REVIEW AND PRODUCTIZATION OF EQUIPMENT FOR COLLECTING, MONITORING, REPORTING, AND TRANSMITTING THE DATA OF SHIPS` FUEL OIL SYSTEMS

Lappeenranta–Lahti University of Technology LUT

Master`s Degree Programme in Energy Technology, EnTeDI

2023

Joona Heljälä

Examiners: Professor Teemu Turunen-Saaresti

Associate Professor Pedro Juliano Nardelli

ABSTRACT

Lappeenranta–Lahti University of Technology LUT

LUT School of Energy Systems

Energy Technology, EnTeDI

Joona Heljälä

Review and productization of equipment for collecting, monitoring, reporting, and transmitting the data of ships` fuel oil systems

Master’s thesis

2023

77 pages, 18 figures and 9 tables

Examiners: Professor Teemu Turunen-Saaresti and Associate Professor Pedro Juliano Nardelli

Keywords: DCS, CII, Fuel oil systems, Equipment, Productization

In 2018, IMO introduced the initial GhG strategy with the aim of reducing emissions from international shipping compared to the 2008 baseline. The strategy aims for a 50 % reduction in annual greenhouse gas emissions by 2050 and a 40 % reduction in carbon intensity by 2030, and strives to achieve a 70 % reduction by 2050. To reach the 2030 carbon intensity reduction target, IMO constructed short-term measures that entered into force in early 2023. The measures included CII to measure the transportation efficiency of ships.

This master`s thesis was carried out for a company that supplies fuel oil supply units for ships` fuel oil systems. As short-term measures, including CII, were known to enter into force, the company decided to productize the equipment to be incorporated into the current design of fuel oil supply units to assist ship owners and operators meet the requirements of CII. The objectives, of this master`s thesis, were to review the available equipment and to study the feasibility of the equipment from technical points of view to create a solution for sales purposes.

This master`s thesis reviewed the available equipment, determined and described the functions of the equipment, studied the feasibility of the equipment from the points of view of different design departments, conducted SWOT analyses on the equipment, and created different delivery alternatives for new build and retrofit sales purposes. During the process of this master`s thesis, the company decided to proceed with the company`s own product.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUT Energiajärjestelmät

Energiatekniikka, EnTeDI

Joona Heljälä

Laivojen polttoöljyjärjestelmien datan keruu-, monitorointi-, raportointi- ja siirtolaitteiston tarkastelu ja tuotteistaminen

Diplomityö

2023

77 sivua, 18 kuvaa ja 9 taulukkoa

Tarkastajat: Professori Teemu Turunen-Saaresti ja Apulaisprofessori Pedro Juliano Nardelli

Avainsanat: DCS, CII, Polttoöljyjärjestelmät, Laitteisto, Tuotteistaminen

Vuonna 2018 IMO esitti alustavan GhG-strategian tavoitteena vähentää kansainvälisen merenkulun päästöjä vuoden 2008 lähtötasoon verrattuna. Strategia tavoittelee 50 % vähennystä vuotuisiin kasvihuonekaasupäästöihin vuoteen 2050 mennessä sekä 40 % vähennystä hiili-intensiteettiin vuoteen 2030 mennessä ja pyrkii saavuttamaan 70 % vähennyksen vuoteen 2050 mennessä. Vuoden 2030 hiili-intensiteetin vähennystavoitteen saavuttamiseksi, IMO rakensi lyhyen aikavälin toimenpiteet, jotka tulivat voimaan vuoden 2023 alussa. Toimenpiteisiin sisältyi laivojen liikennöinnin tehokkuutta mittaava CII.

Tämä diplomityö toteutettiin yritykselle, joka toimittaa polttoöljyn syöttöyksiköitä laivojen polttoöljyjärjestelmiin. Koska lyhyen aikavälin toimenpiteet, mukaan lukien CII, tiedettiin astuvan voimaan, yritys päätti tuotteistaa laitteiston sisällytettäväksi polttoöljyn syöttöyksiköiden nykyiseen designiin auttamaan laivojen omistajia ja käyttäjiä täyttämään CII:n vaatimukset. Tämän diplomityön tavoitteina oli tarkastella käytettävissä olevat laitteistot ja tutkia laitteistojen toteutettavuutta teknisistä näkökulmista ratkaisun luomiseksi myyntitarkoituksiin.

Tämä diplomityö tarkasteli käytettävissä olevat laitteistot, määritteli ja kuvasi laitteistojen toiminnot, tutki laitteistojen toteutettavuutta eri suunnitteluosastojen näkökulmista, suoritti SWOT analyysit laitteistoista ja loi erilaisia toimitusvaihtoehtoja uudisrakennus- ja jälkiasennusmyyntitarkoituksiin. Tämän diplomityön prosessin aikana, yritys päätti edetä yrityksen oman tuotteen kanssa.

ACKNOWLEDGEMENTS

I would like to thank the company for the interesting master`s thesis subject. Working on this thesis has been challenging, but also rewarding. Over the past decade, significant amendments and adoptions have been made to international regulations and measures regarding ships` energy efficiency and greenhouse gas emissions. I hope that this thesis will clarify these regulations and measures. In addition, I hope that this thesis will assist the company to make the best decisions for it now and in the future. I would also like to thank the examiners of this thesis for the advice and perspectives they have given during the process of this thesis. But first and foremost, I would like to thank my family for their support during this thesis and my studies.

ABBREVIATIONS

AE	Auxiliary Engine
AER	Annual Efficiency Ratio
BDN	Bunker Delivery Note
cgDIST	Capacity Gross Ton Distance
CII	Carbon Intensity Indicator
CO_2	Carbon Dioxide
DCS	Data Collection System
DWT	Deadweight Tonnage
ECA	Emission Control Area
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
EEXI	Energy Efficiency Existing Ship Index
GhG	Greenhouse Gas
GISIS	Global Integrated Shipping Information System
GT	Gross Tonnage
HFO	Heavy Fuel Oil
HMI	Human Machine Interface
IMO	International Maritime Organization
IPA	Importance-Performance Analysis
LNG	Liquefied Natural Gas
LSFO	Low Sulphur Fuel Oil
MARPOL	International Convention for the Prevention of Pollution from Ships

MDF	Marine Diesel Fuel
MDO	Marine Diesel Oil
ME	Main Engine
MEPC	Marine Environment Protection Committee
MGO	Marine Gasoil
PLC	Programmable Logic Controller
SECA	Sulphur Emission Control Area
SEEMP	Ship Energy Efficiency Management Plan
SOC	Statement of Compliance
SPM	Shaft Power Meter
SWOT	Strengths, Weaknesses, Opportunities, and Threats

TABLE OF CONTENTS

ABSTRACT

TIIVISTELMÄ

ACKNOWLEDGEMENTS

ABBERVIATIONS

FIGURES

TABELS

1. Introduction

International shipping is crucial to global supply chains and the economy, transporting over 80 % of global trade (UNCTAD 2021, 111). Carbon dioxide (CO_2) emissions from shipping have grown steadily over the past two decades (IEA 2021). Over the years, the International Maritime Organization (IMO), with the support of the Marine Environment Protection Committee (MEPC), has continued to work to reduce greenhouse gas (GhG) emissions from shipping. Over the past decade, IMO and MEPC have made significant amendments and adoptions to international regulations and measures regarding ships` energy efficiency and GhG emissions. The most relevant amendments and adoptions have been made to Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL), which contains regulations and measures regarding the prevention of air pollution caused by ships, including specific regulations and measures regarding the design and operation of ships. (IMO 2021a.)

In 2018, IMO introduced the initial GhG strategy with the aim of reducing emissions from international shipping compared to the 2008 baseline. The strategy aims for a 50 % reduction in annual GhG emissions by 2050 and a 40 % reduction in carbon intensity by 2030, and strives to achieve a 70 % reduction by 2050. To reach the 2030 carbon intensity reduction target, IMO constructed short-term measures that entered into force in early 2023. (IMO 2021a; IEA 2021.) In 2021, the Carbon Intensity Indicator (CII) was adopted. CII is an operational measure, measuring the transportation efficiency of a ship. (DNV 2021a.) From the beginning of 2023, all ships subject to the requirements of CII are required to calculate the attained annual operational CII and report to the ship`s administration or any authorized organization (DNV 2021a; MEPC 2021a, 45-47). In practice, all ships already subject to the requirements of Data Collection System (DCS) for fuel oil consumption are subject to the requirements of CII (IMO 2021e).

The methodology for collecting and reporting fuel oil consumption data was adopted by MEPC in 2016. The requirements of DCS for fuel oil consumption apply to ships equal or above of 5000 Gross Tonnage (GT) and trading internationally. In addition to fuel oils, the requirements also apply to other types of fuel consumed on board. Fuel oil consumption collection and monitoring methods include the use of Bunker Delivery Notes (BDN), the use of flow meters, and monitoring of bunker fuel oil tanks on board. All ships subject to the requirements of DCS are required to collect annual fuel oil consumption data and report to the ship`s administration or any authorized organization. (MEPC 2016a, 3, 12-13, 19.) The requirements of DCS for fuel oil consumption entered into force in 2018 and 2019 was the first reporting year (IMO 2020a).

The attained annual operational CII calculation follows the guidelines adopted by MEPC in 2021. The attained annual operational CII is calculated by dividing the total mass of CO_2 emitted by the total transportation work undertaken during the calendar year. (MEPC 2021b, 3.) Unit of CII is grams of CO_2 emitted per cargo-carrying capacity and nautical mile (DNV 2021b). The total mass of CO_2 emitted is calculated from the total consumption of different fuel types, including individual fuel mass to CO_2 mass conversion factors. The calculated total mass of CO_2 emitted is divided by the total distance travelled and the capacity of the ship to determine the attained annual operational CII. (MEPC 2021b, 3.) In 2022, MEPC adopted guidelines on interim correction factors and voyage adjustments for the attained annual operational CII calculation (MEPC 2022c, 1).

1.1. Background, objectives, and limitations

This master`s thesis is carried out for a company that supplies fuel oil supply units for ships` fuel oil systems. Fuel oil supply units are designed to feed fuel oil to engines and maintain correct process and fuel oil properties during operation. Depending on the design, the fuel oil supply units may include flow meters to monitor the fuel oil consumption of the engines. Flow meters are one of the specified methods for collecting and monitoring fuel oil consumption data of a ship. The total annual consumption of fuel oil can be determined from the data of the flow meters and used in the calculation of the attained annual operational CII.

The company is looking for equipment to incorporate into the current design of fuel oil supply units for CII and other energy efficiency data collection, monitoring, reporting, and transmission purposes. This master`s thesis reviews the available equipment and studies the feasibility of the equipment from technical points of view to create a solution for sales purposes. The objectives and limitations, of this master`s thesis, are outlined below.

1. Review of equipment for CII and other energy efficiency data collection, monitoring, reporting, and transmission purposes.
2. Study the feasibility of the equipment from technical points of view.
3. Create a solution for sales purposes from new build and retrofit points of view.

Requirements for equipment are determined according to the attained annual operational CII calculation method. According to the requirements, the objective is to determine the required functions for the equipment. Equipment, available on the market, as well as the company`s own product, are compared to the requirements to determine the suitability of the equipment. The technical feasibility study includes process, mechanical, electrical, and automation points of view. The objective is to study the applicability of the equipment to the current design of fuel oil supply units. Strengths, weaknesses, opportunities, and threats (SWOT) analyses are conducted on equipment and the company`s own product. The objective is to compare the factors of equipment available on the market with the factors of the company`s own product. Based on the equipment requirements, review, and technical feasibility study, the objective is to create a solution for new build and retrofit sales purposes.

1.2. Literature review

The Full Report of Fourth IMO GhG Study 2020 (IMO 2021f), the first IMO GhG study published since the introduction of the initial GhG strategy, examines the GhG emissions and carbon intensity of international shipping. The estimates included in the report show that between 2012 and 2018, GhG emissions from shipping have increased by 9,6 % and their share in global anthropogenic GhG emissions has increased by 0,13 %, rising to a total of

2,89 %. According to the estimates included in the report, the overall carbon intensity of international shipping was roughly 20-30 % better in 2018 compared to 2008. The report shows that although the carbon intensity of international shipping can still be improved, reaching the 2050 reduction targets with technical or operational measures alone will be difficult. Most of the reduction will come from the use of low-carbon and zero-carbon fuels.

The paper Paradox of international maritime organization’s carbon intensity indicator (Wang et al. 2021) examines the paradoxes associated with CII measures. The paper shows that paradoxes can occur regardless of the CII calculation method, and the adoption of CII measures could in some cases even increase carbon emissions. The paper proposes that more advanced models and calculation methods utilizing real data should be developed to evaluate the functionality of CII measures and the possibility of forming a reformed CII.

The study Importance-Performance Analysis based SWOT analysis (Phadermrod et al. 2019) examines a new approach to SWOT analysis. The study points out that in a traditional qualitative SWOT analysis, SWOT factors are commonly approached exclusively from the point of view of the company, ignoring the point of view of the customer. In practice, a traditional SWOT analysis cannot provide an efficient result and could in some cases even lead to a poor business decision. The study proposes that Importance-Performance Analysis (IPA) based SWOT analysis should be considered, to provide both quantitative and customer-based SWOT factors to improve the deficiencies of traditional SWOT analysis.

1.3. Structure

Chapter 2 presents the regulatory background on which the initiative to review and productize equipment is based. The focus of the chapter is mainly on the presentation of regulations and measures related to the operation of ships. In addition, the chapter shortly presents regulations and measures regarding the design of ships. Chapter 3 presents aspects related to the operation of ships. The focus of the chapter is on the presentation of the properties of fuel oils and the characteristics of ships` fuel oil systems, including fuel oil supply units. Chapter 4 presents Coriolis and positive displacement flow meters, which are the most common flow meters used in ships` fuel oil systems and supply units. In addition, the chapter presents the output signals derived from the flow meters.

Chapter 5 presents the characteristics of the current design of fuel oil supply units. In addition, the chapter presents the requirements set for the equipment and reviews the available equipment, which are divided into low- and high-tier products, as well as the company`s own product. Chapter 6 studies the feasibility of the equipment from the points of view of different design departments and determines the applicability of the equipment to the current design of fuel oil supply units. In addition, the chapter presents a SWOT analysis of low- and high-tier products, as well as a SWOT analysis of the company`s own product. Chapter 7 presents delivery alternatives for new build and retrofit sales purposes. In addition, the chapter shortly presents the characteristics of new build and retrofit projects. The conclusions and summary, of this master`s thesis, are presented in chapters 8 and 9.

2. Regulations and measures

International shipping is guided by regulations and measures developed and maintained by IMO. The regulations and measures ensure the safe, efficient, and environmentally friendly operation of international shipping. The purpose of this chapter is to present the most relevant characteristics of the regulations and measures adopted over the years regarding the energy efficiency and GhG emissions of ships. The chapter begins by presenting the parties behind the regulations and measures. The chapter continues by presenting the contents of MARPOL. The chapter ends by presenting the most relevant regulations and measures adopted in MARPOL Annex VI.

2.1. IMO, MEPC and MARPOL

As a specialized agency of the United Nations, IMO`s responsibility is to oversee the safety of international shipping and to take measures to prevent marine and atmospheric pollution caused by ships. IMO can be considered as the global authority that sets, maintains, and develops regulations and measures to ensure the safe and environmentally friendly operation of international shipping. International shipping covers a large part of global transportation. IMO provides the necessary regulatory framework to ensure sustainable operations. (IMO 2015a.) IMO has continued to participate in actions against climate change over the years. MEPC, working under the remit of IMO, addresses environmental issues. Responsibilities include the control and prevention of pollution caused by ships covered by MARPOL. (IMO 2020b.) MARPOL, which covers the prevention of pollution of the marine environment caused by ship operations or accidents, was first adopted in 1973 and has since been updated with amendments over the years (IMO 2021b).

