/or Vref and their effects cannot be measured in isolation. Therefore, these effects should not be calculated nor certified in isolation but should be treated as part of the vessel's EEDI calculation and verification as described before using EEDI calculation guidelines and EEDI survey and verification guidelines.

Category B: The effects of innovative energy technologies in category (B) are expressed as Peff which would be directly used together with feff in the EEDI formula. The calculation and verification of the above two parameters are described in Annex 1 of the guidelines (see figure below).

Category C: The effects of innovative energy technologies in category (C) are expressed as PAEeff and feff which would be directly used in the EEDI formula. The details of calculation and verification of the above two parameters are detailed in Annex 2 of the guidelines figure below.

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Figure 12.7: Content of guidelines for calculation and verification of innovative technologies

The verification of innovative energy efficiency technologies is an involved process and is fully documented in MEPC.1/Circ.815. This is an interim guidance document and will evolve over time as experience is gained as a result of future use of these technologies.

12.4. Ship Energy Efficiency Management Plan (SEEMP) Development

According to MARPOL Annex VI Regulation 22, it is a requirement for ships of more than 400 GT operating internationally, to have a SEEMP on board from 1st January 2013. The SEEMP should be developed taking into account the relevant IMO guidelines. Existing ships will receive an IEE Certificate when the existence of SEEMP on-board is verified. This will happen at the 1st intermediate or renewal survey of the vessel after 1 January 2013, whichever is the first. It is expected that all the existing ships by now have gone through this process and possess an IEE certificate. IMO has adopted guidelines for the development of SEEMP (Resolution MEPC.213 (63)); from which most of the main features of a SEEMP are described in this section. According to IMO guidelines, the SEEMP establishes a mechanism for shipping companies to improve the energy efficiency of their ships operations. The SEEMP also provides an approach for monitoring of a ship efficiency performance over time. The SEEMP urges the ship owner and operator, that at each stage of the operation of the ship, to review and consider operational practices and technology upgrade to optimize the energy efficiency performance of a ship. SEEMP development should follow the IMO guidelines. In this section, the main aspects of a SEEMP are discussed with a view to understand the regulatory requirements and best practice. The content of this section is mainly developed using the IMO guidelines [Resolution MEPC.213 (63)]. The aim of this section is to cover the SEEMP regulatory requirements, practical aspects of SEEMP planning and development.

12.4.1. SEEMP Purposes

The purpose of a SEEMP is to establish a mechanism for a company and/or a ship to improve the energy efficiency of the ship during its operation. Preferably, the ship-specific SEEMP is linked to a broader corporate energy management system of the company that owns, operates or controls the ship. The ship-specific SEEMP is needed since no two shipping companies or ship-owners are the same, and that ships operate under a wide range of different conditions including geographical and commercial. Many companies normally have an environmental management system (EMS) in place under ISO 14001 (*Also companies may have ISO 50001 on "energy management system" that could be directly linked to SEEMP*) which contains procedures for selecting the best measures for particular vessels and then setting objectives for the measurement of relevant parameters, along with relevant control and feedback features. Monitoring of operational environmental efficiency should therefore be treated as an integral element of broader company environmental management systems. In addition, many companies already develop, implement and maintain a Safety Management System (*"Safety Management System" means a structured and documented system enabling company personnel to implement effectively the company's safety and environmental protection policy, as defined in the International Safety Management Code*). In such cases, the SEEMP may form part of the ship's Safety Management System. The SEEMP is intended to be a management tool to assist a company in managing the on-going environmental performance of its vessels and as such, it is recommended that a company develops procedures for implementing the SEEMP in a manner which limits any on-board administrative burden to the minimum necessary.

12.4.2. SEEMP Framework

The SEEMP should be developed as a ship-specific plan by the ship-owner, operator or any other party concerned, e.g., charterer.

The SEEMP seeks to improve a ship's energy efficiency through four steps:

- Planning;
- Implementation;
- Monitoring; and
- Self-evaluation and improvement.

These are shown in figure below. These stages are similar to PDCA (Plan-Do-Check-Act) stages of any other management system and the continuous improvement cycle.

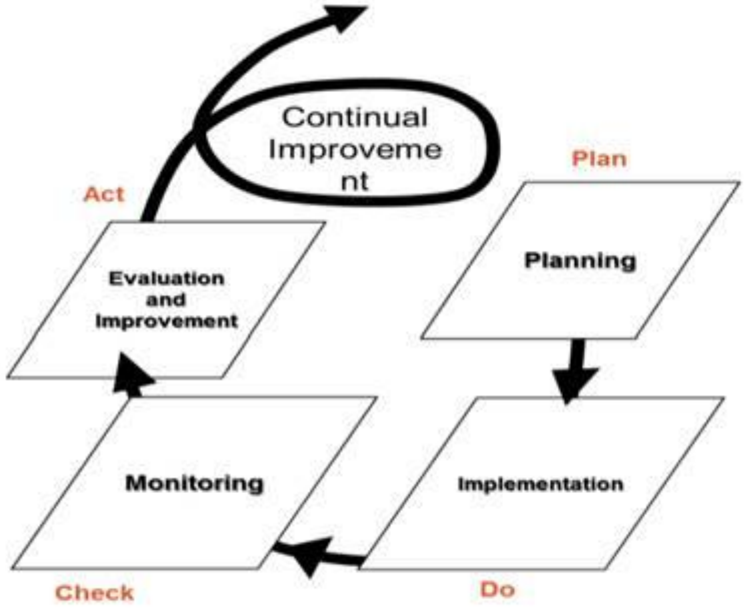


Figure 12.8: SEEMP continuous improvement concept

The PDCA components play a critical role in the continuous cycle to improve ship energy management. With each iteration of the cycle, some elements of the SEEMP will necessarily change while others may remain as before. The above components are further described in the following sections.

Figure below provides more detailed aspects of each stage of the cycle. Further description of each stage of the SEEMP cycle follows with reference to both figures.

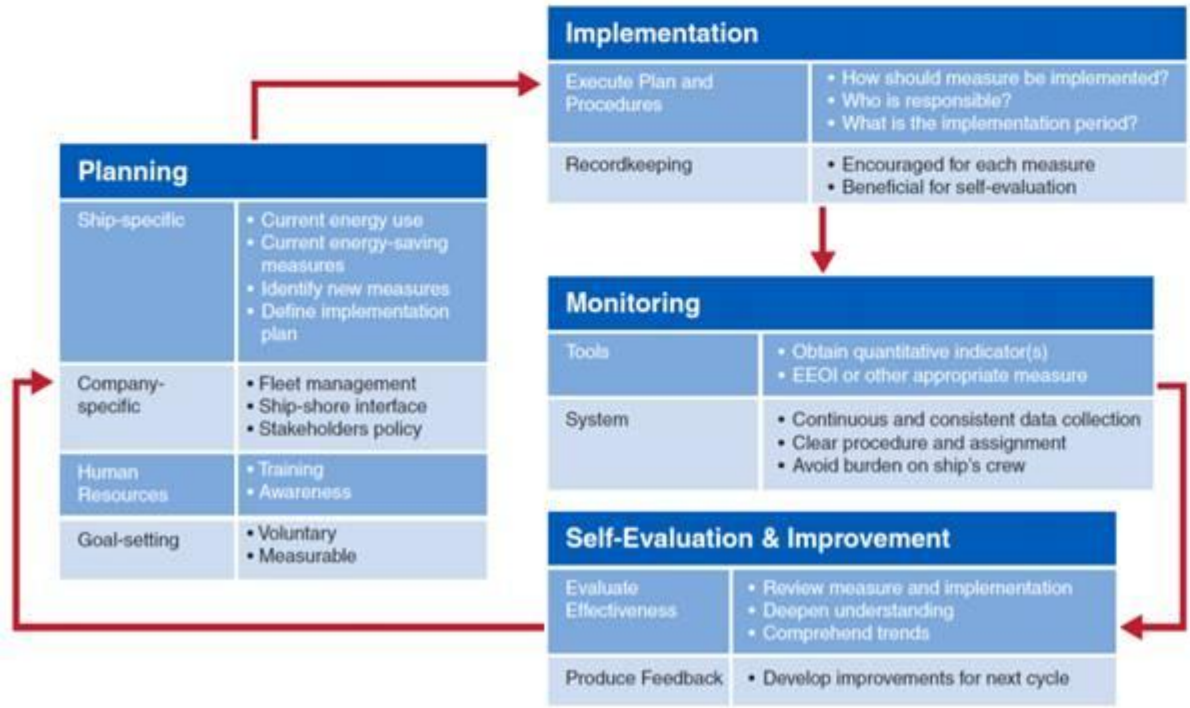


Figure 12.9: SEEMP as a 4-step ship energy management [ABS]

12.4.3. Planning

Planning is the most crucial stage of a SEEMP development. It involves activities such as determination of both:

• The current status of ship energy usage; and

• The expected improvements.

Based on the above and via using further energy reviews or audits, a set of Energy Efficiency Measures (EEMs) are identified and documented as part of the planning phase. The SEEMP planning activities do not stop at identification of EEMs but includes dealing with all aspects of planning for implementation, monitoring and self-assessment of the identified EEMs. Therefore, planning part for ship energy management and SEEMP is crucial and it is essential to devote sufficient time to planning.

12.4.3.1. Identification of Ship's EEM

The first step in energy management planning is to identify the EEMs for improving the energy efficiency of a ship. It is important to note that there are a variety of options to improve a ship's efficiency; that the best EEMs for a ship to improve efficiency differs to a great extent for various ship types, cargoes, routes and other factors, As such, it is recommended that the specific EEMs for each ship needs to be defined.

To do this, there will be a need for carrying out activities such as energy audits or energy reviews (*For energy audit and review techniques, refer to IMO Module 5 of Train the Trainershttp://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution*

/Documents/Air%20pollution/M5%20ship-port%20interface%20final.pdf) for the corresponding ship. SEEMP should be adjusted to the characteristics and needs of individual companies and ships, thus each ship will have its own ship-specific plan.

12.4.3.2. Goal Setting

According to IMO guidelines, goal setting for SEEMP is voluntary and there is no need for announcement to public nor are they subject to external inspection. Purpose of goal setting is to increase commitment to improving energy efficiency; thus the IMO guidelines encourage companies to set goals. The goal should be measurable and easy to understand. It can take any form such as “annual fuel consumption”, “EEOI targets” or other items.

On importance of goal setting, the following may be mentioned:

- Although IMO has made goal setting voluntary, a company with quantitative goals for their ship’s energy efficiency would show more determination in this area.
- A goal will be a measurable indicator and will be used to evaluate if the set objectives are met.
- Many good quality companies already have quantitative goals for their ship energy management, primarily at corporate levels.
- Despite difficulty of goal setting at ship level, it is important that ways for making sure that the continuous improvement is actually taking place could be evaluated.
- Current IMO debates on data collection for ships and future likely MRV is likely to deal with these aspects in the future. As such, SEEMP related regulatory framework is likely to be enhanced in the future.

12.4.3.3. Managing the Stakeholders

The improvement of energy efficiency of a ship does not necessarily depend on ship operator/owner only. A number of stakeholders are involved as shown in figure below.

These are:

- Port authorities who are in charge of port management and thus ships’ use of ports and related delays and so on.
- Cargo owner and charterer that have ultimate authority for ship itinerary and commercial activities of the ship.
- Ship owner could be different from operator/manager and thus will impact ship operational efficiency via decision making on ship technical improvements and relevant investments.

Figure 12.10: Ship energy management stakeholders

More coordination between stakeholders is more rewarding and to do this, the company should do the coordination rather than the ship. Therefore, IMO recommends that a company should also establish a "company energy management plan" to manage its fleet and ensures stakeholders' coordination. This will also reduce the work burden on ship-board staff.

On importance of company-level energy management plan/system, the following may be mentioned:

- The overall ship energy efficiency is highly impacted by many industry stakeholders who have influence on the way the ship is commercially operated.
- Main stakeholders are ship owner, ship operator/manager/ports, regulatory authorities, charterer, cargo owner and so on.
- Management of the above stakeholder to ensure good ship operation and loading profile is essential.
- Without effective stakeholders' management, most of potential energy saving opportunities will not be realized.
- The above could be realised as part of a "company energy management plan" as advocated by the IMO or a "company energy management system" as advocated by ISO 50001.

12.4.3.4. Human Resources Development

According to IMO guidelines, raising awareness and providing necessary training for personnel both on shore and on board are an important element. Such human resource development is encouraged and should be considered as an important component of planning as well as a critical element of implementation.

Additionally, the company should implement procedures, which limit any onboard administrative burden. The company management should 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.

12.4.4. Implementation

Two areas are of importance as far as planning for implementation is concerned:

- Establishment of an implementation system; and
- Record keeping.

Establishment of implementation system: A system for implementation of the selected EEMs needs to be defined via developing the procedures, tasks and assigning roles and responsibilities. The SEEMP should describe how each measure should be implemented and who the responsible person(s) is. The implementation period (start and end dates) of each selected measure should be indicated. The development of such a system can be considered as a part of planning, and therefore may be completed at the planning stage.

Record keeping: According to IMO guidelines, the planned EEMs should be carried out in accordance with the predetermined implementation system. Record-keeping for the implementation of each EEM is beneficial for self-evaluation and should be encouraged.

On the importance of implementation system and record keeping, it can be mentioned that:

• Without proper implementation of EEMs, the energy management objectives could not be completed.

• Assignment of responsibilities for various EEMs together with implementation process and schedules are important indicators that EEMs implementation is managed properly.

• Record keeping is important for not only monitoring purposes but also for use during self-assessment and the next planning phase of continuous improvement cycle.

12.4.5. Monitoring

In a SEEMP, the monitoring aspects also need to be clarified at the planning phase. Consistent data collection is the foundation for monitoring. To allow for meaningful and consistent monitoring, the monitoring system, including the procedures for collecting data and the assignment of responsible personnel, should be developed. The development of such a system can be considered as a part of planning, and therefore should be completed at the planning stage.

To avoid unnecessary administrative burdens on ships' staff, monitoring should be carried out as far as possible by shore staff, utilizing data obtained from existing ship-board log books and data systems. In this monitoring context, the ship's EEOI that is introduced in Section 6 may be advocated as the primary monitoring tool to ensure that the energy management cycle provides expected outcomes.

On the importance of monitoring, the following may be mentioned:

- Monitoring is an essential element of any management cycle. It is well known that "if one cannot measure, one cannot manage". This applies to energy management system as well.
- Monitoring to a large extent relies on data collection and data analysis over long term. Thus, establishment of a data collection and analysis system is an essential part of any monitoring system.
- To effectively analyse and make conclusions, a set of Key Performance Indicators (KPIs) need to be defined for quantitative assessment of the gathered data. As indicated, the KPIs could relate to overall ship performance (such as EEOI) or developed for each EEM.
- Data collection and analysis, performing internal audits, energy reviews, benchmarking, etc. and so on forms the backbone of any good monitoring system.

12.4.6. Self-evaluation and Improvement

Self-evaluation and improvement is the final phase of the management cycle (see figures in SEEMP framework). It should produce meaningful feedback for planning stage of the next improvement cycle.

The purpose of self-evaluation is to evaluate the effectiveness of the planned measures and of their implementation. For this process, procedures for self-evaluation of ship energy management should be developed. Furthermore, self-evaluation should be implemented periodically by using data collected through monitoring.

On importance of self-evaluation and target setting for future improvements, the following may be mentioned:

- Self-evaluation and improvement are the responsibility of the management team.
- The closer this "management team" is to top management of the company, the more effective will be their decisions; thus, is indicative of more corporate management engagement.
- Developing an energy policy, setting quantitative goals and committing investment in energy efficiency technologies and operations are main indications of the top management commitment.
- Results of the self-evaluation form the basis for planning of the next improvement cycle.
- Self-evaluation is normally done periodically for example annually or bi-annually.

12.4.7. SEEMP Format

IMO guidelines [Resolution MEPC.213 (63)] provide a sample template for development of the SEEMP as shown in figure below.

A SAMPLE FORM OF A SHIP EFFICIENCY ENERGY MANAGEMENT PLAN

Name of Vessel:		GT:	
Vessel Type:		Capacity:	

Date of Development:		Developed by:	
Implementation Period:	From: Until:	Implemented by:	
Planned Date of Next Evaluation:			

1 MEASURES

Energy Efficiency Measures	Implementation (including the starting date)	Responsible Personnel
Weather Routeing	<Example> Contracted with [Service providers] to use their weather routeing system and start using on-trial basis as of 1 July 2012.	<Example> The master is responsible for selecting the optimum route based on the information provided by [Service providers].
Speed Optimization	While the design speed (85% MCR) is 19.0 kt, the maximum speed is set at 17.0 kt as of 1 July 2012.	The master is responsible for keeping the ship's speed. The log-book entry should be checked every day.

2 MONITORING

Description of monitoring tools

3 GOAL

Measurable goals

4 EVALUATION

Procedures of evaluation

Figure 12.11: Sample SEEMP template from IMO guidelines

Accordingly, the SEEMP will, as a minimum, include the following elements:

- Ship identification details
- Energy Efficiency Measures and how they should be implemented, responsible persons and timeline
- Monitoring aspects
- Goals (optional)
- Evaluation aspects.

There are already typically developed SEEMPs in public domain. An example is given in Reference [OCIMF 2011] for a tanker.

12.5. Energy Efficiency Operational Indicator (EEOI)

12.5.1. Introduction

EEOI is one element of the IMO regulatory framework that is intended to act as an "energy efficiency performance indicator" during the operational phase of the ship and be used to monitor overall ship energy efficiency performance. IMO Guidelines "MEPC.1/Circ.684" provide the methodology and basis for EEOI development and calculations. In this section, extracts of these Guidelines are provided in order to further understand the EEOI purpose and method of calculation. Additionally, information will be provided on the experience so far in the use of EEOI.

The purpose of EEOI, according to IMO guidelines, is to establish a consistent approach for measuring a ship's energy efficiency for each voyage or over a certain period of time. The EEOI is expected to assist ship-owners and ship operators in the evaluation of the operational performance of their fleet. It is hoped that it will enable the monitoring of individual ships in operation and thereby the results of any changes made to the ship or its operation. In fact The EEOI is advocated to be used as a monitoring tool in the SEEMP.

EEOI, similar to EEDI, represents the amount of CO_2 emissions from a ship per unit of cargo-mile transport service (with a unit of gCO_2 /tonne.mile). However as against the EEDI that is defined for one operating point of a ship, EEOI represents the actual CO_2 emission from combustion of all types of fuels on board a ship during each voyage, which is calculated by multiplying total fuel consumption for each type of fuel (distillate fuel, refined fuel or LNG, etc.) with the respective emission factor of each fuel. The performed transport work is calculated by multiplying the actual mass of cargo (tonnes, number of TEU/cars, or number of passengers) and the corresponding actual distance in nautical mile travelled by the vessel.

At this stage, IMO has developed the EEOI to encourage ship-owners and ship operators to use it on a voluntary basis and to collect information on the outcome and experiences in applying it. So far, the feedback received on effectiveness of EEOI as a monitoring tool has been mixed.

The rest of this section is taken mostly from IMO Guidelines [MEPC.1/Circ.684] with some textual adjustments. The main aim of the section is to become familiar with the IMO guidelines and how EEOI is calculated.

12.5.2. Background and Objectives

The EEOI guidelines can be used to establish a consistent approach for the voluntary use of an EEOI, which will assist ship-owners, ship operators and parties concerned in the evaluation of the performance of their fleet with regard to CO_2 emissions. As the amount of CO_2 emitted from a ship is directly related to its actual fuel consumption, the EEOI can also provide useful information on a ship's performance with regard to its operational fuel efficiency. The objective of the IMO guidelines is to provide the users with assistance in the process of establishing a mechanism to achieve the limitation or reduction of GHG emissions from ships in operation. The EEOI guidelines are intended to provide an example of a calculation method which could be used as an objective, performance-based approach to monitor the efficiency of a ship's operation. The EEOI Guidelines are recommendatory in nature and present a possible use of an operational indicator. However, ship-owners, ship operators and parties concerned may implement either the IMO guidelines or an equivalent method in their environmental management systems and consider adoption of the principles therein when developing plans for performance monitoring.

12.5.3. Basic Definitions

To help with consistent estimation of EEOI, the following definitions are provided in the EEOI guidelines:

Fuel consumption: Fuel consumption is defined as all fuels consumed at sea and in port or for a voyage or period in question (e.g., a day), by main, auxiliary engines, boilers and incinerators.

Distance sailed: Distance sailed means the actual distance sailed in nautical miles (deck log-book data) for the voyage or period in question.

Ship and cargo types: The EEOI guidelines are applicable for all ships performing transport work. The types of cargo are generic and include but not limited to: all gas, liquid and solid bulk cargo, general cargo, containerized cargo, heavy lifts, frozen and chilled goods, timber and forest products, cargo carried on freight vehicles, cars and freight vehicles on Ro-Ro, ferries and passengers (for passenger and Ro-Pax passenger ships).

Cargo mass carried or work done: In general, cargo mass carried, or work done is expressed as follows:

- For dry cargo carriers, liquid tankers, gas tankers, ro-ro cargo ships and general cargo ships, metric tonnes (t) of the cargo carried should be used.
- For containerships carrying solely containers, number of containers (TEU) or metric tons (t) of the total mass of cargo and containers should be used.
- For ships carrying a combination of containers and other cargoes, a TEU mass of 10 t could be applied for loaded TEUs and 2 t for empty TEUs; and
- For passenger ships, including Ro-Pax passenger ships, number of passengers or gross tonnes of the ship should be used.

In some particular cases, work done can be expressed as follows:

- For car ferries and car carriers, number of car units or occupied lane metres.
- For containerships, number of TEUs (empty or full); etc.

It should be generally noted that for specific cases, the choice of cargo definition should fit the purpose of energy management and may vary from one company to the other.

Voyage: Voyage generally means the period between a departure from a port to the departure from the next port. Alternative definitions of a voyage could also be acceptable.

Consistent implementation of the above definitions in a company is essential for subsequent benchmarking of energy performance indicators such as EEOI across the fleet.

12.5.4. Establishing the EEOI

Calculation formula

The basic expression for EEOI for a voyage is defined as:

$$EEOI = \frac{\sum_j FC_j \times C_{Fj}}{m_{cargo} \times D} \qquad (1)$$

The guidelines allow averaging of EEOI over a number of voyages. Where the average of the indicator for a period or for a number of voyages is obtained, the EEOI is calculated as:

$$AverageEEOI = \frac{\sum_{i}\sum_{j}(FC_{ij} \times C_{Fj})}{\sum_{i}(m_{cargo,i} \times D)} \qquad (2)$$

Where:

- j is the fuel type.
- i is the voyage number.
- FC_{ij} is the mass of consumed fuel j at voyage i.
- C_{Fj} is the fuel mass to CO_2 mass conversion factor for fuel j.
- m_{cargo} is cargo carried (tonnes) or work done (number of TEU or passengers) or gross tonnes for passenger ships; and
- D is the distance in nautical miles corresponding to the cargo carried or work done.

The unit of EEOI depends on the measurement of cargo carried or work done, e.g., tonnes CO_2/ (tonnes.nautical miles), tonnes CO_2/ (TEU•nautical miles), tonnes CO_2/ (person•nautical miles), etc. It should be noted that Equation (2) does not give a simple average of EEOI among the number of voyages; thus, simple averaging of the voyages' EEOI must be avoided. Instead, for using the average value as a performance indicator, calculation of rolling average is used.

Rolling average

Rolling average, when used, can be calculated in a suitable time period, for example one year or a number of voyages, for example six or ten voyages, which are agreed as statistically relevant to the initial averaging period. The rolling average EEOI is then calculated for this period or number of voyages by Equation (2) above using the following technique. For a series of voyages (e.g. for 20 voyages), the first element of the rolling average (e.g. for a subset of 4 voyages) is obtained by taking the average of the initial number of voyages (e.g. initial 4). Then the subset is modified by "shifting forward"; that is, excluding the first voyage in the previous subset (e.g. voyage 1) and including the next voyage (e.g. voyage 5). This new subset number two will give the second rolling average element. This process continues until all voyages are covered.

Data sources

Primary data sources selected could be the ship's logbook (bridge logbook, engine logbook, deck logbook and other official records). It is important that sufficient information is collected on the ship with regard to fuel type and quantity, distance travelled and cargo type so that a realistic assessment can be generated.

Amount and type of fuel used (bunker delivery notes or other sources) and distance travelled (according to the ship's logbook or other sources) need to be documented by the ship on a consistent basis. The whole process may be automated if possible.

Fuel mass to CO_2 mass conversion factors (C_F)

C_F is a non-dimensional conversion factor between fuel consumption and CO_2 emissions produced. It is used in EEOI formula; see Equations (1) and (2).

Data collection template

For a voyage or period (e.g., a day), data on fuel consumption/cargo carried and distance sailed in a continuous sailing pattern could be collected as shown in the reporting sheet below.

Name and type of ship						
Voyage or day (i)	Fuel consumption at sea and in port in tonnes				Voyage or time period data	
	Fuel type ( )	Fuel type ( )	Fuel type ( )	...	Cargo (m) (tonnes or units)	Distance (D) (NM)
1						
2						
3						
4						

Note: For voyages with m_{cagro}=0, it is still necessary to include the fuel used during this voyage in the summation above the line.

Table: EEOI data reporting sheet (template) [MEPC.1/Circ.684]

The above template is from IMO guidelines; however alternative templates may be used for the purpose if required.

12.5.5. Further Aspects

Main calculation steps

The EEOI should be a representative value of the energy efficiency of the ship operation over a consistent period which represents the overall trading pattern of the vessel. In order to establish the EEOI, the following main steps will generally be needed:

- Define the period for which the EEOI is calculated
- Define data sources for data collection
- Collect data
- Convert data to appropriate format; and finally
- Calculate EEOI.

Data recording and documentation procedures

Ideally, the data recording method used should be uniform so that information can be easily collated and analysed to facilitate the extraction of the required information. The collection of data from ships should include the distance travelled, the quantity and type of fuel used, and all fuel information that may affect the amount of carbon dioxide emitted.

Monitoring and verification

Documented procedures to monitor and measure, on a regular basis, should be developed and maintained. It is important that the source of figures established are properly recorded, the basis on which figures have been calculated and any decisions on difficult or grey areas of data. This will provide assistance on areas for improvement and be helpful for any later analysis.

Ship and shore responsibility.

Based on IMO guidelines and in order to avoid unnecessary administrative burdens on ships' staff, it is recommended that monitoring of an EEOI should be carried out by shore staff, utilizing data obtained from existing required records such as the official and engineering log-books and oil record books, etc. The necessary data could be obtained during internal audits under the ISM Code, routine visits by superintendents, etc.

12.6. Overview of Management Systems

12.6.1. Introduction

12.6.1.1. Main Aspects of a Management System

The cornerstone of good management is commitment from the top management and dedication from the operating personnel. In matters of safety, pollution prevention and energy saving, it is the commitment, competence, attitudes and motivation of individuals at all levels that determines the end result. The foundation of the ISM Code is largely based on the philosophy of quality management, the key fundamentals of which include:

- Management commitment.
- Staff/personnel empowerment; and
- Continuous improvement.

The role of the top management is crucial when improving the quality or safety or environmental protection or conservation of resources of a company is concerned. Firstly, the management is responsible to set a company policy which describes where and how the company should aim and perform in terms of quality, safety, environmental and energy conservation issues. Secondly, the management is responsible for providing adequate resources and tools in order to ensure that the company policy could be successfully implemented. Also, the management is responsible for setting realistic and achievable targets for the company's quality, safety, environmental and energy performance. The performance should be reviewed on a regular basis and the previous targets should be updated on the basis of actual performance.

The involvement of the personnel is a pre-requisite for a successful management system. Employees should have a feel of ownership in this regard. This is normally achieved by providing an opportunity for them to participate in establishing, implementing and operating the management system at various organisational levels. In many organisations, it is not necessarily lack of knowledge and awareness that is responsible for poor performance, but it is the lack of this feel of ownership and motivation to act and commitment that leads to poor performance in various areas.

12.6.1.2. PDCA cycle of Continuous Improvement

The concept of "continuous improvement" requires that a company improves the quality of its products and services on a continuous basis and at all organisational levels. A common approach to continuous improvement is the PDCA (Plan – Do – Check – Act) process as shown in figure below.

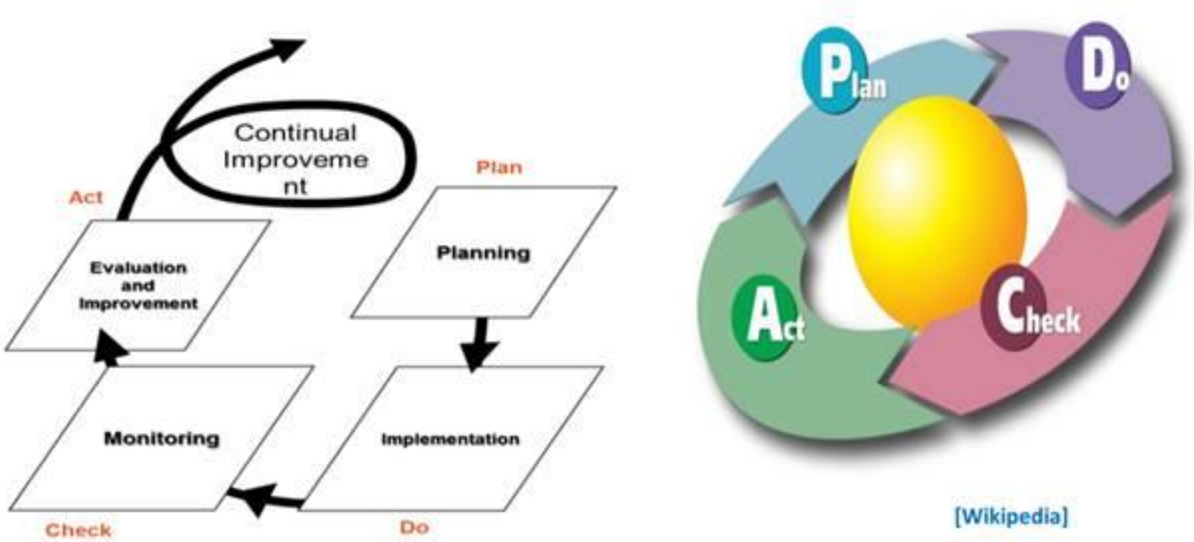


Figure 12.12: PDCA cycle of continuous improvement

The 4 major phases of the continuous improvement cycle are:

- **Plan:** During this first phase of the PDCA cycle, an action plan of the activities that need to be done is prepared together with all relevant implementation details. For this purpose, the company need to have a policy statement and should define the objectives and targets, plan on how to achieve these targets and identify how to implement and how to monitor various activities when the plan is implemented.
- **Do:** In the second phase, the implementation of the selected and documented measures should be carried out in a systematic way. In other words, this is the execution phase of the action plan developed. To be successful, project management of various measures under implementation is very important and the action plan should be executed within the schedule and budget.
- **Check:** In the third phase, one should measure or analyse the results of the implementation via effective monitoring and checking. This is the step under which the results of implementations are measured and monitored to ensure that the perceived objectives are achieved. Without this step, there is no way to know if the implementation has been satisfactory or not. Data collection and analysis plus various aspects of audits and surveys could be used for this purpose.
- **Act:** In in last phase the assessment of the effectiveness of plan is done. The plan is reviewed against the achievements and new targets are set for next cycle of PDCA. If

the check shows that the plan that was implemented led to improvements, then new standard or baseline or targets for future cycle of PDCA activities are set. Otherwise, the reasons for not meeting the objectives need to be evaluated and the plan adjusted according and the new cycle to be started. The above PDCA cycle principles apply to any management system irrespective of area of application. In this module, it will be shown frequently that various shipping related management systems also follow the above generic principles.

12.6.1.3. Management Systems and Shipping

The concept of "management system" is not new to the shipping industry. One of the most prominent management system that is already mandatory in shipping is the ISM Code that as the name implies deals with shipping safety at its core. There are other management systems that although not mandatory, are widely adopted by the shipping companies including the following:

- Quality management system, mainly known as ISO 9001
- Environmental management system, mainly known as ISO 14001
- Health and safety systems such as those based on OHSAS 18001.
- Energy management system such as those specified under ISO 50001.

In the following parts of this section, a brief overview of these standards together with their similarities and overlapping aspects will be given.

12.6.2. ISM Code

According to IMO, the main objective of the ISM code is to provide an international standard for the safe management and operation of ships and for their pollution prevention.

Accordingly:

- Governments are required to take the necessary steps to safeguard the shipmaster in the proper implementation of his/her responsibilities with regard to maritime safety and the protection of the marine environment.
- Recognised the need for the shipping companies to set up appropriate management system to enable them to respond to the need of those on-board ships to achieve and maintain high standards of safety and environmental protection.

The ISM code is effectively a shipping-specific international rules and regulations with the ultimate objectives:

- To ensure safety at sea
- To prevent human injury or loss of life
- To avoid damage to the environment and to the ship.

The ISM code is based on some general principles and objectives. These are expressed in broad terms so that ISM code can have a widespread application to all different type of organisations involved in shipping despite their diverse business. Clearly, different levels of management, whether shore-based or shipboard, will require varying levels of knowledge and awareness of the items outlined.

SOLAS adopted the ISM code in 1994 and incorporated it into its chapter IX. By 2002 almost all of the international shipping community was required to comply with the ISM code. In order to comply with the ISM code, each ship must have a working Safety Management System (SMS). Each SMS would consist of the following elements:

- Commitment from top management
- A top-level defined policy manual
- A "procedures manual" that documents what is done on board the ship, during normal operations and in emergency situations
- Procedures for conducting both internal and external audits to ensure that the ship is doing what is documented in the "procedures manual"
- A designated person ashore to serve as the link between the ship and shore staff and to verify the SMS implementation
- A system for identifying where actual practices do not meet those that are documented, and the associated corrective actions.
- Regular management reviews.

Another requirement of the ISM code is for the ship to be maintained in conformity with the provisions of relevant rules and regulations and with any additional requirements which may be established by the shipping company itself. As part of ISM code, compliance verification should be in place. Each ISM compliant ship is audited, first by the company itself (internal audit) and then each 2.5 to 3 years by the flag State "maritime administration" to verify the effectiveness of the SMS. Once SMS is verified and it is working and effectively implemented, the ship is issued with a Safety Management Certificate (SMC).

It should also be noted that a ship's planned maintenance scheme is a statutory requirement of the ISM code. The ISM code requires that the ship's management provide sufficient resources to maintain the ship safely and the company must supply the necessary resources in the way of parts or shore-side assistance to do this. Poor maintenance can mean that either the ship cannot meet its commercial obligations (for example unable to meet the minimum speed requirements defined in the contract) or can pose a potential safety or environmental hazard. The management should ensure regular audits of ships to verify that the maintenance required by the planned maintenance system is being carried out. This inspection of the ship should be part of the internal audits required by the ISM code and should not be left for statutory or class surveys at a later stage.

12.6.2.1. Standards other than ISM

There are a number of management system standards developed mainly by the ISO that have been extensively used. These are standards and not rules and regulations and as such their use is mostly voluntary. However, some of these well-known standards are widely used by most industries including shipping and will be briefly introduced.

12.6.2.2. ISO 9001: Quality Management System (QMS)

The ISO 9000 series of standards are related to quality management systems and designed to help organizations ensure that they meet the needs of their customers / clients and other stakeholders while meeting statutory and regulatory requirements related to their delivered products or services. The ISO 9001 certification is highly oriented towards "process improvements" taking into account the customer needs. ISO 9001 is the most commonly utilised standard for quality management. Its wider application started initially in manufacturing companies in 1980s. Later on, its application expanded into service business and public administration mainly in the middle of the 1990s. In shipping, many companies so far have adopted the ISO 9001 quality standard as the basis for their company's "quality management system".

12.6.2.3. ISO 14001: Environmental Management System (EMS)

ISO 14000 series of standards relate to environmental management and has been developed to help organizations to minimize the negative impacts of their operation on the environment via ensuring compliance to prevailing applicable laws, regulations, and other environmentally oriented requirements as well as best practice. ISO 14001 requires the organization to assess all of its environmental aspects related to the company's activities, products and services. So, in a nutshell, ISO 140001 main requirement is that the significant environmental aspects of a company should be identified, documented and managed. The first international version of ISO 14001 was published in 1996. Like any other of widely used management system standard, ISO 14001 has evolved over time and the current version of the ISO 14001:2015 includes the concept of continuous improvement process approach.

In a shipping company, the company policy may include the implementation of ISO 14001 on its vessels which contains procedures for selecting the best environmental measures for a particular vessel and then sets objectives for the measurement of relevant parameters along with relevant control and feedback features. The implementation of ISO 14001 has the main advantage of reducing a company's environmental impacts.

As many ships and companies already have an ISM code related management system that should include environmental protection, it would make sense for these companies to have an ISO 14001 compliant environmental management system; however as discussed before this is not mandatory and care should be exercised not cause complications with regard to ISM related Flag State and Port State Control inspections. Once an environmental procedure becomes part of the ship's SMS, it is mandatory to follow the processes even if the requirements are not mandatory in other statuary legislation.

12.6.2.4. OHSAS 18001: Occupational Health and Safety Assessment Specification

OHSAS 18001 is a British Standard (BS) that is used globally and provides a specification for occupational health and safety management in any organization. The OHSAS 18001 is widely used internationally and is intended to help organizations to control occupational health and safety risks. OHSAS 18001 focuses on the need to identify all occupational health and safety hazards for personnel related to the company's activities and facilities and do relevant risk assessment. The result of these assessments is then used to identify the hazards that have to be eliminated or controlled.

The OHSAS 18001 has been harmonized with the ISO 9001 and ISO 14001 standards so that to help organizations to integrate the quality, environmental and safety management systems easier into one common management system.

12.6.2.5. ISO 50001: Energy Management System (EnMS)

ISO 50001 is an international standard for an energy management system. The standard specifies the requirements for establishing, implementing, maintaining and improving an energy management system (EnMS). The purpose of EnMS is to enable an organization to follow a systematic approach in achieving continual improvement of energy performance in their organisation. ISO 50001 establishes systems and processes to improve energy performance and as a result, enable reductions in energy costs, GHG emissions and other environmental impacts.

12.6.3. Commonalities between Management Standards

Although the above categories of standards deal with different management aspects, their overall requirements, processes and procedures have similarities and overlap. Understanding of their similarities and overlaps helps with an integrated approach to their implementation. In this section, some of these aspects are clarified such that if a trainee is familiar with one of these management systems or standards, he/she could relate the other standards to this one as an aid for quicker and deeper understanding. Also, this section aims to provide more information on the requirements of each standard, complementing what mentioned about them in previous section. The commonalities of these standards are so much that there are many publications that compare them and there are many companies who offer an integrated service in dealing with their implementation and certification. In shipping, for example, ABS guidelines for such services [ABS 2012] are written as a unified one that includes all of the above standards in one guideline. DNV also in its publication [DNV 2013] offers a good and systematic comparison of these standards in terms of their common aspects and also their complementary aspects. The following comparisons are mainly a shortened version of the DNV comparisons in this regard [DNV 2013] that is hereby acknowledged.

12.6.3.1. On "Objectives and Policies"

This aspect relates to the role that top-management of the company must play. Many aspects of the requirements for top management roles in the ISM code and the other management standards are similar. Accordingly, the top management shall define policies relevant to the nature of the business and as a framework for objectives and targets. As a minimum, objectives and targets should demonstrate the company's goals for health and safety protection, environmental concern, energy performance and so on. In addition to the above, specific objectives and targets are required by the various standards for compliance purposes.

12.6.3.2. On "System Management"

The "system management" refers to management procedures and assignment of roles and responsibility. Instructions and procedures are required to be in place in order to operate ships safely, protect the environment, control its occupational health and safety risks and comply with relevant international and flag State legislation. Defined levels of authority, responsibility, lines of communication, resources and support, plans for key shipboard operational procedures, risk assessments, accidents and nonconformity reporting procedures, emergency procedures, internal audits and management reviews are all part of the system requirements. For this purpose:

- The ISM code requires designated person(s) to be appointed.
- For ISO 9001, it is required to identify a quality management representative and describe elements in the ISO 9001 standard that not already addressed in the existing safety management system. The customer should be defined and a system for measuring and monitoring the service provided to satisfy the customer's needs have to be put in place.
- For ISO 14001, it is a requirement for top management to appoint an environmental management representative and provide resources to manage and control the environmental system. All environmental aspects shall be assessed, by considering normal and abnormal operations and potential emergency conditions. The significant aspects shall then be identified and managed. Procedures for receiving, documenting and responding to communication from external interested parties shall be established.
- For OHSAS 18001 and similar to ISO 14001, all occupational health and safety hazards must be identified and assessments of risks carried out. A safe system of work must be established, employing a hierarchy of controls. Employee consultation and participation is required.
- As for ISO 50001, the main goal of the standard is a reduction in energy use. This is achieved through continual improvement in energy performance. The organization is required to conduct and document energy planning via an energy review, establish an energy baseline, performance indicators, objectives, targets, action plans etc.

12.6.3.3. Continual Improvement Aspects

The following could be related to ISM code and other standards:

- As part of ISM code, objectives to continually improve safety management skills ashore and on-board via analysis of nonconformities, accidents and hazardous situations need to be achieved. Procedures for maintenance of the ships in the fleet are required. Use of risk assessment techniques is necessary.
- As for ISO 9001, customer needs, expectations and requirements have to be taken into account. A procedure for analysis of data to improve the quality effectiveness of the management system is required. Procedures for eliminating the causes for potential nonconformities are also required.

- For ISO 14001, the company should establish an environmental management programme that addresses all of its objectives and targets including schedules, resources and responsibility for achieving them. The environmental programme helps the company improve its environmental performance and meet its commitment to continual improvement.
- For OHSAS 18001, the company should establish an occupational health and safety programme that addresses all of its objectives and targets, including schedules, resources and responsibilities for achieving them.
- For ISO 50001, the company is required to plan its energy use when working to achieve its energy targets. This means to develop and carry out an energy review and establish energy baselines. The company is required to use performance indicators. Checking and monitoring is done against the indicators.

12.6.3.4. Human Resources/Personnel

On human resources and staff, all the management systems give significant priority to train and motivate the staff in related areas:

- For ISM code, the company should ensure that seafarers are qualified, certified and medically fit.
- As for ISO 90001, the organization shall assign personnel to ensure that those who have defined responsibilities are competent. The company should also evaluate the effectiveness of training.
- As for ISO 14001, all employees shall be trained in and be aware of their roles and responsibilities and the significant environmental impact of their work etc.
- As for OHSAS 18001, all employees shall be aware of their roles and responsibilities, the occupational health and safety consequences of their work activities etc.
- As for ISO 50001, employees should be familiar with their roles and responsibilities. Training in energy management system, benefits of energy management etc. is required. This extends to contractors and third parties working on-board that may be affecting energy use.

12.6.3.5. Ship Maintenance System

The ship maintenance management is also part of the management standards including:

- For the ISM code, maintenance procedures covering at least all items that are subject to class, statutory and additional company requirements are required.
- For ISO 90001, planning and control of appropriate procedures are required, as are purchasing procedures. The maintenance must extend to include care for customer property, including where work on-board affects customer property indirectly.
- For ISO 50001, maintenance plans extend to areas identified and considered as significant energy users in order to avoid a failure affecting the energy performance.

12.6.3.6. Verification and Inspections

Measurement, monitoring, verification and inspections are part of all the management systems.

- Based on ISM code, regular on-board verifications and inspections are required.
- In ISO 14001, the company must have a systematic approach to measure, monitor and evaluate its environmental performance.
- In OHSAS 18001, the company must have a systematic approach to measure, monitor and evaluate its occupational health and safety performance.
- For ISO 50001 compliance, the company should define and regularly review energy measurement needs. An energy measurement plan is required. Measurement equipment must be calibrated with records retained. Standard gives minimum requirements to be considered.

12.6.3.7. Performance Monitoring

Common to all standard, effective procedures for reporting non-conformities and hazardous situations are required. New requirements for e.g. energy management should be reflected in the company management system. Data analysis, implementation of preventive actions and continual improvement procedures are required.

- For ISM code purposes, there is a requirement to have a designated person ashore to monitor safety and pollution prevention aspects.
- For ISO 9001, ways of measuring and monitoring operational performance are required. This includes establishing data analysis processes, improving system effectiveness and continual improvement.
- For ISO 14001, procedures for regular monitoring and measuring key operations that have significant environmental impacts are required. Evaluating compliance with relevant environmental legislation and regulations is also required.
- For OHSAS 18001 compliance, procedures for monitoring and measuring occupational health and safety performance on a regular basis. Evaluating compliance with relevant legislation and regulations is also required.
- As ISO 50001, the company should identify energy performance indicators based on the energy review and the energy baseline. Measurement will be carried out against these performance indicators.

12.6.3.8. Management Reviews

Common to all, the company should verify compliance and evaluate the efficiency and effectiveness of the management system. Management reviews covering all of the company’s systems at defined intervals, are required, including input from master.

- For ISO 9001, monitoring and measurement of management system performance including customer satisfaction is a requirement.

- For ISO 14001, the organisation shall evaluate the environmental performance and the conformance with the environmental policy, objectives and targets. Evaluating compliance with relevant environmental legislation and regulations.
- For OHSAS 18001, the organisation shall evaluate the health and safety performance and the conformance with the policy, objectives and targets. Evaluating compliance with relevant legislation and regulations.
- For ISO 50001, the management review will evaluate the energy performance, the suitability of the performance indicators and whether or not targets have been met. It will also look at projected energy performance. Outcomes may include changes in baseline, performance indicators, resource allocation etc.

12.6.4. Certification and Other Aspects

As indicated above, all the shipping related management systems, whether mandatory such as ISM or voluntary such as ISO 14001 and ISO 50001, have general features that are common between them. This is despite the fact that different systems focuses on different aspects of safety, environment or energy efficiency. Management certification is one way of demonstrating, in particular to external parties, that the company is complying with the above standards.

In shipping the main bodies that provide management system certification services to the industry are classification societies. As indicated by two examples [ABS 2012 and DNV 2013], class societies use integrated processes and guidelines to deal with all the above standards. For example, ABS has published a marked-up version of their guidelines on "Guide for Marine Health, Safety, Quality, Environmental and Energy Management" that shows how for example "energy management" has been added to the previously used guidelines that have been dealing with "Marine Health, Safety, Quality and Environmental" only.

Some class societies have published dedicated rules for certification of "ship energy management" that only deals with SEEMP aspect of energy management. Chinese Classification Society (CCS), in 2011, published their "Rules for Certification of Ship Energy Management" that deal with all aspects of certification including system requirements, data requirements, certification and energy audit for ship-board energy management.

On energy efficiency side, all classification societies provide services in "energy management system certification" and a number of companies have been certified so far. Being a new standard (i.e. ISO 50001), the number of certified shipping companies are not many yet. However, it is expected that with time and due to the significance on climate change debates, more and more companies will allocate resources to deal with energy saving and energy efficiency over the time.

12.7. Shipping Company Energy Management

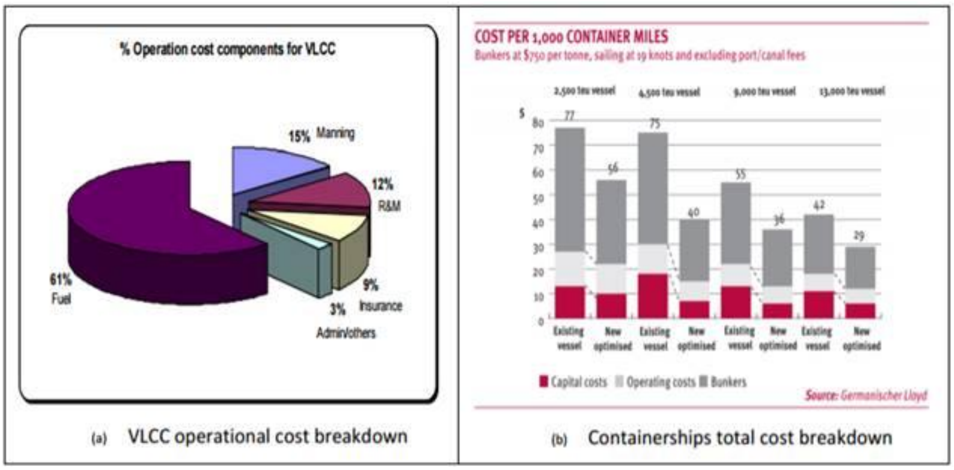
12.7.1. Introduction

Energy management includes planning and operation of corporate activities including all aspects of a company's production, transport and service aspects with the main aim of reducing the energy use. The wider objectives of energy management are resource conservation, environmental (mainly climate global warming) protection and cost savings, while ensuring the security of supply of energy. As such, energy management is closely linked to environmental management, production management, logistics and other related business functions. Within this context, energy management may be referred to as "the proactive, organized and systematic coordination of a company's (and its ships) use of energy to meet the requirements, taking into account environmental and economic objectives".

The translation of the above for a shipping company will mean planning and operation of a fleet of ships with the aim of reducing the total ships' fuel consumption or CO_2 emissions with due consideration for the company's quality delivery of services to customers (under ISO 9001), safety and environmental objectives (under ISM code and ISO 14001) and risk avert and safety of personnel (under for example OHSAS 18001). Reduced fuel consumption is part of a two-prong strategy of reducing GHG emissions from shipping as well as reducing fuel cost to shipping companies; thus, it is a win-win strategy for environment and business profitability.

12.7.2. Fuel (Energy) Cost

In shipping, fuel management is an important part of a shipping company's activities since a significant proportion (more than 30%) of a ship's operational costs are related to fuel costs. Figure (a) below shows typical costs for a tanker, showing high percentage of fuel cost in the overall ship's operational costs. Figure (b) below shows similar data for containerships but includes total cost inclusive of capital costs. Both show high percentage of fuel cost in the overall ship's operational or total costs. The numbers presented are typical and percentages are a function of the ship type, ship size, bunker fuel prices as well as mode of operation of the ships.



(a) VLCC operational cost breakdown (b) Containerships total cost breakdown

Figure 12.13: Typical ship costs and fuel costs

12.7.3. Climate Change

Apart from ship costs, the issue of environmental impact of shipping has been under scrutiny for a number of years. An estimate of the total emissions of exhaust gases from ships that can be attributed to international shipping was made by the IMO and indicated to be at 2.2% of global man-made GHG emissions in 2012 accordingly to IMO Third GHG Study 2014. Also, it was shown if no action takes place, the shipping GHG emissions will increase by 50% to 250% by 2050. This level of growth in shipping GHG emissions is not acceptable by the international community. Thus, a way must be found to reduce shipping GHG emissions much below current day levels.

12.7.4. Scope for Energy Saving

The question of feasibility of reducing shipping fuel consumption has been the subject of numerous studies in the past 15 years. All studies show that on a wider scale, it is possible to significantly reduce the shipping fuel consumption and GHG emissions. Table below shows an example of such studies.

	Saving of CO_2/tonne-mile	Combined	Combined
DESIGN (New ships)			
Concept, speed and capability	2% to 50%†		
Hull and superstructure	2% to 20%		
Power and propulsion systems	5% to 15%	10% to 50%†	
Low-carbon fuels	5% to 15%*		
Renewable energy	1% to 10%		25% to 75%†
Exhaust gas CO_2 reduction	0%		
OPERATION (All ships)			
Fleet management, logistics & incentives	5% to 50%†		
Voyage optimization	1% to 10%	10% to 50%†	
Energy management	1% to 10%		

* CO_2 equivalent, based on the use of LNG.
† Reductions at this level would require reductions of operational speed.

Table: Potential for shipping fuel consumption reduction [IMO Second GHG Study 2009]

There is a large number of operational energy efficiency measures for existing fleet that would yield the above mentioned energy savings. Examples are:

Enhanced ship's technical and operational management: Measures include:

- Enhanced weather routing.
- Optimized trim and ballasting.
- Hull and propeller cleaning.
- Better main and auxiliary engine maintenance and tuning.
- Enhanced voyage execution and performance measurement.
- Monitoring and reporting.
- Efficient operation of major electrical consumers.

- Deployment of cost-effective propulsion, engines and auxiliary technology upgrades.

Enhanced logistics and fleet planning: Measures include:

- Combining cargoes, where possible, to achieve a higher utilisation rate,
- Use of combination carriers' (to reduce ballast voyages).
- Optimisation of logistic chains.
- Enhanced routing and itinerary.
- Fewer/shorter ballast legs.
- Larger cargo batches (better ship load factor).
- Just in time operation and slow steaming.
- Changes to charter-party contract formats between charterer and ship-owner to facilitate the above.

As an example of well-researched results, Table below shows the potential for reduction of fuel consumption and GHG emissions from existing ships (operation) based on a study commissioned by IMO, indicating that a big potential for shipping energy use reduction.

Energy Efficiency Measure	Bulk carrier		Gas tanker		Tanker		Container ship		General cargo/Reefer	
	Handymax 30-40k DWT	Capesize >100k DWT	LNG 125-155k m3	LNG >175k m3	Panamax 60-85k DWT	VLCC >200k DWT	Panamax (4-5k TEU)	NPX (12-14k TEU)	~3.5k DWT	~10k DWT
Engine tuning and monitoring	2.5	1.8	1.8	1.8	2.2	1.6	1.6	1.6	2.9	2.9
Hull condition	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Propeller condition	1.1	0.8	1.1	0.8	1.1	0.8	0.8	0.8	1.1	1.1
Reduced auxiliary power	0.6	0.9	0.7	1	0.6	1.7	0.8	1	2.6	1.1
Speed reduction (increased port efficiency)	15	15	12	10	13	12	10	11	21	13
Trim/draft	0.7	0.7	1	1.4	0.7	0.7	1.7	1.7	0.7	0.7
Voyage execution	2.5	3.4	2.5	3.4	2.5	3.4	1.4	1.4	2.5	2.5
Weather routing	0.1	1	0.1	1	0.2	1	1	0.8	0.1	1
Advanced hull coating	3	3	3	3	3	3	3	3	3	3
Propeller upgrade and aft body flow devices	3	3	3	3	3	3	3	3	3	3
SEEMP potential taking into acc. Overlaps	**28.7**	**29.6**	**25.9**	**26.0**	**26.8**	**27.7**	**24.3**	**25.2**	**36.0**	**28.4**

Table: Operational energy saving potentials in % [LR and DNV]

The above energy efficiency measures and how they lead to energy saving and reduction of GHG emissions, have been explained in detail in TTT modules 3 and 4. The important point to make here is that without having a proper regulatory framework and a good management system in place, the above measures cannot be systematically and successfully implemented on existing ships. In this module, the topic of application of energy management system to a shipping company and its fleet will be discussed further in order to clarify how the above-mentioned systematic approach may be pursued in a shipping company.

12.7.5. Shipping Companies Approach

The central aim of shipping energy management is to reduce energy costs and GHG emissions without compromising the operational and technical aspects of ships operations in particular the safety, availability and service life of the equipment and their reliable and ease of use.

The regulatory framework for shipping energy efficiency for new ships is to a large extent in place. For existing vessels, the SEEMP regulations are in place and work on "further operational measures" is underway and has progressed well so far. For existing vessels, there will be more regulations on data collection and reporting in the future.

Within the IMO guidelines on SEEMP, the shipping companies are encouraged to have a "company energy efficiency management plan" in order to do the overall fleet optimisation and management of the relevant stakeholders. Although the company energy efficiency management plan is not a mandatory requirement, a question is normally raised that how a company energy efficiency management plan should be developed, documented and implemented. In this course, it is advocated that a company is best to develop such a company-level plan under the name of a Company Energy Management System (CEnMS). Also in this course, it is advocated that the CEnMS is best to be developed using principles as described within ISO 50001.

As the requirements for SEEMP (by IMO guidelines) and CEnMS (by ISO 50001) have already been presented and discussed, the aim of this section is to deal with more detailed and practical aspect of application of SEEMP and CEnMS to a shipping company and its fleet to ensure that the company achieves what it has planned. For a shipping company to succeed, it needs to implement SEEMP effectively at ship-level and CEnMS at the company-level. The SEEMP and CEnMS should work hand in hand to manage the overall processes.

12.7.6. CEnMS and SEEMP Scope of Application

Although CEnMS and SEEMP may be assumed to be similar by readers, in fact they are different and will have different scope. Some complementary aspects of the two are highlighted here:

- SEEMP is only applicable to a "specific ship" and is used mainly on-board ships. CEnMS is not for a specific ship but for a "specific company". The CEnMS will be mainly implemented at shore office. Thus, CEnMS will include more generic and higher-level activities than the SEEMP.
- SEEMP contents are primarily implementation oriented. This means that the strength of a SEEMP should be on how to implement the EEMs at the ship-level together with a good definition of what to be done and ship staff's roles and responsibilities. Although aspects of planning, monitoring and self-assessment are included in the SEEMP, they are not normally the responsibility of the ship-board staff to implement.
- The CEnMP on the other hand is more oriented to planning, monitoring and self-assessment of the fleet's SEEMPs effectiveness and other high level management activities relating to energy such as bunkering, provision of third party services to ships and so on. Thus it should provide company-wide and fleet-wide activities that ensure a better planning and energy management activities and a better monitoring and assessment of the results of implementation of these activities along with the external stakeholder management aspects. Along this scope of work, the following are mainly should be reflected in the CEnMS:
- Energy planning activities for improvement of both CEnMS and SEEMPs.
- Energy policy development for the company as a whole inclusive of ships in the fleet.

- Definition of monitoring system and relevant KPIs, baselines, data collection and data analysis systems. Establishment of a monitoring and reporting system for energy efficiency data.
- Methods for the self-evaluation (company level) of the effectiveness of various SEEMPs plus the CEnMS itself.
- Coordination and collaboration with the major external stakeholders that influence fleet's operation.

Based on the above, the scope of the CEnMS and ship-level SEEMPs will be different, and they will be more complementary rather than overlapping. This is important for ensuring that the company does all elements of activities that are foreseen under IMO SEEMP and ISO 50001 in a harmonious way.

12.8. Ship-Level Energy Management Plan (SEEMP)

12.8.1. EEMs at the core of a SEEMP

In this section, ship-level energy management is discussed with specific reference to SEEMP. The methodology for the development of a SEEMP should be based on the IMO MEPC guidelines. Accordingly, the SEEMP development involves all aspects of planning including:

- Identification of current status of the ship in terms of energy use and performance.
- Target setting for energy use or energy performance of the ship (voluntary).
- Identification of EEMs (Energy Efficiency Measures).
- For each selected EEM for implementation, the following should be done:
- Definition of implementation method,
- Definition of monitoring method
- Definition of assessment method
- Documentation of all the above in the SEEMP.

Under IMO SEEMP development guidelines, there is no requirement for the development of an "energy policy" and setting target for energy saving is also voluntary. Monitoring at the overall-level is advocated via use of the EEOI or another indicator but no references are made to the monitoring of individual EEMs. Additionally, it is mentioned that monitoring should be done by shore-based staff rather than ship-board personnel. Also, the SEEMP is ship-specific, thus for every ship a separate SEEMP that is compatible with ship systems, its operation pattern, etc. need to be developed.

12.8.2. Implementation of EEMs

The implementation of a SEEMP could take a variety of forms. It is argued here that each of the EEMs within a SEEMP needs to be implemented as if it is a form of a "technical and operational project". The term project is used here to emphasise that each EEM need to have a starting date and end date, it would have a budget and responsible person(s), it would have criteria for monitoring and measuring success and so on. This approach is different from those currently practiced that just provide a listing of a number of EEMs in a SEEMP and leave them to goodwill of relevant managers and personnel to implement. Development of a CEnMS could help to organise this process.

As far as a shipping company's energy management activities are concerned, the ship-board activities are mostly devoted to the implementation side. This means that various identified EEMs need to be implemented by ship staff. Planning, monitoring and self-assessment of ship-board activities are mainly done by the head-office staff and should be the subject of significant work within the CEnMS framework.

12.8.3. Continuous Improvement Approach

To include continuous improvement, the energy management systems will be done in steps through a number of cycles (see figure below).

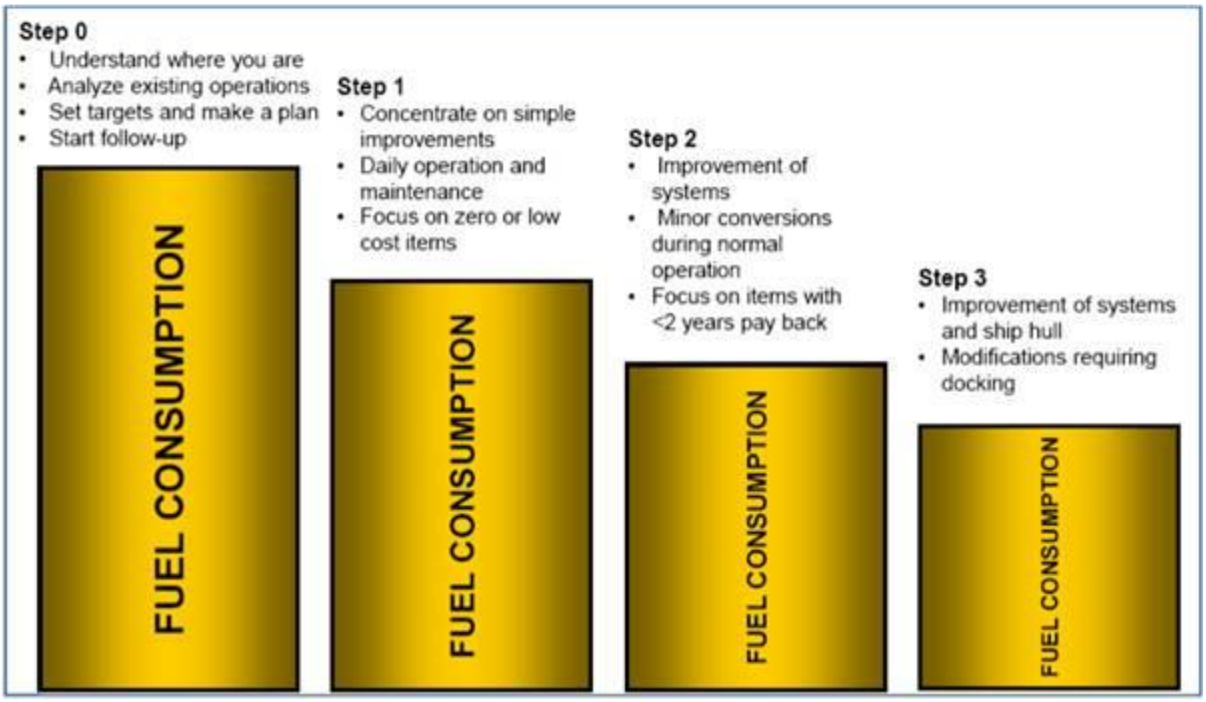


Figure 12.14: The concept of step-by-step approach to energy management

As indicated above, typical steps could be:

- Step 0 (initial planning): Understand where the ship/company is, analyse potential for improvements and decide where the ship/company wants to save energy and start define the target and develop the energy management action plan.
- Step 1 (low-cost measures): These are normally referred to EEMs that can be implemented at zero or very low cost. They are the so-called "low hanging fruits". In this step, the concentration will be on these EEMs that may largely include aspects such as improvement to daily operations and maintenance activities. This implementation may require significant effort of cultural change on how things should be done as against how they are done now.

- Step 2 (medium cost measures): When step 1 targets are achieved, then EEMs that would involve some cost expenditure for implementation will need to be handled. These are measures that could offer a good return on investment and typically have payback periods of less than 2 years.
- Step 3 (high cost measures): These are measures that may have significant cost of implementation (e.g. technology upgrade) or commercial implications (e.g. slow steaming or itinerary changes). These measures need significantly more analysis, deliberations with stakeholders (e.g. charterers) and so on. In fact, the longer-term potential for financial return for these measures may be higher compared to other measures but elements of risks are also higher.

The above step-by-step approach to the issue of energy management is compatible with continuous improvement cycle approach that is built in the SEEMP and ISO 50001. Figure 30.2.3.2 shows the associated costs and payback related to the above three steps. As mentioned, latter steps will include measures that could be more costly as well as return on investment (payback) will not be necessarily in the short term.

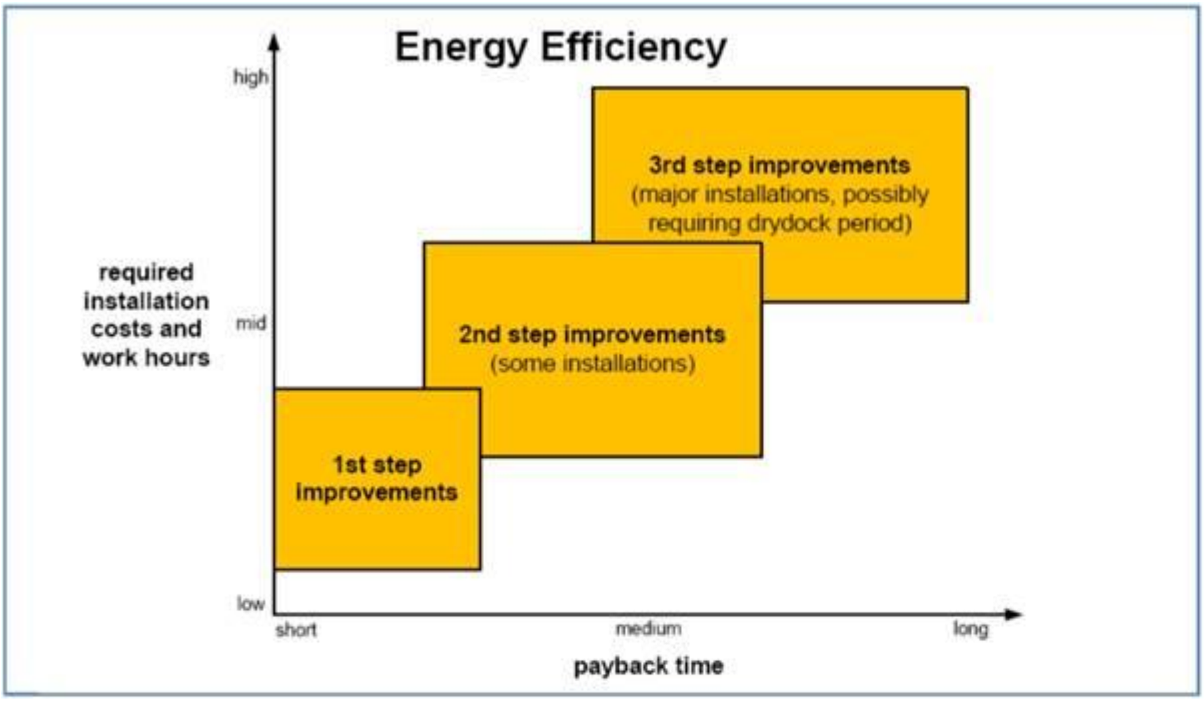


Figure 12.15: Cost and payback for measures under step 1 to step 3

12.9. Company-Level Energy Management System

As advocated under IMO SEEMP, a company needs to have a company energy management system in order to coordinate not only the fleet SEEMPs but also provide company level coordination with external stakeholders such as charterer, shipper, shipbuilder, and other service providers. To do this, the best option will be to develop a CEnMS based on ISO 50001 principles.

The development of company-level CEnMS based on ISO 50001 would need to be defined by the company. As indicated before, the following areas need to be dealt with in a shipping company CEnMS:

- Energy policy, its communication and awareness raising on the subject.
- Monitoring system and its implementation inclusive of KPIs, baselines, data collection, data analysis and so on.
- Self-evaluation methods and how to evaluate the performance of various SEEMPs at top management level
- Training of staff at company-wide level. Increasing motivation and competence to deal with energy saving aspects.
- Reporting to external stakeholders including major clients and regulatory authorities

The above topics will be further discussed with a view to understand that a CEnMS is the home for delivery of the all the above in an integrated fashion while ship-level SEEMPs are exclusively devoted to implementation of EEMs.

12.9.1. Company Energy Policy

The company energy efficiency policy is of vital importance in determining and setting the agenda for GHG emissions and fuel cost reductions in the fleet. It must be recognised that the policy not only will give the top-level management endorsement and support for relevant activities but also will be a significant document for communicating company values and targets, awareness raising and securing commitment by other staff. The policy would include various important aspects including for example stakeholders' management in particular the clients with whom the company intends to work most closely and effectively to achieve the objectives.

The energy policy will need to be prepared for the company as a whole. To achieve maximum reduction of GHGs, it is important that the management has a policy to improve the energy efficiency of all the ships it operates. Looking at individual ships in isolation will not reap the highest benefits. The company management should define and communicate the companies' values and aspirations in the policy and provide details of how they intend to achieve these objectives.

The content of the policy will be influenced and dictated by the company's nature of business, the types of ships, the area of operation, the trade the ships are on, the size of the fleet and overall company strategies. The list below provides some aspects that could be included in the company's energy policy:

- Commitment at the highest level: Creation of policy provides a significant signal by the company management, at the highest level, to demonstrate commitment to a GHG reduction and energy saving policy. This is very important as otherwise it will imply that top management is not taking this issue seriously. If the commitment of top management is not expressed clearly to staff, then it is very unlikely that the operational shore staff or ship's crew will take energy saving activities seriously. One of the best ways to demonstrate the companies' commitment to energy efficiency is by including this commitment in the policy statement right from the beginning.

- Company targets: The policy would need to include targets, if any, to give credibility to the policy statement. Although a policy could be developed without specific targets, it would be much more effective to have targets and monitor progress at a later stage against the target. However, targets should be easy to understand and feasible to be achieved with foreseen workforce and financial resources.
- Communication to staff: The dissemination of information to internal workforce and wider international community is important for motivation of staff and branding of the company. The communication aspects need to be included in the policy statement.
- Monitoring methods: There have to be provisions in the policy how the monitoring of achievements will be made. The company policy should clearly state how the company intends to monitors the energy efficiency activities. The company may decide to implement energy audits or other means for this purpose, it is best that these are mentioned in the policy document.
- Reporting and communication to external stakeholders: The policy document should detail how it intends to measure, monitor and report the energy efficiency activities to external bodies. The reasons/basis for sharing this information need to be mentioned to strengthen the policy statement.
- Importance of ship specific SEEMPs: The policy should also stress the importance of the ship specific SEEMPs for ship-level energy management activities and endorse management commitment to their full implementation.
- Other specific aspects: The policy is best to contain the strategic aspects for improving the utilisation of its fleet's capacity and stress the need for planning. This could include the reduction of long ballast voyages, port times, time it takes to load or discharge or the use of shore power or weather routing services. The policy could also include the replacement of older tonnage with new more efficient ships or technology upgrade aspects that would show financial commitment to future improvements. In short, anything important from top management point of view needs to be included.

The policy document, when developed and endorsed by top management, should be available to all of the employees. The document should be written clearly and unambiguously and set achievable and understandable objectives. The content of CEnMS and SEEMPs should be compatible with the policy statement.

12.9.2. Energy Review

As part of SEEMP and also CEnMS developments, energy planning and reviews or audits need to be carried out. Energy reviews can be used either as part of planning or monitoring phases of the energy management activities. For planning phase purposes, the end result of energy review or audit would be a set of recommendations on best ways of saving energy in the form of a prioritized list of Energy Efficiency Measures (EEMs).

For monitoring phase purposes, the main aim of using energy review or audit would be to check if the implementation of various EEMs or overall reduction in energy performance indicators has undergone according to plan and if any quantitative savings have been accrued. Thus, for the two purposes, two different approaches may be used but techniques used for identifying the potentials will be the same.

The energy review involves a number of activities such as definition of energy baseline(s), energy performance indicators, energy objectives and targets and most of all the energy efficiency measures. The final choice of measures to be implemented will be decided by technical feasibility study as well as economic-cost-effectiveness assessment.

12.9.3. Energy Efficiency Monitoring and Reporting

Energy efficiency performance monitoring should be done as part of SEEMPs or CEnMS for the company's internal purposes to ensure that various EEMs are properly implemented. Monitoring should be part of both SEEMPs and CEnMS with main emphasis on activities to be carried out at the head office. For monitoring of major EEMs and dealing with a large number of fleet wide EEMs, the monitoring could be more of a technical challenge and would involve provision of KPIs and their trends to identify how various ships are performing in relation to energy efficiency. In most cases, one or each set of EEMs (e.g. hull maintenance) will have its own methods and KPIs for monitoring purposes.

12.9.4. Energy Efficiency Training of Staff

Increasing the energy efficiency awareness of the shore-based and ship-board staff by means of training can lead to a change in behaviour that has positive impacts on the reduction of ship-board energy use and fuel consumption. For effective implementation of the company's energy efficiency policy it is necessary to raise awareness and providing the necessary training both for shore based and shipboard personnel.

The company should ensure that as part of each crew member's initial on-board familiarisation, they are instructed on the part that they each can play in reducing on-board ship fuel consumption. The company may also consider the implement 'Computer Based Training (CBT)' program and poster campaign to increase crew awareness of GHG emissions issues. There should be regular on board meetings with all the crew to discuss the effectiveness of the shipboard energy efficiency plan. Ideas of best practice received from the seafarers should be documented and passed back to shore so that they can be evaluated for use on other vessels and perhaps included in a company-wide energy efficiency bulletin.

It is often a good policy for officers and in particular senior officers joining company vessels to be briefed in the shore office by the superintendent responsible for implementing the energy efficiency plan. The senior officers should be asked to study the documented energy policy, relevant SEEMP and be familiar with CEnMS, if applicable. This familiarisation should be assessed and verified prior to joining the vessels. If this is not practical for officers at operating level, then they should be required to study the policy document on board and confirm that they have read and understood it. The designated on-board environmental officer may consider regular on-board awareness and training programs for shipboard personnel which could form part of the on-board Safety Management System (SMS) training program. The results of these training sessions should be reported back to shore office for information.

Company management should also provide regular updates to explain how well the company is performing and if practical provide incentives for those ships or employees that demonstrate both results and commitment to the company's energy policy and objectives. The company magazine or other publicity documents could contain regular articles on not only the company's policies and objectives but general articles of the causes and effects of GHG emissions is a global problem that requires input and efforts by all.

12.9.5. Summary Main Features of Company Energy Management System

A good energy management system will have the following main characteristics:

Corporate leadership:

- Management understanding and commitment via a written energy efficiency policy.
- Allocation of resources (man-power, funding etc.) for implementation.
- Review of energy management performance and setting targets for continuous improvement.

Planning aspects:

- A documented energy efficiency plan is in place.
- Energy efficiency plan is linked to policy, programme and targets on energy efficiency.
- Energy efficiency measures are fully documented and ready for implementation.

Human resources and training:

- Energy management roles and responsibilities and team are defined and operational.
- Increasing awareness through communication and training have created the personnel's commitment and support.
- Recognition system for energy management achievements is in place.