MARPOL contains technical Annexes adopted over the years. Currently, MARPOL contains six technical Annexes. One of the Annexes covers measures to prevent air pollution from ships. (IMO 2021b.) Annex VI, covering air pollution prevention requirements, was first adopted in 1997 (IMO 2021c). Over the past decade, Annex VI has been updated with amendments to address the design and operation of ships. During the 62nd session of MEPC in 2011, the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) were adopted. (IMO 2021d.) During the 70th session of MEPC in 2016, the requirements of DCS for fuel oil consumption were adopted (IMO 2020a). The Energy Efficiency Existing Ship Index (EEXI) and CII were adopted during the 76th session of MEPC in 2021, completing the relevant regulatory framework to date (IMO 2021e). The most relevant amendments and adoptions made to Annex VI over the years are presented in Figure 1 (IMO 2021a; IMO 2015b, 3).

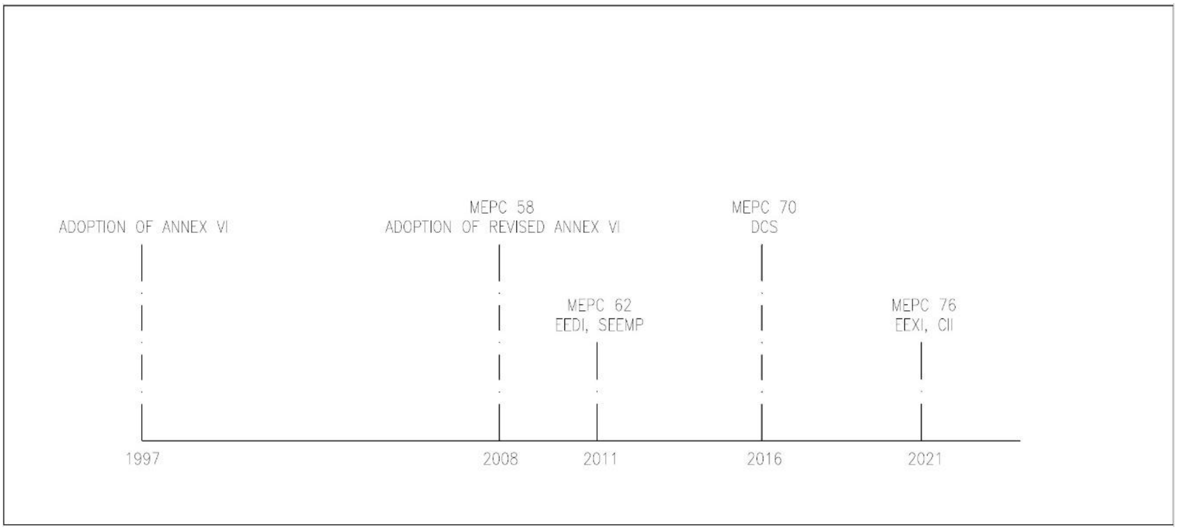

Figure 1. The most relevant amendments and adoptions made to Annex VI over the years (Modified from IMO 2021a; IMO 2015b, 3).

2.2. Energy Efficiency Indexes

During the 62nd session of MEPC in 2011, EEDI was adopted. The requirements of EEDI apply to all new ships equal or above of 400 GT and trading internationally. (MEPC 2011, 5-6, 9.) EEDI was constructed to measure the energy efficiency of a new build ship design and therefore cannot be used as an operational indicator of a ship. The requirements of EEDI entered into force in early 2013. (IMO 2021d.) During the 76th session of MEPC in 2021, EEXI was adopted. The requirements of EEXI apply to all existing ships equal or above of 400 GT and trading internationally. (MEPC 2021a, 11-14, 36.) EEXI can be considered comparable to EEDI. As with EEDI, the focus of EEXI is on measuring the energy efficiency of the design. In practise, EEDI applies to new build ships and EEXI to all existing ships. The requirements of EEXI entered into force in early 2023. (DNV 2021c.)

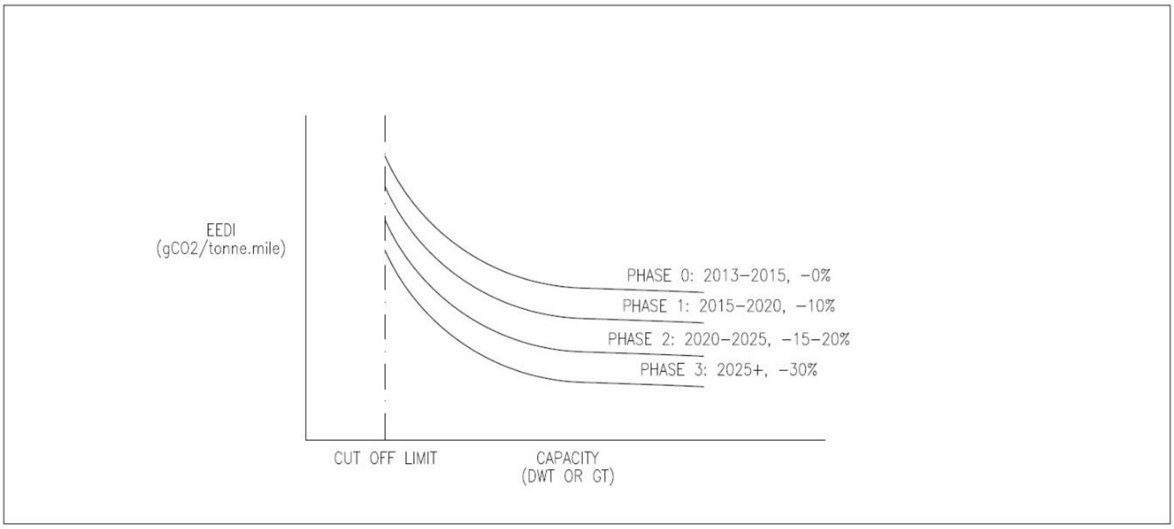

Figure 2. A general overview of EEDI reduction levels and reference lines for different phases (Modified from IMO 2015b, 30).

EEDI sets minimum energy efficiency levels for ship design that must be met. The levels are tightened every 5 years, driving the industry towards more energy efficient solutions. EEDI is expressed in grams of CO_2 per ship's capacity-mile and generally indicates CO_2 emissions per transportation work. (IMO 2021d.) A general overview of EEDI reduction levels and reference lines for different phases is presented in Figure 2. EEDI reduction levels and reference lines depend on the type and size of the ship and vary accordingly. The attained EEDI of a ship must always be less than or equal to the phase requirement. The cut-off limit indicates the size of the ship to which the requirements of EEDI do not apply due to some technical reasons. Cut-off limits vary by ship type. (IMO 2015b, 26-30.) The reduction rate for the first phase was set at 10 % and the levels are determined until 2025 (IMO 2021d).

EEDI promotes continuous technical innovation and the development of all equipment affecting the ship`s fuel efficiency. EEDI only presents a framework for ship design, where ship builders and designers are free to use any solution if the requirements are met and the regulations are complied with. (IMO 2021d.) The EEDI verification process is carried out from design to sea trial, as presented in Figure 3. Preliminary EEDI verification is issued according to EEDI calculations in the design phase and final verification after the sea trial. (IMO 2015b, 5-6, 66.) EEDI is verified by the ship`s administration or any authorized organization (MEPC 2011, 10).

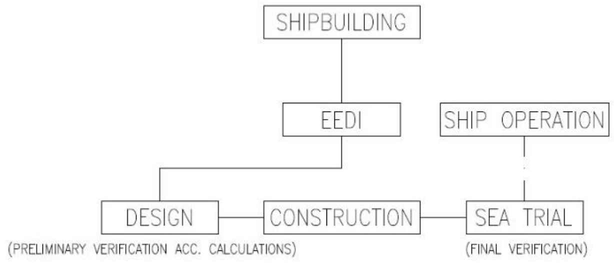

Figure 3. The EEDI verification process (Modified from IMO 2015b, 5-6, 66).

EEXI can be considered comparable to EEDI. The requirements of EEXI apply to all existing ships equal or above of 400 GT and trading internationally. EEXI guidelines follow EEDI guidelines with some differences due to the limited availability of design data. (DNV 2021c.) EEXI is not applied to ships constructed according to the requirements of EEDI phases 2 or 3. EEXI reduction rates and reference lines correspond to EEDI phases 2 and 3, making them almost comparable to current new building. (DNV 2021d.) EEXI is expressed in grams of CO_2 per ship's capacity-mile. As with EEDI, EEXI is a design-related index and therefore cannot be used as an operational indicator of a ship. (DNV 2020.) EEXI is verified by the ship`s administration or any authorized organization once during the ship`s lifespan (DNV 2021c).

2.3. Ship Energy Efficiency Management Plan

During the 62nd session of MEPC in 2011, SEEMP was adopted. The requirements of SEEMP apply to all ships equal or above of 400 GT and trading internationally. (MEPC 2011, 5-6, 9.) SEEMP is an operational measure that provides tools for monitoring and improving a ship's energy efficiency and guides ship owners and operators towards optimizing ship operation, considering new technologies and practises along the way. The requirements of SEEMP entered into force in early 2013. (IMO 2021d.)

SEEMP can optionally include Energy Efficiency Operational Indicators (EEOI) for monitoring energy efficiency. EEOI measures fuel efficiency in relation to operation, considering all changing operational variables. Variables can include regular maintenance of equipment, technical improvements of equipment, and voyage planning. (IMO 2021d.) The SEEMP process is presented in Figure 4. The SEEMP process begins with planning. The plan is then implemented and monitored with optional EEOIs or other appropriate measures. Finally, the results are evaluated, and improvements are made. (IMO 2015b, 5-6.)

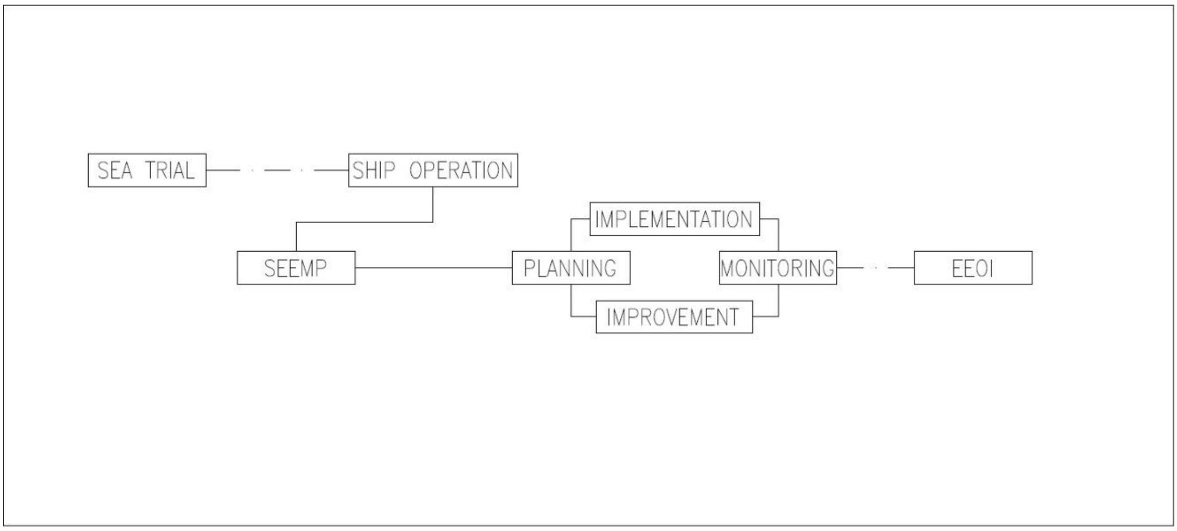

Figure 4. The SEEMP process (Modified from IMO 2015b, 5-6).

2.4. Data Collection System

During the 70th session of MEPC in 2016, the requirements of DCS for fuel oil consumption data collecting and reporting were adopted. According to the requirements, all ships equal or above of 5000 GT and trading internationally are required to collect fuel oil consumption data for each fuel oil type used during the calendar year. In addition, ships are required to provide the ship`s identity number, period time of data collection, specific technical characteristics of the ship, distance travelled, and hours underway. Within three months of the end of each calendar year, the data is reported to the ship`s administration or any authorized organization, which, after verifying the data, issues a Statement of Compliance (SOC) to the ship. A description of the methods used to collect fuel oil consumption data must be included in the ship`s SEEMP. After the SOC is issued, the administration or any authorized organization forwards the data to the IMO Ship Fuel Oil Consumption Database. The database is part of the Global Integrated Shipping Information System (GISIS). IMO is required to provide an annual report to MEPC summarizing fuel oil consumption data. The requirements of DCS for fuel oil consumption data collecting and reporting entered into force in 2018 and 2019 was the first reporting year. (IMO 2020a; MEPC 2016b, 1, 3-6.)

The collected and reported fuel oil consumption data includes all fuel oil consumed on board during the calendar year. Fuel oil consumption is collected from all consumers and for each type of fuel oil used. In addition to fuel oils, the requirements also apply to other types of fuel consumed on board. Consumers include main engines (ME), auxiliary engines (AE), gas turbines, boilers, and other fuel oil consumers. Fuel oil consumption is measured and collected continuously, regardless of whether the ship is underway or not. Fuel oil consumption collection and monitoring methods include the use of BDNs, the use of flow meters, and monitoring of bunker fuel oil tanks on board. The method of using BDNs determines the annual total amount of fuel oil consumed based on the BDNs received during the calendar year. (MEPC 2016a, 12-13, 19.) BDN is a standard document required by MARPOL Annex VI, containing information regarding the delivery of fuel oil. BDN`s information includes the receiving ship`s name, port, date, supplier information, fuel oil amount, and fuel oil properties. (Wärtsilä 2016.) In the BDN method, bunkered fuel oil amounts are used to determine the annual total amount of fuel oil consumed, also considering the amounts of fuel oil that remained from the previous calendar year and that were carried over to the next calendar year. BDNs are required to be kept on board for three years after the delivery of the fuel oil. The method of using flow meters determines the annual total amount of fuel oil consumed based on consumer specific fuel oil flows. The total annual consumption of fuel oil can be determined from the combined data of the flow meters. In the event of breakdown or malfunction of the flow meters, alternative fuel oil consumption measuring methods must be conducted instead. The method of monitoring bunker fuel oil tanks determines the annual total amount of fuel oil consumed based on tank level readings. (MEPC 2016a, 12-14.)