On technical and operation management

- This includes considering energy efficiency in ship design, purchasing of material and equipment, maintenance and ship operation.
- Accurate analysis of the energy use in all processes and equipment is in place.
- Best-practice performance monitoring for assessment of success level.
- Best-practice maintenance of equipment for energy efficiency.
- Operation profile controls and ship itinerary (activity) management are important aspects in this regard.

Information gathering and management

- Company collects and keeps history of accurate energy use and performance data.

- Clear and effective communication procedures are in place to keep the staff and external stakeholders informed of progress.
- A proper information management system is implemented.

Reviews and assessment

- The organisation monitors and controls the energy management system performance on a continuous basis.
- The organisation has in place appropriate KPI's for checking the energy management performance.
- The organisation conducts management review on a regular basis to track the achievements and identify opportunities for further improvement.

12.10. Energy Audit and Review

12.10.1. Introduction

Energy audits or reviews are key to a systematic approach to an effective planning for energy management. It represents a quantitative assessment of a company/facility/ship energy inputs and outputs and attempts to balance the total energy inputs, output and losses at top level as well as for major energy using systems and equipment. As such, it is used to assess all the energy streams in a facility (such as a ship) with the main objective of identifying ways to reduce its energy consumption, energy baselines and so on.

Energy audit or review helps to understand in detail about the ways energy and fuel are used in any industry, thus helps in identifying the areas where waste can occur and where scope for improvement exists. The scope of an energy audit or review varies from industry to industry but generally could include supporting the corporate aspects such as reducing energy costs, reducing environmental impacts, ensuring availability and reliability of supply of energy, use of appropriate energy mix, identify energy conservation technologies, retrofit for energy conservation equipment etc.

Energy audit or review seeks to identify the technically feasible energy conservation solutions taking into account economic and other organizational considerations within a specified time frame. Energy audit and reviews are mandated activities in some of the existing management standards. For example, in development of a CEnMS based on ISO 50001, carrying out energy review is a requirement.

Another example is the EU Directive on Energy Efficiency [Directive 2012/27/EU] that makes energy audit of enterprises a requirement unless they are certified for ISO 50001 that implies they have already undertaken an energy review.

So, in terms of requirement, various standards may have a varied level of requirements on how energy audit or review should be done or documented. For example, on the need for documentation and certification, ISO 50001 advocates the following:

- The methodology and criteria used to develop the energy review shall be documented.

- The energy review shall be updated at defined intervals, as well as in response to major changes in facilities, equipment, systems, or processes.

However, technically speaking, energy audit and review are not that much different. As such, in this section, the techniques for carrying out an energy audit is described, assuming that same techniques could be used to perform energy reviews.

Energy audit is defined in EU Directive 2012/27/EU as:

"Energy audit means a systematic procedure with the purpose of obtaining adequate knowledge of the existing energy consumption profile of a building or group of buildings, an industrial or commercial operation or installation or a private or public service, identifying and quantifying cost-effective energy savings opportunities, and reporting the findings."

EU has also developed European standards for energy audits. EN 16247:2012 series of standards provide more formal techniques for energy audits. An abstract of EN 16247-1:2012 states that [CEN website]:

"This European standard specifies the requirements, common methodology and deliverables for energy audits. It applies to all forms of establishments and organisations, all forms of energy and uses of energy, excluding individual private dwellings. This European standard covers the general requirements common to all energy audits. Specific energy audit requirements will complete the general requirements in separate parts dedicated to energy audits for buildings, industrial processes and transportation."

12.10.2. Types of Energy Audit

The types of energy audit to be performed depend on:

- Function and type of industry (for example for shipping it will be somewhat different from a production factory).
- Depth and details to which the final audit is needed. This defines the scope of audit and what sort of output is expected from it.
- Potential and magnitude of cost reduction desired.

As a result, energy audit can have varied scopes; however, in general terms energy audits are classified into the following two types.

- Preliminary energy audit
- Detailed energy audit

Preliminary Energy Audit: A preliminary energy audit is a relatively quick review of energy performance of facility that aims to:

- Establish overall energy consumption and its profile in the organization/facility.
- Estimate the scope for energy saving.
- Identify the most likely and the easiest areas that could provide saving potentials.
- Identify immediate (especially no or low-cost) improvements/ savings.

- Set a 'reference point' or establish a baseline for the organisation/facility.
- Identify areas for more detailed study/measurement for subsequent assessments.

For preliminary energy audit, normally existing or easily obtainable data are used and does not include any independent measurement campaign. A preliminary energy audit is sometimes referred to as a "walk-through energy audit" as it does not involve significant level of data analysis.

Detailed Energy Audit: A detailed energy audit provides a more comprehensive approach to the issue with detailed data gathering and data analysis for identifying and analysing the EEMs. It aims to provide enough information to enable decision making process or development and planning of energy saving projects. It effectively evaluates all major energy using systems. This type of audit offers the most accurate estimate of energy savings and cost. It considers the interactive effects of all energy saving measures, accounts for the energy use of all major equipment and includes detailed energy cost saving calculations and project costs.

In a detailed energy audit, one of the key elements is to establish the energy balance for the facility or organisation. This is based on an inventory of energy using systems, assumptions of current operating conditions and calculations of energy use. This estimated energy use, together with some degree of system modelling that compares well to the actual fuel and energy used, can provide insight into the way energy is procured and consumed.

12.10.3. Ship Energy Audit Process

12.10.3.1. Ship Energy Audit Process Overview

A ship energy audit is considered as a specific energy audit that is tailored made for evaluation of a ship energy performance and identification of a ship's Energy Efficiency Measures (EEMs). It is therefore a review and assessment of the overall fuel/energy consumption and efficiency of a ship with the main objective of identifying a set of EEMs *(The ship's EEMs refer to those operational, technical and technology upgrade aspects of a vessel that if implemented, would lead to improved energy performance of a ship)* that when implemented would lead to reduced ship's fuel consumption. Identification of EEMs is the first step for development and implementation of a ship-specific energy saving programme as well as developing an organisations' energy management system (i.e. CEnMS) and a ship's energy management plan (i.e. SEEMP).

In ship energy audit, the focus is on identifying the existing status of a ship's operational processes and technical activities, and their comparison to best-practice or benchmarks. The analysis, depending on scope of the energy audit, involves some level of data collection and data analysis. As a result, areas of energy savings are identified, analysed and documented.

Figure below shows the generic process diagram for such an energy audit / review.

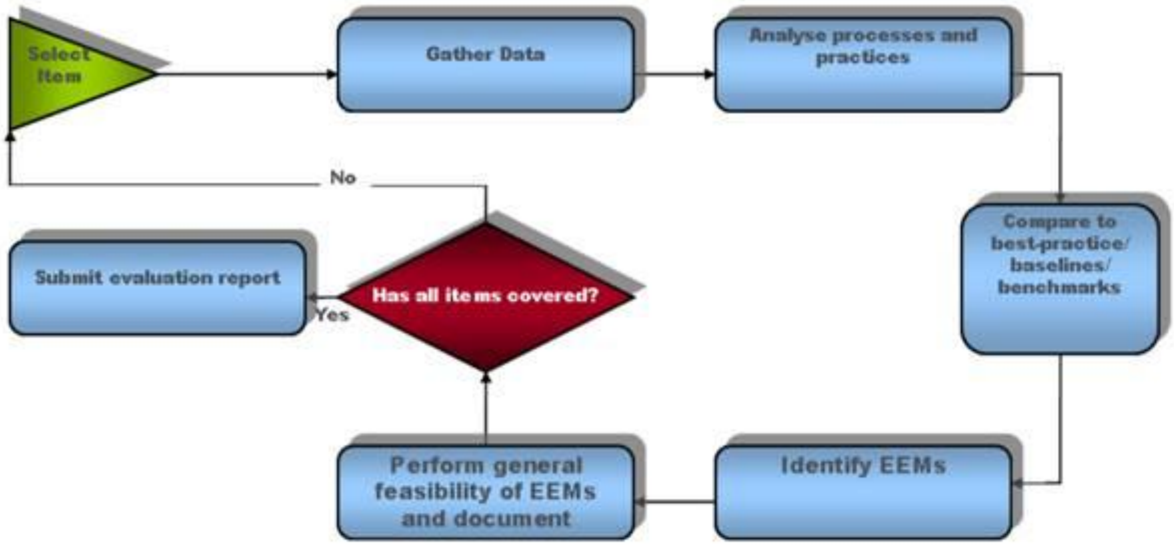


Figure 12.16: Energy audit or review process [Bazari 2012]

In figure above, each "item" (see green triangle) could be a ship engineering system, machinery / equipment or operational activity that needs to be systematically analysed for energy efficiency. For each "item", relevant data need to be collected, and relevant benchmarks defined. Table and figure below show examples of main areas and aspects of a ship that should be investigated one by one as part of the ship energy audit.

Hull condition and performance
Ship's operation and fuel consumption profiles
Ship voyage management and weather routing
Main engine's condition and performance
Auxiliary engines' condition and performance
Ship's auxiliary electrical loads reduction
Auxiliary machinery utilisation and performance

Fuel quality and fuel treatment system
Lighting system and types of lamps
Compressed air system
Steam boilers
Steam system and piping condition
Technology upgrade potential (equipment retrofit)
Personnel training needs
Etc.

Table: Ship energy audit – Example areas to be assessed

Figure 12.17: Ship energy audit – Example areas to be assessed [DNV 2011]

12.10.3.2. Ship Energy Audit Phases

Generally, a ship energy audit involves a ship-board survey and thus the audit as a whole may be carried out in three phases:

- **Phase I** – Pre-audit: This relates to all activities before the ship visit and survey. Activities under this phase could include:
- Preliminary data gathering: The data would include ship's design data, speed trials data and operational data.
- Initial data review: The preliminary data gathered are reviewed, preliminary candidate areas for further investigation are identified, some benchmarks are developed and the shipboard "energy audit" plan is prepared.
- **Phase II** - Audit: This includes ship survey, data analysis and reporting. Activities under this phase could include aspects such as: o Ship energy survey: The ship is visited and the planned survey activities are carried out, facilitated by ship personnel. This stage consists of a number of activities that involve walkthrough of ship engine room, deck and cargo control room, brainstorming and discussion with relevant personnel in particular the master and chief engineer and detailed investigations and data gathering from relevant record books, manuals, digital archives, etc.
- Data analysis: Final data analysis is performed with the objective of identifying the final list of EEMs, their relevant energy saving level and the techno-economic feasibility analysis of each EEM.
- Energy audit report: A report inclusive of findings and supporting evidence is prepared.

- **Phase III** – Post-audit: This refers to activities that may be needed to support the post audit implementation by the client.

12.10.4. Typical Data Analysis

12.10.4.1. Ship Operation Profile

For improved voyage management and itinerary optimisation, evaluation of ship operation profile is an important area. The objective of this evaluation is to make sure that the itinerary and voyage management are planned and performed according to best practise. The assessment of ship operation profile will normally give an indication of excessive waiting periods or lack of ship activity. For this purpose, the ship duration of stay in ports, anchorage, etc. is an important factor that needs to be evaluated. Figure below shows an example of such a profile for an oil tanker.

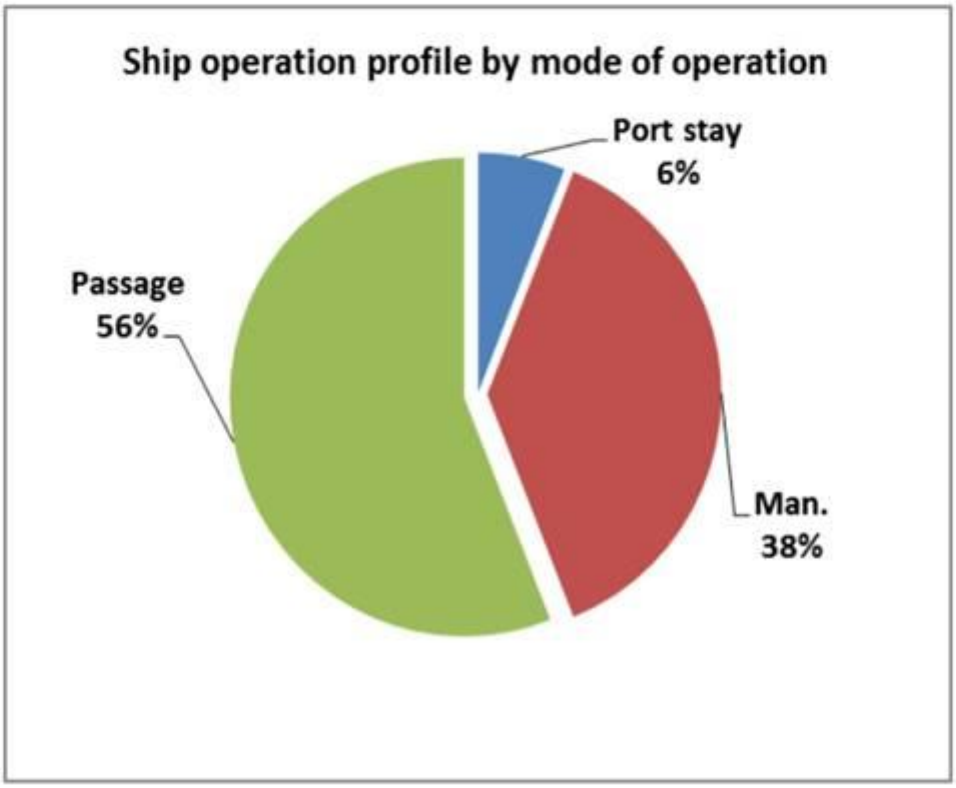


Figure 12.18: Typical ship's operation profile by operation mode

Analysis of the above timings for this tanker then need to be carried out against ideal cases with no waiting by considering time for loading, unloading and bunkering, etc. As a result, it could be decided if there are opportunities for improvement or not.

12.10.4.2. Fuel Consumption Profile

The ship fuel consumption profile represents the balance of fuel used by different combustion systems (e.g. main engines, auxiliary engines and boilers). It can give an indication if any of the ship systems consume relatively higher fuel compared to expected best-practice levels. This then could be a good lead for further investigations of the causes of excessive fuel consumption and thereby identification of energy efficiency measures.

Figure below shows an example of a ship's fuel consumption profile, indicating percentages of fuel used by various systems. Comparing these with industry benchmarks and other ships in the fleet will indicate if any of the system may have been used inefficiently.

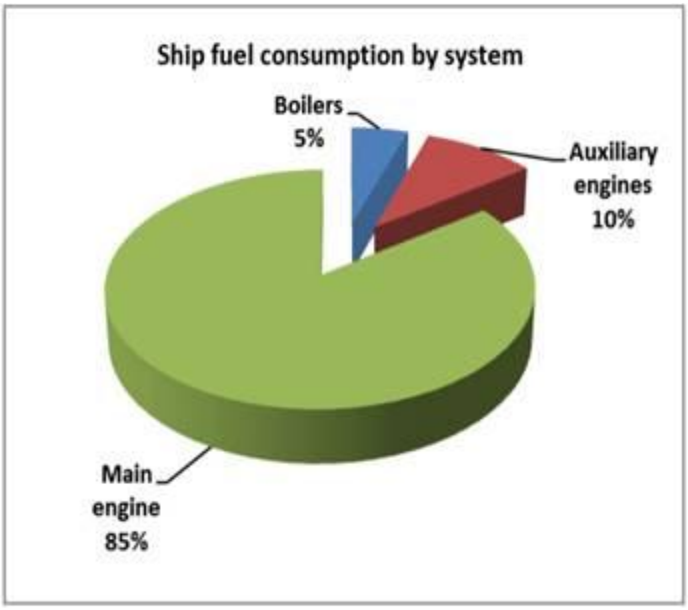


Figure 12.19: Ship fuel consumption profile by system

12.10.4.3. Hull Performance Assessment

Analysis of a ship's speed-power or shaft rpm-power is the main analytical way for identification of hull and propeller fouling (see figure below. Under-water inspection of hull and propeller is an alternative technique. The data analysis techniques used for this type of investigations are similar to those performed under "ship performance monitoring".

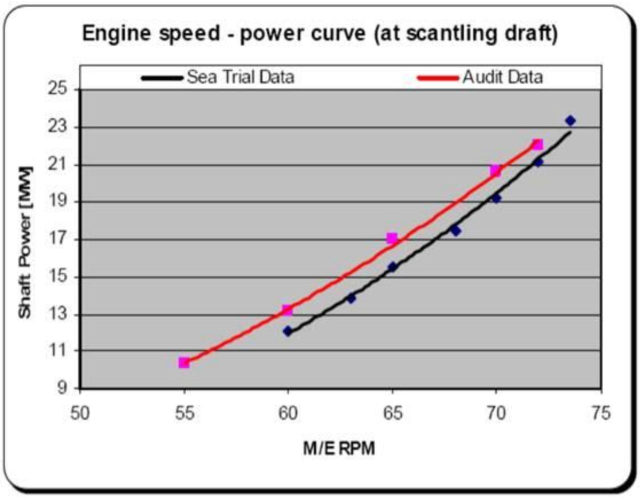


Figure 12.20: Speed-power curve analysis [Bazari 2012]

12.10.4.4. Engine Performance Assessment

The methodology used for engine performance assessment (for both main and auxiliary engines) is based on what is normally used on-board for engine's condition and performance monitoring. Almost all ships perform engine cylinder pressure measurement (see figure below as example). The system used normally analyse the cylinder pressure diagram and fuel injection profile (if measured) that would indicate anomalies with fuel injection system, cylinder liners, piston rings of engine valves. This test and its analysis are normally carried out on a monthly basis as part of the ship's planned maintenance system.

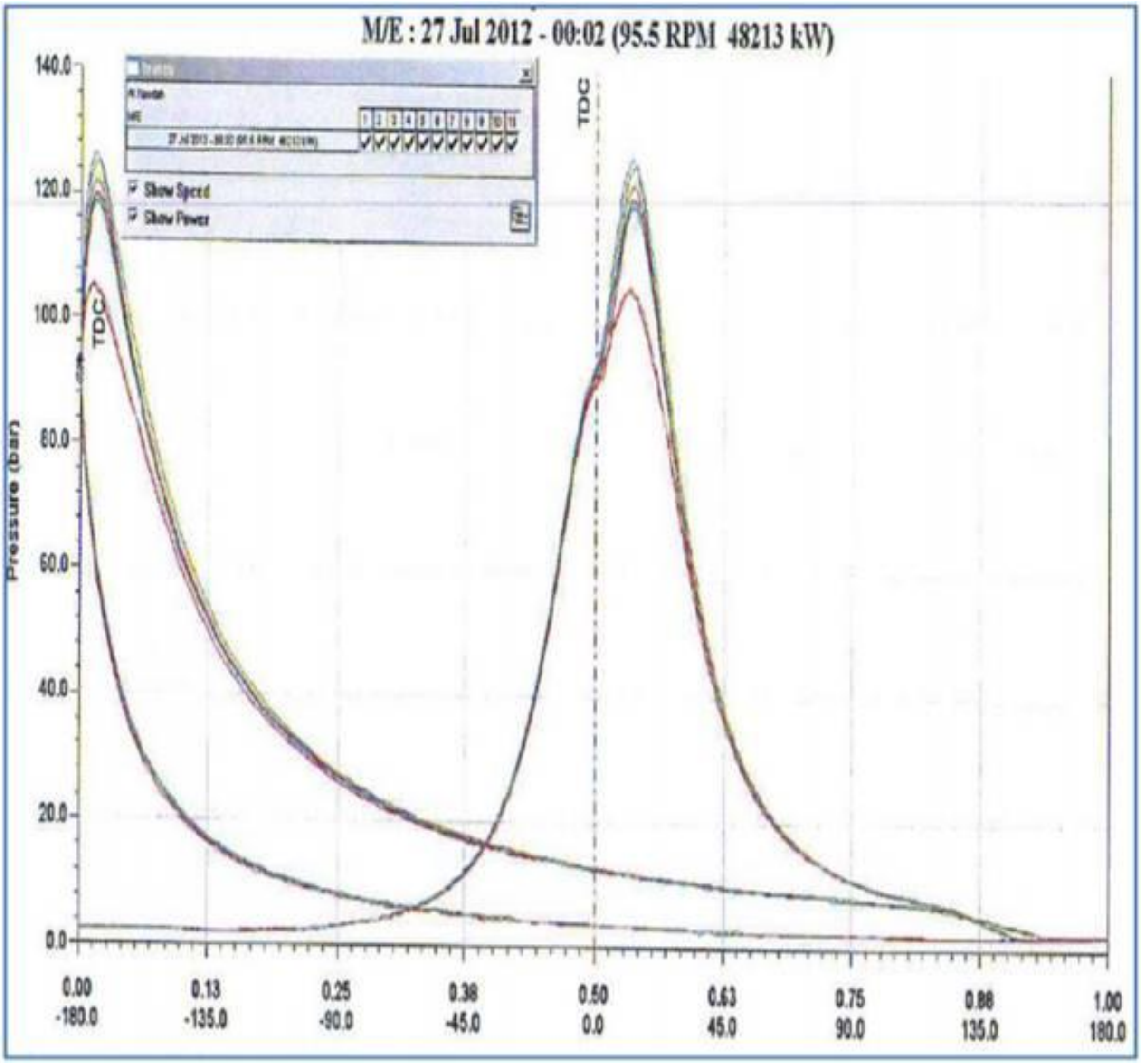


Figure 12.21: Typical on-board cylinder pressure measurement [Bazari 2012]

Such monthly data are normally available on-board ships and can be gathered and analysed for this purpose. Additionally, data such as turbocharger speed, scavenge pressure and temperature can be used to re-enforce if the engine is optimised or not. The techniques used during energy audit to assess the performance of the engines are similar to those used for engine performance monitoring.

12.10.5. Techno Economic Analysis

Identification of EEMs and their potentials for energy saving does not warrant that the saving potential could be realised in practice. Technical aspects and/or economic aspects could act as barriers.

Therefore, each EEM needs to be assessed both technically and economically to find out if they are feasible and cost-effective. As part of the energy audit, such preliminary techno-economic analysis of each identified measure may be carried out.

For a company who is serious about energy saving and efficiency, the techno-economic feasibility will be very important to be carried out correctly. The reason for this is that:

• The choice of EEMs for implementation purposes should be based on a sound technical feasibility assessment by the company. The barriers for proper implementation needs to be identified and planned to be resolved if the EEMs are going to be included in SEEMP and CEnMS.

• Implementation of any measure for energy saving will involve cost either in the form of additional capital or operating expenditures plus additional staff time that can be converted to money as cost.

• Taking these costs in relation to energy saving and cost saving will indicate the cost effectiveness of the adopted measure.

12.10.5.1. Technical Feasibility Assessment

The technical feasibility aspect focuses on mainly design, operation and technical aspects as well as shipboard details such engineering changes needed, space availability, etc. The extent of technical feasibility study depends on the type of the measure. The preliminary feasibility can be assessed as part of the energy audit during ship survey; however, for major investment EEMs, the ship owner would normally carry out further technical feasibility studies before implementation.

For a specific case of slow steaming or virtual arrival, as suggested in the section on contract of carriage a particular ship on a particular voyage on a particular contact may or may not be able to slow steam or apply virtual arrival techniques, which is why both the ship managers and chartering department must be involved in any policy decision or feasibility analysis of the proposal. Efficiency is also dependent on ships being of a suitable design and size for trade. There must however be sufficient transport demand. Use of large ships may be constrained by port, canal, lock, berth dimensions, cargo gear capacity and the depth of the approach channel. If this is the case the cargo may have to be trans-shipped from a hub port by feeder ships which are smaller and less efficient so negating the gain of using the larger ships particularly with the extra energy and cost of discharging and loading on to another vessel. So, these are the aspects that need to be taken in the technical feasibility of this specific proposal.

12.10.5.2. Economic Cost-Effectiveness Assessment

Perhaps the most important factor when considering energy management is the cost of fuel that can either make or break a GHG strategy particularly when it involves buying expensive equipment to reduce fuel costs. Some approaches to reduce GHGs emissions are only financially viable when oil prices reach a specific level and are expected to stay above that level long enough to provide an adequate financial return on the investment in the particular energy efficiency improvement method. There will therefore always be an element of financial risk or reward when deciding on such policies especially when the price of fuel is volatile. When the price of oil is high, many measures are becoming cost effective, and return on investment is proportionally linked to fuel price and is higher. The economic assessment of the measures is required to show if the measures are economically cost effective. For economic evaluation, capital costs and running costs (energy use, maintenance, manning, etc.), and fuel price need to be considered. Economic data is normally difficult to find, and they are changing from one ship to another. The extent of economic assessment depends on the type of measure. Economic assessment could be based on simple pay-back period calculations or somewhat more involved methods such as Net Present Value (NPV) techniques. For preliminary feasibility analysis, simple pay back is sufficient. The main techniques are described below [MEPC 62/INF.7].

12.10.5.3. Payback Period

The simplest method to evaluate investments is by estimating the payback period. The payback period is simply the investment divided by the net savings per period. The investment will include cost of technology plus installation. The net saving will include saving due to fuel cost minus any additional operating costs (personnel, maintenance, etc.). For example, an investment of $1000 that saves $400 annually has a payback period of 2.5 years. While the payback period is often used as a rule-of-thumb evaluation of investments, it has some disadvantages. First, it does not properly account for the time value of money as it has no discount rate. Second, it gives no information on the total profits over the life of the investment.

Net Present Value (NPV)

A more sophisticated way to evaluate new investments is the Net Present Value (NPV). It is an indicator of the value of an investment. By definition, this is the difference between the capital costs of an investment and the present value of the future flow of profits. The formula for NPV is:

$$\boxed{NPV = R_0 + \sum_{t=1}^{T} \frac{R_t}{(1+i)^t}}$$

Where:

• R_o – the investment at t=0; to be given a negative number.

• T – the lifetime of the investment

• R_t – the net cash flow (cash inflows minus expenditures) at time t

• i – the discount rate

When calculating the NPV, assumptions must be made on the lifetime of the investment and the discount rate must be determined. The discount rate can be based on the company's borrowing rate or cost of capital or any other rate the company uses for such investments.

For example, an investment of $500,000 today is expected to return net $100,000 of cash each year for 10 years. The $500,000 being spent today is already a present value. However, the future cash receipts of $100,000 annually for 10 years need to be discounted to their present value. Let's assume that the receipts are discounted by 14% (the company's required return). This will mean that the present value of the future receipts will be approximately $522,000. The $522,000 of present value coming in is compared to the $500,000 of present value going out. The result is a NPV of $22,000 coming in.

Investments with a positive NPV would be acceptable and those with negative NPV value would be unacceptable.

Internal Rate of Return (IRR)

Another way to evaluate investments is to calculate the internal rate of return (IRR). It is an indicator of the yield of an investment, not of its value. By definition, the IRR is the discount rate for which the NPV is zero. Therefore, the above formula for NPV can be used but this time NPV=0 and T that is the lifetime of investment is assumed to be known (e.g. 5 years). The term "i" here is referred to as IRR and needs to be calculated. This is a more sophisticated way of appraisal of investment than the payback period that does not consider any discount rate at all.

NPV is the most accurate approach to evaluate investments as it gives information on the total expected profits and requires the cost of capital as an input in addition to the assumption on the lifetime of the investment. It is not the intention of this course to evaluate the differences between the above economic assessment methods. For those engaged in energy saving activities and not the economic decision making, the simplest method of pay-back period calculation will suffice.

12.10.5.4. MACC and its Development

For overall presentation of cost effectiveness of results as well as potential CO2 reductions for a ship or a fleet and for management purposes, development of MACC (Marginal Abatement Cost Curves) for the company fleet or ships will be a useful way of communicating the results and priorities on the basis of each EEM and as a whole.

Additionally, and apart from ship energy audit, the economic assessment of the EEMs is of utmost importance in CO2 reduction activities. Many organisations including IMO have carried out studies in this area. The basic requirement is that how much it costs to reduce CO2 emissions when different measures are implemented. Off course the answer will be specific for each ship.

To answer the above quest, calculation of the Marginal Abatement Cost (MAC) is advocated. Also, presentation of results in the form of MAC Curve (MACC) is commonplace. In shipping, SNAME and IMarEst collaboratively have conducted a comprehensive study of MAC. Some of the material in this part is taken from this report [MEPC62/INF.17].

What a MACC shows

Marginal Abatement Cost Curve (MACC) is used to show potential CO2 reduction of various EEMs versus associated costs/benefits in a very visual and simple way. The MACC shows the reduction potential (tonne/year) and abatement cost ($spent/tonne CO2 reduction) on one diagram. A typical one developed for international shipping as a whole is shown in figure below as example. The X axis represents CO2 reduction potential and Y axis shows the relevant costs per unit of CO2 abatement.

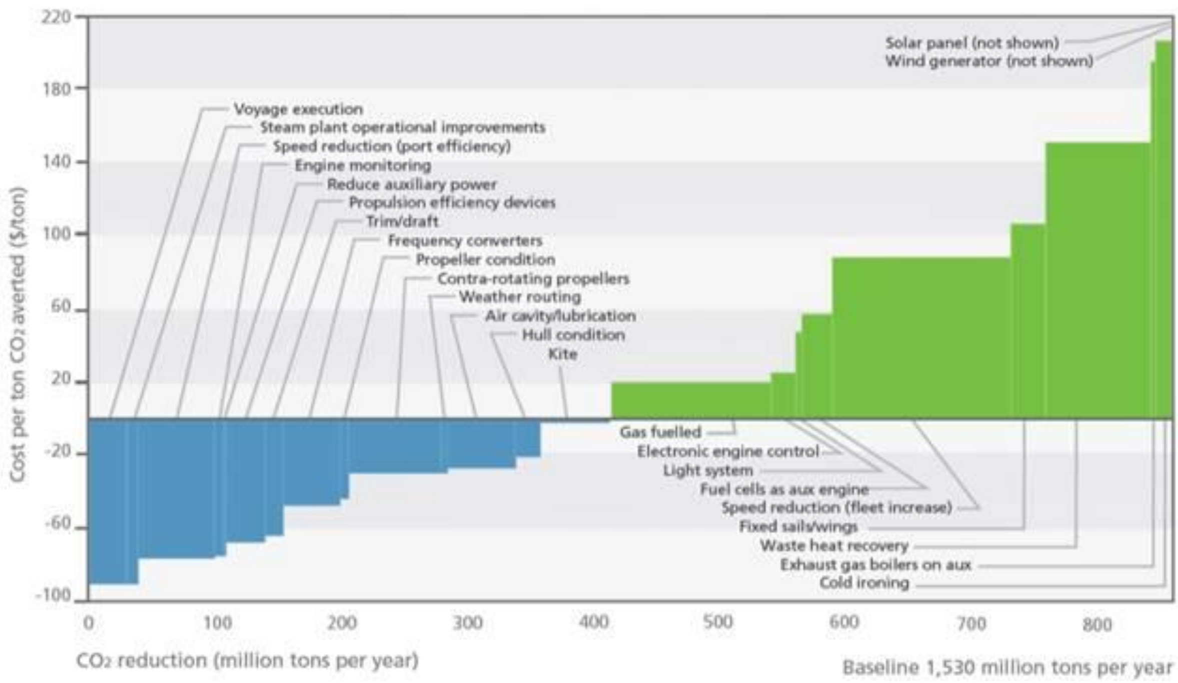


Figure 12.22: Typical MACC for international shipping [DNV 2010]

How to develop a MACC

To develop the MAC curve as in figure above but for a single ship, the following steps need to be taken:

1. Step 1 – Identify EEMs and their energy saving potentials in terms of for example percent reduction in the ship's fuel consumption. This is best to be done via an energy audit or review as explained above. From fuel consumption reduction, one can calculate the CO2 reduction level using relevant emission factor and normalise to an annual value. This will provide a number that later on could be used for X axis.

2. Step 2 - Calculation of the cost-effectiveness of individual measures: Cost-effectiveness is by definition the ratio of costs to saving levels both measured financially. There are

various financial methods to estimate the cost effectiveness including payback period, IRR and NPV as discussed earlier. However, and for CO2 studies, a far better method is use of Marginal Abatement Costs (MAC). The relevant calculations can be done as outlined below. The MAC calculation per unit of CO2 reduction will be used for Y axis.

3. Step 3 – Ranking and putting in order the EEMs from lowest MAC to highest MAC (i.e. lowest cost EEM to highest cost EEMs).

4. Step 4 – Plotting the MACC. Use the ranking system, each EEM represented by a rectangle where its vertical side is the MAC, and the horizontal side is the CO2 reduction level. These rectangles will be next to each other as shown in figure above.

Thus, MACC is formed by plotting of the cost effectiveness of measures against the resulting cumulative reduction in CO2 emissions. For each combination of ship type, size and age, there are a suite of technical and operational measures that can be applied, thus MACC for ships will change depending on their circumstances.

Simple formula for MAC development

The following formulas can be used to estimate the X and Y axis value for the MACC [MEPC62/INF.17].

$$\boxed{\Delta C_j = K_j + S_j - E_j + \sum O_j} \text{ - - - - - - - - - - - - -(1)}$$

Where:

• ΔC_j is the change of annual cost of for the implementation of EEM_j, estimated as per equation (1)

• K_j is the capital cost of the EEM_j, discounted by the interest rate and written down over the service years of the technology or the remaining lifetime of the ship, whichever is shortest.

• S_j is the service or operating costs related to the application of EEM_j.

• ΣO_j is the opportunity cost related to lost service time and/or space due to the installation of the EEM_j such as the cost of days off hire for the vessel; and

• E_j is the fuel cost savings as a result of the EEM_j, which is a product of the price of fuel and the saving of fuel as described in Equation (2).

$$E_j = \alpha_j \times F \times P \text{ - - - - - - - - - - - (2)}$$

Where:

• α_j is the fuel reduction rate of EEM_j (% reduction in ship fuel consumption).

• F is the pre-installation or original fuel consumption for a ship,

• P is the fuel price.

The MAC value is then calculated as the ratio of change in annual cost divided by the relevant reduction in CO2 emissions as shown in equation (3).

$$MAC = \frac{\Delta C_j}{\alpha_j \times CF \times F} = \frac{K_j + S_j - E_j + \sum O_j}{\alpha_j \times CF \times F} \quad \text{------------ (3)}$$

Where:

• CF is the carbon factor of fuel that shows the tonne CO2 generated per tonne of fuel burnt.

• F is total annual fuel consumption.

As the above formulas indicate, the main inputs to formulas are the estimated fuel saving potential in percent, the capital and operating costs associated with implementation of the EEM, the total fuel consumption of the ship (or any other system under consideration) and most important of all, the fuel price. Any uncertainty in the input data will make the result uncertain. For this reason, in developing MACC, evaluation of the sensitivity to input parameters should be considered. As some of the parameters are uncertain in particular the future fuel prices, this sensitivity analysis will provide a way to making a better financial decision.

12.11. Ship Performance Monitoring and Reporting

12.11.1. Ship Performance Monitoring and Reporting Introduction

In shipping industry, there has been a continuous demand and interest in ship performance monitoring (SPM) overall and also the monitoring of ship's major operations or machinery systems. When high fuel prices and air emissions control take centre stage in the marine industry, the urge to increase a ship's energy efficiency using SPM is normally higher. Additionally, the more sophisticated engines with their recent developments in the combustion process (with thermal efficiencies reaching up to 52%), waste heat recovery systems (with reported benefits of 10% extra energy efficiency), use of emission reduction technologies such as SOx scrubbers and the persistent issues of variable quality fuel; all dictate a closer monitoring on the fuel engine itself, and exhaust system as a matter of best practice. The propulsive (hull and propeller) efficiency can be improved significantly by reducing hull and propeller surface roughness. Frictional resistance forms about 70- 90% of the total resistance of a ship for bulk carriers and tankers (approx. 50% for cruise liners and container vessels) and is directly affected by hull roughness, which in turn is affected by fouling. Keeping the hull and propeller smooth and free from fouling is therefore essential for optimal ship energy efficiency.

Hull fouling is affected by type of paints. In the past, hull fouling has been combated by antifouling coatings for example Tributyltin (TBT) that is now regarded as environmentally toxic. The complete ban on TBT in marine antifouling systems by the IMO in 2008 resulted in an increased use of biocide free foul-release coatings. There is not extensive experience on the effectiveness and performance of new paint systems in terms of long-term frictional resistance and fouling in service. The effectiveness of the coatings can be assessed by doing SPM over a long period and comparing speed and power capabilities with clean-hull performance.

As a result of energy efficiency regulations (see Module 2), a large number of energy efficient technologies has been identified that could be used on board ships. However, uncertainty in level of savings due to each technology, and inaccuracies associated with measurement and verification of saving level are major barriers for use of such technologies. An effective SPM would support the uptake of these technologies.

In this section, various aspects of ship performance monitoring (SPM) are discussed. Various methods are proposed, and main components of such systems are identified. The analysis methods, practical systems and scope of applications are discussed. The intention is to show that performance monitoring is a key technology for ensuring an effective ship energy management campaign that aims for a reduction in ships' fuel consumption and environmental pollutions.

12.11.2. Benefits of Ship Performance Monitoring

Knowledge and understanding of a ship's performance and condition in terms of a ship's speed and power, engines' condition, voyage performance, port operation performance, etc. are useful both from economic and environmental points of views. The following overall capabilities and benefits may be attributed to an effective and integrated SPM system [Thijs Willem Frederik Hasselaar]:

- **Assessment of hull condition:** If a proper hull performance analysis system can be developed, it could be an invaluable tool for assessment of hull roughness, hull fouling, the quality of coatings and paints. Also, it could be very effective in determination of the economically optimum intervals for hull cleaning or dry-docking with due consideration for economic penalties and delays due to fouling, etc.
- **Assessment of engine condition:** With a proper engine performance monitoring, the effects of any adjustments in the timing of injection system, valve timing changes or important engine faults such as worn or damaged piston rings, faulty injection, burned valves, fouled turbochargers, air filters, air coolers etc. can be evaluated and diagnosed. Such a system is needed for protection of the engines themselves that are high value costs and safeguards the safety of ships in addition to economics benefit of having the highest engine efficiency possible.
- **Feedback to a better ship design:** When the actual performance of a ship in service is known and the degradation after a number of years is evaluated, the correct service and engine margins can be estimated for definition of design point, definition of ship-propeller-engine matching as well as more informed choice of propeller and engine for future ships.
- **Improved commercial aspects for chartering and technology upgrade:** A more accurate estimate of the ship performance is essential not only for improvement to charter party agreements but also for use of energy efficient ships, and decision making on use of energy efficient technologies. When it is feasible to determine a ship's

performance accurately with due consideration to operational environmental and loading conditions, agreements between charterers and ship-owners or technology supplier and owners (for technology upgrade activities) can be defined more precisely.

- **Long term operational optimisation:** When the ships' performance and process parameters are measured simultaneously at frequent intervals and over time, a large database could be organised which facilitates more effective monitoring of a ship's or fleet's performance. Trim, draft, autopilot and engine settings in different environmental conditions are examples of areas that can be optimised. Moreover, with the availability of reliable information of the vessel's sailing performance, the ship's crew would be able to obtain a better understanding of the impact of their actions.
- **Environmental assessment:** As a response to global pressures caused by environmental concerns on ship GHG emissions and the introduction of CO_2 indexing schemes such as the IMO Energy Efficiency Operational Indicator [MEPC.1/Circ484] and Ship Energy Efficiency Management Plan [MEPC.203(62) and MEPC.213(63)], and current debate at IMO on data collection system; all in all, the requirements for continuous performance monitoring and benchmarking of fuel consumption, ship energy efficiency and exhaust emissions have increased. An effective SPM will support this process.

12.11.3. Performance Monitoring System Design

To assess the performance of a ship and provide the benefits outlined above, tools that would provide simple but would provide technically robust results need to be established. In an ideal case, the tool will be a total-ship integrated performance monitoring system that would provide not only an overall performance assessment of the ship but also specific assessment results for the propulsion system, engines, machinery and voyage optimisation. Figure below shows the basic concept of a ship performance monitoring system.

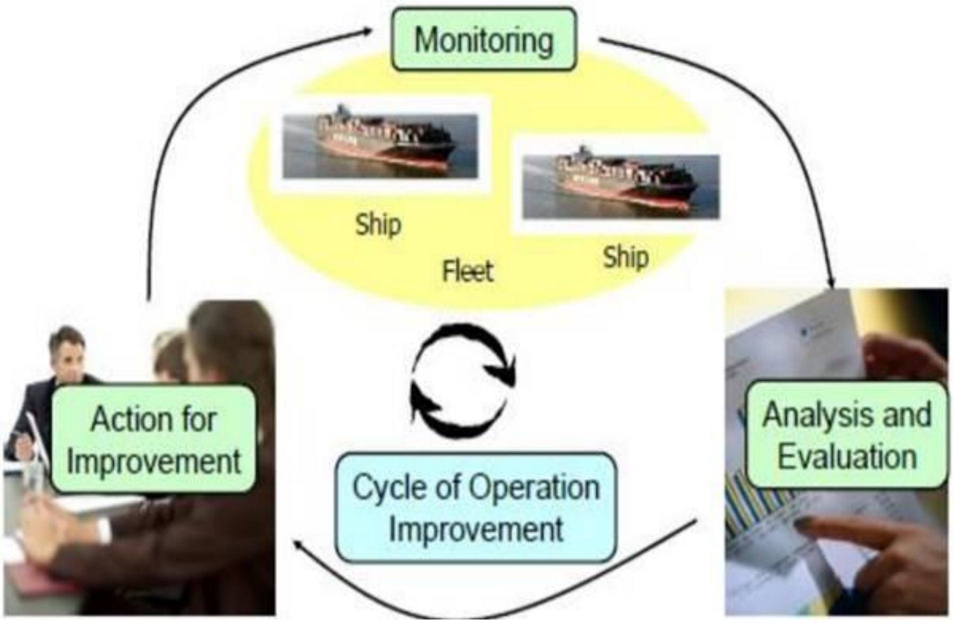


Figure 12.23: The general concept for a ship performance monitoring [Hideyuki Ando, NYK]

At the heart of a ship performance monitoring system is the data gathering, data analysis and data presentation aspects. This is conceptually shown in figure below.

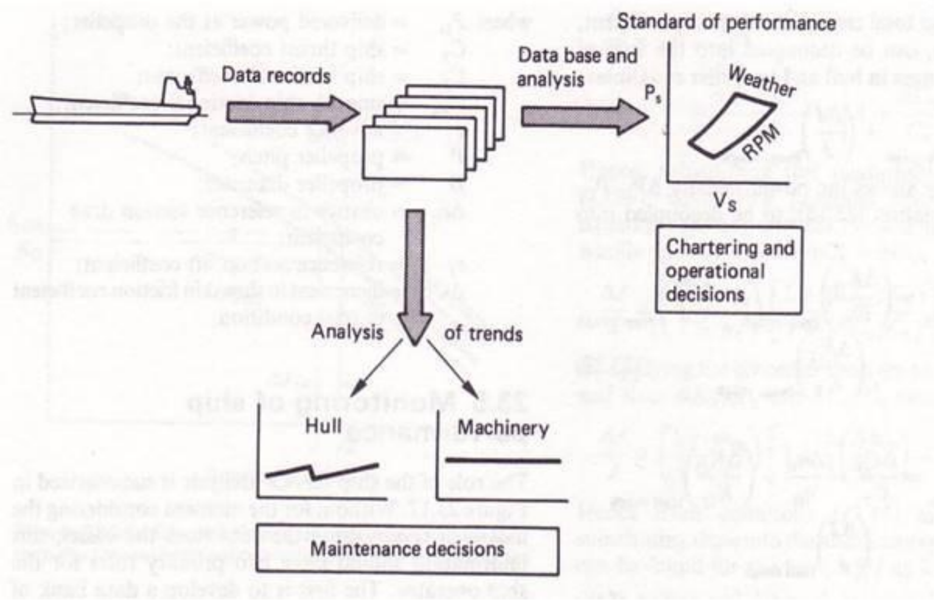


Figure 12.24: Performance monitoring data collection, analysis and presentation concepts

A SPM, depending on its design and purpose, could provide various functionalities. Generally, a SPM may include modules that provide capabilities in performance monitoring of the below aspects of a ship:

- Ship voyage and operation
- Hull and propeller
- Engines
- Auxiliary machinery
- Etc.

For an integrated performance monitoring system, detail information by using automatic data collection and analysis are necessary. There is a need to go through feedback loops for operation performance improvement as indicated in Figure 33.3.1. The combined system, especially the combination between voyage performance, weather routing and performance monitoring is important. An integrated SPM provides organisational improvement process for energy efficient fleet operation that is in-line with IMO activities with regard to SEEMP, EEOI and future data collection and reporting.

The issue of design and development of such a system is out of scope of this section; suffice to say that a good design for a condition or performance monitoring will include [Hideyuki Ando, NYK]:

- Interface to existing on-board equipment and data systems is essential as already most of the required data are measured on-board ships.
- Automatic data processing and transferring to shore.
- Least additional workload on crews.

- High reliability and 24/7 operation.
- Low cost of implementation.
- Flexibility of customization to existing ship-board systems.

12.11.4. Types of Performance Monitoring Systems

Broadly speaking, the SPMs can fall into the following three main categories based on their method of data collection and analysis:

- Manual: Systems with manual data logging, data analysis and reporting (for example once every 24 hours)
- Automatic: Systems with automatic data logging, data analysis and reporting (sampling can be every 1 sec or above and analysis can be either scheduled, continuous or on demand).
- Hybrid: Hybrid systems with some manual and automatic elements.

In practice, most of the systems are of hybrid nature with some elements of manual data logging or actions on data. Some are significantly on the manual side, and some are significantly on the automatic side.

12.11.4.1. Manual Systems

The manual systems normally rely on data that are gathered manually from various measurement devices or logbooks. On-board most merchant ships, daily logbooks are used to record the engine, fuel, navigation and cargo parameters for monitoring and regulatory purposes. Engine-logs are mainly of interest for engine maintenance and provide technical data to assess the condition of the engine and machinery. Deck- or navigation logbooks are used for voyage planning, insurance/safety and ship handling analysis, while loading logbooks are used for stability assessment, cargo planning etc. Additionally, there is significant additional ship-board information such as fuel oil analysis records, engine condition analysis records, etc. that could be utilised.

Engine and deck logbooks are traditionally filled-in either once a day (noon-noon logs) or every watch (4 hours) and averaged over 24 hours to form ‘log abstract’. The number of variables that are logged depends on the requirements from the shipping company, the available instrumentation and the motivation and training of the crew [Thijs Willem Frederik Hasselaar]. A typical deck log contains information about the ship’s position, speed, propeller revolutions, slip, draft, and sea state. A typical engine logbook will include engine-related data such as power, rpm, temperatures, fuel oil consumption, etc.

Because logbooks are used on all ships, they are often used for performance and condition monitoring; primarily by the chief engineers. Their wider application for ship performance monitoring is limited since ship performance monitoring requires a higher level of data resolution and accuracy than what logbooks can provide. Also, the details in the logbook are average values for a long period of time (e.g. 24 hours) that hides some of issues from observation. The following shortcomings of manual data logging can be named [Thijs Willem Frederik Hasselaar]:

- Uncertainty in the used instrumentation. To increase redundancy, critical sensors for ship performance are often duplicated. Experience indicates however that duplicate instruments often show differences. Unless well described, this causes confusion in which instrument indicates the best true representation and should be used for performance monitoring. Furthermore, if the source of the instrument is unknown, the reliability of the logged data is low.
- Wrong data collection timing: A time lag of an hour in sampled data may represent two completely different performance conditions if environmental or sailing conditions have changed in this period. Most parameters, such as torque, are affected by even the smallest change in environment, and require therefore that all parameters are logged at the same time.
- Insufficient training: If parameters cannot be measured using dedicated instruments, for example for measurement of sea wave characteristics, visual observations must be made. They can be accurate, if done by highly experienced officers, but change of shifts and quick changing vessel crew causes inconsistent observations.
- Inaccurate data collection: Certain parameters (wind, speed, torque etc.) must be averaged over a time period to be meaningful. Spot measurements result in errors. Furthermore, it is normal practice for officers to enter higher sea states than actually experienced in order to cover the vessel if delays are experienced (due to engine problems, strong currents, course alterations etc.). This may be done to avoid claims from the charterer on the level of a vessel's capabilities.
- Limited logging frequency: The high workload of the officers on duty limits the logging frequency for performance monitoring. With the recent increase in regulations, the number of administrative tasks and safety checks has increased dramatically with many officers complaining that there is little time left for watch keeping and optimal ship operation.
- Errors in data entry: Experience indicates that abstract logbooks frequently contain data inconsistencies, e.g. wind, water and ground speeds are mixed up, unrealistically high or low parameters are entered or relative wind instead of true wind speed is logged. The errors may be the result of unclear logging protocols, inaccurate sensors or insufficient training. In such cases, error tracking is difficult.

On the positive side, with the developments in satellite communication, internet and email, electronic logbooks have emerged and are used more and more. They replace paper abstract logbooks and enable logs to be send via email or web to shore, allowing ship performance to be analysed on a daily basis. Furthermore, with electronic communications, it is easier to identify anomalies directly at source and, if applicable, daily feedback of the ship's operation can be sent back to the vessel. The data however still represents manual spot measurements with relevant key weaknesses.

12.11.4.2. Automatic Systems

With the introduction of electronic remote measurement and wireless data transmission from ships, it is now possible to collect many ship performance parameters electronically. A central data acquisition system interconnected to all necessary instrumentation can monitor and store data for either instantaneous or offline analysis (see figure below for the concept).

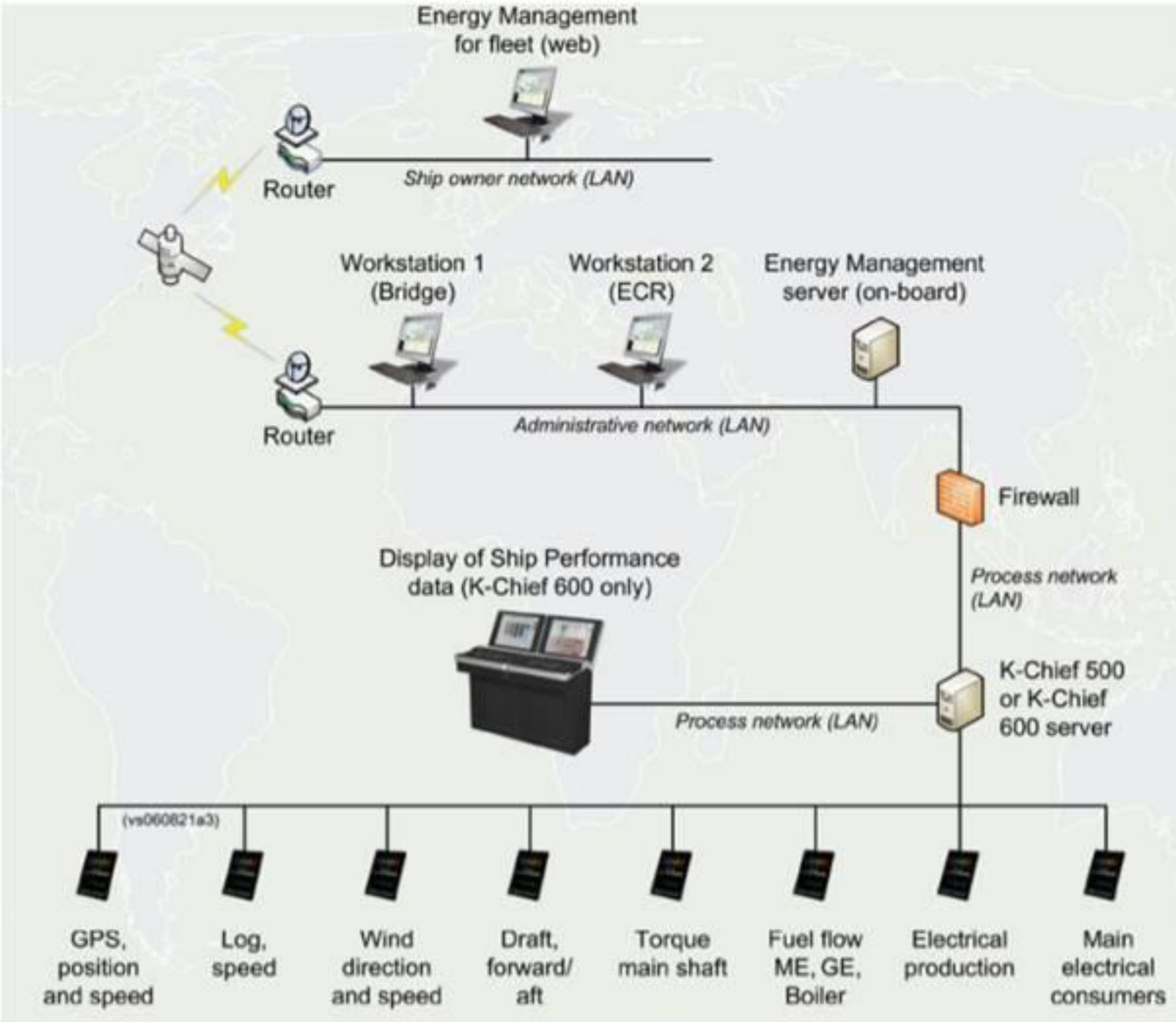


Figure 12.25: Automatic systems using satellite navigation [Kongsberg]

The automation of data collection has the following advantages:

- Contributes significantly to the improvement of data quality.
- Allows signal validation, filtering and averaging for increased accuracy and reliability
- The source and characteristics of each sensor can be described and documented accurately, which reduces the uncertainty and errors in data entry
- Automatic data collection allows real-time data analysis, which can be used for monitoring for alarm in extreme operating conditions or real time feedback on vessel operation.

An example of automatic data logging systems is a ship's Voyage Data Recorders (VDR). A VDR is an automatic data logging system for accident investigation collecting information concerning the position, speed, physical status, command and control of a vessel over the period leading up to and following an incident [Thijs Willem Frederik Hasselaar]. Based on IMO regulations, use of VDR (that is like a black box) is mandated on certain ship types and sizes. Many parameters logged by a VDR are required for performance monitoring. The use of the VDR data for performance monitoring is not advocated here; however, an automatic performance monitoring system will provide similar type of data collection functionality.

12.11.5. Hull Performance Monitoring

12.11.5.1. Introduction

It is well known that ship resistance increases with service life. Figure below shows the ship resistance caused by degraded hull and propeller conditions, at design draft and design speed, as a percentage of the total ship resistance "as new".

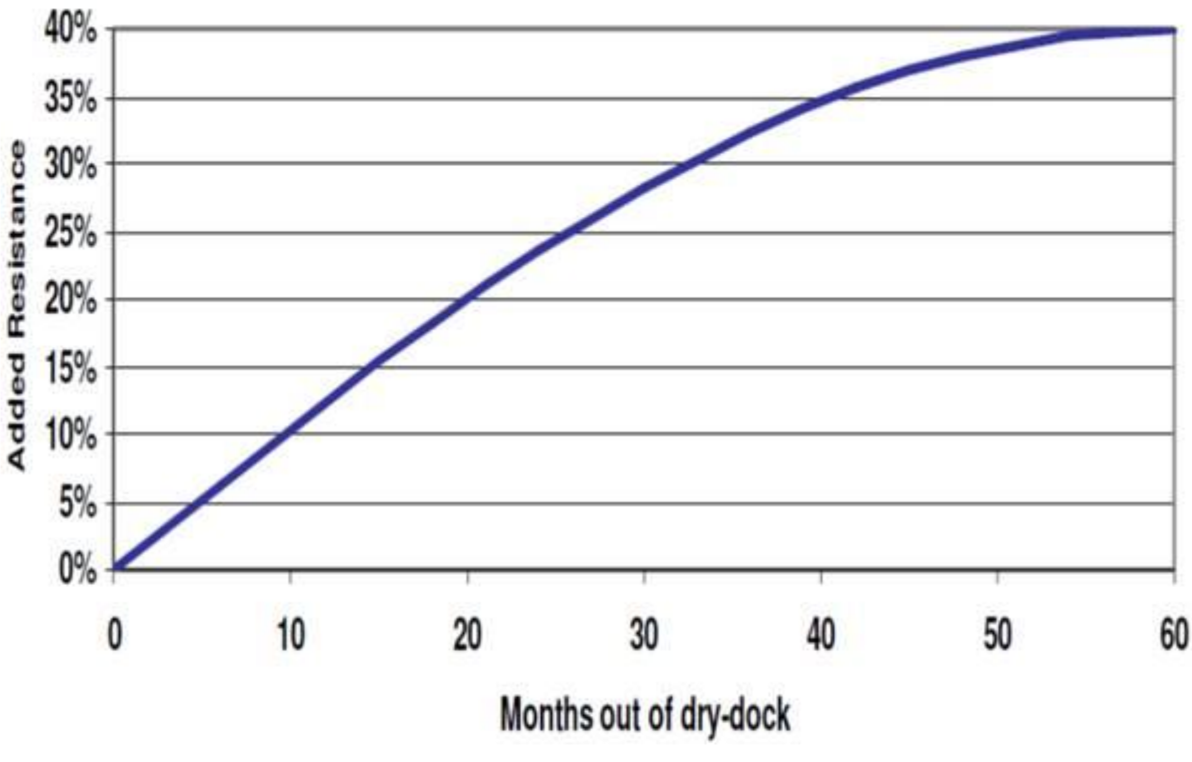


Figure 12.26: Development of added resistance normally expected as a function of time [Torben Munk]

The addition of added resistance would lead to higher power required from the propulsion engine and thus higher fuel consumption. Typical increases reported is shown in figure below as example that indicates reduction of fuel consumption before and after hull brushing and cleaning.

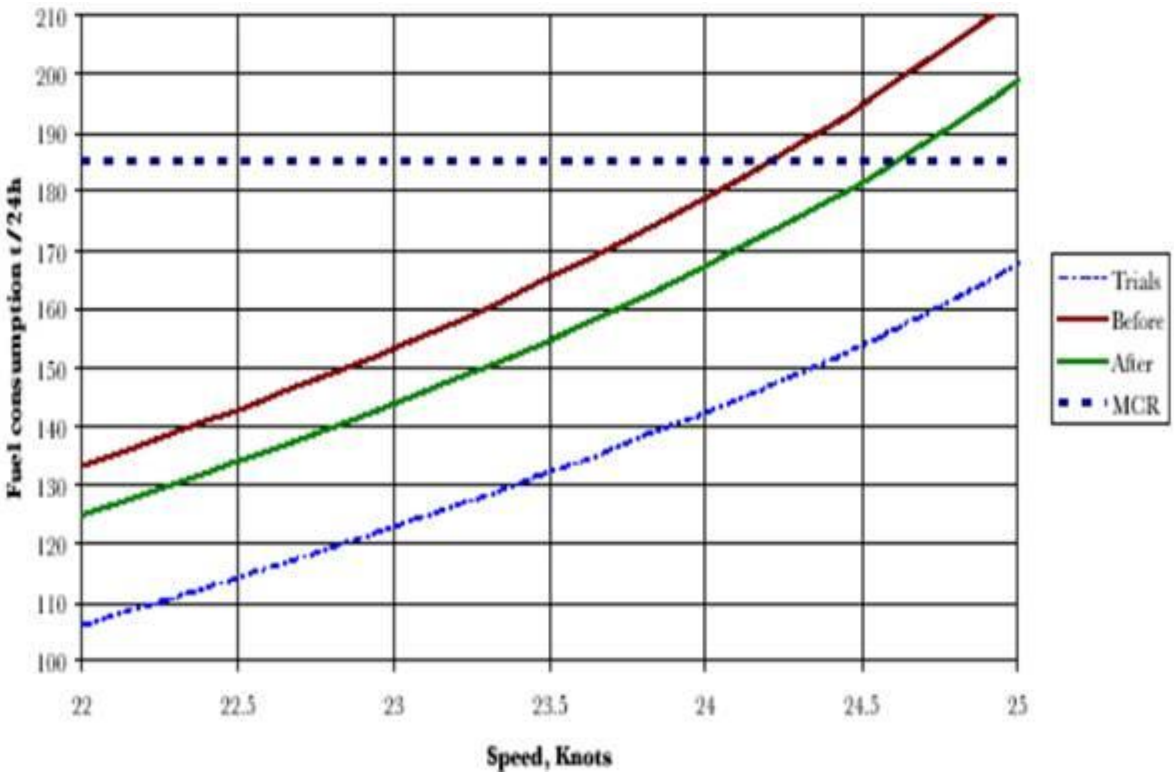


Figure 12.27: Fuel consumption penalty of hull fouling and benefits of condition-based cleaning [Torben Munk]

Based on the above, the need to justify the importance of assessment of hull and ensuring that it remains clean during ship operation is self-evident. The main question to be answered is how the monitoring can be done and if current technologies and systems are effective.

12.11.5.2. Methodology

A variety of methods have been proposed for assessment of hull surface condition including:

- Assessment of ship speed-power curve relative to a baseline.
- Assessment of level of added resistance relative to a baseline (e.g. figure below)
- Use of divers to visually inspect the hull and propeller conditions and decide on the best course of action.
- Etc.

As an example, the 1st methodology above is described here. To monitor the propulsion performance of the vessel, a reliable and accurate speed – power curve should be developed. This curve should then be compared to its counterpart as developed under commissioning speed trial (as baseline) to evaluate deviations from base line conditions. To enable this process the following data should be collected under a number of ship speeds (to cover full range of ship speed):

- Propulsion data

- Propulsion shaft power and rpm
- Ship speed both over ground and through water
- Main engine fuel consumption and relevant properties.
- Environmental conditions
- Wind (speed, direction, etc.)
- Sea state (wave force, direction, etc.)
- Etc.

The above list is only a guide and need to be more detailed for data collection purposes. Additionally, and for analysis purposes, some of the hull and superstructure data and ambient pressure and temperature will also generally be needed.

To collect the required data, ideally, the actual tests should be done in a way that the impact of sea currents is eliminated (using double run tests where the ship is sailed in opposite direction and then results are averaged). However, in practice, this is not commercially feasible; thus, trials under calm sea conditions in areas with little currents are recommended.

To determine the actual speed – power performance of the ship in a changing ambient condition – an analysis method is required. To be effective, this method should eliminate the effect of wind and waves. Currently, evaluation of hull fouling is difficult due to unavailability of proper environmental correction methods.

Based on this methodology, ship speed power curves can be developed as show in figure below.

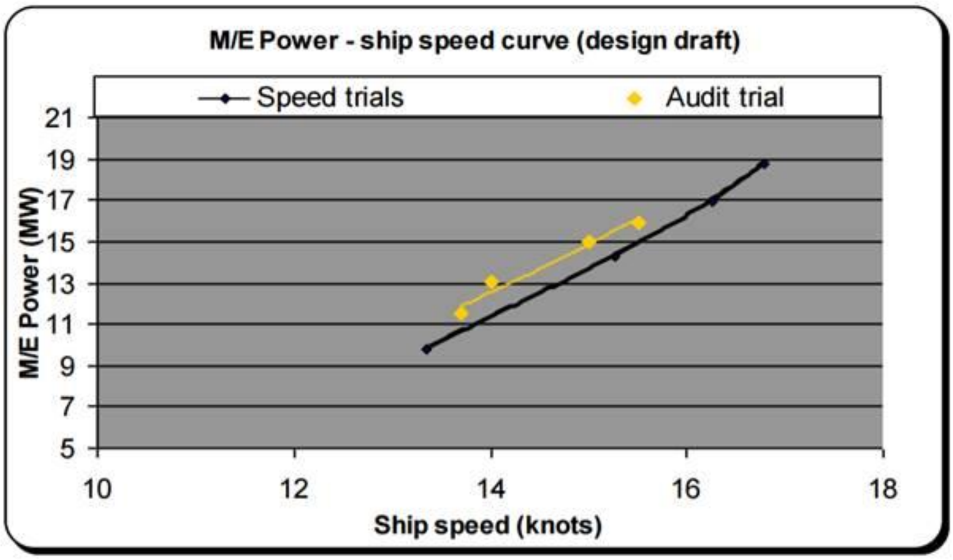


Figure 12.28: Example of speed-power curve development [Bazari 2012]

This method is highly influenced by ship's ambient conditions; and data correction methods are still evolving. However, the use of this technique has been successful when tests are done under controlled conditions, well-defined test procedure and good sea conditions. Propulsion Dynamics (http://www.propulsiondynamics.com/our-service.html) uses the notion of added resistance for their performance monitoring services. Figure below shows example of their results and the way they predict hull fouling.

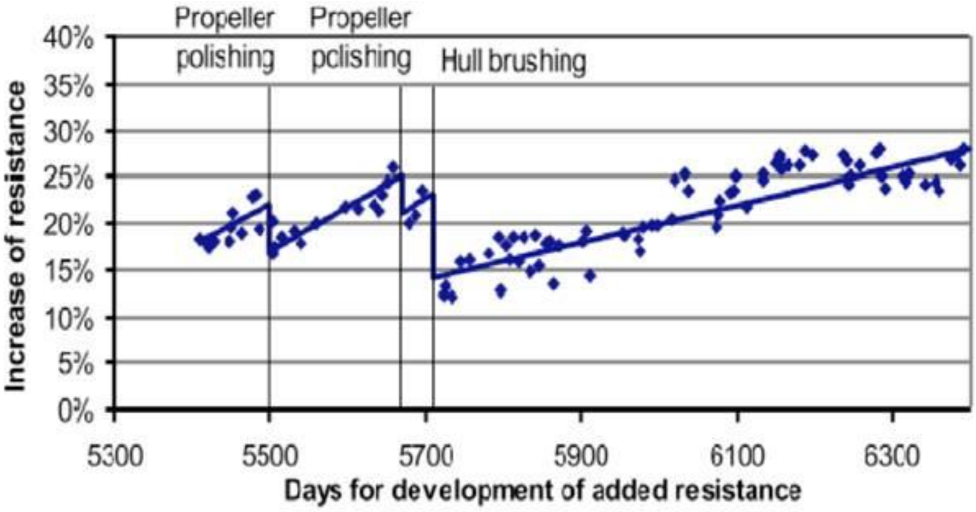


Figure 12.29: Added resistance method used by Propulsion Dynamics [Torben Munk]

12.11.6. Engine Performance Monitoring

12.11.6.1. Introduction

The main purpose of a diesel engine performance monitoring system can be defined as "the monitoring, indication and subsequent assessment of the operational efficiency and performance levels of the diesel propulsion engine and its respective subsystems". The objectives of this form of performance monitoring are:

- To facilitate the efficient, economic and optimal operation of the diesel engines.
- To reduce the possibility of "off design" operation that generally leads to degradation of both the individual components and the overall system reliability and service life.

Diesel condition monitoring has longer history of application in marine diesel engines. It is regarded as "the monitoring of component or system wear and degradation in order to predict scheduled maintenance or at least to avoid catastrophic failure". When dealing with condition monitoring, a number of techniques are normally used such as:

- Vibration monitoring
- Thermography monitoring
- Lube oil monitoring
- Performance process monitoring

Referring to the definition of performance monitoring, the last item of condition monitoring on "process parameter monitoring" closely ties up with performance monitoring. While in condition monitoring, the aim is to identify degradation in order to prevent failures and improve maintenance, in performance monitoring the constant strive is for economic or environmental efficiency of the system; thus it goes beyond simple condition monitoring or maintenance management.

It is important to note that when a process parameter monitoring system is to be applied, the success rate is determined by choosing the right parameters to monitor, select accurate sensors and signal processing systems and implement the output of the processing system.

12.11.6.2. Methodology

Engine performance monitoring mainly relies on monitoring of engine's in-cylinder conditions in particular the cylinder pressure diagram (or "indicator diagram" as commonly known historically). A very good indication of engine health as well as its energy efficiency is the maximum cylinder pressure. Lower than expected cylinder pressure generally means that engine settings are not optimal, or its components may be faulty. Thus, use of measured cylinder pressure data forms the core of engine performance monitoring systems (as well as condition monitoring systems). Figure below shows a typical cylinder pressure diagram, with important characterising parameters marked on it.

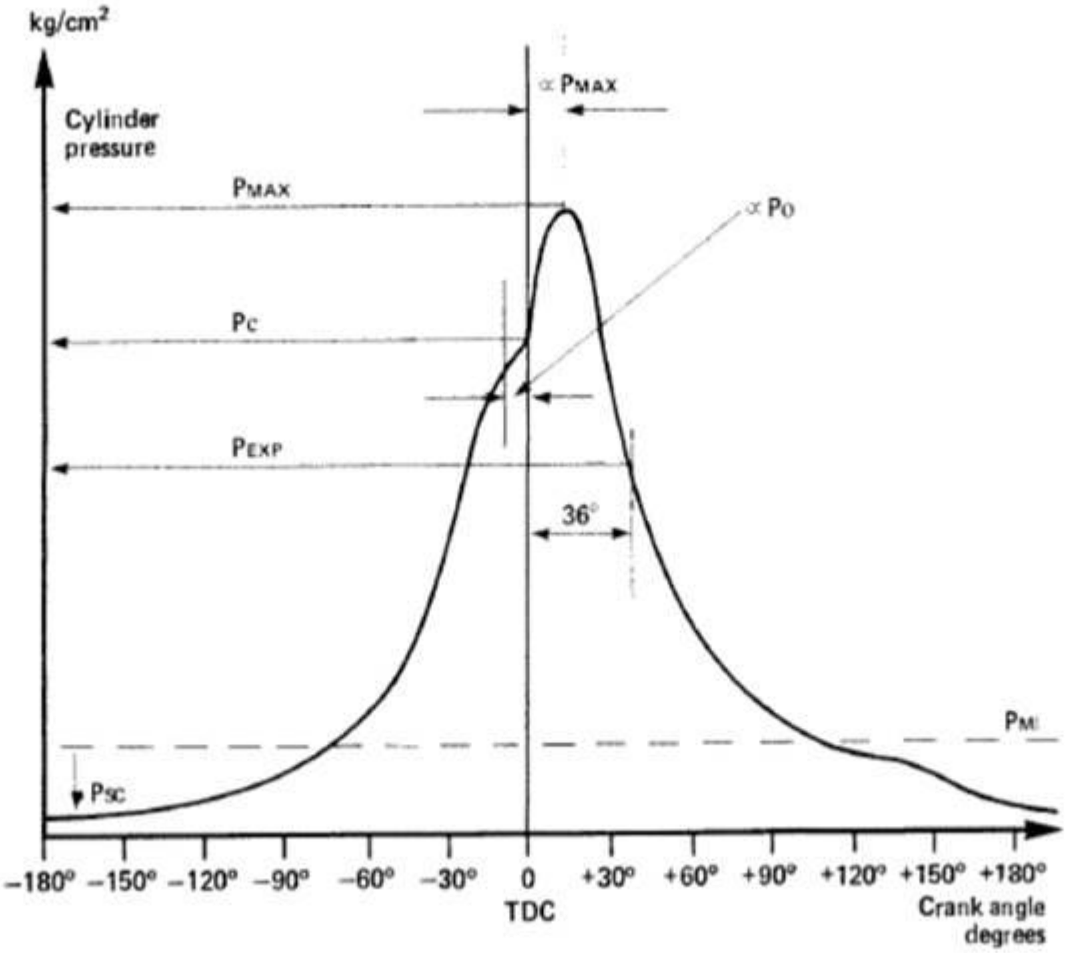


Figure 12.30: Typical engine indicator diagram

The above diagrams can be measured digitally/electronically these days on the majority of commercial vessels (this is normally done on a monthly basis). Using the measured diagram as above, the following information can be extracted (automatically):

- Maximum cylinder pressure (Pmax)
- Angle of Pmax– The angle at which Pmax occurs.
- Cylinder compression pressure (Pcom) – Pressure when piston is at Top Dead Centre position.
- Ignition angle – The angle at which combustion starts.
- Indicated power - Engine power as measured on top of the piston. Due to mechanical frictional losses, this indicated power is higher than the brake power that is measured at output shaft of the engine.
- Etc.

In addition to cylinder pressure diagrams, current day systems collect other data such as:

- Engine rpm
- Engine brake power
- Scavenge pressure
- Fuel injection pressure diagram and relevant information such as injection timing.
- Turbocharger rpm
- Etc.

Following the measurement of the above process data, they need to be corrected, if applicable, and compared to benchmark levels to identify if they are within the acceptable range. The benchmarks are normally extracted from the engine shop test data. The engines' shop test results are generally measured and corrected for standard environmental conditions. Therefore, to enable comparison of measured values against earlier corrected results, the parameters may need to be corrected to shop trial conditions. To calculate the engine's BSFC (Brake Specific Fuel Consumption), a correction for the density and heating value of the fuel will be required.

When the data have been collected and corrected, the relevant graphs are constructed in order to monitor and evaluate the engine's condition and performance. The following comparisons could form the basis for performance deviation diagnostic purposes:

Cylinder pressure: Low maximum combustion pressure relative to baseline is indicative of retarded injection timing or low scavenge pressure, provided that injectors, valves and rings conditions are evaluated as satisfactory.

Turbocharger speed: Higher turbocharger speed relative to reference data will indicate that engine settings may not be optimised. A high turbocharger speed may indicate the following:

- A retard injection with more energy going to exhaust rather than conversion to work in cylinder.
- A fouled turbine casing that may result in slightly higher engine back pressure.

Exhaust gas temperature: A higher-than-normal exhaust gas temperature could be due to few reasons such as high ambient temperature and high scavenge temperature (possibly due to charge cooling issues) or a retarded injection. Figure below shows a sample of cylinder pressures monitored, showing anomaly with one of the cylinders (red line).

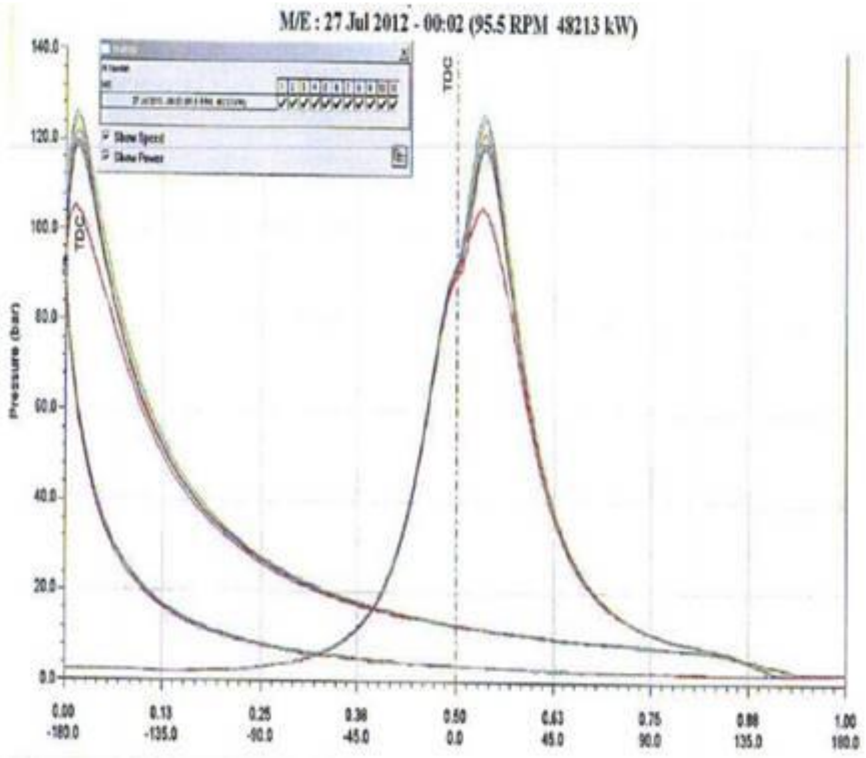


Figure 12.31: Typical on-board in-cylinder measurement [Bazari 2012]

12.11.7. Auxiliary Machinery Monitoring

The monitoring of auxiliary machinery may be carried out in a variety of ways. For energy efficiency purposes, one way is to monitor the level of utilisation of machinery that is represented by their run hours. This will demonstrate if the ship's redundant parallel machineries are used too much beyond requirements. This is done via evaluation of utilisation factor and their comparison to benchmark values.