2.5. Carbon Intensity Indicator

During the 76th session of MEPC in 2021, CII was adopted (IMO 2021e). CII is an operational measure, measuring the transportation efficiency of a ship (DNV 2021a). From the beginning of 2023, all ships subject to the requirements of CII are required to calculate the attained annual operational CII and report to the ship`s administration or any authorized organization (DNV 2021a; MEPC 2021a, 45-47). In practice, all ships already subject to the requirements of DCS for fuel oil consumption are subject to the requirements of CII (IMO 2021e). A description of the methods used to calculate the attained annual operational CII must be included in the ship`s SEEMP (MEPC 2021a, 45). During the 76th session of MEPC in 2021, guidelines for the calculation of the attained annual operational CII were adopted. The attained annual operational CII is calculated by dividing the total mass of CO_2 (M) emitted by the total transportation work (W) undertaken during the calendar year. (MEPC 2021b, 3.) Unit of CII is grams of CO_2 emitted per cargo-carrying capacity and nautical mile (gCO_2/DWT or GT-mile) (DNV 2021b). The attained annual operational CII of individual ships (attained CII_{SHIP}) is calculated as follows (MEPC 2021b, 3).

$$\text{attained } \mathrm{CII}_{\mathrm{SHIP}} = \mathrm{M}/\mathrm{W} \tag{1}$$

where:

$\mathrm{M} = \text{The total mass (g) of } \mathrm{CO_2} \text{ emitted}$

$\mathrm{W} = \text{The total transportation work undertaken (DWT or GT} - \text{mile)}$

The total mass of CO_2 (M) emitted is the sum of CO_2 emissions (g) of all fuels consumed during the calendar year as reported under DCS and is calculated as follows (MEPC 2021b, 3).

$$\mathrm{M} = \mathrm{FC_j} \times \mathrm{C_{F_j}} \qquad (2)$$

where:

$\mathrm{FC_j} = \text{The total mass (g) of consumed fuel type (j) (DCS)}$

$\mathrm{C_{F_j}} = \text{Fuel mass to } \mathrm{CO_2} \text{ mass conversion factor for fuel type (j)}$

Fuel mass to CO_2 mass conversion factors (C_F) for different fuel types (j) are specified in resolution MEPC.308(73) and presented in Table 1 (MEPC 2021b, 3; MEPC 2019, 5-6).

Table 1. Fuel mass to CO_2 mass conversion factors (C_F) for different fuel types (Modified from MEPC 2019, 5-6).

Type of fuel (j)	Reference	Lower calorific value (KJ/kg)	Carbon content	C_F (t-CO_2/ t-Fuel)
Diesel/Gas Oil	ISO 8217 Grades DMX through DMB	42,700	0,8744	3,206
Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	41,200	0,8594	3,151
Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	40,200	0,8493	3,114
Liquefied Petroleum Gas (LPG)	Propane	46,300	0,8182	3,000
	Butane	45,700	0,8264	3,030

Liquefied Natural Gas (LNG)	-	48,000	0,7500	2,750
Methanol	-	19,900	0,3750	1,375
Ethanol	-	26,800	0,5217	1,913

The attained annual operational CII can be calculated as demand-based or supply-based. In demand-based calculation, the ship`s capacity is based on the actual or estimated mass or volume of the shipment carried on board. In supply-based calculation, the ship`s capacity is taken as proxy of the actual mass or volume of the shipment carried on board. In supply-based calculation, depending on the ship type, either GT or Deadweight Tonnage (DWT) is used as the ship`s capacity. A supply-based calculation using DWT as capacity is referred to as Annual Efficiency Ratio (AER) and calculation using GT is referred to as Capacity Gross Ton Distance (cgDIST). The distance travelled reported under DCS, is used as the total distance travelled (D_t). (MEPC 2021b, 2-3.) Concerns have been raised regarding the demand-based calculation method, as the data of the shipment carried on board is not included in the requirements of DCS. Possible alternative data sources for the demand-based CII calculation method are said to be under investigation. The demand-based calculation method is currently left unclear. (IMO 2022, 7-8.) Supply-based transportation work (W_S) is calculated as follows (MEPC 2021b, 3).

$$W_S = C \times D_t \tag{3}$$

where:

C = The ship`s capacity according to type (DWT or GT)

D_t = The total distance travelled in nautical miles (DCS)

Before attained CII_{SHIP} is verified against the required annual operational CII ($CII_{req.y}$), a reference line for the ship type must be defined. The reference lines for each ship type are defined as a curve as illustrated in Figure 5 for Bulk carriers < 279000 DWT. CII reference lines are based on 2019 data reported under DCS. The CII reference lines (CII_{ref}) for each ship type are calculated as follows. (MEPC 2021c, 2.)

$$\mathrm{CII}_{\mathrm{ref}} = \mathrm{aCapacity}^{-\mathrm{c}} \qquad (4)$$

where:

$\mathrm{CII}_{\mathrm{ref}} =$ The reference value of year 2019 for the ship type

$\mathrm{a, c} =$ Ship type parameters

$\mathrm{Capacity} =$ Ship type capacity (DWT or GT)

Table 2. Parameters for defining the 2019 ship type specific $\mathrm{CII}_{\mathrm{ref}}$ lines (Modified from MEPC 2021c, 3; MEPC 2022a, 4).

Ship type		Capacity	a	c
Bulk carrier	279,000 DWT and above	279,000	4745	0,622
	Less than 279,000 DWT	DWT	4745	0,622
Gas carrier	65,000 DWT and above	DWT	1,4405E+11	2,071
	Less than 65,000 DWT	DWT	8104	0,639
Tanker		DWT	5247	0,610
Container ship		DWT	1984	0,489
General cargo ship	20,000 DWT and above	DWT	31948	0,792
	Less than 20,000 DWT	DWT	588	0,3885
Refrigerated cargo carrier		DWT	4600	0,557
Combination carrier		DWT	5119	0,622
LNG carrier	100,000 DWT and above	DWT	9,827	0.000
	65,000 DWT and above, but less than 100,000 DWT	DWT	1,4479E+14	2,673
	Less than 65,000 DWT	65,000	1,4779E+14	2,673
Cruise passenger ship		GT	930	0,383
Ro-ro cargo ship		GT	1967	0,485
Ro-ro cargo ship (vehicle carrier)	57,700 GT and above	57,700	3627	0,590
	30,000 GT and above, but less than 57,700 GT	GT	3627	0,590
	Less than 30,000 GT	GT	330	0,329

Ro-ro passenger ship	Ro-ro passenger ship	GT	2023	0,460
	High Speed Craft designed to SOLAS Chapter X	GT	4196	0,460

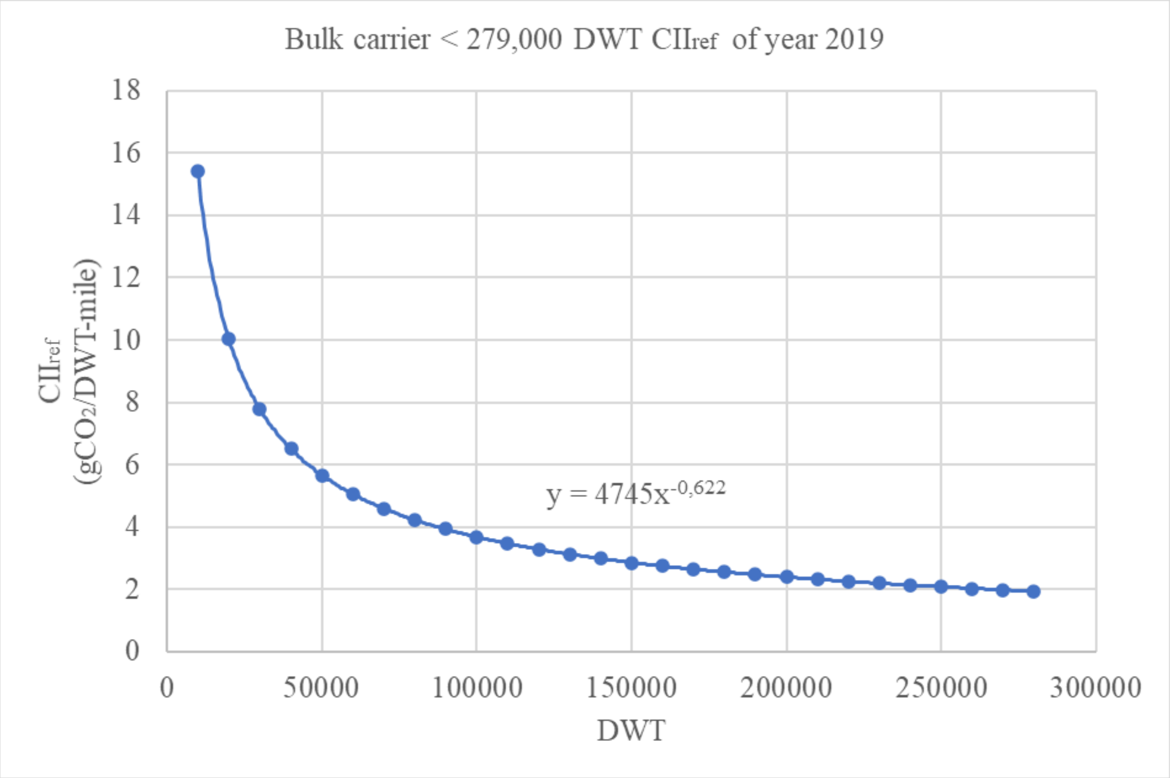

Figure 5. Example of year 2019 $\mathrm{CII}_{\mathrm{ref}}$ line for Bulk carriers < 279000 DWT.

The required annual operational CII ($\mathrm{CII}_{\mathrm{req.y}}$) of a ship type for a specified year is determined according to the general reduction factor (Z) for that year. The required annual operational CII of the ship type for the specified year ($\mathrm{CII}_{\mathrm{req.y}}$) is calculated as follows. (MEPC 2021d, 4.)

$$\mathrm{CII}_{\mathrm{req.y}} = \left(1 - \frac{Z_y}{100}\right) \times \mathrm{CII}_{\mathrm{ref}} \qquad (5)$$

where:

Z_y = Reduction factor (%) for the specified year (y)

$\mathrm{CII}_{\mathrm{ref}}$ = The reference value of year 2019 for the ship type

Table 3. Reduction factors (Z) for the specified year (y) relative to 2019 (Modified from MEPC 2021d, 4).

Year (y)	Reduction factor (Z) relative to 2019
2023	5 %
2024	7 %
2025	9 %
2026	11 %
2027	To be developed
2028	To be developed
2029	To be developed
2030	To be developed

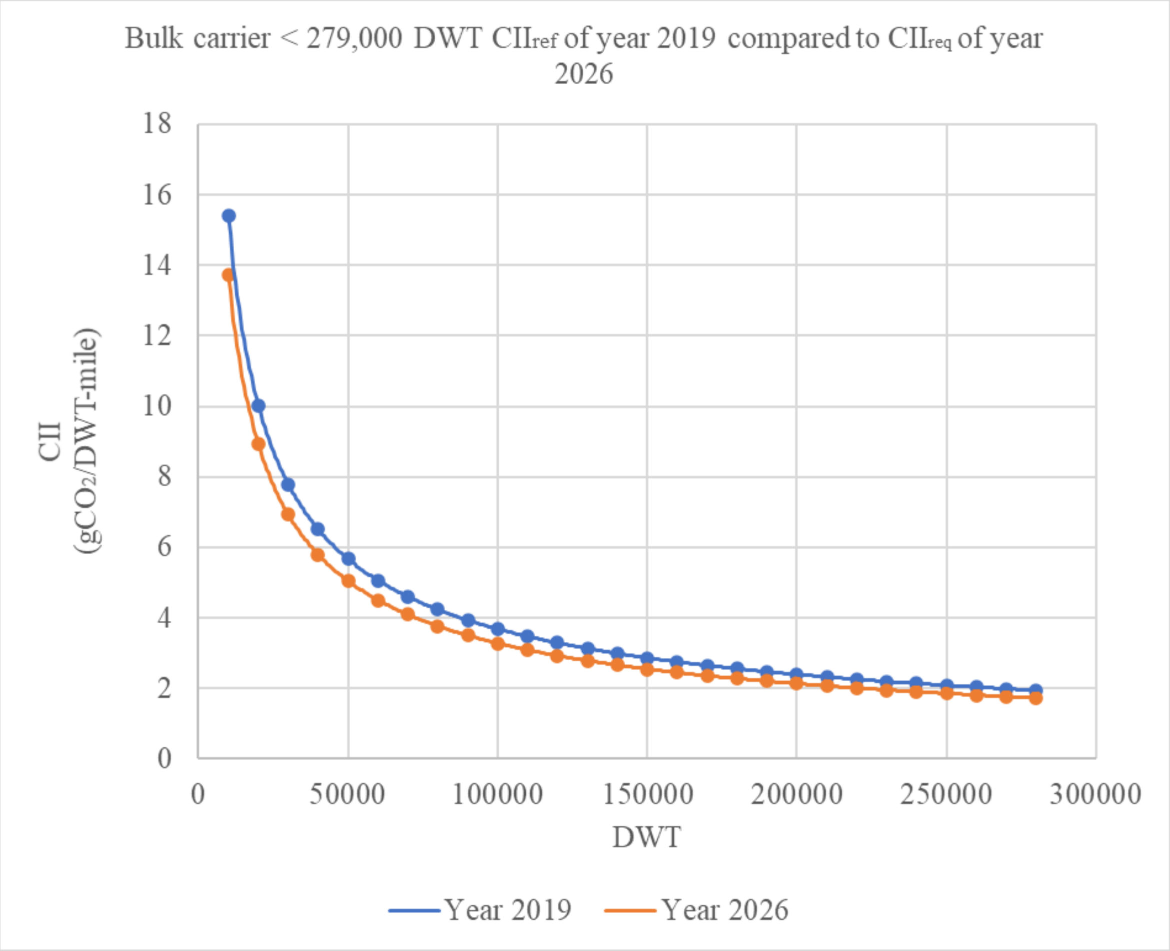

Figure 6. Example of year 2019 CII_{ref} line compared to year 2026 CII_{req} line for Bulk carriers < 279000 DWT.

The attained CII_{SHIP} must be verified against $\text{CII}_{\text{req.y}}$ to determine the ship`s CII rating. Ratings are indicated from A to E, representing different levels of performance. Verification is carried out by the ship`s administration or any authorized organization. (MEPC 2021a, 48.) A general representation of the trajectories of $\text{CII}_{\text{req.y}}$ is presented in Figure 7 (DNV 2021b). The middle line of rating C represents the value equivalent to $\text{CII}_{\text{req.y}}$. If the ship has received rating D in three consecutive years or rating E in a single year, corrective action plans and initiatives must be made to achieve $\text{CII}_{\text{req.y}}$. Plans and initiatives must be reviewed and implemented in the ship`s SEEMP and verified by the ship`s administration or any authorized organization. (MEPC 2021a, 48.)

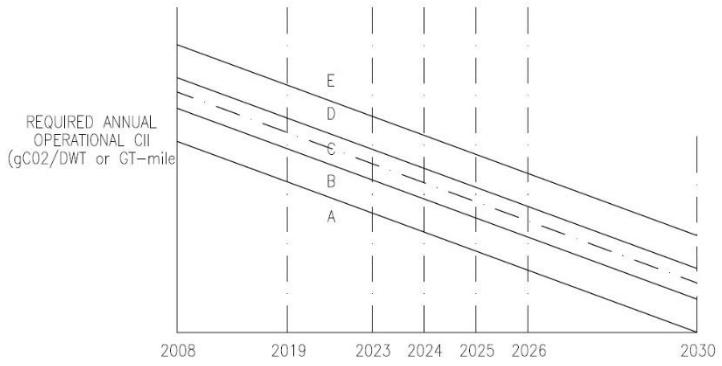

Figure 7. A general representation of the trajectories of $\text{CII}_{\text{req.y}}$ (Modified from DNV 2021b).

CII rating boundaries from A to E can be determined by ship type vectors, as presented in Figure 8. The vectors indicate the deviation of the rating boundaries from $\text{CII}_{\text{req.y}}$. The vectors are referred to as dd vectors. (MEPC 2021e, 3.)