Figure below shows an example of such an analysis for a number of auxiliary machinery, where the actual and reference utilisation factor for some major energy consuming machinery is shown.

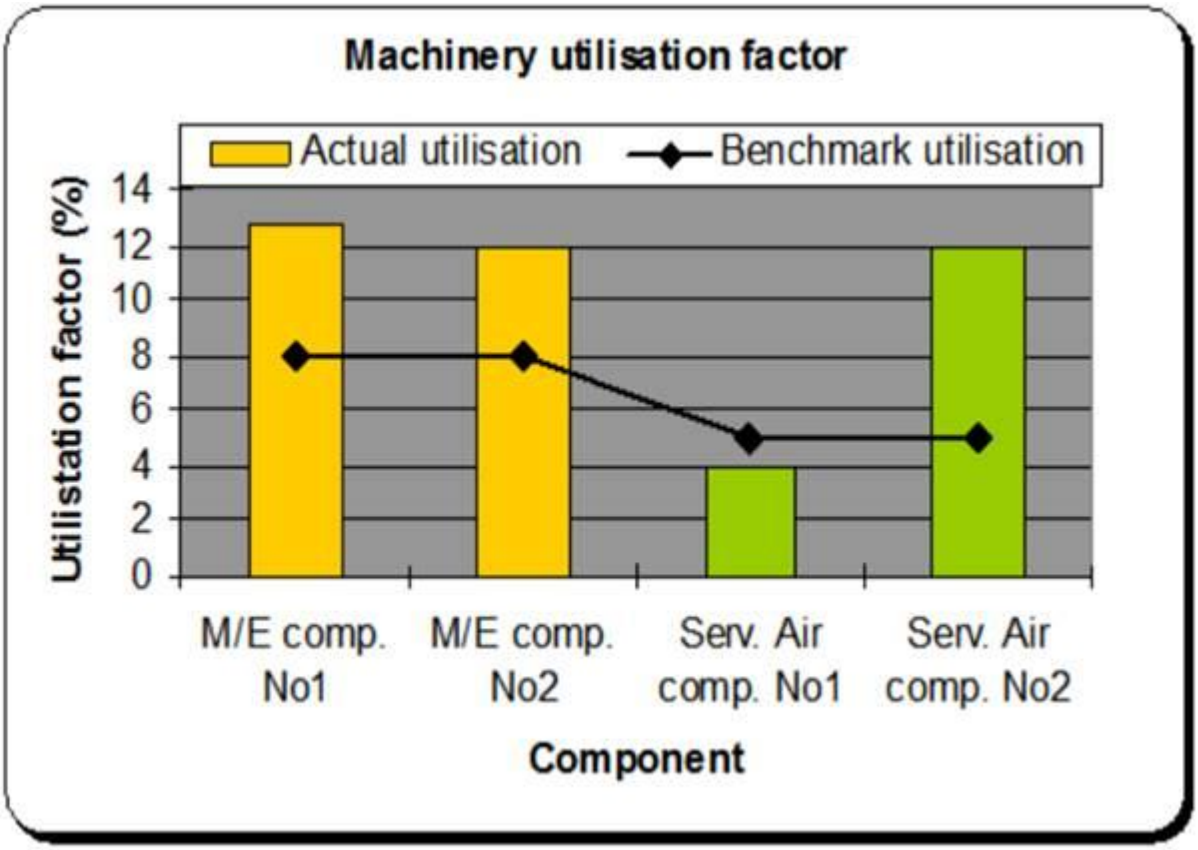


Figure 12.32: Machinery utilisation [Bazari 2012]

Presentation of the above data over time will ensure optimisation and reduction of ship's auxiliary machinery run hours that would lead to not only lower energy use but less need for maintenance.

12.11.8. Voyage Performance Analysis

To improve the ship's itinerary and voyage management, a rigorous process that examines all aspects of the ship's operations needs to be in place. Data that could be used to evaluate the ship's operations should be collected and compared against developed benchmarks/baselines. The important data elements for voyage analysis will include analysis of ship operation events and their time durations (e.g. cargo loading, cargo unloading, port waiting, port berth times, passage operation, etc.).

To acquire such data, a computerised system will be required. However, such data are also available manually from deck logbooks as well as port reports that are available on-board ships. Additionally, full and continuous recording capability of voyage information as shown in figure below, inclusive of detailed propulsion system data, would support to optimise voyage operational performance.

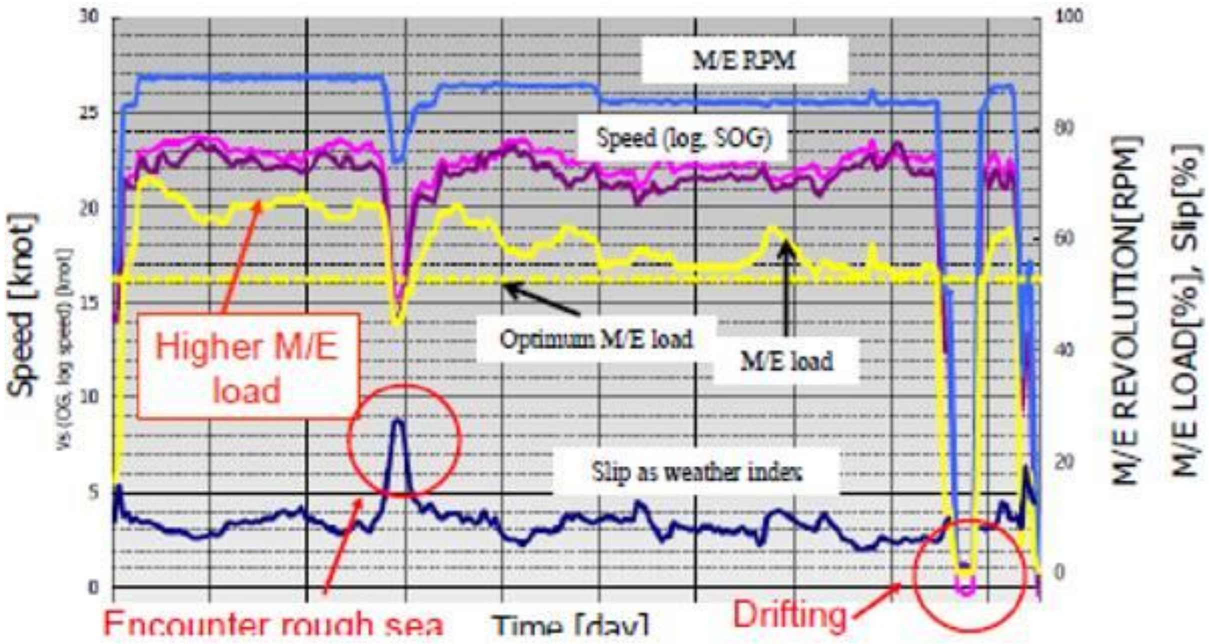


Figure 12.33: Overview of a ship operation from one port to next port using performance monitoring [Hideyuki Ando, NYK]

For voyage performance analysis, these days, the weather routing service providers offer voyage performance analysis. In such a case, comparison between voyage plan and actual including ship performance (rpm, speed, fuel consumption) as a function of weather condition (wind and ship motion) are estimated and compared.

12.11.9. Monitoring and Reporting to External Bodies

The other aspect of energy performance monitoring mainly relates to obligation of the company to report to external stakeholders. The stakeholders could be the commercial clients or shippers or could be regulatory authorities. On the regulatory authority side, two initiatives are important for further consideration:

12.11.9.1. IMO Data Collection System

IMO MEPC Working Group on "further energy efficiency measures" has been working on the subject for some time and still continuing this work at the time of writing these texts. The approach advocates "data collection" as applied to ship fuel consumption and possibly other parameters. The system will have three main elements: (1) Data collection by ships (2) Flag State functions (data verification and submission) and (3) Establishment of a centralised database by the IMO and annual submissions.

The regulatory aspects of the IMO data collection and reporting system was introduced in Module 1 together with progress so far in its development and adoption. The reader should refer to module 1 for details; however, the main features of the scheme are summarily mentioned below as:

- It will be applicable to ships greater than 5000 GT.

- The reporting period will be annually with no need for voyage data declaration.
- IMO number for ship will be part of the data for ship identification purposes.
- Ship's registered owner will be responsible for submission of data to Administration. Responsibility of reporting remains with the ship.
- Flag Administration will be responsible for verification of the data; this can be delegated to Recognized Organizations (e.g. Class Societies).
- A Statement of Compliance (SOC) will be issued to the ship annually.
- Port State Control will examine the validity of SOC for enforcement.

Main aspects that have yet to be decided by the IMO MEPC in its future meetings are:

- Confidentiality of the data and who will have access to collected data.
- Guidelines will be developed to deal with various aspects of relevant regulations detailing main features of data collection method and data verification.
- The need for transport work data or energy efficiency indicator and other relevant data has yet to be debated and decided.

12.11.9.2. EU MRV

EU has for long worked as an advocate of reducing GHG emissions from international shipping. Because of this, EU not only supported the IMO regulatory developments but also has kept one step ahead in pushing forward the GHG reduction agenda. Generally, the EU plan of action is a phased approach to regulating CO2 emissions as follows:

- Phase 1: Establish an agreed global energy efficiency standard as part of the IMO regulatory framework.
- Phase 2: Implement an MRV scheme to establish the fuel consumption and CO2 emissions from international shipping, preferably within the IMO framework.
- Phase 3: Identify whether the efficiency standards are achieving the EU's desired absolute CO2 emissions reductions from shipping, and if not, determine what else should be done, e.g. introduction of a Market Based Measure (MBM).

Phase 1 has already been accomplished and is in place in the form of IMO energy efficiency regulations for ships. It is phase 2 that is the subject of the IMO data collection system and EU-MRV. EU for some time have advocated that any plan to reduce shipping CO_2 emissions in the long term would have to be based on representative and accurate data on shipping fuel consumption and GHG emissions inventories. Within EU MRV, a reporting system is regulated that is going to provide such data. In effect, EU has developed and adopted its MRV legislation force certain ships to report their fuel consumption, energy efficiency performance and related data.

The EU MRV will be described in some detail in the following texts. Lloyd's Register in its summary publication in May 2015 entitled "European Union Regulation on Monitoring, Reporting and Verification of Carbon Dioxide from Ships" provides a succinct but comprehensive introduction to the EU MRV. The material in this section is mainly taken from this publication with some amendments; this is acknowledged here.

Applicability

EU legislation for the EU-MRV regulations was approved by the European Council in 29 April 2015 via amending the Directive 2009/16/EC [Regulation (EU) 2015/757]. Accordingly, the EU-MRV will be implemented in the EU regions and the ships that operate solely in this region or those travelling in and out of the region. The system will work according to the following:

- Irrespective of flag, the regulation applies to ships greater than 5,000 GT (with some exceptions10) undertaking one or more voyages into, out of and between EU ports.
- It requires per-voyage and annual monitoring of CO2 emissions, as well as other parameters including energy efficiency indicators and amount of cargo carried.
- Annually, shipping companies must provide an emissions report for the previous calendar year's activity. In addition, this will include the technical efficiency of the ship for example in the form of its EEDI.
- Ships are exempted from the obligation to monitor this information on a per-voyage basis if they undertake more than 300 voyages within the reporting period or if all their voyages during the period either start or end at a port under the jurisdiction of an EU member state.

Implementation schedule

The following timescales have been set as part of the regulation for its implementation:

- Preparation and adoption of supporting technical legislation in 2015/2016 including broad stakeholder and expert involvement.
- Accreditation of verifiers in 2017.
  31st August 2017 – Monitoring plan for each ship to be prepared and submitted for approval by an accredited verifier.
- 1st January 2018 – Commence per-voyage and annual monitoring by applicable ships.
- 2019 onwards – By 30th April each year, submit a verified emission report to the EC and relevant flag State
- 30th June 2019 onwards – Ships will need to carry a valid Document of Compliance (DOC) relating to the relevant reporting period.
- 30th June each year – The EC will make each ship's emissions reports publicly available including information specific to that ship, its fuel consumption, CO2 emissions, technical efficiency (e.g. EEDI) along with other parameters.

Data collection

Each company will be required to produce a monitoring plan which will be used to monitor data on a per-voyage basis. This data will be aggregated annually and reported for all voyages conducted into, out of and between EU ports. The differing requirements for monitoring and reporting on a per voyage basis and on a yearly basis are shown in table below.

Annual reporting requirements	Per voyage reporting requirements
Aggregated annual CO_2 emissions from all voyages between, from and to ports under a Member State's jurisdiction during the reporting period	Port of departure and arrival including the date and times in and out.
Aggregated annual CO_2 emissions from all voyages between, from and to ports under a Member State's jurisdiction during the reporting period	
Details of the method used for emissions monitoring	
Technical efficiency of the ship (EEDI or EIV as applicable)	
Vessel identification	
Total annual amount/weight of cargo carried	
Annual average efficiency (e.g. EEOI, fuel consumption per distance and cargo carried)	
Total annual fuel consumption	
Total CO_2 emitted	CO_2 emitted
Total distance travelled	Distance travelled
Total time spent at sea and at berth	Time spent at sea

Table: EU MRV monitoring requirements [Lloyd's Register 2015]

CO_2 emissions measurement

The most critical data in table above is CO_2 emissions measurement and reporting. The overall EU MRV processes are shown in figure below schematically.

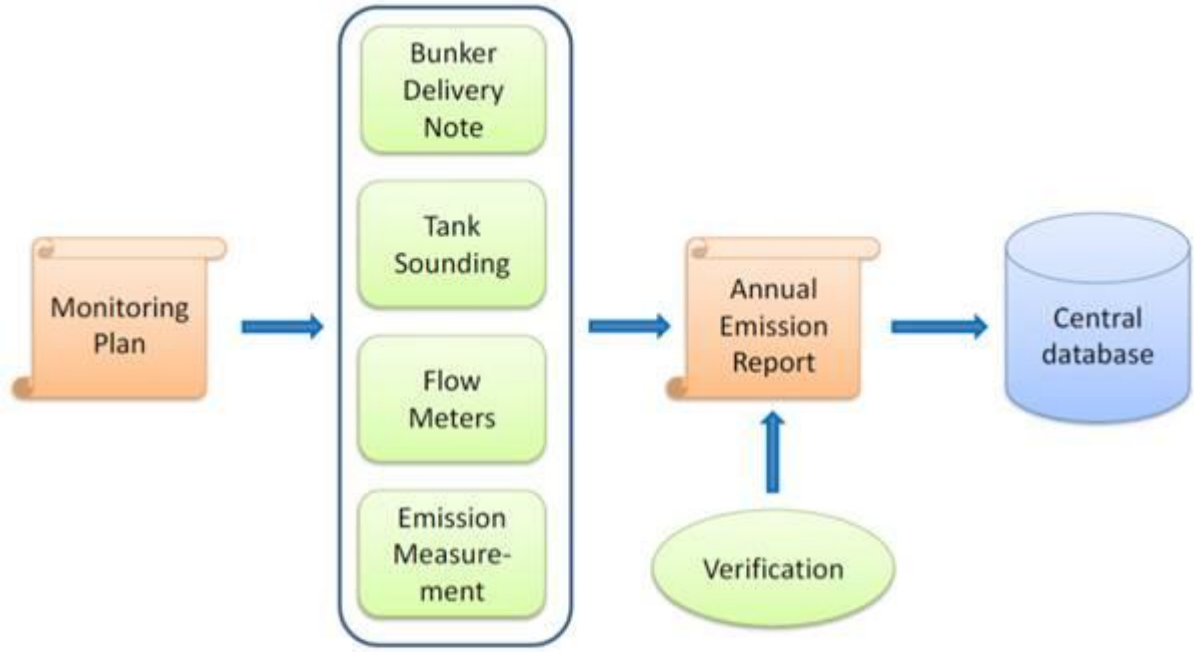


Figure 12.34: MRV scheme overview [Lloyd's Register 2015]

As indicated in figure above, CO_2 emissions will be calculated based on:

- Either fuel consumption measurement (by (1) bunker delivery notes or (2) use of tank sounding or (3) use of fuel flow meters) and use of appropriate fuel related CO_2 emission factor for the fuel type being consumed,

- Or by direct emissions monitoring/measurement, with a back-calculation of the fuel consumption using the relevant emissions factor.

The above options are detailed in Annex I of the EU Directive [Regulation (EU) 2015/757]. As part of the monitoring plan, companies will be able to choose one or more of four methods shown in figure above for CO_2 calculations. Use of a combination of these methods is also permitted if it would improve the accuracy of the CO_2 emission measurement.

The EU MRV regulations also refer to energy efficiency as part of the monitoring and reporting requirements, including 'transport efficiency' and 'average energy efficiency'. These are defined within the Annex II to the EU Directive [Regulation (EU) 2015/757] and have similarities to the methodology for calculating the IMO's Energy Efficiency Operational Indicator (EEOI).

Verification

Tasks related to the check of monitoring plans, emission reports, communication with ship owners and operators and the issuance of Document of Compliance (DOC) will be done by accredited third party verifiers which most likely include classification societies. The EU Directive [Regulation (EU) 2015/757] sets out guidance on the requirements for verification and the main such requirements are summarised as follows:

- Verifying conformity of the monitoring plan against the requirements laid out in the regulation;
- Verifying conformity of the emission report with the requirements laid out in the regulation and issuance of verification report.
- Ensure that emissions and other climate-related data have been determined in accordance with the monitoring plan;
- Determining and making recommendations for improvement to the monitoring plan.

Certification

Upon satisfactory verification of the emission report, the verifier will then issue a Document of Compliance (DOC) to the company. The EU MRV regulations will not be a flag State requirement; instead it will be enforced through Port State Control within European ports.

References

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3. Resolution MEPC.212 (63): “2012 Guidelines on the Method of Calculation of the Attained EEDI for new ships”, Adopted by IMO MEPC on 2 March 2012.

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Chapter 13: Environmental Concerns and IMO Response

13.1. IMO Response: Maritime Environmental Regulatory Framework

International shipping is ruled by a set of international legal and regulatory frameworks. In this section, such regulatory frameworks are defined with a focus in understanding the shipping impact on climate change and the various provisions developed through the IMO to address this issue. The marine related international regulations to address the consequences of air emissions can be found in the UNCLOS and in the IMO MARPOL regulations. The UNCLOS regulations form the basis of the international law regulating the seas, while the IMO specifically regulates the international shipping. Both develop comprehensive regulatory regimes to be enforced by States.

13.1.1. UNCLOS (United Nations Convention on the Law of the Sea) Regulations and Environment

As previously mentioned, the UNCLOS possesses extensive references to the protection of the environment. In its preamble, the UNCLOS recalls the importance to:

"Promote the peaceful uses of the seas and oceans, the equitable and efficient utilization of their resources, the conservation of their living resources, and the study, protection and preservation of the marine environment."

In addition to this statement, a complete part of the text is dedicated to the protection of the environment. Part XII reflects the main objectives of the UN in terms of environmental protection which occurred in parallel to the extensive negotiations to develop the UNCLOS. The most significant articles demonstrating the importance of State responsibility to protect the environment are presented below:

Article 192: "General obligation

States have the obligation to protect and preserve the marine environment".

Article 194: "Measures to prevent, reduce and control pollution of the marine environment.

States shall take all measures necessary to ensure that activities under their jurisdiction or control are so conducted as not to cause damage by pollution to other States and their environment, and that pollution arising from incidents or activities under their jurisdiction or control does not spread beyond the areas where they exercise sovereign rights in accordance with this Convention."

Article 195: *"Duty not to transfer damage or hazards or transform one type of pollution into another* In taking measures to prevent, reduce and control pollution of the marine environment, States shall act so as not to transfer, directly or indirectly, damage or hazards from one area to another or transform one type of pollution into another."

Article 197: *"Cooperation on a global or regional basis* States shall cooperate on a global basis, an as appropriate, on a regional basis, directly or through competent international organizations, in formulating and elaborating international rules, standards and recommended practices and procedures consistent with this Convention, for the protection and preservation of the marine environment, taking into account characteristic regional features."

Article 204: "Monitoring of the risks or effects of pollution

1. States shall, consistent with the rights of other States, endeavour, as far as practicable, directly or through the competent international organizations, to observe, measure, evaluate and analyse, by recognized scientific methods, the risks or effects of pollution of the marine environment.

2. In particular, States shall keep under surveillance the effects of any activities which they permit or in which they engage in order to determine whether these activities are likely to pollute the marine environment."

Article 212: "Pollution from and through the atmosphere

1. States shall adopt laws and regulations to prevent, reduce and control pollution of the marine environment from or through the atmosphere, applicable to the air space under their sovereignty and to the vessels flying their flag or vessels or aircraft of their registry, taking into account internationally agreed rules, standards and recommended practices and procedures and the safety of air navigation.
2. States shall take other measures as may be necessary to prevent, reduce and control such pollution
3. States, acting especially through competent international organizations or diplomatic conference, shall endeavour to establish global and regional rules, standards and recommended practices and procedures to prevent, reduce and control such pollution."

In addition, various articles deal with the enforcement mechanisms by Flag State (Article 217), Port State (Article 218) and Coastal State (Article 220).

In short, the UNCLOS recalls:

- The States duties to protect the environment and responsibility not to harm others.
- The measures developed should not transfer the damage or risks.
- The global and regional cooperation are paramount in environmental protection.
- The risks and effects of pollution must be assessed scientifically.
- The air pollution is an established concern.
- Compliance Monitoring and Enforcement systems have to be developed to verify the compliance of the activities.

UNCLOS demonstrates the importance of protecting the environment and developing proper enforcement mechanisms which can be materialized through certification and inspection regimes.

13.1.2. Overview of the IMO Structure

In 1948, a UN body in charge of maritime affairs was created. The International Maritime Organization (IMO) acquired its final name in 1982.

The IMO presently consists of an Assembly, a Council, a number of Committees and a Secretariat. The structures of the IMO and its secretariat can be simplified as shown in figure below:

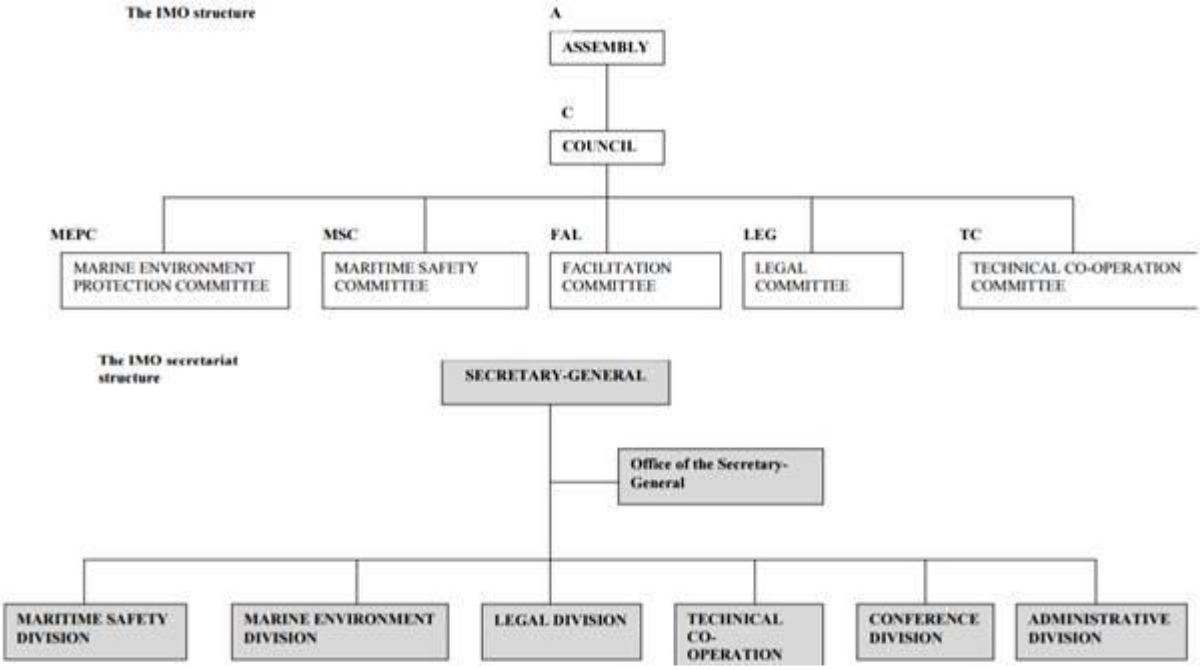

Figure 13.1: IMO and its secretariat structures

The aims of the IMO are summarized in the Article 1 of its constitutive Convention:

(a) To provide machinery for co-operation among Governments in the field of governmental regulation and practices relating to technical matters of all kinds affecting shipping engaged in international trade; to encourage and facilitate the general adoption of the highest practicable standards in matters concerning the maritime safety, efficiency of navigation and prevention and control of marine pollution from ships; and to deal with administrative and legal matters related to the purposes set out in this Article;

(b) To encourage the removal of discriminatory action and unnecessary restrictions by Governments affecting shipping engaged in international trade so as to promote the availability of shipping services to the commerce of the world without discrimination; assistance and encouragement given by a Government for the development of its national shipping and for purposes of security does not in itself constitute discrimination, provided that such assistance and encouragement is not based on measures designed to restrict the freedom of shipping of all flags to take part in international trade;

(c) To provide for the consideration by the Organization of matters concerning unfair restrictive practices by shipping concerns in accordance with Part II.

(d) To provide for the consideration by the Organization of any matters concerning shipping and the effect of shipping on the marine environment that may be referred to it by any organ or specialized agency of the United Nations.

(e) To provide for the exchange of information among Governments on matters under consideration by the Organization."

For environmental purposes, the IMO have to support the enforcement of highest practical standards as well as maintain a close link with other UN bodies on such matters. The IMO provides governing tools and policies but the implementation and enforcement of IMO tools falls in the hand of the member States and their governments. "The IMO's role is thus primarily to adopt legislation, while enforcement lies with the Contracting Governments (the flag States)." (IMO, 2009)

13.1.3. IMO Commitment to Environmental Protection

Since 1959, the IMO has proactively taken responsibility for the issues related to pollution by shipping. The Organization supports the development of regulations aiming to prevent pollution to the marine environment and addresses the introduction of technologies and specifics as defined by the UNCLOS:

- Article 1. "(4) "pollution of the marine environment" means the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuary, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities;"
- Article 196 "States shall take all measures necessary to prevent, reduce and control pollution of the marine environment resulting from the use of technologies under their jurisdiction or control, or the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto."

Maritime Environment Protection Committee (MEPC) is the IMO committee in charge of addressing the environmental issues for the IMO. This Committee is supported by Sub-Committees sometimes shared with the Maritime Safety Committee. Also, the MEPC sets up working groups that deal with various items of its agenda (e.g. ballast water, air pollution, GHG emissions, etc.). The Committees and its working groups are supported by the IMO Secretariat that deals with all related administrative aspects.

The MEPC may issue circulars and resolutions as well as draft resolutions to be adopted by the Assembly. The MEPC meets three times over two years (twice 1st year and once second year). During the MEPC sessions, various working groups or correspondence groups may be established to address particular issues. All States represented at the IMO may participate to discuss the issues related to pollution prevention and control as well as industry representatives and NGOs (Non-Governmental Organisations). Decisions are normally reached through consensus but if there is a need for voting, only Parties to relevant Convention (e.g. MARPOL Annex VI, Ballast Water Management) are eligible to cast their votes.

The IMO's Marine Environment Division supports the MEPC and deals on a daily basis with relevant environmental issues but above all supports the working of MEPC and other IMO divisions in related areas. Today, the IMO regulations cover the whole ship's pollution risks as presented in figure below. Specifically, IMO deals with the following Conventions:

- **MARPOL Convention** dealing with various types of pollutions.
- **Anti-Fouling System Convention**, entered into force in 2008, prohibits the use of harmful organotin compounds in anti-fouling paints used on ships and establishes a mechanism to prevent the potential future use of other harmful substances in anti-fouling systems. Antifouling systems to be prohibited or controlled are listed in the Convention.
- **Ballast Water Management Convention** entitled "International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM)" was adopted in 2004 and awaits at this point in time (2015) ratification by enough member states. It aims to prevent the spread of harmful aquatic organisms from one region to another, by establishing standards and procedures for the management and control of ships' ballast water and sediments.
- **Hong Kong Convention** entitled "International Convention for the Safe and Environmentally Sound Recycling of Ships" was adopted in 2009 and awaits at this point in time (2015) ratification by enough member states. It aims at ensuring that ships, when being recycled after reaching the end of their operational lives; do not pose any unnecessary risk to human health and safety or to the environment.
- **London Convention** entitled the "Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972", is dealing with dumping into marine environment and has been in force since 1975. Its objective is to promote the effective control of all sources of marine pollution and to take all practicable steps to prevent pollution of the sea by dumping of wastes and other matter.

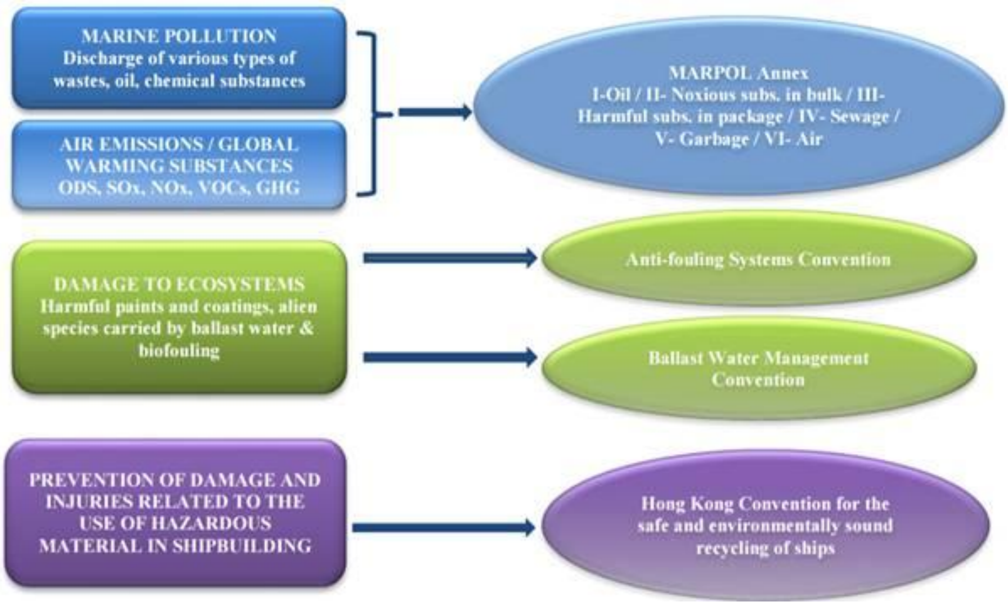

Figure 13.2: IMO Conventions relating to the prevention of marine pollution relating to ship operations

As stated above, the latest Conventions adopted but not yet entered into force are the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004, and the Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, 2009. The 1973 International Convention for the Prevention of Pollution from Ships (MARPOL) integrated the issue concerning the air pollution by ships in the Convention's adoption of the 1997 Protocol creating the MARPOL Annex VI. The IMO and its member States recognize the importance of the environmental protection which became over the years a major item of concern for the Organization. During his MEPC 63 speech on 27 February 2012, the IMO Secretary General Sekimizu stated:

"*…+ I see the promotion of sustainable shipping and sustainable maritime development as one of the major priorities of my tenure. *…+Rio+20 is an opportunity to launch a vision for sustainable maritime development that will underpin future maritime developments within a green economy in which IMO should play a major and significant role."

In addition, the IMO shows a strong willingness to address the issue of the climate change by promoting innovative regulations in the framework of the UN discussion on GHG emissions. This disposition has been demonstrated through the adoption of various instruments during MEPC 62 in 2011 and the intensive discussions on developing further technical and operational measures such as data collection system for ships as part of wider MRV (Monitoring, Reporting and Verification) debate.

"IMO will continue to make its contribution to global efforts to reduce greenhouse gas emissions within the context of the ongoing UN-wide debate on climate change. We will continue to cooperate closely with the United Nations Framework Convention on Climate Change and with other relevant UN bodies, as appropriate. Also in this context, IMO will evaluate the implications for shipping of any mechanism to be established for the envisaged Green Climate Fund and impress upon the UNFCCC that any contributions must be proportionate to shipping's contribution to the global emission of greenhouse gases.

While participating in the Climate Change debate at the UN, IMO will proceed in parallel with its own programme of work. In this respect, it is encouraging that last December's Durban Conference on climate change welcomed the progress made by IMO. "(IMO SG Mr. Sekimizu speech, 27 February 2012)

13.1.4. MARPOL Convention

The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of pollution of the marine environment by ships. It was adopted on 2 November 1973 at IMO and subsequently amended by its Protocol in 1978. The combined instrument entered into force on 2 October 1983. The Convention includes regulations aimed at preventing and minimizing pollution from ships, both accidental pollution and that from routine operations, and includes six technical Annexes:

Annex I - Regulations for the Prevention of Pollution by Oil (entered into force 2 October 1983): Covers prevention of pollution by oil from operational measures as well as from accidental discharges. The 1992 amendments to Annex I made it mandatory for new oil tankers to have double hulls and brought in a phase-in schedule for existing tankers to fit double hulls.

Annex II - Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk (entered into force 2 October 1983): Details the discharge criteria and measures for the control of pollution by noxious liquid substances carried in bulk; some 250 substances were evaluated and included in the list appended to the Convention; the discharge of their residues is allowed only to reception facilities until certain concentrations and conditions.

Annex III - Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form (entered into force 1 July 1992): Contains general requirements for the issuing of detailed standards on packing, marking, labelling, documentation, stowage, quantity limitations, exceptions and notifications. For the purpose of this Annex, the “harmful substances” are fully defined.

Annex IV - Prevention of Pollution by Sewage from Ships (entered into force 27 September 2003): Contains requirements to control pollution of the sea by sewage; the prohibition of discharge of sewage into the sea, approved sewage treatment plant, etc. with lots of details on the subject.

Annex V - Prevention of Pollution by Garbage from Ships (entered into force 31 December 1988): Deals with different types of garbage and specifies the distances from land and the manner in which they may be disposed of; the most important feature of the Annex is the complete ban imposed on the disposal into the sea of all forms of plastics.

Annex VI - Prevention of Air Pollution from Ships (entered into force 19 May 2005): Sets limits on sulphur oxide (SO_x) and nitrogen oxide (NO_x) emissions from ship exhausts and prohibits deliberate emissions of ozone depleting substances; sets designated Emission Control Areas with more stringent standards for SO_x and NO_x. A new chapter adopted in 2011 covers mandatory technical and operational energy efficiency measures aimed at reducing GHG emissions from ships. A State to become a Party to MARPOL must ratify MARPOL Annexes I and II. The rest of Annexes are voluntary as far as membership to MARPOL Convention is concerned.

13.1.5. MARPOL Annex VI

MARPOL Annex VI is the latest added part to MARPOL Convention in 1997 that entered into force in 2005. Major modifications / amendments to MARPOL Annex VI occurred in 2008 on NOx Technical Code and 2011 with the insertion of a new Chapter 4 which deals with energy efficiency regulations for ships (effectively dealing with GHG emissions).

Therefore, today, the Annex VI encompasses air pollutants and GHG emissions combined. The regulations include also elements like bunker fuels, incinerators, reception facilities, Emission Control Areas, Ozone Depleting Substances, etc. The scope of MARPOL Annex VI is depicted in figure below.