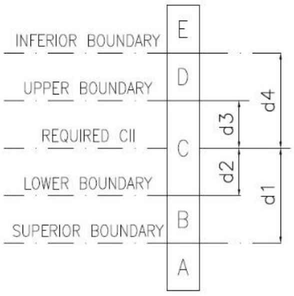

Figure 8. A general overview of the determination of CII rating boundaries (Modified from MEPC 2021e, 3).

The CII rating boundaries compared to $\mathrm{CII}_{\mathrm{req.y}}$ are calculated as follows (MEPC 2021e, 4).

$$\begin{cases} \text{Superior boundary} = \exp(d_1) \times \mathrm{CII}_{\mathrm{req.y}} \\ \text{Lower boundary} = \exp(d_2) \times \mathrm{CII}_{\mathrm{req.y}} \\ \text{Upper boundary} = \exp(d_3) \times \mathrm{CII}_{\mathrm{req.y}} \\ \text{Inferior boundary} = \exp(d_4) \times \mathrm{CII}_{\mathrm{req.y}} \end{cases} \tag{6}$$

where:

$\mathrm{CII}_{\mathrm{req.y}}$ = The required annual operational CII of the ship type for the specified year

$\exp(d_1, d_2, d_3, d_4)$ = dd vector

Table 4. Ship type dd vectors for determining CII rating boundaries (Modified from MEPC 2021e, 5; MEPC 2022b, 6).

Ship type	Capacity in CII calculation	dd vectors (after exponential transformation)			
		exp (d1)	exp (d2)	exp (d3)	exp (d4)
Bulk carrier	DWT	0,86	0,94	1,06	1,18

Gas carrier	65,000 DWT and above	DWT	0,81	0,91	1,12	1,44
	Less than 65,000 DWT	DWT	0,85	0,95	1,06	1,25
Tanker		DWT	0,82	0,93	1,08	1,28
Container ship		DWT	0,83	0,94	1,07	1,19
General cargo ship		DWT	0,83	0,94	1,06	1,19
Refrigerated cargo carrier		DWT	0,78	0,91	1,07	1,20
Combination carrier		DWT	0,87	0,96	1,06	1,14
LNG carrier	100,000 DWT and above	DWT	0,89	0,98	1,06	1,13
	Less than 100,00 DWT	DWT	0,78	0,92	1,10	1,37
Ro-ro cargo ship (vehicle carrier)		GT	0,86	0,94	1,06	1,16
Ro-ro cargo ship		GT	0,76	0,89	1,08	1,27
Ro-ro passenger ship		GT	0,76	0,92	1,14	1,30
Cruise passenger ship		GT	0,87	0,95	1,06	1,16

The ship´s CII rating from A to E for a specified year is calculated as follows (DNV 2022).

$$\begin{cases} \mathrm{A - rating = attained\ CII_{SHIP}} \leq \mathrm{CII_{reg.y}} \times \exp(\mathrm{d_1}) \\ \mathrm{B - rating = attained\ CII_{SHIP}} \leq \mathrm{CII_{reg.y}} \times \exp(\mathrm{d_2}) \\ \mathrm{C - rating = attained\ CII_{SHIP}} \leq \mathrm{CII_{reg.y}} \times \exp(\mathrm{d_3}) \\ \mathrm{D - rating = attained\ CII_{SHIP}} \leq \mathrm{CII_{reg.y}} \times \exp(\mathrm{d_4}) \\ \mathrm{E - rating = attained\ CII_{SHIP}} > \mathrm{CII_{reg.y}} \times \exp(\mathrm{d_4}) \end{cases} \tag{7}$$

A general overview of the attained annual operational CII calculation is presented in Figure 9. The ship can reduce the attained annual operational CII by different measures. The attained annual operational CII can be improved by speed reduction, regular maintenance work, implementing energy efficient technologies and using alternative fuels. (DNV 2021b.)

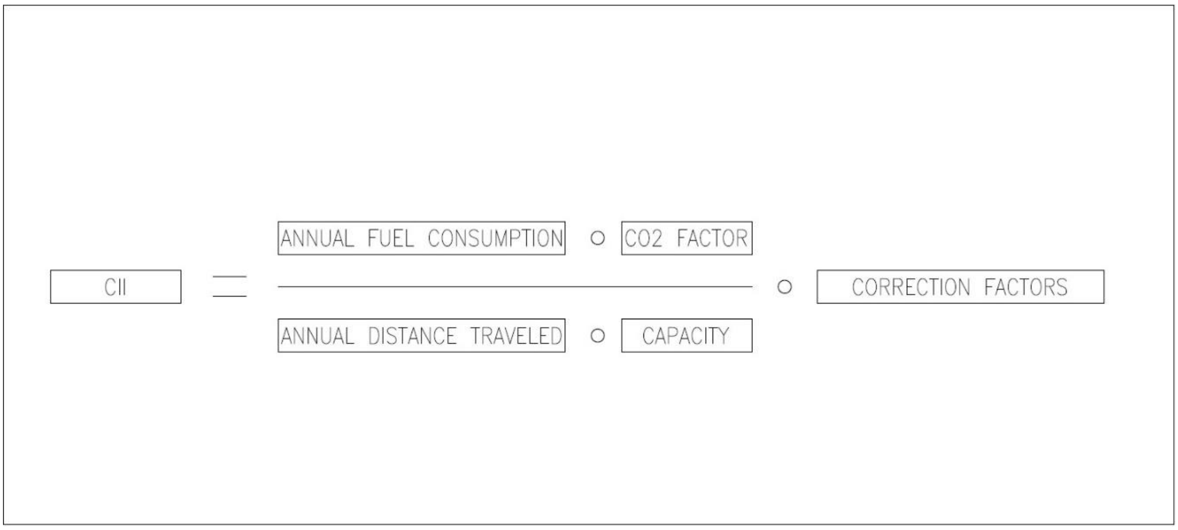

Figure 9. A general overview of the attained annual operational CII calculation (Modified from DNV 2021b).

In 2022, MEPC adopted guidelines on interim correction factors and voyage adjustments for the attained annual operational CII calculation (MEPC 2022c, 1). Guidelines for interim correction factors and voyage adjustments were constructed to consider special ship designs and operating conditions (DNV 2021b). The correction factor refers to the factor in the numerator or denominator of the CII equation, adjusting the calculation of the attained CII_{SHIP}. A voyage adjustment refers to the deduction of the relevant fuel consumption and distance travelled from the calculation of the attained CII_{SHIP} for those defined voyage periods when the voyage adjustments are allowed to be applied. The attained annual operational CII calculation equation (1) changes when correction factors and voyage adjustments are applied. Verification against $CII_{req.y}$ must be done with the corrected attained annual operational CII (attained $CII_{SHIP.C}$). Correction factors $FC_{electrical}$, FC_{boiler}, and FC_{others} should not be used for the periods when voyage adjustments are applied. The corrected attained annual operational CII (attained $CII_{SHIP.C}$) is calculated as follows. (MEPC 2022c, 4-6.)

$$\text{attained } CII_{SHIP.C} = \frac{\Sigma_j C_{F_j} \times \{FC_j - \left(FC_{voyage,j} + TF_j + (0{,}75 - 0{,}03y_i) \times \left(FC_{electrical,j} + FC_{boiler,j} + FC_{others,j}\right)\right)\}}{f_i \times f_m \times f_c \times f_{i,VSE} \times C \times (D_t - D_x)} \qquad (8)$$

where:

j = The fuel type

C_{F_j} = Fuel mass to CO_2 mass conversion factor for fuel type (j)

FC_j = The total mass (g) of consumed fuel type (j) (DCS)

$FC_{voyage,j}$ = The mass (g) of fuel type (j) consumed in voyage periods, which is allowed to be deducted acc. to paragraph 4.1 of G5 guidelines

TF_j = The quantity of fuel type (j) removed for STS or shuttle tanker operation

$$TF_j = (1 - AF_{Tanker}) \times FC_{s,j} \quad (9)$$

where:

$FC_{s,j} = FC_j$ for shuttle tankers

or:

$FC_{s,j}$ = The total quantity of fuel type (j) used on STS voyages for STS ships

AF_{Tanker} = The correction factor to be applied to shuttle tankers or STS voyages acc. to paragraph 4.2 of G5 guidelines

if:

$TF_j > 0$

then:

$FC_{electrical,j} = FC_{boiler,j} = FC_{others,j} = 0$

y_j = A consecutive numbering system starting at $y_{2023} = 0, y_{2024} = 1, y_{2025} = 2$, etc.

$FC_{electrical,j}$ = The mass (g) of fuel type (j) consumed for production of electrical power, which is allowed to be deducted acc. to paragraph 4.3 of G5 guidelines

$FC_{boiler,j}$ = The mass (g) of fuel type (j) consumed by the boiler, which is allowed to be deducted acc. to paragraph 4.4 of G5 guidelines

$\text{FC}_{\text{others,j}}$ = The mass (g) of fuel type (j) consumed by other related fuel consumption devices acc. to paragraph 4.5 of G5 guidelines

f_{i} = The capacity correction factor for ice – classed ships

f_{m} = The factor for ice – classed ships having IA Super and IA

f_{c} = The cubic capacity correction factors for chemical tankers

$\text{f}_{\text{i,VSE}}$ = The correction factor for ship – specific voluntary structural enhancement

C = The ship`s capacity according to type (DWT or GT)

D_{t} = The total distance travelled in nautical miles (DCS)

D_{x} = The distance travelled in nautical miles for voyage periods, which is allowed to be deducted from CII calculation acc. to paragraph 4.1 of G5 guidelines

More comprehensive calculation methods and guidelines on correction factors and voyage adjustments are specified in the document Interim Guidelines for Correction Factors and Voyage Adjustments for CII Calculations (CII Guidelines, G5) (MEPC 2022c).

3. Ships and fuel oils

Today`s ships are often equipped with diesel engines that run on different grades of fuel oil. Fuel oils are specified in the ISO 8217 standard, presenting the requirements for marine fuel oils. Fuel oil systems, including fuel oil supply units, provide fuel oil to engines with sufficient flow, pressure, viscosity, and degree of purity. The purpose of this chapter is to present the properties of fuel oils and the characteristics of ships` fuel oil supply systems. The chapter begins by presenting the properties of fuel oils. The chapter ends by presenting the characteristics of the most common fuel oil systems and supply units.

3.1. Engines and fuel oils

Depending on the size and type, ships are equipped with one or several engines, some of which are MEs, and some are AEs. The engines are generally either two- or four-stroke diesel engines that run on different grades of fuel oil. (Kampichler et al. 2011, 577-578.) Some engines are capable of running on both gaseous and liquid fuels. These types of engines are referred to as dual fuel engines. (Wärtsilä 2017, 6.) In larger ships, apart from cruise ships, two-stroke engines are usually used as MEs and four-stroke engines almost exclusively as AEs (Latarche 2021, 561; Kampichler et al. 2011, 577). Four-stroke engines are usually used as MEs in smaller ships and as MEs in ships with strict space requirements, such as Ro-ro ships (Kampichler et al. 2011, 577).

Diesel engines run on different grades of fuel oil. Fuel oils are specified in the ISO 8217 standard, presenting the requirements for marine fuel oils. Fuel oils can be divided into distillate and residual fuel oils. Distillate fuel oils are generally referred to as Marine Gasoil (MGO) and Marine Diesel Oil (MDO). Residual fuel oils are generally referred to as Heavy Fuel Oil (HFO). The ISO 8217 standard is also applicable to Low Sulphur Fuel Oils (LSFO) with sulphur contents of 0,5 % and 0,1 %. In the ISO 8217 standard, residual and distillate fuel oils are divided according to kinematic viscosities. Distillate fuel oils have a much lower kinematic viscosity compared to residual fuel oils. Marine fuel oils are produced through the refining process of crude oil. (Vermeire 2021, 3-10.)

The sulphur content of marine fuels has been progressively reduced over the last decade as presented in Figure 10. From 2008 to date, the sulphur content of marine fuels has been reduced globally from 4,5 % to 0,5 % and in Emission Control Areas (ECA), also referred to as Sulphur Emission Control Areas (SECA), the sulphur content has been reduced from 1,5 % to 0,1 %. Due to the progressive reduction of the sulphur content of marine fuels, the demand for LSFO is increasing, requiring changes to refining processes to increase capacities. These changes to refining processes can lead to increased GhG emissions. Alternative marine fuels may help reduce air pollution and GhG emissions in SECA areas. It is estimated that alternative marine fuels could cover half of shipping`s energy demand by 2050, while the rest would still be filled with traditional fuel oils. (Chu Van et al. 2019.)

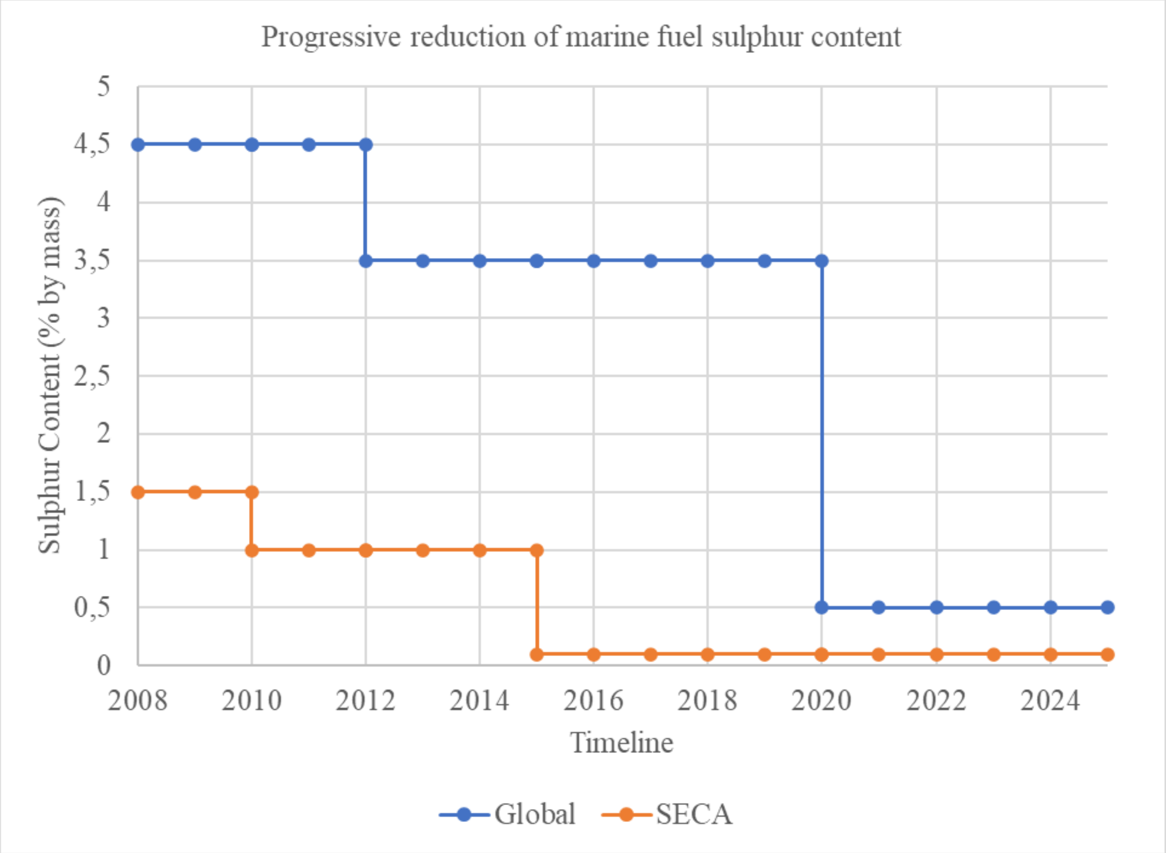

Figure 10. Progressive reduction of marine fuel sulphur content (Modified from Chu Van et al. 2019).

3.2. Fuel oil systems and supply units

The design and characteristics of fuel oil systems, including fuel oil supply units, may vary by engine type, number of engines and fuel oil. However, the general purpose and required functions of fuel oil systems remain the same. The general purpose of fuel oil systems is to provide fuel oil to engines with sufficient flow, pressure, viscosity, and degree of purity. Depending on the fuel oil, heating or cooling is required to attain and maintain the recommended viscosities at the engine’s inlet. (Wärtsilä 2021, 55.) Acceptable fuel oil properties are based on the ISO 8217 standard for distillate and residual fuel oils. The engine manufacturer MAN specifies the recommended fuel oil viscosities at the engine inlet for their two-stroke engine as presented in Table 5. Guidelines for the design and characteristics of the fuel oil systems of different engines are described in the engine makers’ product guides. (MAN 2021, 243-266; Wärtsilä 2021, 43, 55-75.)

Table 5. Recommended fuel oil viscosities at engine inlet (Modified from MAN 2021, 265).

Range	Fuel oil viscosity at engine inlet, cSt
Minimum	2
Normal, MDF	3 or higher
Normal, HFO	10-15
Maximum	20

The general design and main characteristics of the fuel oil system of Wärtsilä`s four-stroke engine(s), using both residual fuel oil (HFO) and distillate fuel oil, henceforth referred to as Marine Diesel Fuel (MDF), are presented in Figure 11. HFO and MDF are stored in separate day tanks T1 and T2, where the temperatures of HFO and MDF are maintained at recommended levels. (Wärtsilä 2021, 58, 68.) The fuel oil system can additionally include an additional LSFO day tank (MAN 2021, 245).

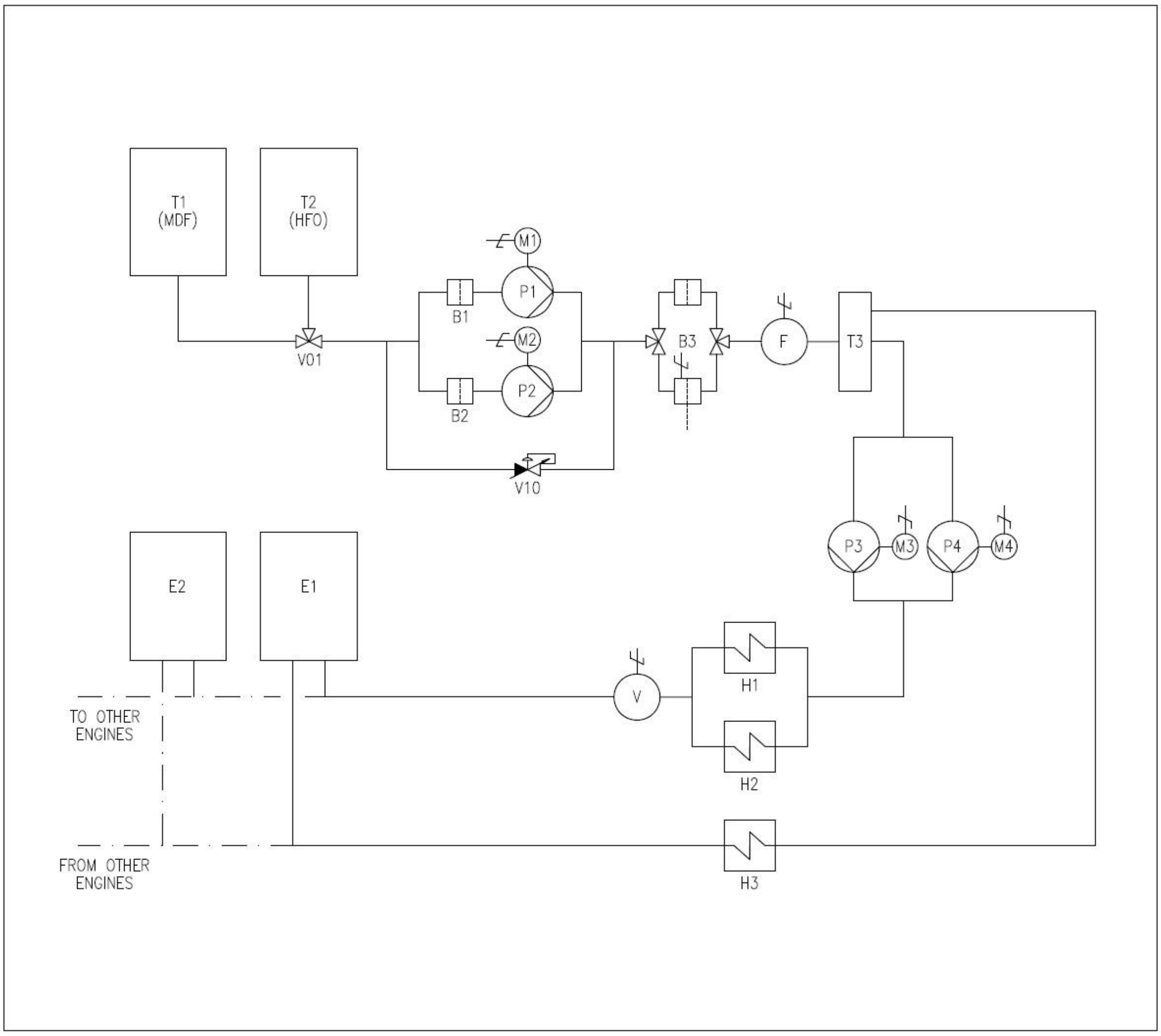

Figure 11. The general design and main characteristics of the fuel oil system of Wärtsilä`s four-stroke engine(s), using both HFO and MDF (Modified from Wärtsilä 2021, 67-68).

The components of the fuel oil supply unit, which is also referred to as the feeder-booster unit, are generally constructed and combined on a common steel frame. HFO or MDF enters the unit through the changeover valve V01. Fuel oil flows through suction strainers B1 and B2 to the suction side of feeder pumps P1 and P2. The feeder pumps maintain the system pressure and provide the necessary flow according to the fuel oil consumption of the engine(s), the amount of automatic filter B3 backflush, and the specified capacity margin. The pressure control valve V10 maintains the pressure in the de-aeration tank T3 by directing the excess flow back to the suction side of the feeder pumps. The components installed before the de-aeration tank are part of the feeder side of the unit. (Wärtsilä 2021, 70-72.)

After the feeder pumps, the fuel oil flows through the automatic filter B3 and the flow meter F to the de-aeration tank T3. The automatic filter removes impurities from the fuel oil with a specified filter fineness. The flow meter is installed before the de-aeration tank, as in this position the flow meter measures the total consumption of the engine(s). As presented in Figure 11, the fuel oil flows in a closed circuit from the de-aeration tank to the engine(s) and back. This closed circuit is also referred to as the booster circulation side. Engine(s) E1 and E2 consume a certain amount of fuel oil from this circulation flow. The amount of fuel oil consumed by the engine(s) is met by the flow of the feeder pump. (Wärtsilä 2021, 72-73.) In some designs, it is recommended to install the automatic filter B3 on the circulation side (MAN 2021, 245).

Fuel oil flows from the de-aeration tank to the suction side of booster pumps P3 and P4. Booster pumps circulate the fuel oil in the system and maintain the required pressure at the engine(s). After the booster pumps, the fuel oil flows through heaters H1 and H2, which maintain the viscosity and temperature of the fuel oil at the recommended levels. In practise, fuel oil heating is only required in HFO operation due to the higher kinematic viscosity properties. After the heaters, the fuel oil flows through the viscosity sensor V to the engine(s). The viscosity sensor controls the power of the heaters according to the viscosity set point. A temperature sensor is installed near the viscosity sensor for temperature control, operating as a backup for viscosity control. After the engine(s), the fuel oil flows through the cooler H3 back to the de-aeration tank. In practise, fuel oil cooling is only required in MDF operation, as the viscosity of MDF can drop below recommended viscosity levels. (Wärtsilä 2021, 73-74.) In some designs, it is recommended to install the cooler before the booster pumps (MAN 2021, 245).

The general design and main characteristics of the fuel oil system of Wärtsilä`s four-stroke engine(s) using only MDF are presented in Figure 12. MDF enters the unit through duplex suction strainer B4 and flow meter F1 to the suction side of booster pumps P5 and P6. Suction strainers can also be simplex-type strainers, as presented in Figure 11. Booster pumps circulate MDF in the system and maintain the required pressure at the engine(s). After the booster pumps, MDF flows to the engine(s) through the safety filter B5. The safety filter can either be included in the unit or delivered separately for external installation. After the engine(s), MDF flows back to the day tank T4 through the cooler H4 and the flow meter F2. If the MDF return from the engine(s) is directed directly to the day tank instead of the de-aeration tank, as presented in Figure 12, two flow meters are required. One flow meter is installed upstream from the engine(s) and one downstream. The fuel oil consumption of the engine(s) can be determined from the combined data of the flow meters. In a multi-engine installation configuration, two flow meters per engine are required to measure the fuel oil consumption of an individual engine. (Wärtsilä 2021, 63-65.)

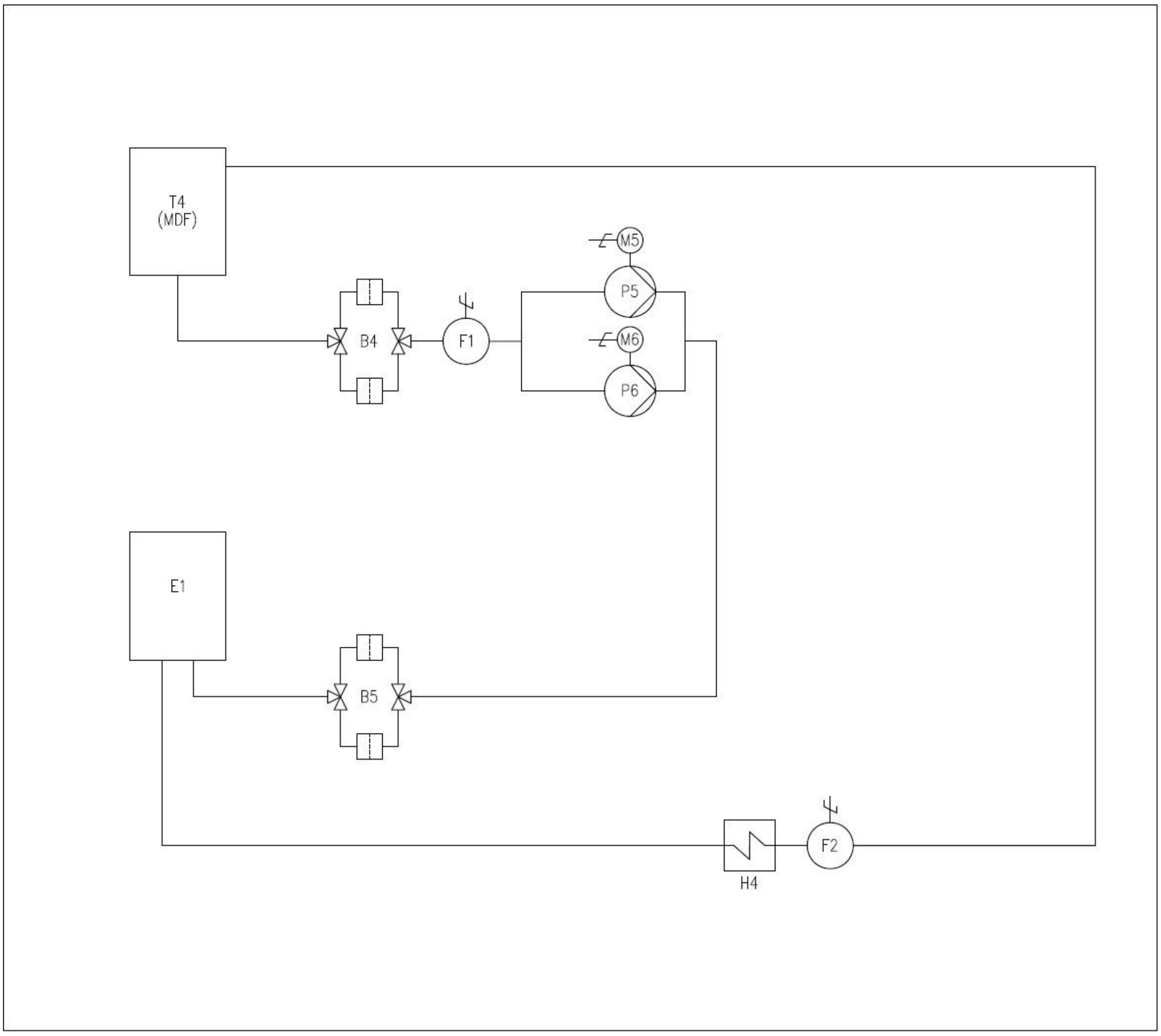

Figure 12. The general design and main characteristics of the fuel oil system of Wärtsilä`s four-stroke engine(s) using only MDF (Modified from Wärtsilä 2021, 63).

4. Flow meters and signals

Flow meters are one of the specified methods for collecting and monitoring fuel oil consumption data of a ship. The output signals derived from the flow meters provide the fuel oil consumption data to the data collection and monitoring equipment. The purpose of this chapter is to present Coriolis and positive displacement flow meters, which are the most common flow meters used in ships` fuel oil systems and supply units. In addition, the purpose is to present the output signals derived from the flow meters. The chapter begins by shortly presenting the basics of flow measurement and meters. The chapter continues by presenting the characteristics of Coriolis and positive displacement flow meters. The chapter ends by presenting the output signals derived from the flow meters.

4.1. Flow measurement and meters

In a closed pipeline, fluid flow is the result of converting upstream pressure energy into downstream velocity. Fluid viscosity and density have a direct effect on fluid flow. Both viscosity and density affect the Reynolds number, which determines the type of flow. For instance, is the flow laminar or turbulent. The viscosity of the fluid resists the flow and can be considered as the thickness of the fluid and is dependent on the temperature. In the case of a liquid, the more the temperature of the liquid increases, the more the viscosity decreases. (Basu 2019, 5-10.) There are two basic types of flow measurements, including volumetric and mass flow measurements. Liquid and gas flow can be measured as volumetric and mass flow. Volumetric and mass flow measurements can be converted between each other if the density of the fluid and the process conditions are known. (Basu et al. 2019, 279.)

The desirable characteristics of a flow meter depend on the application in which the flow meter is installed. There are a few general desirable characteristics such as wide operating range, high sensitivity, reliability and overall accuracy, low permanent pressure loss, suitable mechanical properties, easy calibration, installation, and maintenance characteristics, communication capability, and operational safety throughout the lifespan. Accuracy is an important selection criterion when selecting a flow meter. Accuracy is highly dependent on the turndown ratio, which indicates the range within which accurate fluid measurement is possible for the flow meter. In addition, the placement of the flow meter, such as the necessary length of straight pipe upstream and downstream of the flow meter, affects the accuracy of the flow measurement. (Basu 2019, 8, 19-20.)