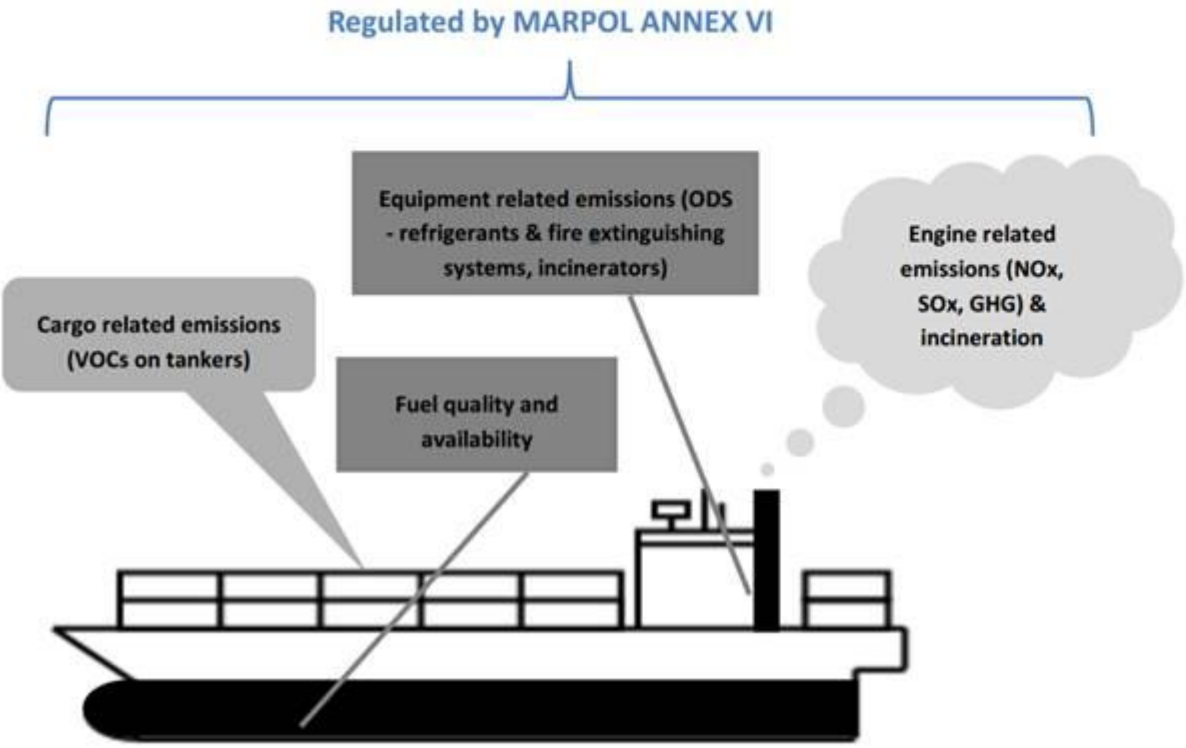

Figure 13.3: Ship's air emissions regulated by MARPOL Annex VI

MARPOL Annex VI currently comprises of a number of chapters that are briefly described below with their encompassing regulations.

Chapter 1 – General: Introduces some of the basics of the Convention as well as certain useful definitions. Under this chapter, the following regulations are fully specified:

- Regulation 1 – Applications: This specifies the application domain of MARPOL Annex VI.
- Regulation 2 – Definitions: This provides definitions for terms that have regulatory significance.
- Regulation 3 - Exceptions and exemptions: This regulation describes the conditions under which a ship or a marine platform could be exempted from complying with MARPOL Annex VI.
- Regulation 4 – Equivalents: This allows the use of alternative method of compliance and the conditions under which they will be acceptable.

Chapter 2 – Survey, certification and means of control: describe the survey requirements, certification system and control principles including port State control issues and violation detection and enforcement. Under this chapter, the following regulations are fully specified:

- Regulation 5 - Surveys: This regulation describes the survey and inspection requirements.
- Regulation 6 - Issue of endorsement of certificate: The rules for issuance of certificates, forms of certificates, etc. are specified under this regulation.

- Regulation 7 - Issue of a certificate by another party: This regulation allows another Party to issue a certificate on behalf of a Party.
- Regulation 8 - Form of certificates: The forms of various certificates are specified here.
- Regulation 9 - Duration and validity of certificates: The duration and validity certificates are discussed under this regulation.
- Regulation 10 - Port State control and operational requirements: The port State control aspects and relevant rules are explained in this regulation.
- Regulation 11 - Detection of violation and enforcement: Specific aspects under which a ship could be detained are described under this regulation.

Chapter 3– Requirements for control of emissions from ships: this chapter details the measures to address various air pollutants and important related issues as bunker management and incinerator. Under this chapter, the following regulations are fully specified:

- Regulation 12 –Ozone-depleting substances (ODSs): This regulation prohibits deliberate release of ODSs and sets timeline for phasing out of certain ODSs.
- Regulation 13 – Nitrogen oxides (NO_x): This part of the Annex regulates the NO_x emissions by ship for engines installed on ships constructed after 2000. Three tiers describe the NO_x limits to be achieved after 2000, 2011 and 2016. In addition to the International Air Pollution Prevention (IAPP) Certificate, the ship must comply with the NO_x Technical Code 2008, have an Engine International Air Pollution Prevention (EIAPP) Certificate and possesses NO_x Technical File and a record book of engine parameters.
- Regulation 14 – Sulphur oxides (SO_x): This regulation sets maximum sulphur contents for fuels used on ships (3.50% after January 2012) and the concept of SO_x emission control area (SECA) with the current designated SECAs as well as relevant sulphur limits.
- Regulation 15 – Volatile Organic Compounds (VOCs): The regulation emphasizes on the need to reduce VOC releases occur during loading in oil ports and terminals. All oil tankers visiting such regulated ports/terminals (ports/terminals that are designated as VOCs control ports/terminals based on this regulations) must be equipped with collection systems and after 2010 a VOC management plan must be implemented.
- Regulation 16 – Shipboard incineration: Incinerators have to be approved and meet the IMO standards. Various substances are prohibited to incinerate.
- Regulation 18 – Fuel oil availability and quality: The regulation covers the availability, the quality, the supervision of suppliers, the PSC aspects, fuel sampling and sample retentions, the bunker delivery note, etc.

The NO_x Technical Code and some other IMO Resolutions support the implementation of this part of MARPOL Annex VI.

Chapter 4 – Regulation on energy efficiency for ships: This chapter 4 was developed to regulate energy efficiency of ships. It came into force in January 2013. Under this chapter, the following regulations are specified:

- Regulations 19 – Application: This regulation specifies the application domain and scope of the Chapter 4 regulations.
- Regulations 20 – Attained Energy Efficiency Design Index (Attained EEDI): This regulation specifies the requirements on Attained EEDI including the calculation processes and survey and verification aspects.
- Regulations 21 – Required EEDI: This regulation deals with the Required EEDI, its calculation using reference lines and reduction factors and its calculation processes. Regulation 21.5 also makes provisions that the EEDI must not impair the safe manoeuvrability of the ships.
- Regulation 22 - Ship Energy Efficiency Management Plan (SEEMP): This regulation specifies the requirement for ships to have a SEEMP on board and how the SEEMP should be developed.
- Regulation 23 - Promotion of technical co-operation and transfer of technology relating to the improvement of energy efficiency of ships: This regulation emphasizes the importance to enhance technical cooperation and transfer of technology to support energy efficiency improvements on the world fleet, in particular for the benefit of developing countries.

13.2. IMO Response to control of GHG Emissions from International Shipping

13.2.1. Shipping GHG Emissions Context and IMO Role

Growth of shipping transport

Around 90% of world trade is carried by the international shipping industry. Without shipping the import and export of goods for a modern and globalised world will not be possible. International shipping trade continues to expand, bringing benefits for producers and consumers across the world through competitive freight costs. There are over 50,000 merchant ships trading internationally, transporting every kind of cargo.

Shipping, world trade and the economy are very well intertwined and linked as clearly shown in figure below.

“Given that for shipping, all stands and falls with worldwide macroeconomic conditions, the developments in world seaborne trade mirrored the performance of the wider global economy.” (UNCTAD, 2011)

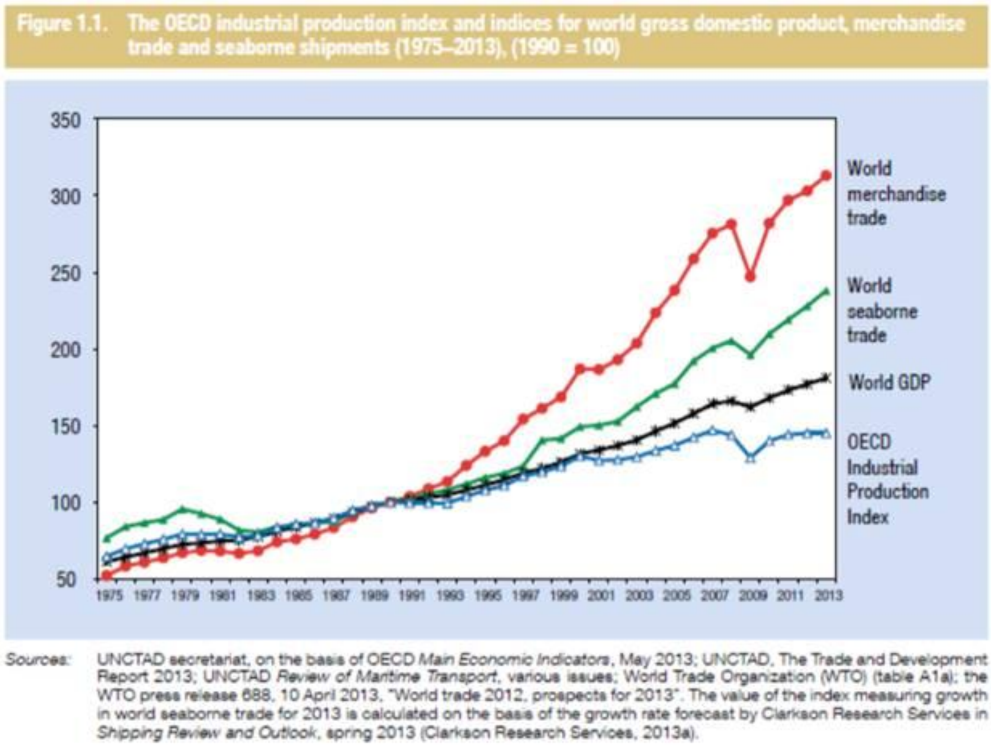

Figure 13.4: UNCTAD, Review of the Maritime Transport 2013

While shipping, in comparison to other transport modes, is the most efficient mode of cargo transport and was considered environmentally friendly, the significant growth of seaborne trade and its externalities and societal costs have modified this perception. The growth of transportation by ships increased the energy consumed by shipping and, in spite of the improvement in the energy efficiency of ship engines, the global shipping emissions amplified quantitatively. This number and volume growth not only have implications for oceans as sea routes but also affects air quality in port areas and coastal zones.

Finally, it should be noted that oceans cover 70% of our planet; and nearly 50% of the world's population live in coastal areas. Therefore, protection of the marine environment not only has implications for each country but also significant global benefits. This is especially true for environmental issues (in particular the GHG emissions) which is truly global in nature; and any benefits accrued at national level will fully contribute to the global benefits.

Responsibility under UN Framework Convention for Climate Change

As indicated before under UNFCCC and Kyoto Protocol, the responsibility for dealing with GHG emissions from international shipping and aviation are given to the IMO and the ICAO respectively (see figure below). Based on Article 2 of Kyoto Protocol: "The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively"

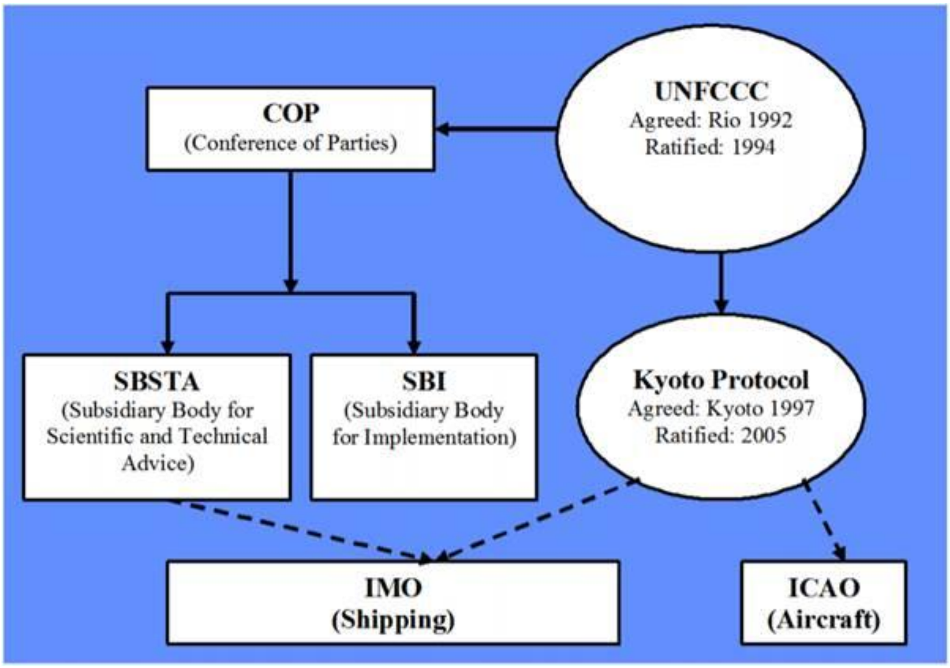

Figure 13.5: IMO responsibility within the international framework for control of GHG emissions [Reynolds and Bazari, 2005]

As such and after the adoption of Kyoto Protocol, shipping could not stay away from the international efforts on GHG reduction. Work by IMO started in 1997, lead to a number of regulations and work still continues on further regulatory measures. Before that, IMO relevant studies will be introduced first. During the period 1997 till now, IMO conducted three major studies on GHG emissions from international shipping as explained in the following sections.

13.2.2. First IMO GHG Study 2000

As an outcome of the 1997 MARPOL Conference, the decision to study CO_2 emission from ship led to the launching of a complete study on the topic. Released in 2000, the first study constituted the initial step of deliberations about the development of new rules to address the GHG controls in shipping. This study, using data from 1996, estimated that ships emitted about 420 million tonnes of CO_2 per year and thereby contributed about 1.8% of the world's total anthropogenic CO_2 emissions that year.

The Study also stated that technical and operational measures have a limited potential for contributing to reduced emissions from ships if the increase in demand for shipping services and market requirement for increased speed and availability continued.

The main outputs of the study were:

• Shipping is considered an efficient means of transportation compared to others.

• It is difficult to assess with accuracy the overall impact of shipping - because of discrepancy in data concerning bunker figures and the uncertainties in the fuel consumption models.

• The impact of air emission should include NO_x, SO_x and GHG emissions.

• Significant reduction of GHG emission can be achieved through operational and technical measures. However, the increase in demand for shipping services may impede operational and technical savings.

• Environmental indexing, market-based mechanisms and design standards may be appropriate measures to implement in the future.

Despite its relevance, no immediate regulation followed after the presentation of this study. The lengthy discussion on the IMO involvement and approach to the climate change necessitated an updated study.

13.2.3. Second IMO GHG Study 2009

The second IMO GHG study was commissioned in 2007 and delivered in 2009. This study updated the GHG emissions figures/inventory for shipping and estimated the potential for reduction of emission according to the implementation of different technologies and operational energy efficiency measures. In addition, cost effectiveness and policy evaluation options were considered. This second study initiated a proposed framework to support the regulatory decision-making process.

Presented during the Copenhagen UNFCCC's COP discussions on climate change in December 2009, the Second IMO GHG Study 2009 forms the scientific background for the present IMO policy and regulatory frameworks that was developed soon thereafter. The intention of the document was to provide a solid research-based data and information to the shipping community in order to help them for regulatory decision making. Mr. Mitropoulos, the then Secretary General of the IMO recalled in a foreword to the document its objectives:

"I trust that this Second IMO GHG Study will become the paramount reference for the Organization's Marine Environment Protection Committee in making well-informed and balanced decisions towards the development and adoption of a robust regime to regulate shipping emissions at the global level." (IMO, 2009)

This study is documented under nine chapters as follows:

1. Executive Summary

2. Introduction to shipping and its legislative framework

3. Emissions from shipping 1990–2007

4. Reductions in emissions achieved by implementation of MARPOL Annex VI

5. Technological and operational potential for reduction of emissions

6. Policy options for reductions of GHG and other relevant substances

7. Scenarios for future emissions from international shipping

8. Climate impact

9. Comparison of emissions of CO_2 from ships with emissions from other modes of transport

A large number of Appendices are also included in the report. Below, some of the chapters more relevant to topic of this training course are further elaborated.

Chapter 3: Emissions from shipping 1990-2007

Before making the inventory of the GHG emission by shipping, the chapter begins with few introductory comments on the scope and uncertainties. Accordingly, the scope of the emission included in the inventory is taken the same as those in the UNFCCC guidance.

"In line with the above-mentioned guidelines for creating an inventory of emissions, the following pollutants were considered for exhausts: NO_x, SO_2, PM_{10}, CO, CO_2, N_2O, CH_4 and NMVOC." (IMO, 2009)

The limitations on estimation of the emissions levels are then deliberated and the following considerations are made:

- Exhaust gases uncertainties are the same as those of the previous study and are estimated to be around +/- 20%.
- Emission of ODS is detailed by sources: Refrigerants, reefer ships & reefer containers; calculation limits are presented.
- Limits and uncertainties in estimating the release of Methane (CH_4) and Non-Methane Volatile Organic Compound (NMVOC) are presented.
- Sulphur hexafluoride (SF_6) and Fluorocarbon (PFCs) on board ships are not emitted to any sufficient degree to be considered as significant issues.

Despite all these limitations, the emissions levels from international shipping were established. As table below indicates, amongst various types of the GHG emissions, the GHG emissions from shipping are overwhelmingly dominated by CO_2. Thus, CO_2 is established as the main GHG concern for shipping that should be the subject of future regulations. All other GHG emissions by international shipping are considered as negligible.

	International shipping (million tonnes)	Total shipping	
		million tonnes	CO_2 equivalent
CO_2	870	1050	1050
CH_4	Not determined*	0.24	6
N_2O	0.02	0.03	9
HFC	Not determined*	0.0004	≤6

* A split into domestic and international emissions is not possible.

Table: Summary of GHG emissions from shipping in 2007 [Second IMO GHG Study 2009]

In addition, the data presented highlight that the emissions of GHG nearly doubled during the period concerned by the study (1990-2007), see table below:

	NOx	SOx	PM	CO	NMVOC	CO_2	CH_4	N_2O
Increase from 1990 to 2007	78.6%	89.9%	80.0%	92.3%	100.0%	86.8%	100.0%	200.0%

Table: Increase of exhaust emissions from total shipping 1990-2007 [Second IMO GHG Study 2009]

Chapter 4: Reduction in emissions achieved by implementation of MARPOL Annex VI

This chapter assesses the effectiveness of the existing regulations that existed at the time of study, to reduce emissions. The increase of seaborne trade induces an increase in absolute volumes of emission. Therefore, the calculations consider the emission reduction according to two scenarios: no-regulation hypothesis and MARPOL Annex VI regulation.

Impact of Regulation 12 – Ozone-depleting substances. The MARPOL Annex VI plus the Montreal Protocol demonstrate a serious efficiency in emission reduction (see table below).

	1998 RTOC Total	2006 RTOC Total	Reduction
CFC	750	15	735 (98%)
HCFC-22	14,000	3,100	10,900 (78%)
HFC	100	415	−315 (−315%)

* Merchant marine, naval, fishing and reefer.

Table: Reduction in estimated annual emissions (tonnes) of refrigerants from ships [Second IMO GHG Study 2009]

Impact of Regulation 13 – Nitrogen Oxides (NO_x): To address this element, typical emission levels before and after 2000 had to be assessed because NO_x emission depends on engine type, conditions and settings but also on fuel quality. These numerous factors made the evaluation complicated. However, it was estimated then that the reduction achieved with the new regulation is about 7%.

Impact of Regulation 14 – Oxides of Sulphur (SO_x): The SO_x emitted is directly correlated with the sulphur content of the fuel burned. Therefore, the reduction of sulphur content from 4.5% to 3.5% is estimated to have a small impact on SO_x emissions because even before the enforcement of this control limit, the fuel oil used by ships rarely contained more than 3.5% sulphur. So, in order to demonstrate the impact of stringent regulation on such emissions, the SO_x Emission Control Area were analysed and compared to the total. As table below indicates, most of the reductions are due to ECA-SO_x (or SECA).

	Hypothetical baseline	MARPOL Annex VI	Reduction
Global total	14.9	14.4	3.4%
SECA	1.2	0.7	42%

Table: Estimated emissions (million tonnes) of SO2 (2008) [Second IMO GHG Study 2009]

Impact of Regulation 15 – Volatile Organic Compounds (VOCS): The study concludes that the regulation addressing the issue seemed to have been properly implemented on tankers but not on shore terminals. Overall, the analysis of NO_x, SO_x & VOCs demonstrated the effectiveness of the regulations to reduce the rate of emission of these pollutants.

Chapter 5: Technological and operational potential for reduction of emissions

This chapter proposes a number of technological and operational techniques for reduction of shipping CO_2 emissions. This analysis supported the development of a comprehensive emission reduction policy that later on led to the shipping energy efficiency regulations.

Four solutions for reduction of GHG emissions from international shipping were investigated:

- Improving shipping operational energy efficiency.
- Using renewable energy sources as alternative technologies/energy.
- Using fuels with less total fuel-cycle emission per unit of work done.
- Using emission reduction and abatement technologies.

The first item above, improving energy efficiency of shipping, remains the main and easiest target to reduce GHG emissions. Table below highlights the main measures for improving the energy efficiency in shipping and their probable impact on CO_2 emission reduction based on this study.

	Saving of CO_2/tonne-mile	Combined	Combined
DESIGN (New ships)			
Concept, speed and capability	2% to 50%†		
Hull and superstructure	2% to 20%		
Power and propulsion systems	5% to 15%	10% to 50%†	
Low-carbon fuels	5% to 15%*		
Renewable energy	1% to 10%		25% to 75%†
Exhaust gas CO_2 reduction	0%		
OPERATION (All ships)			
Fleet management, logistics & incentives	5% to 50%†		
Voyage optimization	1% to 10%	10% to 50%†	
Energy management	1% to 10%		

* CO_2 equivalent, based on the use of LNG.
† Reductions at this level would require reductions of operational speed.

Table: Assessment of potential reductions of CO_2 emissions from shipping by using known technology [Second IMO GHG Study 2009]

Two other ideas emerged from this part of report are the potential for use of renewal energy on board as alternative power source; and LNG as alternative fuel; both of which in addition to CO_2 reduction are serious alternatives to achieve significant reduction NO_x, PM and SO_x and compliance to relevant requirements.

Chapter 9: Comparison of emissions of CO_2 from ships with emissions from other modes of transport

This part of the study investigates the energy efficiency in terms of CO_2 emission efficiency of various transportation means. The unit used to calculate and compare the modes of transport is CO_2 emitted per tonne*kilometres cargo carried as indicated in figure below; this is directly related to fuel consumption.

9.3 For a given period, the CO_2 emission efficiency is then defined as:

$$CO_2 \text{ efficiency} = \frac{CO_2}{\text{tonne} * \text{kilometre}}$$

where:

CO_2 = total CO_2 emitted from the vehicle within the period

tonne*kilometre = total actual number of tonne-kilometres of work done within the same period

Figure: CO2 emission efficiency calculation [Second IMO GHG Study 2009]

Despite large variations and uncertainties in the emission assessments, ranges of efficiencies are determined for sea, air, road and rail (figure below).

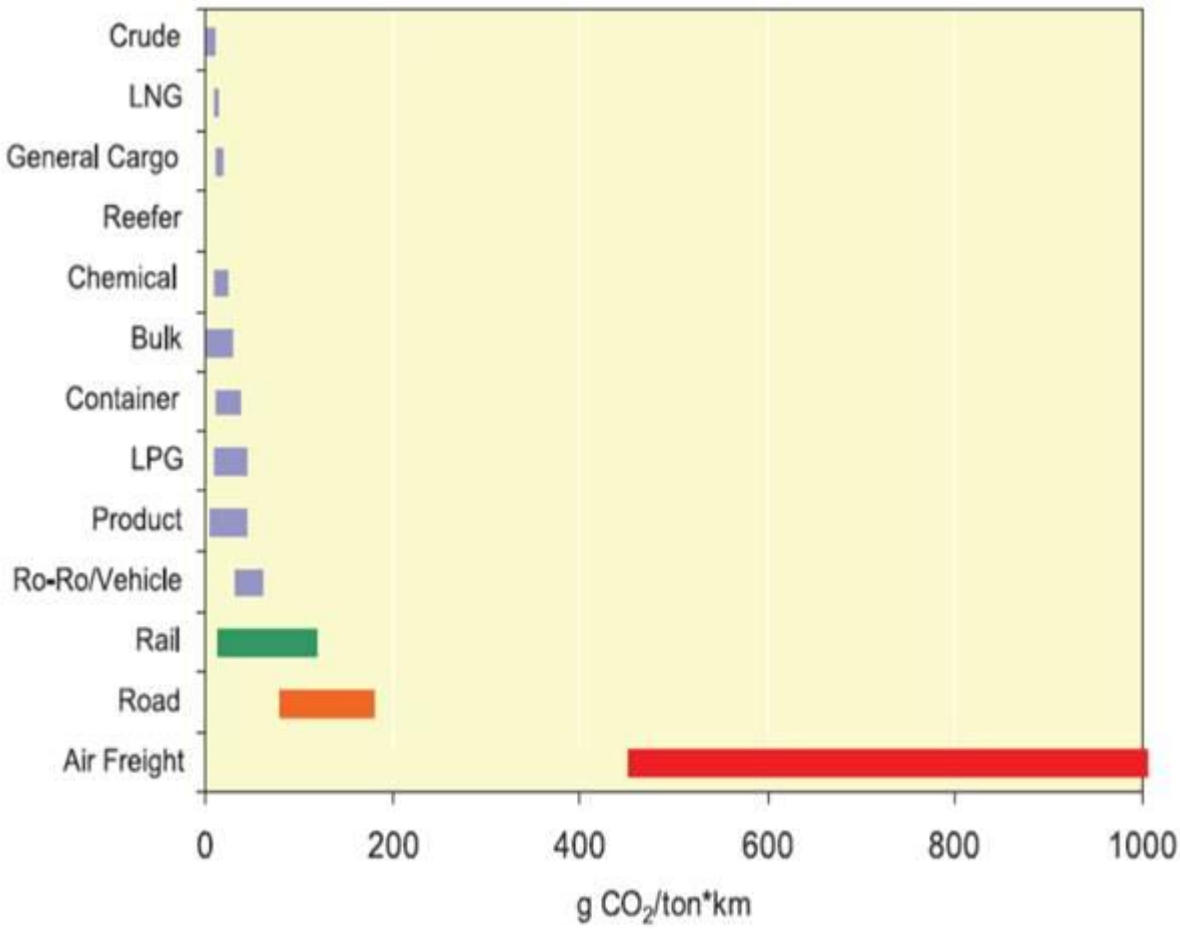

Figure 13.6: Typical range of ship CO2 efficiencies compared to rail, road and air freight [Second IMO GHG Study 2009]

The benchmarking of sectors highlights the significantly higher energy efficiency of sea transport modes. The historic trend toward efficiency is established and shows that the growing size enhances their efficiency. In addition, the share of shipping emissions is presented in relation with the total emissions (figure below).

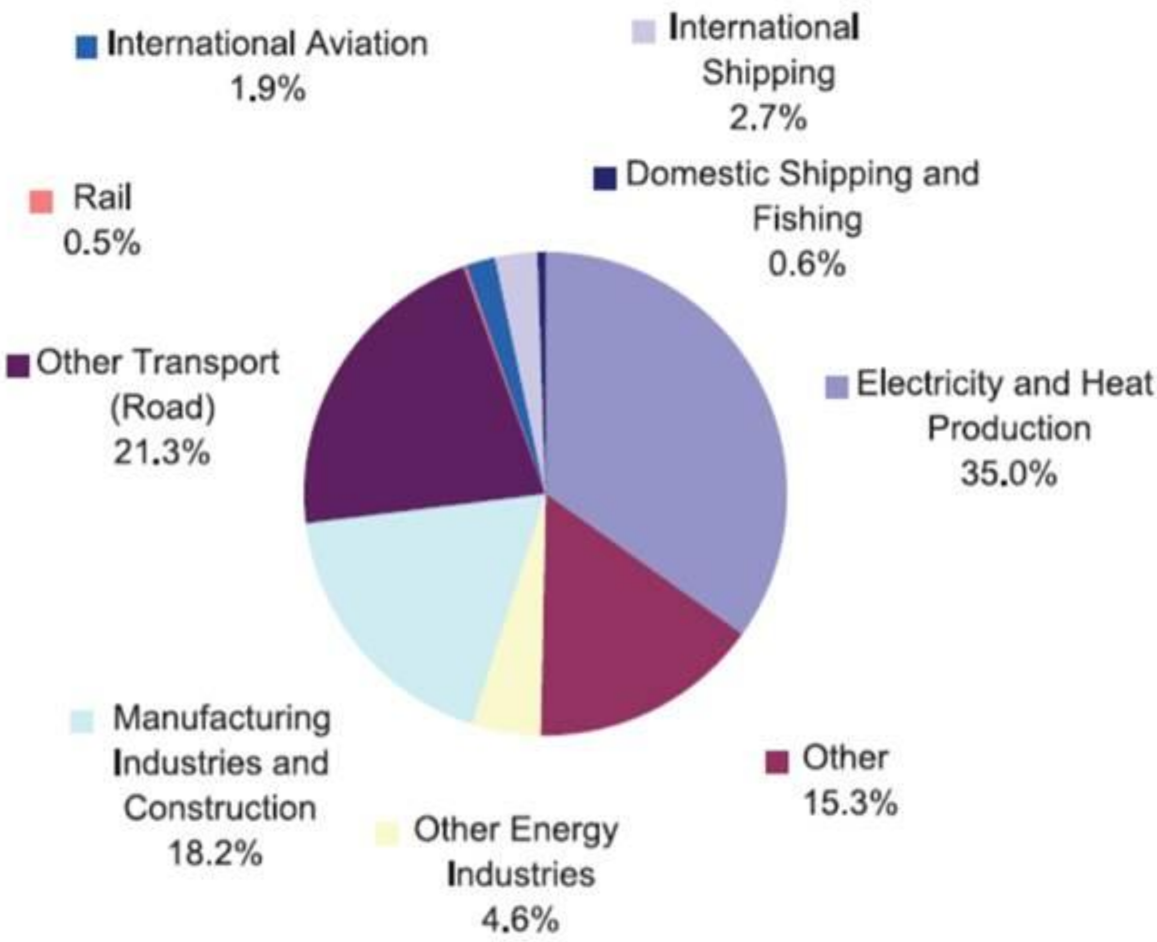

Figure 13.7: Emissions of CO_2 from shipping compared with global emissions [Second IMO GHG Study 2009]

Policy options for international shipping

The Second IMO GHG Study 2009 discuss policy options that include technical, operational and market-oriented approaches (see figure below). Among the several policies detailed in the Second IMO GHG study 2009, three groups of policies are intensively discussed at the IMO. The technical and operational approaches focus on ships and ship management while the economical approach seeks to achieve a global reduction of GHG by promoting incentives and penalties.

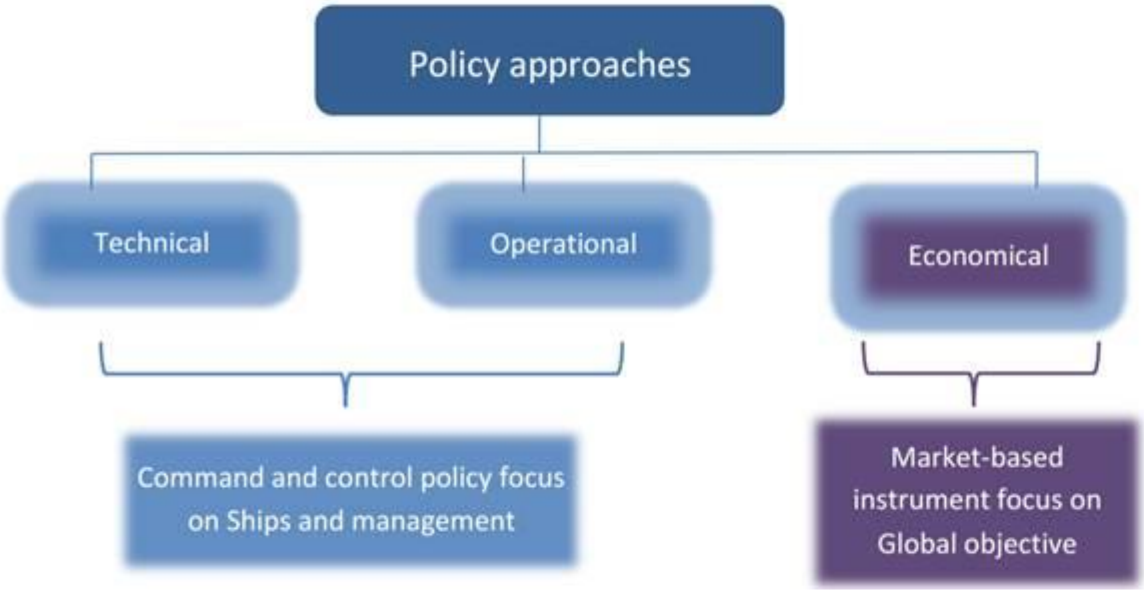

Figure 13.8: IMO policy approaches of the GHG emission reduction

Subsequently, the policy options on technical and operational measures were progressed and led to relevant regulations. The debate on Marked-Based Measures (MBMs) for the international shipping proved to be a particularly sensitive issue amongst IMO member States due to a number of reasons and the sheer complexity of the proposed schemes. As such, this policy option is still on hold within the IMO GHG control regulatory framework.

Main conclusions of report

The main conclusions reached by the Second IMO GHG Study 2009 include the following:

- Shipping was estimated to have emitted 1046 million tonnes of CO_2 in 2007, which corresponded to 3.3% of the global emissions during 2007. International shipping was estimated to have emitted 870 million tonnes, or about 2.7% of the global emissions of CO_2 in 2007.
- Exhaust gases were the primary source of air emissions and carbon dioxide was the most important GHG emitted by ships. Both in terms of quantity and of global warming potential, other GHG emissions from ships were less important.
- A significant potential for reduction of GHG emissions through technical and operational measures had been identified. Together, if implemented, these measures could increase efficiency and reduce the emissions rate by 25% to 75% below the current levels. Many of these measures appeared to be cost-effective, although non-financial barriers may discourage their implementation.
- A number of policies to reduce GHG emissions from ships were conceivable. The report analysed options and concluded that a mandatory limit on the Energy Efficiency Design Index for new ships was a cost-effective solution that could provide an incentive to improve the design efficiency of new ships. However, its environmental effect was limited because it only applied to new ships and because it only incentivized design improvements and not improvements in operations.

- Shipping had been shown, in general, to be an energy-efficient means of transportation compared to other modes.

If the climate was to be stabilized at no more than 2°C warming over pre industrial levels by 2100 and emissions from shipping continue as projected in the scenarios that were given in the report (growth of ship emissions by 200 to 300% by 2050 relative to 2007), then shipping would constitute between 12% and 18% of the global total CO_2 emissions in 2050. This would then require significant effort by shipping between 2050 and 2100 to achieve the stabilization targets.

13.2.4. Third IMO Study on GHG 2014

Purpose of the study MEPC 63 noted that uncertainty exists in the estimates and projections of emissions from international shipping and agreed that further work should take place to provide the Committee with reliable and up to-date information to base its decisions. The Third IMO GHG Study 2014 was therefore commissioned by the IMO in order to update the Second IMO GHG Study 2009, with the main objective of focussing on the following topics:

- Development of the inventories of CO_2 emissions from international shipping for 2007–2012
- Development of the inventories of other air emissions from international shipping for 2007– 2012
- Development of future shipping scenarios and projection of shipping emissions for 2012–2050

The study was performed in 2013-2014 by an international consortium with a foresight role by a Steering Committee. The report of the study was approved by MEPC 67 in October 2014.

Methodology

Both bottom-up and top-down methods were used, but consortium concluded that the bottom-up approach provides best-estimate. The bottom-up method used in this study, is similar to the Second IMO GHG Study 2009, however, in this study instead of using ship type, size and annual average activity for analysis purposes, the calculations of shipping's activity, fuel consumption and air emissions (GHG and pollutants) are performed for each in-service ship using detailed satellite information. The satellite data on an hourly basis for the full period of 2007-2012 were used for estimation of emissions. The hourly estimates are then aggregated to find the totals of emissions and fuel consumption, first per each fleet or ship type and then for international shipping and total shipping (international, domestic and fishing vessels combined) separately. Figure below shows an overview of satellite routes that represent the data used for this study.

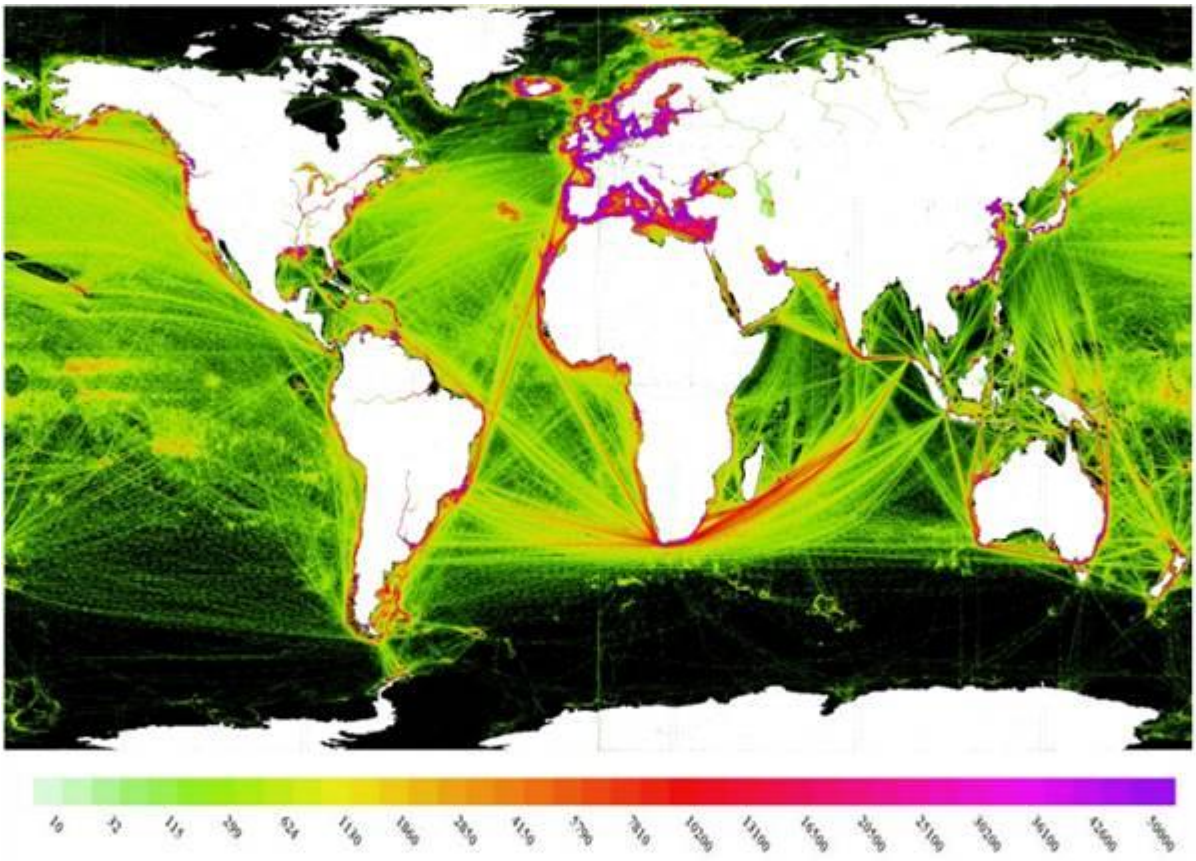

Figure 13.9: Geographical coverage using AIS data and shipping satellite data [Third IMO GHG Study 2014]

New CO_2 estimates (inventory)

Using the methodology, the international shipping CO_2 emissions estimates for 2007-2012 was established. The consensus CO_2 emissions estimate in tonnes and as a % share of global CO_2 emissions is shown in table below.