4.1.1. Coriolis flow meter

For mass flow measurement, Coriolis flow meters, based on the Coriolis force are the most common (Basu 2019, 71). Coriolis flow meters create a Coriolis acceleration on the flowing fluid through the interaction between the flowing fluid and the conveying structure of the flow meter. The reaction caused by the Coriolis acceleration on the conveying structure is then detected. (Wang et al. 2014.) The fluid flows through the tube(s) of the Coriolis flow meter, which are set to vibrate at a natural frequency. When fluid flows through the tube(s), the flow will cause a change in the tube(s) vibration. As a result of the flow, the tube(s) will twist. The twisting of the tube(s) result in a phase shift that is proportional to the mass flow. (Basu 2019, 72-73, 545.)

Due to the versatility of Coriolis flow meters, they are widely used in many applications. In practise, Coriolis flow meters can be used in any fluid application with sufficient mass flow. Typical applications include harsh chemicals, low to medium viscosity liquids, foods, slurries, and blending systems. When selecting a Coriolis flow meter, the maximum allowable pressure drop across the flow meter must be considered. The pressure drop must not affect the desired system flow rate. This is highly important in applications where the flow meter measures high flow rates or highly viscous fluids. (Spitzer 2005, 185, 191-192, 194-195.)

Coriolis flow meters are highly accurate and in some cases are even used to check other flow meters. The specified minimum accuracy of the flow meter determines the low-end flow rate and the maximum pressure drop across the flow meter determines the high-end flow rate.

The turndown ratio can be determined from the ratio of the high-end and low-end flow rates. In addition to accuracy, the advantages of Coriolis flow meters include easy installation and maintenance characteristics and the fact that Coriolis flow meters do not require a long upstream or downstream pipe section. (O`Banion 2013, 44.) The relatively high cost of Coriolis flow meters is one of the disadvantages (Spitzer 2005, 185; O`Banion 2013, 44).

4.1.2. Positive displacement flow meter

Positive displacement flow meters are suitable for measuring the volumetric flow of fluids. The internal mechanical moving parts of the flow meter separate the fluid into known volumes according to the physical dimensions of the flow meter. The measurement principle can be thought of as a cycle of filling and emptying the inner compartments of the flow meter. The known volumes are counted and totalized to determine the flow through the flow meter. (Basu 2019, 52; Boyes 2010, 44.) Positive displacement flow meters have a high turndown ratio and are well suited for measuring the volumetric flow of highly viscous fluids (Basu 2019, 52, 335-336).

Applications for positive displacement flow meter are often those where high accuracy is required. The accuracy of a positive displacement flow meter is not affected by pulsating flow, but the accuracy can vary notably between applications depending on the properties and flow rate of the fluid being measured. (Basu 2019, 52; Boyes 2010, 43-44.) Positive displacement flow meters are often equipped with internal temperature compensation to avoid measurement errors due to volumetric expansion of the fluid at fluctuating temperatures (Basu 2019, 389).

When selecting a positive displacement flow meter for an application, the effects of viscosity on the pressure drop across the flow meter must be considered. As the viscosity increases, the pressure drop across the flow meter increases accordingly. Potential clogging, fragility, and measurement error in conditions where there is gas present in the liquid are few of the disadvantages of positive displacement flow meters. Positive displacement flow meters do not have strict upstream or downstream pipe length requirements. (Spitzer 2005, 245-246.)

4.2. Transmitters and signals

Flow meters can be delivered with a transmitter and its basic purpose is remote communication. Transmitters have a variety of communication methods, including analog and digital output signals and serial communication. (Basu 2019, 388-399.) A digital output signal, such as a pulse output signal, provides pulses at a frequency proportional to the flow. The pulse output frequency is scaled to represents a specific value of volume or mass that has flowed through the flow meter. The pulses can be totalized to determine the flow through the flow meter. (Boyes 2010, 223.) A graphic representation of a pulse output signal is presented in Figure 13 (Spitzer 2005, 74).

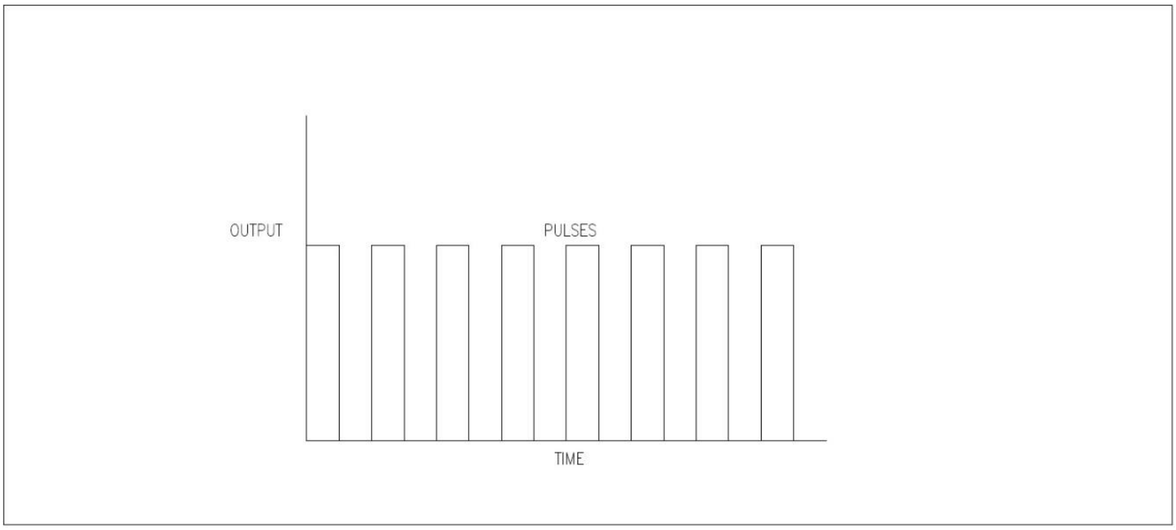

Figure 13. A graphic representation of a pulse output signal (Modified from Spitzer 2005, 74).

The conventional analog output signal is a continuous 4-20 mA output signal (Boyes 2010, 222-223; Spitzer 2005, 73). A graphic representation of linear and non-linear 4-20 mA output signals is presented in Figure 14. 0 % flow represents a 4 mA signal and 100 % flow represents a 20 mA signal. The mA output signal of a linear flow meter is directly proportional to the flow. The mA output signal of a non-linear flow meter, such as an orifice plate or other differential pressure flow meter, is proportional to the square of the flow. (Spitzer 2005, 63-64, 74.)

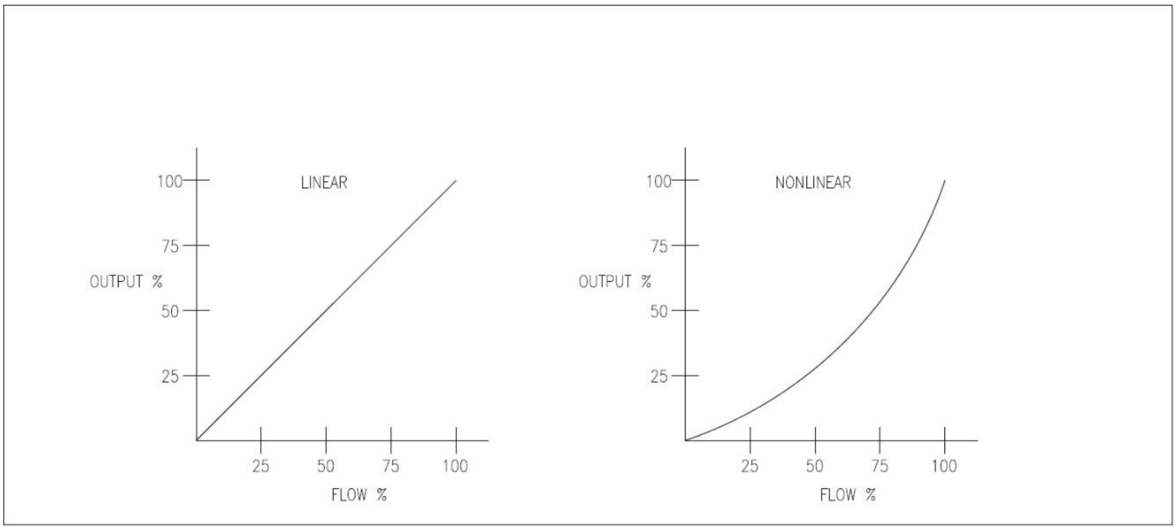

Figure 14. A graphic representation of linear and nonlinear 4-20 mA output signals (Modified from Spitzer 2005, 64, 74).

5. Unit design and equipment review

The company supplies fuel oil supply units for ships` fuel oil systems. Depending on the design, the units may include flow meters to monitor the fuel oil consumption of the engines. The company is looking for equipment to incorporate into the current design of the units for CII and other energy efficiency data collection, monitoring, reporting, and transmission purposes. The purpose of this chapter is to present the current design characteristics of the units and review the available equipment. The chapter begins by presenting the characteristics of the current design of the units. The chapter continues by presenting the requirements for the equipment and the characteristics of the available equipment. The chapter ends by presenting the low- and high-tier products into which the equipment available on the market are divided, as well as an overview of the company`s own product.

5.1. Unit design

The company supplies fuel oil supply units with the necessary components, constructed and combined on a common steel frame. In general, the main components include fuel oil changeover valve, feeder pump suction strainers, feeder pumps, pressure control valve, automatic filter, flow meter(s), de-aeration tank, booster pumps, HFO heaters, viscosity sensor, and MDF cooler. In addition, the units include the necessary shut-off, non-return, and other valves, manometers, thermometers, and a possible safety filter. Unit design and characteristics may vary according to each engine manufacturer`s guidelines and recommendations.

In the current design of the units, unit control can be carried out either with hardwired control functions or with Programmable Logic Controller (PLC) control functions. In addition, control can be carried out as a combination of both. Currently, PLC control functions are preferred. Figure 15 presents an example of a fuel oil supply unit. All components, including control cabinets, are installed on a common steel frame. Control of components such as pumps, automatic filter, HFO heaters, and other design-related components is possible from rotary switches, push buttons, and individual controllers installed on the control cabinet. In the case of a PLC, partial or complete control of the unit is possible from the Human Machine Interface (HMI) panel installed on the control cabinet. Depending on the design, the unit can include either one common flow meter or consumer-specific flow meters. The flow meters are usually equipped with a display or a transmitter, from which monitoring of the flow and totalizer is possible. Alternatively, the data from the flow meters can be realized on the control cabinet with an electronic flow rate indicator and totalizer, or the data can be displayed on the HMI panel.

Figure 15. An example of a fuel oil supply unit.

As presented in chapter 2.5, the attained annual operational CII is calculated by dividing the total mass of CO_2 emitted by the total transportation work undertaken during the calendar year. The total mass of CO_2 emitted is calculated from the total consumption of different fuel types, including individual fuel mass to CO_2 mass conversion factors. The calculated total mass of CO_2 emitted is divided by the total distance travelled and the capacity of the ship to determine the attained annual operational CII. Flow meters are one of the specified methods for collecting and monitoring fuel oil consumption data of a ship. The total annual consumption of fuel oil can be determined from the data of the flow meters and used in the calculation of the attained annual operational CII. In the current design of the units, only fuel oil consumption data is available. Suitable equipment should be incorporated into the current design of the units for CII and other energy efficiency data collection, monitoring, reporting, and transmission purposes. The following chapters present the requirements for the equipment and the characteristics of the available equipment.

5.2. Requirements and equipment review

The attained annual operational CII calculation method sets some essential and non-essential functions for the equipment used to collect, monitor, report, and transmit the data required for the calculation process. It is essential that the equipment include fuel oil consumption measuring equipment as well as data collection and monitoring equipment. As the requirement is to measure and monitor all fuel oil consumed, as required by DCS, the equipment should include a function to determine what type of fuel oil is consumed. This is especially important in fuel oil systems where both HFO and MDF are supplied to engines. The consumption data must be divided according to each type of fuel oil. The consumption data must also be expressed in mass as required by the attained annual operational CII calculation method. In addition, it is essential that the equipment include a function for determining the distance travelled in accordance with the requirements of DCS. Since the equipment are intended to be incorporated into the current design of fuel oil supply units that supply fuel oils according to the ISO 8217 standard, other fuels will be ignored for the time being. The inclusion of other fuels such as Liquefied Natural Gas (LNG) and methanol should be considered in the future.

Since CII can be considered a continuum of the requirements of DCS, reporting follows DCS guidelines. The attained annual operational CII must be calculated based on the ship`s DCS data and reported together with the DCS data to a verifier such as the ship`s classification society. DCS data and calculated attained annual operational CII must be reported within three months of the end of each calendar year. Some ship classification societies, such as DNV, require the DCS report to be divided into event-specific sections. In practice, this means reporting at least all port departures and arrivals. Basically, reporting of all individual voyages. According to DNV, ships basically have three options for reporting, including departure from port and arrival at port, daily reports, or a combination of the two. Therefore, it is essential that the equipment include a function for reporting individual voyages or the possibility for daily reporting.

The inclusion of fuel mass to CO_2 mass conversion factors to determine the mass of CO_2 emitted can be considered an essential function for the equipment. The function should cover the total mass of CO_2 emitted during the calendar year as well as the mass of CO_2 emitted during individual voyages. Fuel mass to CO_2 mass conversion factors can be considered as non-dimensional fixed factors that are not affected by the ship`s operation. The attained annual operational CII can be calculated as demand-based or supply-based. In supply-based calculation, the ship’s capacity is taken as proxy of the actual mass or volume of the shipment carried on board. In supply-based calculation, the ship`s capacity is a fixed factor. In demand-based calculation, the ship`s capacity is based on the actual or estimated mass or volume of the shipment carried on board. Although the demand-based calculation method is currently left unclear, it is worth considering the inclusion of the necessary functions. In demand-based calculation, the ship`s capacity is a variable factor, meaning it is essential that the equipment allow the capacity to be modified for each individual voyages according to the actual or estimated mass or volume carried on board. The inclusion of correction factors and voyage adjustments for special ship designs and operation conditions will be ignored for the time being, as even if correction factors or voyage adjustments are applied, the ship must still report the total consumption of fuel oil and the total distance travelled. Necessary reservations for remarks for specific voyages and events where correction factors or voyage adjustments are applied should be considered in the future. The equipment are not necessarily required to perform the overall attained annual operational CII calculation, but to collect the data required for the calculation process.

It is essential that the equipment include the necessary storage capacity for the collected data. The storage capacity should be sized at least to the size of the data collected during the calendar year and three months of additional capacity reserve. Event-specific data and reports are not required to be kept on board, provided that the data and reports can be made available by other means. Data and reports are not usually verified on board. The data transmission function can therefore be considered an essential function for the equipment.

There are basically two options for the function, internal and external. The internal transmission function refers to the function with which the equipment can transmit data and reports to onshore either directly or with the help of an external system. In the absence of an internal transmission function, it is essential that the data and reports can be converted into a transferable format, so that the data and reports can be transmitted to onshore via an external system.