		IMO GHG Study 2014 CO_2			
Year	Global CO_2[1]	Total shipping	Percent of global	International shipping	Percent of global
2007	31,409	1,100	3.5%	885	2.8%
2008	32,204	1,135	3.5%	921	2.9%
2009	32,047	978	3.1%	855	2.7%
2010	33,612	915	2.7%	771	2.3%
2011	34,723	1,022	2.9%	850	2.4%
2012	35,640	938	2.6%	796	2.2%
Average	**33,273**	**1,015**	**3.1%**	**846**	**2.6%**

Table: Estimated emissions of CO_2 (million tonnes) from total shipping and international shipping [Third IMO GHG Study 2014]

The estimates in table above indicate an overall reduction in CO_2 emissions from international shipping in both absolute terms and as a percentage of global CO_2 emissions for period 2007 to 2012.

For the year 2012, total shipping emissions were approximately 938 million tonnes CO_2 and 961 million tonnes CO_2e (CO_2 equivalent) for GHGs combining CO_2, CH_4 and N_2O. International shipping emissions for 2012 are estimated to be 796 million tonnes CO_2 and 816 million tonnes CO_2e for total GHGs emissions combining CO_2, CH_4 and N_2O. Accordingly, international shipping accounts for approximately 2.2% and 2.1% of global CO_2 and GHG emissions on a CO_2 equivalent (CO_2e) basis respectively.

Figure below shows the breakdown of CO_2 emissions per ship type.

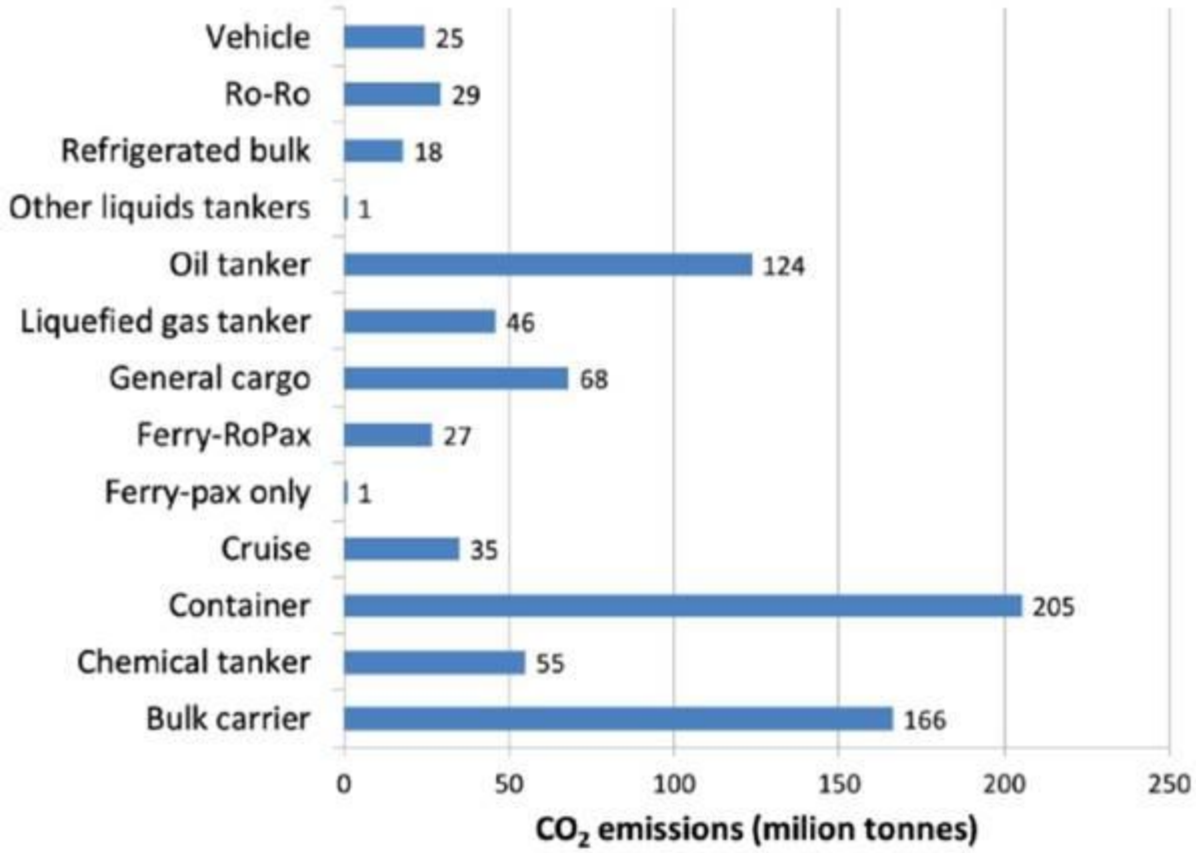

Figure 13.10: CO_2 emissions from international shipping by ship type for 2012 [Third IMO GHG Study 2014]

This Figure indicates that container ships, bulk carriers and oil tankers dominate the international shipping CO_2 emissions.

Trend and overall emissions inventories

Figure below shows the summary estimates of the air emissions inventories under this study.

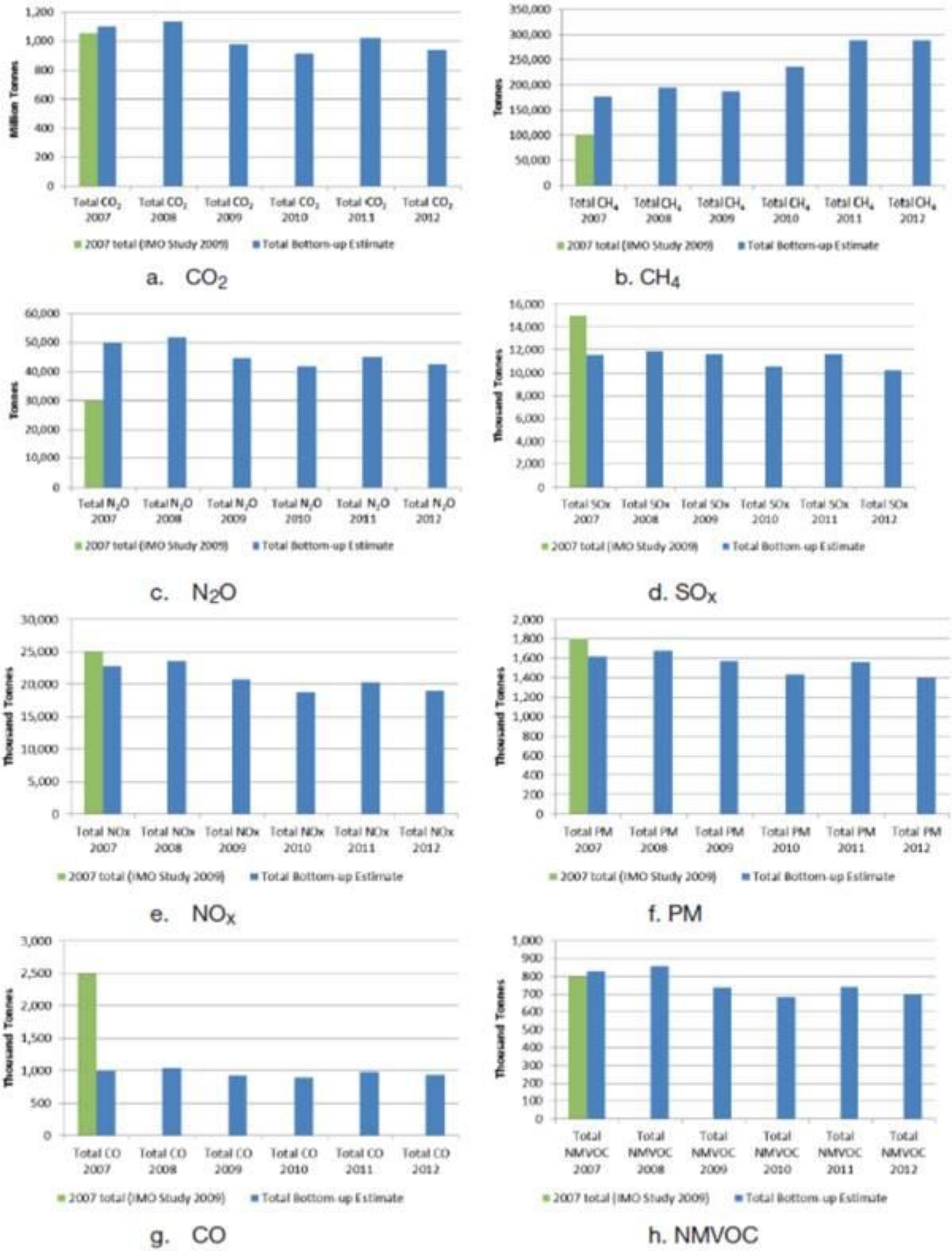

Figure 13.11: Emissions estimates for all shipping for period 2007 to 2012. Green bar represents the Second IMO GHG Study 2009 estimate [Third IMO GHG Study 2014]

From figure above, the following conclusions may be made:

NO_x and SO_x: This study estimates multi-year (2007–2012) average annual totals of 20.9 million and 11.3 million tonnes for NO_x and SO_x respectively from all shipping. Annually, international shipping is estimated to produce approximately 18.6 million and 10.6 million tonnes of NO_x and SO_x respectively. Global NO_x and SO_x emissions from all shipping represent about 15% and 13% of global NO_x and SO_x from anthropogenic sources reported in the IPCC Fifth Assessment Report (AR5), respectively. International shipping NO_x and SO_x represent approximately 13% and 12% of global NO_x and SO_x totals, respectively.

Fuel consumption: Over the period 2007–2012, average annual fuel consumption ranged between approximately 247 million and 325 million tonnes of fuel consumed by all ships within this study, reflecting top-down and bottom-up methods, respectively. Of that total, international shipping fuel consumption ranged between approximately 201 million and 272 million tonnes per year, depending on whether consumption was defined as fuel allocated to international voyages (top-down) or fuel used by ships engaged in international shipping (bottom-up), respectively. The total fuel consumption of shipping is dominated by three ship types: oil tankers, containerships and bulk carriers.

Figure below shows the breakdown of shipping fuel consumption per combustion system. As expected most of fuel consumption occurs in main engines followed by auxiliary engines. Consistently for all ship types, the main engines (propulsion) are the dominant fuel consumers while boilers use relatively smaller amount of fuel compared to auxiliary engines.

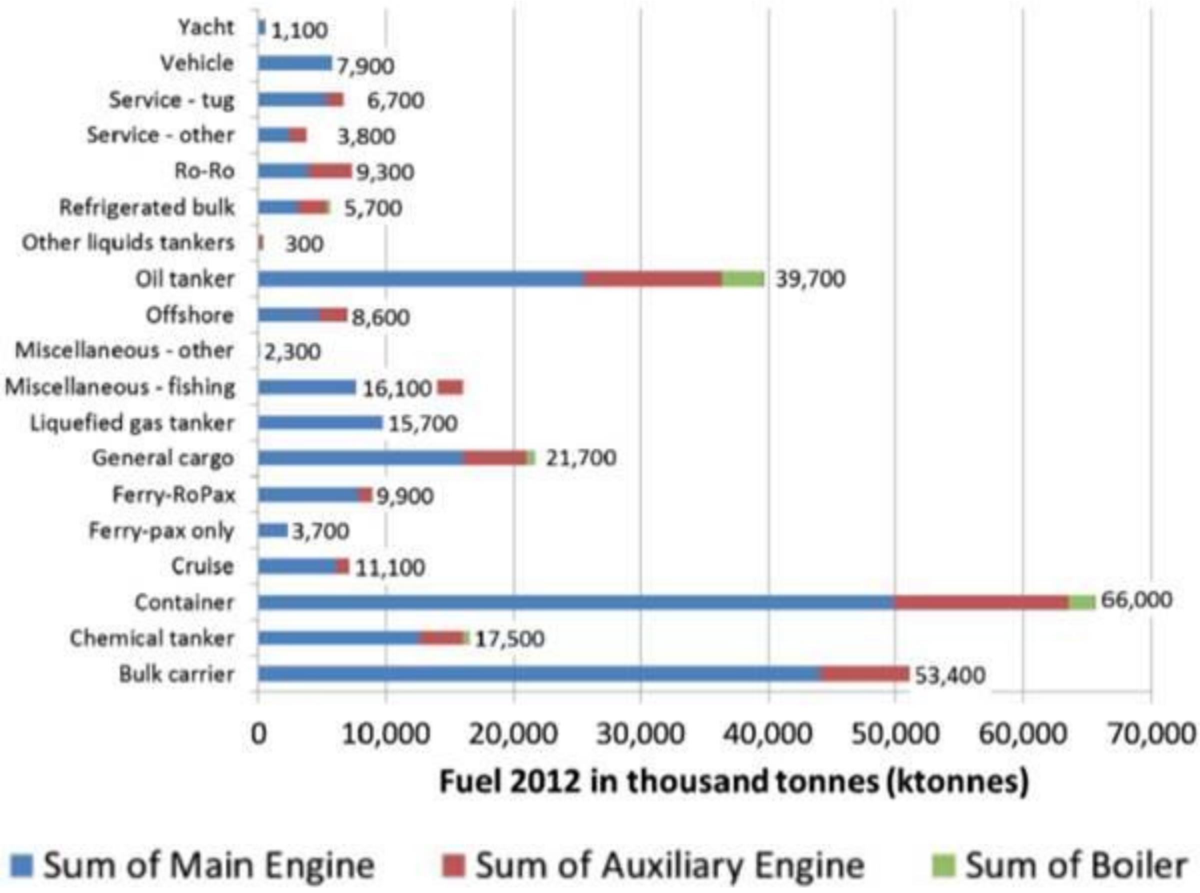

Figure 13.12: Annual shipping fuel consumption per ship type and combustion system [Third IMO GHG Study 2014]

CO_2 emissions: CO_2 emissions from shipping are estimated to range between approximately 739 million and 795 million tonnes per year in top-down results, and to range between approximately 915 million and 1135 million tonnes per year in bottom-up results. International shipping CO_2 estimates range between approximately 596 million and 649 million tonnes calculated from top-down fuel statistics, and between approximately 771 million and 921 million tonnes according to bottom-up results.

CO_2 emissions projections for international shipping

As part of the study, scenario modelling was used to estimate the projected levels of the international shipping CO_2 emissions. A very large number of scenarios (altogether 16) were modelled that included the following options:

- Low and high LNG uptake as marine fuel
- Constant ECAs and more future ECAs
- High transport efficiency and low transport efficiency
- Various RCPs (Representative Concentration Pathways) for future shipping demand based on demand for commodities
- Various SSPs (Shared Socioeconomic Pathways) denoting economic activities and future economic growth

Figure below shows the CO_2 emissions projections for international shipping. The thick lines show the case for closely related scenarios.

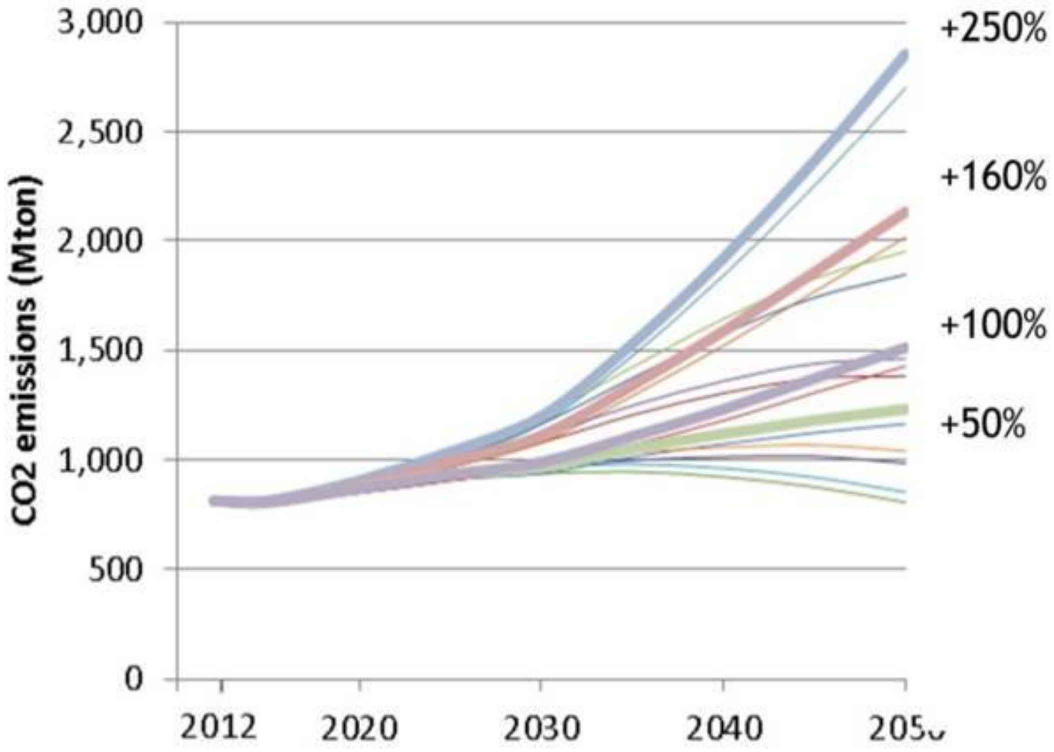

Figure 13.13: CO_2 emissions projections for international shipping [Third IMO GHG Study 2014]

Accordingly, and depending on future scenarios, international shipping CO_2 emissions are projected to increase by 50% to 250% in the period to 2050, despite fleet average efficiency improvements of about 40% (in some scenarios, an efficiency improvement of 60% have been assumed). This study shows that under almost all the perceived scenarios, the CO_2 emissions will not decline in 2050 relative to 2012. Thus, further action on efficiency and emissions will be needed to stabilize GHG emissions from international shipping or bring it below 2012 levels in 2050.

Emissions projections demonstrate that improvements in efficiency are important in mitigating the emissions and reduce their rise. The scenarios also show that compared to regulatory or market-driven improvements in efficiency, changes in the fuel mix have a limited impact on GHG emissions, assuming that fossil fuels remain dominant.

13.2.5. History of IMO GHG-Related Activities

With a view to addressing the issue of air emissions from international shipping, IMO in its 1997 MARPOL Conference adopted MARPOL Annex VI on prevention of air pollution from ships and also adopted Resolution 8 on "CO_2 emissions from ships" as a starting point inviting:

- the IMO Secretary-General to co-operate with the Executive Secretary of UNFCCC in the exchange of information on the issue of GHG emissions.
- IMO to undertake a study of GHG emissions from ships for the purpose of establishing the amount and relative percentage of GHG emissions from ships as part of the global inventory of GHG emissions; and
- The Marine Environment Protection Committee (MEPC) of IMO to consider feasible GHG emissions reduction strategies.

This was the starting point for IMO debates and decisions on GHG emissions from international shipping that still continues. Figure below provides the important chronological order of the IMO activities so far since 1997.

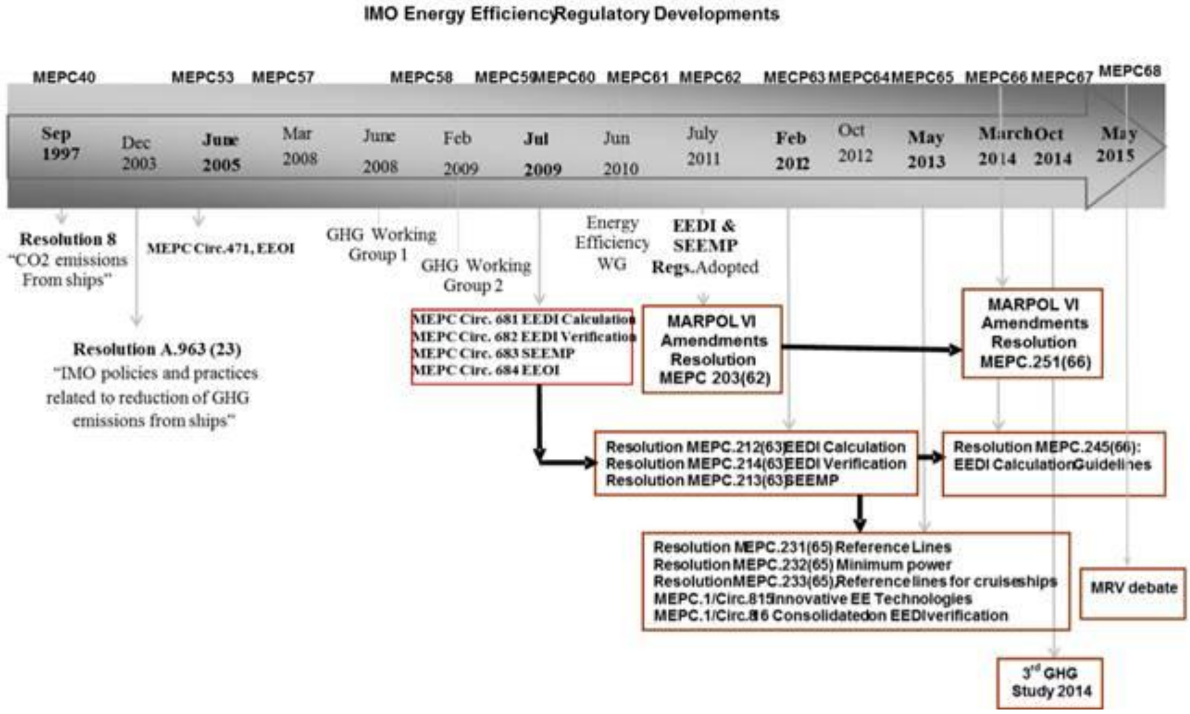

Figure 13.14: IMO GHG control related activities in chronological order

Further details of the IMO activities are given below in chronological order.

1997-2003

As a follow-up to Resolution 8, the First IMO GHG Study 2000 was completed and presented to the forty fifth session of the MEPC (MEPC 45) in June 2000.

2003-2008

In an effort to further address the issue of GHG emissions from ships, the IMO Assembly adopted, in December 2003, Resolution A.963 (23) on "IMO Policies and Practices related to the Reduction of Greenhouse Gas Emissions from Ships." As follow-up to this resolution, MEPC 55 (October 2006) approved the MEPC's "Work plan to identify and develop the mechanisms needed to achieve the limitation or reduction of CO_2 emissions from international shipping," inviting Member Governments to participate actively in the work plan.

MEPC 55 also agreed to update the "First IMO GHG Study 2000" to provide a better foundation for future decisions and to assist in the follow-up to resolution A.963 (23). MEPC 56 (July 2007) adopted the terms of reference for the updating of the study. The report of this study prepared by a consortium and was submitted to MEPC in 2009 under the title "Second IMO GHG Study 2009".

MEPC 59 (July 2009)

The MEPC work plan culminated at MEPC 59 with the MEPC agreeing to a package of technical and operational measures to reduce GHG emissions from international shipping and also agreed on a plan for further consideration and development of suitable and efficient Market Based Measures (MBMs) to complement the technical and operational reduction measures and to provide economic incentives for the shipping industry. The MEPC further agreed that any regulatory scheme to control GHG emissions from international shipping should be developed and enacted by IMO as the most competent international body.

IMO's GHG / energy efficiency work plan at the time contained three distinct components:

- The technical measures that will mainly be applied to new ships. This was reflected in the development of EEDI related regulations.
- The operational measures for all ships in operation (new and existing). This was reflected in the development of SEEMP and EEOI.
- The MBMs providing market / competition incentives to the shipping industry by setting a sort of cost item for CO_2 emitters and incentives for those who reduce their CO_2 emissions.

Technical and operational measures: MEPC 59 finalized a package of technical and operational measures in the form of Guidelines for EEDI, SEEMP and EEOI. Relevant Guidelines developed and approved (in the form of Circulars) for the then voluntary application.

Market Based Measures (MBMs): The agreed package of the above technical and operational measures is a very important step in ensuring that the shipping industry has the necessary mechanisms to reduce its GHG emissions. However, the MEPC recognized that these measures would not be sufficient to satisfactorily reduce the amount of GHG emissions from international shipping in view of the growth projections of world trade. Therefore, MBMs was considered as a market-driven option by the MEPC in line with its GHG work plan. At the time, it was understood that a good MBM would serve two main purposes: (1) Offsetting in other sectors of growing ship emissions and (2) Providing a fiscal incentive for the maritime industry to invest in more fuel-efficient ships and technologies and to operate ships in a more energy efficient manner.

MEPC 60 (2010)

The main work accomplished during this session was the preparation of the “draft regulatory text” on mandatory requirements for the EEDI for new vessels and on the SEEMP for all ships in operation. The MEPC realised that to finalise the regulatory text, it is required to decide on issues concerning ship size, ship types, target dates and reduction rate in relation to the EEDI requirements. The MEPC agreed in principle on the basic concept that a vessel's Attained EEDI shall be equal or less than the Required EEDI, and that the Required EEDI shall be drawn up based on EEDI reference lines and reduction rates. This became the subject of additional work and use of concrete methods for calculating the EEDI reference line using data from existing ships in the IHS Fairplay database. With regard to MBM, the MEPC agreed to establish an Expert Group on the subject to undertake a feasibility study and impact assessment of the various proposals submitted for a MBM instrument for international maritime transport.

MEPC 61 (2010)

Technical and operational measure: Having considered means by which technical and operational measures could be introduced in MARPOL Annex VI, there was further debates and agreement on how these regulatory texts should be introduced. The debate concentrated for the IMO Secretary-General to circulate proposed amendments to MARPOL Annex VI for mandatory application of EEDI and SEEMP regulatory text and relevant Guidelines that have already been disseminated for voluntary use. The issue of circulation by the Secretary General was the subject of much debate as some States did not consider it appropriate.

Market-Based Measures: The scope of the work of the Expert Group was to evaluate the various proposals on possible MBMs, with the aim of assessing the extent to which they could assist in reducing GHG emissions from international shipping, giving priority to the maritime sectors of developing countries, least developed countries (LDCs) and Small Island Developing States (SIDS). The MBM proposals under review ranged from a GHG Fund or levy on all CO_2 emissions from international shipping or only from those ships not meeting the EEDI requirement, via emission trading systems, to schemes based on a ship's actual efficiency, both by design (EEDI) and operation (SEEMP).

The MEPC agreed Terms of Reference for an intercessional meeting of the "Working Group on GHG Emissions from Ships" to deal with relevant schemes and submissions and report back to MEPC 62.

MEPC 62 (July 2011)

The final breakthrough came at MEPC 62. As a result of lengthy deliberations, the amendments to MARPOL Annex VI in the form of "energy efficiency regulations for ships" was added as a new Chapter 4 to MARPOL Annex VI as a result of which EEDI and SEEMP became mandatory for applicable ships. Other amendments to Annex VI included addition of new definitions and the requirements for survey and certification, including the format for the International Energy Efficiency Certificate.

MEPC 63 (2012)

An important series of guidelines to support the uniform implementation of mandatory measures for ship energy efficiency (EEDI and SEEMP) was adopted by the MEPC in this session. During this session, the MEPC also continued its intensive discussion on MBMs for application to international shipping.

MEPC 64 (2013)

The MEPC continued to refine relevant Guidelines on calculation and verification of EEDI. MEPC additionally approved the following:

- A number of UIs (Unified Interpretations) on definition of "new ships" for various EEDI phases, on timing of ships to have a SEEMP on-board and also on "major conversion" for energy efficiency purposes.
- Decided on development of interim guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions and draft Guidelines on treatment of innovative energy-efficiency technologies.
- A debate on Regulation 23 of chapter 4 of MARPOL Annex VI on "promotion of technical cooperation and transfer of technology" that led to a text of a draft resolution3

on issues relating to technology transfer for the improvement of energy efficiency of ships.

- In principle endorsed and outline for an update of the previous GHG Studies including GHG inventory. Finally, it decided to defer debates on MBMs to MEPC 65.

MEPC 65 (2013)

During this MEPC meeting, the following were accomplished:

- Resolution on MEPC.229 (65) on Promotion of Technical Co-operation and Transfer of Technology Relating to the Improvement of Energy Efficiency of Ships was adopted.
- Study to update the previous GHG Study approved: The MEPC approved the terms of reference and agreed to initiate a study for an update of previous IMO GHG Studies.
- Development of energy-efficiency regulations continued: The MEPC continued its work on further developing the EEDI and SEEMP framework. This included approval of draft amendments to MARPOL Annex VI to extend the application of EEDI to ro-ro cargo ships (vehicle carrier), LNG carriers, cruise passenger ships having non-conventional propulsion, ro-ro cargo ships and ro-ro passenger ships; and to exempt ships not propelled by mechanical means, and platforms including FPSOs and FSUs and drilling rigs, regardless of their propulsion; as well as cargo ships having ice-breaking capability.
- Adopted amendments to update a number of Guidelines on EEDI. Adopted those Guidelines that were approved under MEPC 64.
- *Further measures to improve the energy efficiency of ships:* The MEPC considered the importance of enhancing the existing framework (EEDI and SEEMP) for further reduction of shipping GHG emissions. As such the MEPC agreed to establish a sub-agenda item for discussion of further technical and operational measures for enhancing energy efficiency for international shipping, and to establish a working group under this sub-agenda item at MEPC 66.

MEPC 66 (April 2014)

The following aspects were discussed but no substantive decision made:

- Energy-efficiency measures for ships considered: The MEPC continued its work on further developing guidelines to support the uniform implementation of the regulations on energy-efficiency for ships.
- Technical co-operation and technology transfer discussed: The MEPC discussed the implementation of resolution MEPC.229 (65) on Promotion of Technical Co-operation and Transfer of Technology Relating to the Improvement of Energy Efficiency of Ships. The Ad Hoc Expert Working Group on Facilitation of Transfer of Technology for Ships (AHEWG-TT), established in accordance with the resolution, met during the session and agreed a work plan with the following terms:
- Assessing the potential implications and impacts of the implementation of the energy efficiency regulations in chapter 4 of MARPOL Annex VI, in particular, on developing States, as a means to identify their technology transfer and financial needs;
- Identifying and creating an inventory of energy efficiency technologies for ships;

- Identifying barriers to transfer of technology, in particular to developing States, including associated costs, and possible sources of funding; and making recommendations, including the development of a model agreement enabling the transfer of financial and technological resources and capacity building between Parties, for the implementation of the energy efficiency regulations.
- Further measures for improving energy efficiency of ship: The MEPC discussed various submissions relating to proposals to establish a framework for the collection and reporting of data on the fuel consumption of ships.

MEPC 67 (October 2014)

The following activities were carried out:

- Energy-efficiency measures for ships considered: During the session, the MEPC adopted a number of changes to various Guidelines including:
- The 2014 Guidelines on survey and certification of the Energy Efficiency Design Index (EEDI), updating the previous version to include, for example, identification of the primary fuel for the calculation of the attained EEDI for ships fitted with dual-fuel engines using LNG and liquid fuel oil.
- The MEPC also adopted amendments to the 2013 Interim Guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions.
- A correspondence group was established to review the status of technological developments relevant to implementing phase 2 of the EEDI regulatory framework as foreseen under Regulation 21.6.
- *Further measures* - Data collection system for fuel consumption of ships: The MEPC agreed, in principle, to develop a data collection system for ships and, having agreed on the general description of the data collection system for fuel consumption of ships, agreed to the reestablishment of an intersessional correspondence group to develop full language regulatory text so that it can be readily used for voluntary or mandatory application of the system. The core elements of the data collection system included: (1) data collection by ships, (2) flag State functions in relation to data collection including verification and (3) establishment of a centralized database by the IMO.
- *Third IMO GHG Study 2014 approved:* The MEPC approved the Third IMO GHG Study 2014 providing updated estimates for GHG emissions from ships (see Section 6.3 for details of this study).

MEPC 68 (May 2015)

In this session of the MEPC, the following were agreed:

- Further development of energy-efficiency guidelines for ships: The MEPC continued its work on further develop and approved/adopted guidelines to assist in the implementation of the mandatory energy-efficiency regulations in particular the EEDI.

- EEDI review work to continue: The progress of the Correspondence Group established to review the status of technological developments relevant to implementing phase 2 of the EEDI regulations, as required under regulation 21.6 of MARPOL Annex VI, was received and MEPC decided to re-establish the Correspondence Group to further the work.
- Text agreed for further development of a data collection system: On "further measures", the MEPC agreed that the full language text for the data collection regulations need to be enhanced. The proposed text was preliminary agreed, and the Correspondence Group was re-convened to continue work on this text and report back to future MEPC meetings.

All the above activities will be reported back to MEPC 69 in March 2016.

13.2.6. Current Regulatory Framework

As discussed in previous section, through extensive discussions within the IMO, mandatory measures to reduce emissions of GHG from international shipping were adopted by Parties to MARPOL Annex VI at MEPC 62 in July 2011. This provided the first ever mandatory global GHG reduction regime for an international industry sector.

This amendments to MARPOL Annex VI Regulations for the prevention of air pollution from ships, added a new chapter 4 on Regulations on Energy Efficiency for Ships to make mandatory the Energy Efficiency Design Index (EEDI), for new ships, and the Ship Energy Efficiency Management Plan (SEEMP) for all ships. Other relevant amendments to Annex VI included new definitions and the requirements for survey and certification, including the format for the International Energy Efficiency Certificate. Additionally, voluntary Guidelines for calculation of Energy Efficiency Operational Indicator (EEOI), that was developed and agreed in 2009, can be used for operational monitoring of ships energy efficiency measures.

These technical and operational measures are collectively shown in figure below, which also indicates how EEDI, SEEMP and EEOI will work collectively to cover both ship design and operation.

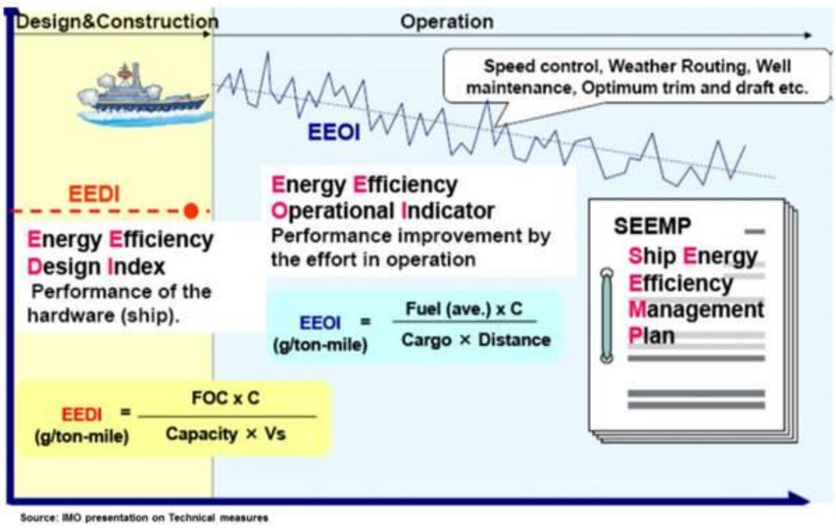

Figure 13.15: Main components of the IMO energy efficiency regulations

An important series of guidelines to support the uniform implementation of the above mandatory measures are adopted, paving the way for the regulations to be smoothly and uniformly implemented by Administrations and industry. Some examples of these Guidelines include:

- 2012 Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP);
- 2013 Guidelines for calculation of reference lines for use with the Energy Efficiency Design Index (EEDI).
- 2014 Guidelines on survey and certification of the Energy Efficiency Design Index (EEDI), as amended; and
- 2014 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships, as amended;

13.2.7. IMO Further Energy Efficiency Measures

A number of studies including IMO MEPC 63/INF.2 by Bazari and Longva (2011) and the Third IMO GHG Study 2014 indicate that successful implementation of the shipping technical and operational energy efficiency regulations could reduce shipping GHG emissions significantly, but on their own they are not sufficient to prevent the rising trend in shipping GHG emissions under all existing growth scenarios. Consequently, the IMO began working on further technical and operational measures including the development of a global shipping data collection system for energy efficiency as a first step priority area.