There is a significant number of ready-made equipment packages available on the market for collecting, monitoring, reporting, and transmitting DCS, CII, and other energy efficiency data. The equipment packages differ at the component level, but the main function remains the same. Since the annual fuel oil consumption is one of the factors in determining the attained annual operational CII, the equipment packages include flow meters to measure the fuel oil consumption. Depending on the supplier, flow meters are generally either positive displacement or Coriolis flow meters. In addition to flow meters, the equipment packages include data collection and monitoring equipment, including an HMI panel. Equipment packages may additionally include components for measuring and monitoring other energy efficiency data. There are differences between the equipment packages in terms of data monitoring functions. Equipment packages can generally be divided into two categories. Equipment packages of the first category include data collection, monitoring, reporting and transmission functions. Equipment packages of the second category additionally include a web-based platform from which it is possible to monitor DCS, CII, and other additional energy efficiency data from onshore. Equipment packages, divided into two categories, are henceforth referred to as low-tier and high-tier products.

5.2.1. Low- and high-tier products

Low-tier products include data collection, monitoring, reporting and transmission functions. Supplier Emerson (Emerson 2019; Emerson 2018) provides a system that includes Coriolis flow meters and data collection and monitoring equipment, including an HMI panel. The components of the system are installed on board. Coriolis flow meters allow direct mass flow measurement. The system includes functions to determine what type of fuel oil is consumed and the distance travelled. The system allows the capacity to be modified for each individual voyages according to the actual or estimated mass or volume carried on board. With the help of fuel mass to CO_2 mass conversion factors, the system is able to determine the mass of CO_2 emitted. The system provides the necessary storage capacity for the collected data and enables the reporting of individual voyages. Data and reports can be converted into a transferable format and transmitted to onshore via an external system. Monitoring and control of the system is possible from the HMI panel. A general system diagram of Emerson is presented in Figure 16.

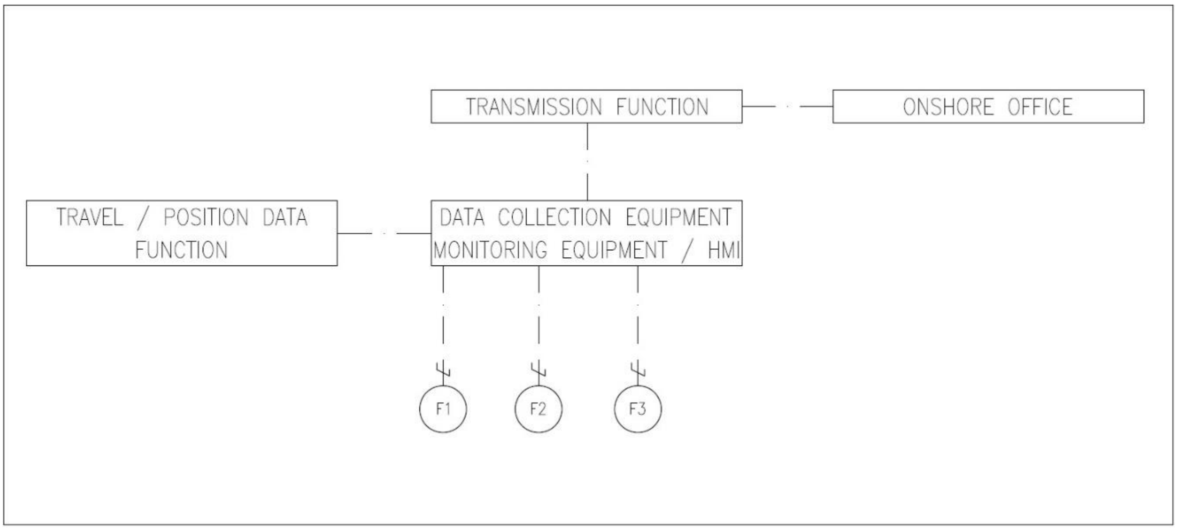

Figure 16. A general system diagram of Emerson.

In addition to data collection, monitoring, reporting and transmission functions, high-tier products include a web-based platform for more comprehensive monitoring purposes. Supplier Aquametro (Aquametro 2020; Aquametro 2018) provides a system that includes positive displacement flow meters, a Shaft Power Meter (SPM), data collection and monitoring equipment including an HMI panel, and a web-based monitoring platform. The components of the system are installed on board. Positive displacement flow meters allow volumetric flow measurement. The system includes a function to convert volumetric flow into mass flow, as well as functions to determine what type of fuel oil is consumed and the distance travelled. The system allows the capacity to be modified for each individual voyages according to the actual or estimated mass or volume carried on board. With the help of fuel mass to CO_2 mass conversion factors, the system is able to determine the mass of

CO_2 emitted. The system provides the necessary storage capacity for the collected data and enables reporting of individual voyages. Data and reports can be transmitted to onshore, where monitoring is possible from a web-based platform. Monitoring and control of the system is possible from the HMI panel. The system includes additional functions for collecting and monitoring other energy efficiency data. With the help of flow meters, SPM, and the above data, fuel efficiency and engine performance data can be collected for monitoring and analysis purposes. Functions can be considered as EEOIs for monitoring the ship`s energy efficiency. The additional functions of the equipment related to other energy efficiency data collection and monitoring purposes can be considered as non-essential functions, provided that the data is not required for the attained annual operational CII calculation process.

Supplier VAF (VAF 2021; VAF 2017) provides a system that includes positive displacement flow meters, a SPM, data collection and monitoring equipment including an HMI panel, and a web-based monitoring platform. The components of the system are installed on board. Positive displacement flow meters allow volumetric flow measurement. In addition, VAF provides a viscosity sensor from which the density of the fuel oil can be derived for mass flow conversion. The system includes functions to determine what type of fuel oil is consumed and the distance travelled. The system allows the capacity to be modified for each individual voyages according to the actual or estimated mass or volume carried on board. With the help of fuel mass to CO_2 mass conversion factors, the system is able to determine the mass of CO_2 emitted. The system provides the necessary storage capacity for the collected data and enables reporting of individual voyages. Data and reports can be transmitted to onshore, where monitoring is possible from a web-based platform. Monitoring and control of the system is possible from the HMI panel. The system provided by VAF includes similar additional energy efficiency functions as the system provided by Aquametro. A general system diagram of Aquametro and VAF is presented in Figure 17.

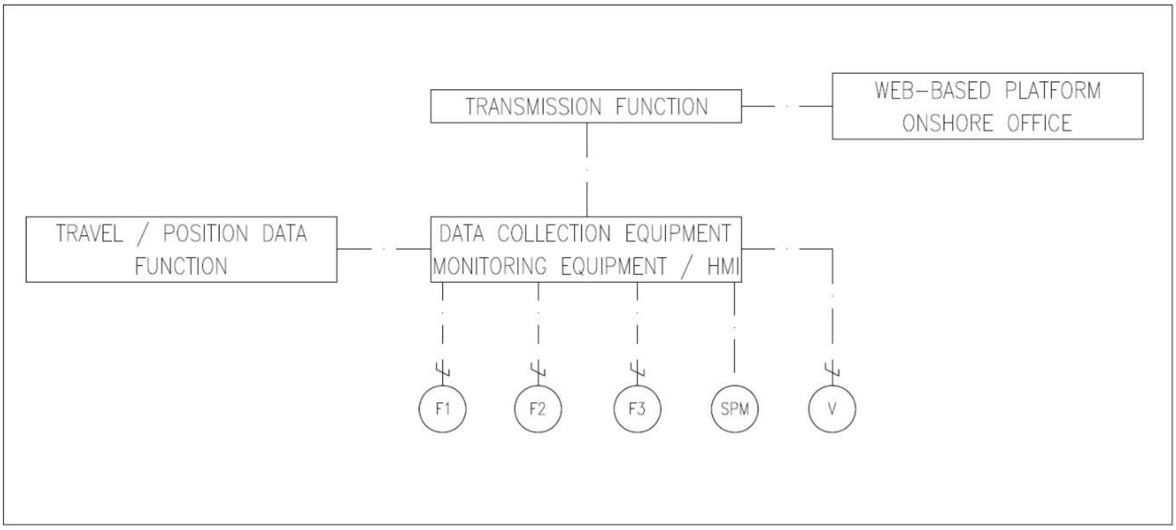

Figure 17. A general system diagram of Aquametro and VAF.

5.2.2. Own product

The company`s own product refers to a product that can be developed through internal product development. The company has different alternatives for how the product can be constructed and what functions the product includes. The product alternative with the most comprehensive functions is presented in this chapter. Henceforth, when referring to the company`s own product, this alternative is meant. Through internal product development, the company is able to provide a system that includes either positive displacement flow meters or Coriolis flow meters, a SPM, data collection and monitoring equipment including an HMI panel, and a web-based monitoring platform. In addition, other field components can be included in the system for more comprehensive data collection and monitoring purposes. The components of the system are installed on board. The system enables the use of either positive displacement flow meters or Coriolis flow meters for flow measurement. The use of Coriolis flow meters is preferable as Coriolis flow meters allow direct mass flow measurement. The system includes functions to determine what type of fuel oil is consumed and the distance travelled. The system allows the capacity to be modified for each individual voyages according to the actual or estimated mass or volume carried on board. With the help of fuel mass to CO_2 mass conversion factors, the system is able to determine the mass of CO_2 emitted. The system provides the necessary storage capacity for the collected data and enables reporting of individual voyages. Data and reports can be transmitted to onshore, where monitoring is possible from a web-based platform. Monitoring and control of the system is possible from the HMI panel. The HMI panel, web-based monitoring platform, and other functions can be customized and developed according to current and future requirements. As with the systems provided by Aquametro and VAF, the system includes and can be developed to include additional functions for other energy effiency data collection and monitoring purposes. A general system diagram of the company`s own product is presented in Figure 18.

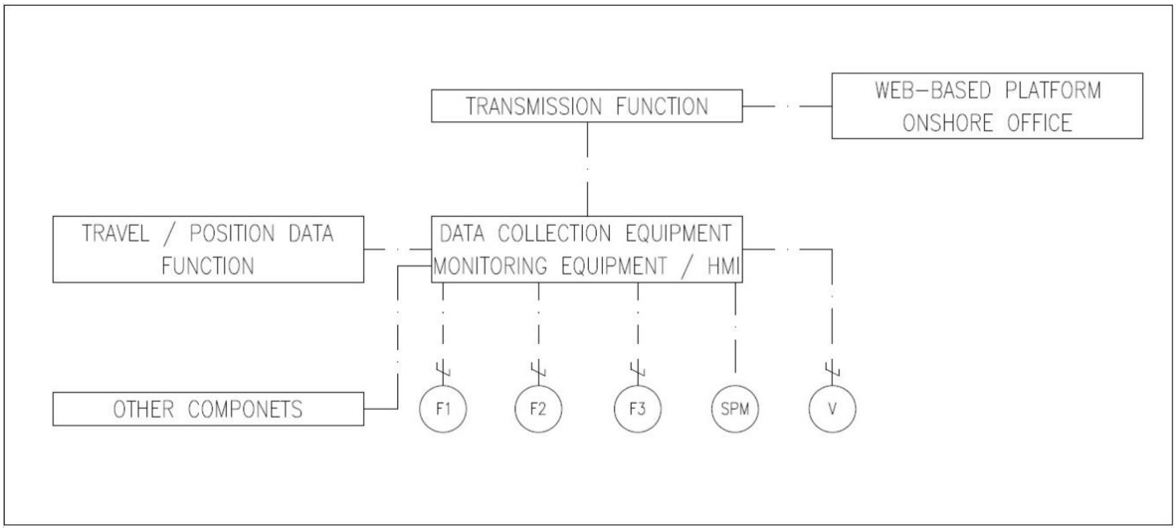

Figure 18. A general system diagram of the company`s own product.

6. Equipment feasibility

Since the equipment include new components, such as data collection and monitoring equipment, the applicability of the equipment to the current design of fuel oil supply units must be studied. The purpose of this chapter is to study the feasibility of the equipment from the points of view of different design departments, and to conduct SWOT analyses on the equipment. The chapter begins by presenting the points of view of process and mechanical design. The chapter continues by presenting the points of view of electrical and automation design. The chapter ends by presenting a SWOT analysis of low- and high-tier products, as well as a SWOT analysis of the company`s own product.

6.1. Technical feasibility

From the point of view of process design, the design is only affected by the inclusion of field components such as flow meters and viscosity sensor. In terms of process design, it does not matter in itself whether the components are installed in the unit or whether the components are delivered separately for external installation. Generally, flow meters are selected according to the customer`s specification and the continuous maximum flow passing through the flow meters. The selection of flow meters is affected by the maximum allowed pressure drop, the desired accuracy, and the desired units for indication and output. In current unit designs, the flow meters are generally either positive displacement or Coriolis flow meters. The use of different types of flow meters or flow meters from different suppliers does not affect the functionality of the unit, as the main function is to measure, indicate, and transmit the fuel oil consumption data of the engines. The flow meters provide pulse and mA output signals to data collection and monitoring equipment. Flow meters from Emerson, VAF, and Aquametro can and have been used in unit designs. From the point of view of process design, the inclusion of a low- or high-tier product in the current design of the units can be carried out without issues.

From the point of view of mechanical design, the design is affected by the inclusion of field components and data collection and monitoring equipment. In terms of mechanical design, it matters whether the components and equipment are installed in the unit or whether the components and equipment are delivered separately for external installation. The use of different types of flow meters or flow meters from different suppliers affects the mechanical design of the units as the dimensions of the flow meters vary. The most significant is the effect on the piping arrangement of the flow meter section of the unit. However, for the mechanical design, it is possible to modify the pipping arrangement according to the mechanical characteristics of the selected flow meter without major issues. In addition, the unit may include additional flow meters, which require additional space on the frame. In some cases, the flow meters may be delivered separately for external installation, in which case the flow meter section is replaced by the piping section. In those cases where the original flow meter is replaced with another flow meter, the flow meter installation and piping may have to be arranged outside the unit frame, as the flow meter may not fit in place of the original flow meter. Low- and high-tier products include data collection and monitoring equipment, including an HMI panel. As presented in Figure 15 of chapter 5.1, the installation space for electrical cabinets on the frame is limited. In the case of local installation, the inclusion of an additional electrical equipment affects the dimensions of the frame, probably increasing its length. In the case of external installation, no additional space is required on the frame. The compact mechanical design of the units is one of the key factors, as the installation spaces for the units on ships are quite limited. The inclusion of a low- or high-tier product affects the mechanical design. However, from the point of view of mechanical design, the inclusion of a low- or high-tier product in the current design of the units can be carried out without major issues.

From the point of view of electrical and automation design, the design is only slightly affected by the inclusion of field components and data collection and monitoring equipment. This is because the data collection and monitoring equipment are delivered as a ready-made package that can be included directly in the design. In terms of electrical and automation design, it matters whether the components and equipment are installed in the unit or whether the components and equipment are delivered separately for external installation. In the case of local installation of components and equipment, the power supply to the components and equipment is derived internally. All necessary outputs from the flow meters and field components are wired directly to the data collection and monitoring equipment. In the case of external installation of data collection and monitoring equipment, the power supply to the equipment is derived externally and all outputs from the components installed in the unit are wired to the local control cabinet and externally wired to the equipment. In the case of external installation of components and equipment, the power supply to the components and equipment as well as the wiring between the components and equipment must be carried out externally. From the point of view of electrical and automation design, the inclusion of a low- or high-tier product in the current design of the units can be carried out without issues.

From the points of view of process, mechanical, electrical, and automation design, the inclusion of the company`s own product in the current design of the units can be carried out without issues. In terms of process, mechanical, electrical, and automation design, the company`s own product is subject to the similar design-related characteristics as low- and high-tier products. The use of the company`s own product requires the inclusion of an additional electrical component in the local control cabinet. The additional component requires space inside the cabinet, but it is unlikely to increase the overall size of the cabinet. All necessary outputs are routed through the component to the data collection and monitoring equipment.