Since April 2014 as a result of MEPC 67 and 68 meetings, IMO reached preliminary conclusions on a general description of such a global data collection system. Based on results of the relevant MEPC working group deliberations, the data collection and reporting requirements would apply to ships involved in international shipping over a certain size threshold and regardless of their flag State.

The draft developed data collection system identifies three core elements including: (1) data collection by ships, (2) flag State functions in relation to data collected including verification and (3) establishment of a centralized database by the IMO. As it stands now (2015), the following features are under considerations for the IMO data collection system:

- Applicable to ships of gross tonnage more than 5000 GT
- Annual reporting
- IMO number for ship identification
- Confidentiality of some data such as transport work will be observed.
- Guidelines will be developed to deal with various details of data collection and verification activities.
- Registered owner will be responsible for submission of data to Administration
- Administration will be responsible for verification (can be delegated to Recognized Organizations).

- A Statement of Compliance (SoC) will be issued by the Administration to each ship annually.
- PSC (Port State Control) will examine SoC for enforcement
- In addition to ship's fuel consumption, other data may be collected such as transport work and distance sailed. These will be discussed and decided later.

Thus in summary, beginning at a specific date, ships should annually submit their data to a centralized database maintained and managed by the IMO. Flag States should put in place mechanism(s) to ensure compliance by the ships entitled to fly their flag with the annual data collection requirements; and that data included in annual reports is sent to the centralized database. The compliance system of the flag State should have provisions for the transfer of ownership and change of flag. The above is the current general agreement; however, this is a work-in-progress at the IMO that is planned to be finalised in the future (expected by MEPC 70 in late 2016). It is worth noting that EU has already legislated an MRV (Measurement, Reporting and Verification) system for shipping that has similarities to IMO current work.

13.2.8. Implementation and Enforcement Support

IMO supports to extent possible the implementation aspects of its regulations in particular supporting the developing countries. In this section, such activities are described further.

IMO Technical Co-operation (TC) programme.

IMO through its Technical Cooperation Department and relevant budgets as well as through donor country funds organises a number of activities mainly in area of capacity building in the form of training workshops. In specific area of shipping GHG control, the following activities have been done so far:

- National and regional workshops on MARPOL Annex VI and GHG emissions from international shipping with the main aim of raising awareness on the subject. A number of such workshops have already been conducted in a number of countries and regions.
- Under the IMO's Integrated Technical Co-operation Programme, a sum of $400,000 was allocated for the 2012 to 2013 biennium for various national and regional capacity building activities. This sum financed regional training and seminars supporting capacity building and information exchange and sharing.
- A further $400,000 has been allocated for the 2014 to 2015 biennium to sustain the level of technical cooperation interventions in various regions, for the effective implementation and enforcement of energy efficiency measures for ships.
- In addition, some IMO members made donations for capacity building activities/workshops to support the implementation of the existing international energy efficiency rules and assess the need for technology transfer. The IMO completed in 2013 a major technical cooperation project on "Building capacities in East Asian countries to address GHG emissions from ships" with $700,000 funding support of the Korea International Cooperation Agency (KOICA). Additionally, funding received for other

donors such as the Government of Canada in promoting adoption and implementation of the MARPOL Annex VI with specific emphasis on GHG emissions from shipping.

IMO-UNDP-GEF Initiative

In 2014, the IMO Secretariat submitted a proposal to Global Environment Facility (GEF) for funding a two-year global project entitled 'Transforming the Global Maritime Transport Industry towards a Low Carbon Future through Improved Energy Efficiency' to assist the developing countries in the implementation of new energy efficiency measures adopted by IMO. This project was endorsed by GEF in 2015.

The main activities under this project are foreseen to include the following components: all related to promotion of low carbon shipping in the participating pilot countries:

1. Legal, Policy and Institutional Reforms (LPIR): This is the priority component within the project and aims to improve the host country legal, policy and institutional frameworks. This will be achieved via carrying out country status / baseline assessment, development of global guidance and model legislations, support for customisation and finally the implementation.

2. Capacity building and knowledge exchange: The core of this activity includes the long-term capacity-building for the accelerated implementation of IMO energy efficiency regulations. This will be achieved via extensive set of training activities, workshops, participation in international events as well as dissemination of information.

3. Public-private partnership for innovation and R&D: This activity primarily aims to catalyse maritime sector energy efficiency innovation and R&D. To achieve this, the project aims to promote partnerships such as (1) global forums to highlight best practices and R&D on maritime energy efficiency and (2) formation of a Global Industry Alliance for industry, academia and ship design and operation R&D community to promote debates and R&D.

Technology transfer debate

The amendments to MARPOL Annex VI which introduced “the energy efficiency regulations for ships” also included a new Regulation 23. Regulation 23 encourages the Parties to MARPOL Annex VI in cooperation with the IMO and other international bodies:

• To promote and provide, as appropriate, support directly or through the IMO to States, especially developing States that request technical assistance.

• Co-operate actively with other Parties, subject to its national laws, regulations and policies, to promote the development and transfer of technology and exchange of information to States which request technical assistance, particularly developing States, in respect of the implementation of Chapter 4 of MARPOL Annex VI.

Moreover, it was agreed at the time of the adoption of energy efficiency regulations, to complement them with a resolution on “promotion of technical co-operation and transfer of technology relating to the improvement of energy efficiency of ships”, which was adopted in May 2013 as Resolution MEPC.229 (65). This Resolution provides a framework for the promotion and facilitation of capacity building, technical cooperation, and technology transfer to support the developing countries in the implementation of the EEDI and the SEEMP. Amongst others, it invites international and regional organizations, non-governmental organizations and the industry to contribute in any manner possible and as appropriate to enhancing the effective implementation of chapter 4 of MARPOL Annex VI.

An AHEWG-TT (Ad Hoc Expert Working Group on Facilitation of Transfer of Technology for Ships) was set up by IMO MEPC to deal with implementation of the Resolution with terms of reference that include:

- Assess the potential implications and impacts of the implementation of chapter 4 regulations, in particular, on developing States, as a means to identify their technology transfer and financial needs;
- Identify and create an inventory of energy efficiency technologies for ships.
- Identify barriers to transfer of technology, in particular to developing States, including associated costs, and possible sources of funding and make recommendations.
- Develop a model agreement enabling the transfer of financial and technological resources and capacity-building between Parties.

The AHEWG-TT activities had so far had a number of meetings and produced a number of documents. At the time of writing this Module (2015), the work of AHEWG-TT is in progress with completion date of MEPC 70 (October 2016).

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Chapter 14: International Energy Management Standards

14.1. ISO 50001 Energy Management System

14.1.1. Overview

ISO 50001 is a voluntary international standard developed by the International Organization for Standardisation (ISO) to provide various organizations with an internationally recognized framework to manage and improve their energy performance. The standard addresses the following:

- Energy use and consumption evaluation via conducting energy reviews and development of energy policies.
- Measurement, documentation and reporting of energy use and consumption.
- Design and procurement practices for energy-using equipment, systems, and processes.
- Development of an energy management plan and other factors affecting energy performance that can be monitored and influenced by the organization.

ISO 50001 applies to all different types of companies and industry sector. It provides a framework for an “Energy Management System (EnMS)” through which each organization can set and pursue its own goals for improving energy performance. From the ISO 50001 perspective, an EnMS is a series of processes that enables an organization to use data and information to maintain and improve energy performance, while improving operational and energy efficiencies and reducing environmental impacts.

Using the ISO 50001 framework provides a systematic approach to managing energy within a company. Conformance to the standard provides proof that a company has implemented international energy management systems, completed and developed a baseline of its energy use and is committed to continual improvement in energy performance. ISO 50001 is designed for widespread use by all industries (power, oil and gas, manufacturing, transport, etc.), buildings and other organizations; thus, it is applicable beyond shipping. The use of ISO 50001 is expected to be driven by factors such as regulatory/legislative developments, corporate social responsibility (CSR), environmental management programs as well as the economic benefits of energy and CO_2 reductions.

As discussed in previous section, ISO 50001 is based on a standard management system model based on the Plan-Do-Check-Act approach already employed in ISO 9001, ISO 14001 and IMO SEEMP. Figure below shows the continual improvement process of the ISO 50001.

Figure 14.1: ISO 50001 energy management cycle [ISO 50001]

The Plan-Do-Check-Act features of the IMO 50001 are best shown in figure below where various sections of ISO 50001 are shown together with the standard relevant headlines.

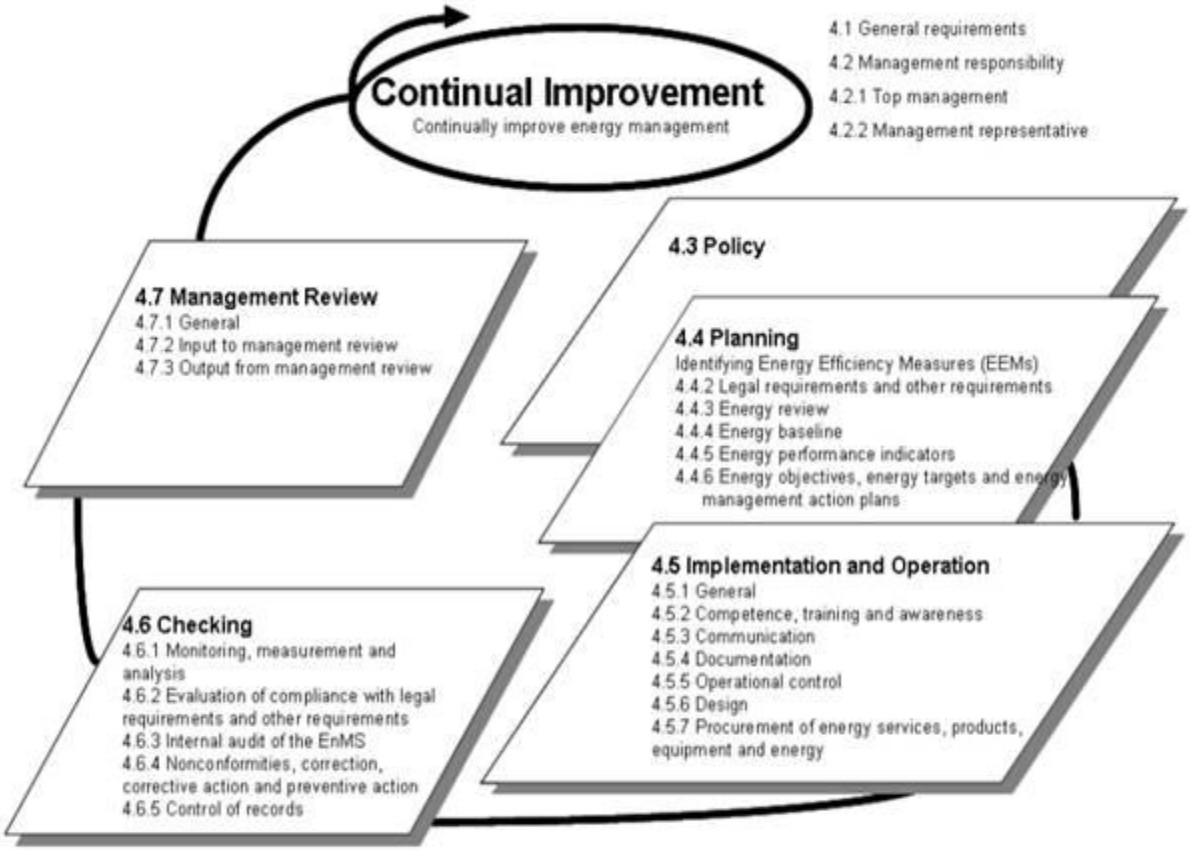

Figure 14.2: Structure of ISO 50001 [Bazari 2012]

In order to develop and implement the ISO 50001, normally some level of preparatory work needs to be undertaken. These include, inter alia, aspects such as:

- Development of an energy policy that includes commitment to the EnMS from top management
- Assignment of a management representative to lead the implementation of the EnMS
- Establishment of a team from various departments that have influence on ship fuel procurement, treatment, storage and use.

Upon completion of the preparatory work, the steps towards planning for implementation of an EnMS could include aspects such as:

- Undertaking an energy review to identify significant energy users, their energy consumption, and opportunities for improvement
- Establishment of energy baselines for the company and various facilities
- Identification of energy performance indicators and benchmarks for tracking energy performance improvement against the baseline.

14.1.2. Target Setting and Performance Criteria

ISO 50001 does not prescribe specific performance criteria or target levels with respect to energy efficiency performance; however, it requires the organization to continually improve energy performance. For a shipping company this practically implies that it should select key performance indicators in order to demonstrate improved energy performance. IMO has developed the Energy Efficiency Operational Indicator (EEOI), that may be used as a performance indicator for a company when applying the EnMS to shipping. Off course, other indicators may be used for this purpose.

14.1.3. Scope of EnMS

A shipping company EnMS will include features that need to be undertaken both at head office and on-board ships. The ship-related aspects include:

- Defining each ship's energy efficiency measures (EEMs).
- Documenting each ship EEMs and their implementation, monitoring and improvement processes.
- Implementation of energy saving projects on-board ships.

The above will normally be included in a ship's SEEMP. The shipping company's EnMS should also include provisions for activities at shore-based offices. These include, but not limited, to the following activities:

- Planning improvement and management of the whole fleet energy efficiency.
- Gathering of fleet (all ships) information with a view to benchmarking and data sharing.
- Analysis and evaluation of actual state of energy use by ships in a fleet.
- Preparation of the SEEMP for each ship and its implementation and monitoring activities.
- Fleet benchmarking, monitoring and reporting to top management.

As will be argued in the following Section, the application of EnMS in a shipping company should be fully in harmony with shipboard SEEMP and vice a versa.

14.1.4. Certification

There are a large number of companies who offer ISO 50001 certification. These are normally accredited certification bodies via their national standardisation agencies (e.g. British Standard in the case of UK) that are competent to certify organizations for conformance to ISO 50001. These companies normally employ certified ISO 50001 auditors to assess an organization's or company's compliance to ISO 50001. As discussed earlier, in shipping, normally classification societies provide these services.

It should be noted that ISO 50001 certification is voluntary, and companies are free to take action to start improving energy management without becoming certified. However, certification to ISO 50001 provides a structured approach that incorporates energy management into company culture, resulting in sustained energy savings and continual improvements in energy performance over time.

This can help justify initial investments in energy projects and ensure return on investment. Without a structured approach, there is no guarantee that energy savings will be sustained, or that return on investment will be maximised. As such, the certification is a useful exercise and is highly recommended.

14.1.5. Responsibilities

Within ISO 5001, definition of roles and responsibilities for various activities are foreseen. Amongst these, the responsibility of top management is crucial. Within ISO 50001, a significant responsibility is given to top management. Accordingly, top management shall demonstrate its commitment to support the EnMS and to continually improve its effectiveness by:

- Defining, establishing, implementing and maintaining an energy policy;
- Appointing a management representative and approving the formation of an energy management team.
- Providing the resources needed to establish, implement, maintain and improve the EnMS and the resulting energy performance.
- Identifying the scope and boundaries to be addressed by the EnMS.
- Communicating the importance of energy management to those in the organization.
- Ensuring that energy objectives and targets are established.
- Ensuring that “energy performance indicators” are appropriate to the organization.
- Considering energy performance in long-term planning;
- Ensuring that results are measured and reported at determined intervals.
- Conducting management reviews.

Top management should also appoint a management representative(s) with appropriate skills and competence with responsibility and authority to:

- Ensure the EnMS is established, implemented, maintained, and continually improved.
- Identify person(s), to work with the management representative in support of energy management activities (energy team).
- Report to top management on the actual and the performance of the EnMS.
- Ensure that the planning of energy management activities is designed to support the organization's energy policy;
- Define and communicate responsibilities and authorities in order to facilitate effective energy management.
- Determine criteria and methods needed to ensure that both the operation and control of the EnMS are effective.
- Promote awareness of the energy policy and objectives.

Other roles and responsibilities need to be defined according to the requirements.

14.1.6. Energy Policy

ISO 50001 requires that a company should have an "energy policy". Accordingly, the energy policy shall state the organization's commitment to achieving energy performance improvement. This energy policy shall be defined and endorsed by top management and ensure that it:

- Is appropriate to the nature and scale of the organization's energy use and consumption.
- Includes a commitment to continual improvement in energy performance.
- Includes a commitment to ensure the availability of information and of necessary resources to achieve objectives and targets.
- Includes a commitment to comply with applicable legal and other requirements.
- Provides the framework for setting and reviewing energy objectives and targets.
- Supports the purchase of energy-efficient products and services, and design for energy performance improvement.
- Is documented and communicated at all levels within the organisation?
- Is regularly reviewed and updated as necessary.

The energy policy is one of the first documents that need to be prepared as it will show the intentions of the top management. All other planning activities then will be based on energy policy.

14.1.7. Planning

Planning is the most crucial stage of a SEEMP development. It involves activities such as determination of both:

- The current status of ship energy usage; and
- The expected improvements.

Based on the above and via using further energy reviews or audits, a set of Energy Efficiency Measures (EEMs) are identified and documented as part of the planning phase. The SEEMP planning activities do not stop at identification of EEMs but includes dealing with all aspects of planning for implementation, monitoring and self-assessment of the identified EEMs. Therefore, planning part for ship energy management and SEEMP is crucial and it is essential to devote sufficient time to planning.

- Identification of ship's EEM
- Goal Setting
- Managing the stakeholders
- Human resources development

14.1.8. Monitoring

In a SEEMP, the monitoring aspects also need to be clarified at the planning phase. Consistent data collection is the foundation for monitoring. To allow for meaningful and consistent monitoring, the monitoring system, including the procedures for collecting data and the assignment of responsible personnel, should be developed. The development of such a system can be considered as a part of planning, and therefore should be completed at the planning stage.

To avoid unnecessary administrative burdens on ships' staff, monitoring should be carried out as far as possible by shore staff, utilizing data obtained from existing ship-board log books and data systems. In this monitoring context, the ship's EEOI that is introduced in Section 6 may be advocated as the primary monitoring tool to ensure that the energy management cycle provides expected outcomes.

On the importance of monitoring, the following may be mentioned:

- Monitoring is an essential element of any management cycle. It is well known that "if one cannot measure, one cannot manage". This applies to energy management system as well.
- Monitoring to a large extent relies on data collection and data analysis over long term. Thus establishment of a data collection and analysis system is an essential part of any monitoring system.
- To effectively analyse and make conclusions, a set of Key Performance Indicators (KPIs) need to be defined for quantitative assessment of the gathered data. As indicated, the KPIs could relate to overall ship performance (such as EEOI) or developed for each EEM.
- Data collection and analysis, performing internal audits, energy reviews, benchmarking, etc. and so on forms the backbone of any good monitoring system.

14.1.9. Management Review

Within ISO 50001, the management review has been clarified and is a requirement. For the review purposes, some inputs to management review meetings are required and some output is expected to be generated. Inputs to the management review include:

- Follow-up actions from previous management reviews;

- Review of the energy policy;
- Review of energy performance and related indicators.
- Results of the evaluation of compliance with legal and other requirements.
- The extent to which the energy objectives and targets have been met.
- The EnMS audit results.
- The status of corrective actions and preventive actions.
- Projected energy performance for the following period.
- Recommendations for improvement.

Outputs from the management review are expected to be items such as:

- Changes in the energy performance of the organization.
- Changes to the energy policy;
- Changes to the energy performance indicators.
- Changes to objectives, targets or other elements of the EnMS.
- Changes to allocation of resources.

Based on the above outputs, a new cycle of continual improvement will begin.

14.1.10. Summary Points

In this section, the main aspects of the ISO 50001 standard on "energy management system" are described. It was advocated that a company EnMS is a useful, structured and systematic way for improving the corporate energy performance. Although the development of an EnMS is a voluntary undertaking by a company, its implementation by shipping companies will help them with more effective compliance with the IMO energy efficiency regulatory framework, environmental (climate change) protection and energy (fuel) cost savings. For the development of the company EnMS, ISO 50001:2011 provides the best-practice available framework. ISO 50001 requirements include development of an energy policy, performing energy reviews, identification of energy performance indicators and baselines, defining various energy efficiency projects and action planning and effective use of monitoring techniques and internal audits and management reviews. Also, ISO 50001 require full commitment by the top management that will be reflected in a written "energy policy" and effective review of the system in formal EnMS performance review meetings. Certification for ISO 50001 is not mandatory but having a certificate is part of best-practice and a way of demonstrating to external organisations that company's EnMS is fully in place.

14.2. ISO 19030 and Application of SEEMP for EEOI Requirements

14.2.1. SEEMP Main Features

Shipping is a relatively efficient mode of transport compared to land and air when you consider the CO_2 emissions produced per mile that each tonne of cargo is transported. However, shipping is also coming under increased scrutiny to lower its GHG by the international community and, under its remit, the IMO is looking at promoting measures to control these by improving ship efficiency through better management and implementation of best practice. The SEEMP provides a means to formally capture processes by which a shipowner can seek to improve the environmental efficiency aspects of their operations both onboard each of their ships as well as companywide. The SEEMP is a 'live' document, containing energy improvement measures identified by the ship owner, which will be kept onboard each ship. The document will be reviewed regularly to establish the relevance and impact of each measure on ship and fleet operations. Each SEEMP will be ship specific but should be linked to a broader corporate energy management policy of the shipowner. In some cases, the SEEMP may form part of the ship's Safety Management System (SMS), and many shipowners will already have an Environmental Management System (EMS) under ISO 14001 which contains relevant practices for environmental improvement that may augment the SEEMP. There are four key processes that the SEEMP must address and describe and together they form a continuous improvement process as shown in figure below. Each process, taken from the SEEMP Guidelines (MEPC.213 (63), has been summarised in the following sections.

Figure 14.3: SEEMP processes

14.2.2. SEEMP and EEOI

The Ship Energy Efficiency Management Plan (SEEMP) is an operational measure that establishes a mechanism to improve the energy efficiency of a ship in a cost-effective manner. The SEEMP also provides an approach for shipping companies to manage ship and fleet efficiency performance over time using, for example, the Energy Efficiency Operational Indicator (EEOI) as a monitoring tool. The guidance on the development of the SEEMP for new and existing ships incorporates best practices for fuel efficient ship operation, as well as guidelines for voluntary use of the EEOI for new and existing ships (MEPC.1/Circ.684). The EEOI enables operators to measure the fuel efficiency of a ship in operation and to gauge the effect of any changes in operation, e.g. improved voyage planning or more frequent propeller cleaning, or introduction of technical measures such as waste heat recovery systems or a new propeller. The SEEMP urges the ship owner and operator at each stage of the plan to consider new technologies and practices when seeking to optimise the performance of a ship.

14.2.3. ISO 19030

The ISO 19030 was developed for hull and propeller performance assessment for ships in service. It outlines initial motivation, purpose and implementation of the standard. The standard is intended to serve the wider community as well as support shipping operators and suppliers in better business practice.

Today hull and propeller performance is a ship efficiency killer. According to the Clean Shipping Coalition in MEPC 63-4-8, poor hull and propeller performance accounts for around 1/10 of world fleet energy cost and GHG emissions. This points to a considerable improvement potential; 1/10 of world fleet energy costs and GHG emissions translates into billions of dollars in extra cost per year and around a 0.3% increase in man-made GHG emissions. The culprits are a combination biofouling and mechanical damages. Most vessels leave the new build yard or subsequent dry-docking with their hull and propeller in a fairly good condition. Then on account of a combination of biofouling and mechanical damage, hull and propeller performance begins to deteriorate.

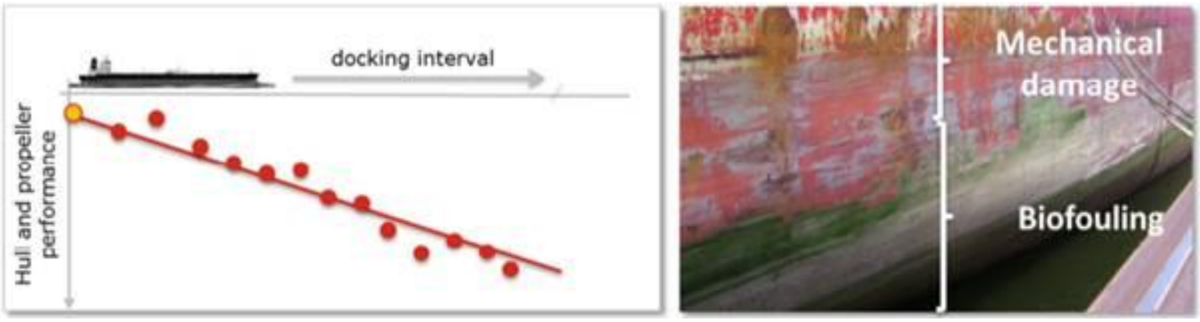

Figure 14.4: Hull and propeller performance

There are technologies and solutions on the market that can protect the hull and maintain good performance over the full duration of the docking interval - why then is hull and propeller performance still so poor?

In the past the problem has been a lack of measurability. If one cannot measure it, one cannot manage it. Now a multitude of measurement methods are being introduced in the market; some quite good, some really bad, most of them proprietary (black box) and many using their own yardsticks. It is becoming challenging, however, even for the most resourceful to determine which of these methods can be relied upon and which cannot. Moreover, the measurement methods have different and incompatible yard sticks resulting in the measurement output serving to confuse rather than inform.

This standard is intended for all stakeholders that are striving to apply a rigorous, yet practical way of measuring the changes in hull and propeller performance. It could be ship-owners and operators, companies offering performance monitoring, shipbuilders and companies offering hull and propeller maintenance and coatings. ISO 19030 will make it easier for decision makers to learn from the past and thereby make better informed decisions for tomorrow. It will also provide much needed transparency for buyers and sellers of technologies and services intended to improve hull and propeller performance. Finally, it will make it easier for the same buyers and sellers to enter into performance-based contracts and thereby better align incentives.

14.2.4. What ISO 19030 Covers

ISO 19030 outlines general principles of, and defines both a default as well as alternative methods for, measurement of changes in hull and propeller performance. The standard defines sensor requirements, measurement procedures, including various filters and corrections, as well as how to calculate a set of four performance indicators for hull and propeller related maintenance, repair and retrofit activities.

One of the performance indicators is “In-service performance”. In-service performance refers to the average change in hull and propeller performance over the dry-docking interval. Performance over the first year following the docking is compared with performance over whatever remains of the docking interval – typically two to four years.

This performance indicator (figure below) is useful for determining the effectiveness of the underwater hull and propeller solution – for example the hull coating system used.

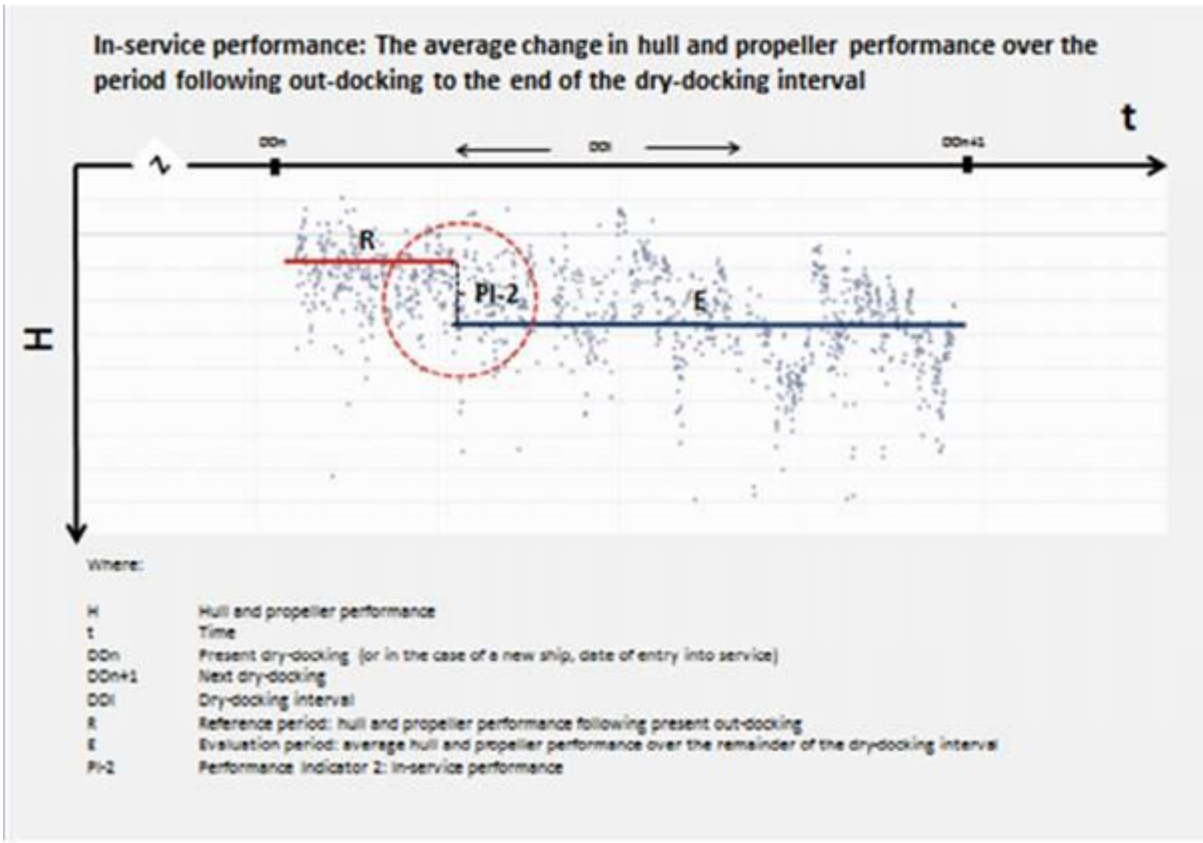

Figure 14.5: Performance indicators in ISO 19030 – In-service performance

The three additional performance indicators are “Dry docking performance”, “Maintenance trigger” and “Maintenance effect”:

- Dry docking performance: Hull and propeller following the present out-docking is compared with the average performance from previous out dockings. This provides useful information on the effectiveness of the docking.
- Maintenance trigger: Hull and propeller performance at the start of the dry-docking interval is compared with a moving average at a point in time. Useful for determining when hull and propeller maintenance is needed – including propeller polishing or hull cleanings.

- Maintenance effect: Hull and propeller performance in the period preceding the maintenance event is compared with performance after. This provides useful information for determining the effectiveness of the event.

ISO 19030 is fairly all-encompassing. It covers what sensors are required, how these are to be maintained, step-by-step procedures for filtering and correcting the data, and finally how the individual performance calculators are to be calculated.

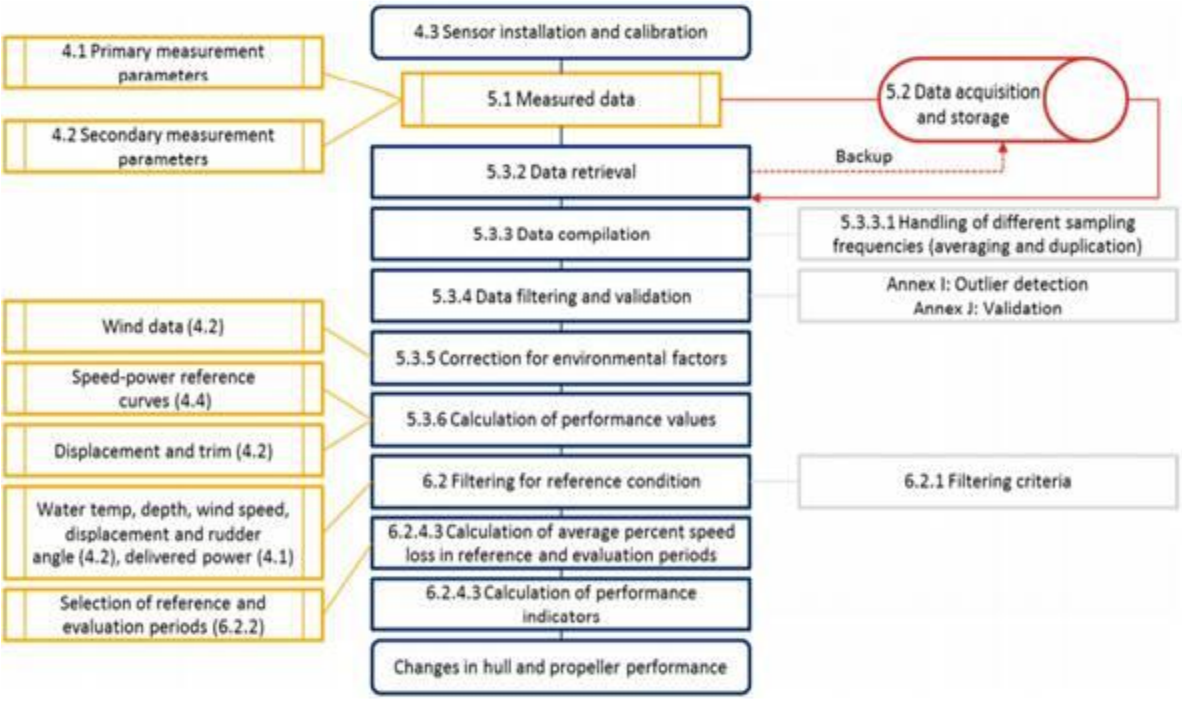

Figure 14.6: ISO 19030 scope

The standard is organized into three parts:

- ISO 19030-1 outlines general principles for how to measure changes in hull and propeller performance and defines the 4 performance indicators for hull and propeller maintenance, repair and retrofit activities.
- ISO 19030-2 defines the default method for measuring changes in hull and propeller performance. It also provides guidance on the expected accuracy of each performance indicator.
- ISO 19030-3 outlines alternatives to the default method. Some will result in lower overall accuracy but increase applicability of the standard. Others may result in same or higher overall accuracy but include elements which are not fully validated in commercial shipping.

Descriptions and explanations are outlined in ISO 19030-1. Methodological alternatives that are state of-the-art and mature are addressed in ISO 19030-2. Alternatives that are state of the art but not fully mature have either been included in ISO 19030-3 or will be addressed in future revisions of the standard. Alternatives that give the same overall accuracy are included as options in ISO 19030-2. Finally, alternatives that yield lower overall accuracy but increase applicability of the standard are covered in ISO 19030-3.

14.2.5. How ISO 19030 has been developed.

The process towards developing the ISO19030 started when the Environmental NGO Bellona Foundation and Jotun A/S had informal discussions on how to improve energy efficiency within the maritime sector. Bellona Foundation looked for a robust and verifiable way to reduce CO_2 emissions, whereas Jotun A/S saw the need for a more transparent approach to verify a myriad of performance claims on hull and propeller maintenance.

A series of workshops held in accordance with Chatham House Rules involved a steadily increasing number of stakeholders and paved the way for a common understanding among performance monitoring companies, measurement manufacturers, ship maintenance system providers, classification societies, shipbuilders and ship-owners and their associations. Bellona Foundation and Jotun subsequently held a side-event at IMO-MEPC meetings and presented the embryo for a reliable and transparent hull and performance standard at several maritime conferences.

Work on the ISO-Standard was initiated in June 2013 when Working Group 7 under SC2 TC8 was formed. Svend Søyland from Nordic Energy Research serves as the Convener of the working group and Geir Axel Oftedahl from Jotun has the role as Project Manager. A series of Working Group meetings were held; Oslo (June 2013), Tokyo (November 2013), Hamburg (July 2014), Pusan (November 2014), San Ramon (February 2015) and Copenhagen (September 2015). More than 50 experts and observers, representing ship owners, shipping associations, new build yards, coatings manufacturers, performance monitoring companies, academic institutions, class societies and NGOS participated in the ISO working group that reached consensus on ISO 19030 standard.

Additional industry stakeholders have been consulted and involved as a part of this extensive process. World class experts shared their deep expertise in a truly collaborative effort and put aside their professional ties. A determination to find workable compromises was the hallmark of the drafting process. Representatives that in other contexts would be fierce competitors share expertise, policies and performance data etc. This was a larger than usual Working Group under the ISO-system and the by far largest with the Ship Technology section. The drafting process uncovered a need to address both the most rigorous methods available and the most commonly used approaches used. This led to the division into three parts.

A Committee Draft of part 1 and 2 was submitted in March 2015. A Ballot among P-members was concluded in May 2015 with sound support. The target date for submitting a Draft International Standard (DIS) of all three parts was December 2015. An ISO-Ballot was concluded in March 2016, and it is expected the Standard will achieve final approval and official publication by June 2016. The Working Group (WG7) will remain operational in order to prepare future revisions and refining the standard. The preparation for the Standard was followed with great interest for both trade journals and all relevant stakeholders. Many stakeholders are in the process of incorporating the standard in their daily operations and prepare contracts that use the ISO-standards as a point of departure.

Ship owner associations are drafting guiding documents and ISO 19030 may also become the bedrock for a carbon offset/crediting scheme incentivising greenhouse gas emission reductions.

References

ISO 50001 Energy Management System 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. ISO 50001:2011 “Energy management systems -- Requirements with guidance for use”, ISO publications.
2. ISO website, “ISO 50001 - Energy management”, http://www.iso.org/iso/home/standards/management-standards/iso50001.htm, cited September 2015.
3. ISO brochure “Win the energy challenge with ISO 50001 “, http://www.iso.org/iso/iso_50001_energy.pdf, cited September 2015.
4. “IMO train the trainer course material”, developed by WMU, 2013.

ISO19030 and Application of SEEMP for EEOI Requirements References and further readings.

1. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Technical-and-Operational-Measures.aspx

2. http://www.nordicenergy.org/wp-content/uploads/2016/04/S%C3%B8yland-oftedal-paper_HullPIC2016.pdf

3. IMO (2014), Third IMO Greenhouse Gas Study 2014, IMO, London http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/GHGEmissions.aspx