6.2. SWOT analyses

SWOT analysis is a planning framework that allows a company to evaluate its competitive position and develop strategic plans. In practise, the SWOT analysis allows the company to decide how and whether to proceed with the planned action by analysing and positioning the company’s resources and environment into four groups, which consist of internal and external factors. Internal controllable factors, including strengths and weaknesses, either support or prevent the company from achieving its goal. External uncontrollable factors, including opportunities and threats, either promote or limit the company from achieving its goal. In the SWOT analysis, the factors of each group are identified and combined into the SWOT matrix. Factors can then be analysed and compared within and between each group using the pair-wise comparison method to determine the importance of each factor. (Phadermrod et al. 2019.)

A traditional qualitative SWOT analysis of low- and high-tier products is conducted. The analysis begins by identifying the factors of each group and combining the factors into the SWOT matrix. Pair-wise comparisons are performed within and between each group to add quantitative properties to each factor. In practice, factors are prioritized. The SWOT matrix of low- and high-tier products is presented in Table 6.

Table 6. The SWOT matrix of low- and high-tier products.

Internal	Strengths	Weaknesses
	• Straightforward and instant implementation	• Product management, knowledge, and development • Product flexibility
External	Opportunities	Threats
	• Additional customer value • Additional advantage over competitors	• Product cost control • Product availability

The use of a low- or high-tier product allows straightforward and instant implementation of the equipment into the current design of the units. This enables the ability to respond to potential customer needs instantly. In addition, the products could provide additional value to the customer and assist ship owners and operators meet the requirements of CII. By including the products in the current design of the units, the company could gain an additional advantage over other fuel oil supply unit suppliers if a similar product is not included in the competitors` designs.

The use of low- or high-tier products means that product management, knowledge, and development become weaknesses as these factors are in the hands of an external supplier.

This causes problems for product management and development, as the company is unable to take the product in the direction it deems suitable. In addition, external product development affects internal product knowledge, as information related to product changes or new features may not be communicated smoothly. Customers may have different requirements and specifications regarding the type of flow measurement, which means that one standardized low- or high-tier product cannot be used for every application. The use of several different types of products for each different application instead of one standardized product for all applications creates an unnecessary load on product management. Of course, it is possible to discuss the type of flow measurement with the customer. Although it seems possible to combine one supplier`s data collection and monitoring equipment with another supplier`s flow meters and other field components, it is not recommended, as the data collection and monitoring equipment supplier cannot guarantee the functionality of the entire system. In addition, it may seem that using several different types of products for each different application creates product flexibility, but as mentioned above, using one standardized product for all applications is more practical. The use of low- or high-tier products means that the company is not able to effectively control product costs. The supplier of the product may increase the overall costs, making it more difficult for sales to provide feasible offers to the customer. In addition, as with all products, changing market conditions put pressure on product availability, which may make it difficult to maintain delivery schedules.

Although all factors are important, factors can be prioritized. Product management, knowledge, and development can be chosen as the most important factors, as these factors are key factors in enabling sustainable, profitable, and customer-oriented operations. These factors can be considered the basis of current and future operations. Product cost control can be chosen as the second most important factor, as this factor is a key factor in providing feasible offers and obtaining sales. Product availability can be chosen as the third most important factor, as despite the possible problems of maintaining delivery schedules, product availability can be solved with effective supply management. Straightforward and instant implementation can be chosen as the fourth most important factor, as it enables the ability to respond to customer needs instantly. Product flexibility can be chosen as the fifth most important factor, as even if the use of several different types of products for each different application is not practical, it can be implemented if necessary. Additional customer value and advantage over competitors can be chosen as the sixth and seventh most important factors, as although these factors are important, the product must first be feasible from the company`s point of view.

For comparison, a traditional qualitative SWOT analysis of the company´s own product is conducted. As with low- and high-tier products, the analysis begins by identifying the factors of each group, combining the factors into the SWOT matrix, and performing pair-wise comparisons within and between each group. The SWOT matrix of the company`s own product is presented in Table 7.

Table 7. The SWOT matrix of the company´s own product.

Internal	Strengths	Weaknesses
	• Product management, knowledge, and development • Product flexibility • Product cost control	• Product responsibility
External	Opportunities	Threats
	• Additional customer value • Additional advantage over competitors	• Product availability

The use of the company`s own product means that product management, knowledge, and development are in the hands of the company. Through product management and development, the company is able to take the product in the direction it deems suitable, and the company can use one standardized product with small modifications for each application, which provides product flexibility. In addition, the company has better control over the overall costs of the product, which means that sales can provide more feasible offers to the customer. However, the use of the company`s own product means that product responsibility is in the hands of the company. Guaranteeing the functionality of the product involves financial and customer satisfaction related risks, which the company must evaluate carefully. Therefore, the introduction of the company`s own product is not as straightforward as with low- or high-tier products.

As with low- and high-tier products, product management, knowledge, and development, and product cost control can be chosen as the most important and second most important factors. These factors enable sustainable, profitable, and customer-oriented operations. Product responsibility can be chosen as the third most important factor, as despite the financial and customer satisfaction related risks, these issues can be solved with effective product management and knowledge. With the same points of view as for low- and high-tier products, product availability, product flexibility, additional customer value, and additional advantage over competitors can be chosen as the fourth, fifth, sixth, and seventh most important factors.

7. Productization

Based on the equipment requirements, review, and technical feasibility study, a solution can be created for new build and retrofit sales purposes. While there are similarities between new build and retrofit projects, the delivery alternatives have slightly different characteristics. The purpose of this chapter is to present delivery alternatives for sales purposes. The chapter begins by presenting the characteristics and delivery alternatives of new build projects. The chapter ends by presenting the characteristics and delivery alternatives of retrofit projects.

7.1. New build

New build refers to a project or operation where the product is constructed according to the latest design principles and with the latest modern components. From the company`s point of view, new build refers to a project or operation where the entire fuel oil supply unit is designed, manufactured, and delivered in accordance with the customer`s requirements, the latest design principles, and the latest modern components. In new build projects, all variables related to design, manufacturing, or components can be considered at an early stage, meaning that changes or modifications to the design or components are unlikely to be required at a later stage. The inclusion of a low- or high-tier product or the company`s own product in new build projects can be implemented at an early stage. Low- and high-tier products, as well as the company`s own product, include different components that can be included in the delivery. In addition, there are alternatives for the installation location of the components. Table 8 presents the availability of components for each product as well as the installation location alternatives for the components for new build projects. The availability of components and installation location alternatives are based on the characteristics of the products and their inclusion methods, presented in chapters 5.2 and 6.1.

Table 8. Availability of components for each product and installation location alternatives for components for new build projects.

Availability L = Low-tier product H = High-tier product O = Own product	Location of installation I = Internal E = External W = Web	Note
Main component(s)		
Flow meter(s)	(L, H, O) (I, E)	Type and selection according to customer and process requirements. Included in unit or delivered separately for external installation.
Data collection and monitoring equipment (HMI)	(L, H, O) (I, E)	Included in unit if required or requested. Preferably delivered separately for external installation.
Web-based platform	(H, O) (W)	Included if required or requested.
Supplementary component(s)		
Viscosity sensor	(H, O) (I, E)	Can be considered a main component depending on the supplier of the product. Included in unit. Additional viscosity sensor(s) delivered separately for external installation if required or requested.
SPM	(H, O) (E)	Delivered separately for external installation if required or requested.
Other field component(s)	(O) (I, E)	Included in unit or delivered separately for external installation.

As presented in Table 8, the products consist of components with different installation location alternatives. For simplicity, the products can be divided into three delivery scope alternatives for new build projects as presented below.

1. Complete product or partially delivered product.
2. Data collection and monitoring equipment, including a web-based platform.
3. Individual component(s).

In the first alternative, where a complete product is delivered, the functionality of the entire system can be guaranteed, as compatibility between the equipment, components, and signals can be ensured. Flow meters and data collection and monitoring equipment are the basis of this alternative. The alternative can be supplemented with different components as presented in Table 8. In addition, it is possible to deliver the product partially, although it is not recommended from the point of view of low- and high-tier products. An example of such a case is that the customer delivers a specific component, for instance SPM, to be included in the system. In the case of a partially delivered product, the compatibility of the externally delivered components and their signals with the system must be ensured. In the second alternative, where data collection and monitoring equipment, including a web-based platform, is delivered, compatibility between the equipment and the externally delivered components and their signals must be ensured. Data collection and monitoring equipment, optionally including a web-based platform, are the basis of this alternative. In the third alternative, where individual component(s) are delivered, compatibility between the external system and the delivered components and their signals must be ensured.

7.2. Retrofit

Retrofit refers to a project or operation where the entire product, section of the product, or component of the product is modified or replaced with newer or modified parts. Retrofit also refers to projects or operations in which an entire product, section of a product, or component of a product is added to an existing system, or the original product of an existing system is modified for a new purpose. From the company`s point of view, retrofit refers to a project or operation where the entire fuel oil supply unit, section of the unit, or component of the unit is modified, replaced, or added to an existing system or an existing unit is modified for a new purpose. Generally, in retrofit projects, all variables related to design, manufacturing, or components have already been implemented, meaning that modifications or replacements almost always must be made to the original design and components. In addition, the retrofit project may concern a unit that was not designed or manufactured by the company, in which case modifications and replacements are certainly required. The inclusion of a low- or high-tier product or the company`s own product in retrofit projects can be implemented at a later stage with suitable design modifications and necessary component replacements or additions. As with new build projects, depending on the product, different components can be included in the delivery. In addition, there are alternatives for the installation location of the components. Table 9 presents the availability of components for each product as well as the installation location alternatives for the components for retrofit projects. The availability of components and installation location alternatives are based on the characteristics of the products and their inclusion methods, presented in chapters 5.2 and 6.1.

Table 9. Availability of components for each product and installation location alternatives for components for retrofit projects.

Availability L = Low-tier product H = High-tier product O = Own product	Location of installation I = Internal E = External W = Web	Note
Main component(s)		
Flow meter(s)	(L, H, O) (I, E)	Type and selection according to customer and process requirements. Replaced or added to unit or delivered separately for external installation if required or requested.
Data collection and monitoring equipment (HMI)	(L, H, O) (I, E)	Added to unit if required or requested. Preferably delivered separately for external installation.
Web-based platform	(H, O) (W)	Included if required or requested.
Supplementary component(s)		
SPM	(H, O) (E)	Delivered separately for external installation if required or requested

Viscosity sensor	(H, O) (I, E)	Can be considered a main component depending on the supplier of the product. Replaced or added to unit or delivered separately for external installation if required or requested.
Other field component(s)	(O) (I, E)	Added to unit or delivered separately for external installation.
Supplementary work related to unit or component modifications, replacements, or additions		
Design work	(L, H, O)	Design-related modifications, replacements, or additions related to unit or component modifications, replacements, or additions. (i.e., piping modification, wiring modification, etc.)
Manufacturing work	(L, H, O)	Included if required or requested for design-related modifications, replacements, or additions. (i.e., piping modules for flow meter replacements, etc.)
Other work	(L, H, O)	Included if required or requested. (i.e., installation work, commissioning work, etc.)

As with new build projects, the products can be divided into three delivery scope alternatives for retrofit projects as presented below.

1. Complete product or partially delivered product.
2. Data collection and monitoring equipment, including a web-based platform.
3. Individual component(s).

The delivery alternatives for retrofit projects follow the same principles as for new build projects. Despite the similarities, the most apparent difference between new build and retrofit projects is that retrofit delivery alternatives are almost always supplemented with supplementary work and components. For instance, in the case of a complete product or partially delivered product delivery alternative, outdated or incompatible original components such as flow meters may need to be replaced with newer compatible flow meters. If the flow meters are mechanically different from the original flow meters, the replacement may require mechanical design work and manufacturing work to produce the piping modules to be installed in the original installation location. The same applies to other component modifications, replacements, and additions. In addition, the partially delivered product alternative may quickly change to the alternative of delivering data collection and monitoring equipment, including a web-based platform, as the customer may want to use original components without component modifications, replacements, or additions. Individual components can be delivered separately or with supplementary work.

8. Conclusion

The attained annual operational CII calculation method set some essential and non-essential functions for the equipment. It was essential that the equipment include fuel oil consumption measuring equipment as well as data collection and monitoring equipment. As the requirement is to measure and monitor all fuel oil consumed, as required by DCS, it was essential that the equipment include a function to determine what type of fuel oil is consumed. It was also essential that the consumption data be expressed in mass as required by the attained annual operational CII calculation method. In addition, it was essential that the equipment include a function for determining the distance travelled in accordance with the requirements of DCS. The inclusion of fuel mass to CO_2 mass conversion factors to determine the mass of CO_2 emitted, a function for reporting individual voyages or the possibility for daily reporting, allowing the capacity to be modified for each individual voyages according to the actual or estimated mass or volume carried on board, necessary storage capacity for the collected data, and data transmission function were considered essential functions. Additional functions of the equipment related to other energy efficiency data collection and monitoring were considered non-essential functions, provided that the data is not required for the attained annual operational CII calculation process. The equipment were not necessarily required to perform the overall attained annual operational CII calculation, but to collect the data required for the calculation process. The inclusion of other fuels such as LNG and methanol as well as the inclusion of correction factors and voyage adjustments were ignored for the time being.

Based on the equipment review, it can be stated that both low- and high-tier products as well as the company`s own product meet the requirements. The equipment review showed that the products differ at the component level, but the main functions remain the same. The most significant difference between the products was that the high-tier products and the company`s own product include a web-based platform for more comprehensive monitoring purposes. During the process of this master`s thesis, it was found that CII can be considered as a continuum of the requirements of DCS. Since the requirements of DCS have been in force since 2018 and 2019 was the first reporting year, one would imagine that ship owners and operators already have a solution to meet the requirements of CII. In other words, the products may not provide a revolutionary new solution to assist ship owners and operators meet the requirements of CII. The most significant additional feature could be a web-based monitoring platform where ship owners can monitor DCS, CII, and other additional energy efficiency data at the individual ship or fleet level. In addition, since the products are intended to be incorporated into the current design of fuel oil supply units that supply fuel oils according to the ISO 8217 standard, the applicability of the products for projects with dual fuel engines requires further study, as the attained annual operational CII calculation includes all the fuel consumed on board. The company`s own product could be the most flexible to adapt to these projects. In conclusion, all products can be used to assist ship owners and operators meet the requirements of CII, but further studies on the actual need for the product and the applicability of the products for projects with dual fuel engines should be considered.

The applicability of the equipment to the current design of fuel oil supply units was studied from the points of view of different design departments. Based on the technical feasibility study, it can be stated that the inclusion of a low- or high-tier product as well as the company`s own product in the current design of the units can be carried out without major issues. Based on the SWOT analyses, it can be stated that the company`s own product provides more desired factors compared to low- and high-tier products. The use of the company`s own product keeps product management, knowledge, and development in the hands of the company, allowing the company to take the product in the direction it deems suitable. In addition, the company has better control over the overall costs of the product, and the company can use one standardized product with minor modifications for each application. However, guaranteeing the functionality of the product involves financial and customer satisfaction related risks, which the company must evaluate carefully. Therefore, the introduction of the company`s own product is not as straightforward as it would be with low- or high-tier products. In conclusion, incorporating the company`s own product into the current design of the units is more feasible. Since the SWOT factors presented in SWOT analyses are approached from the company`s point of view, ignoring the customer`s point of view, it is worth considering an IPA-based SWOT analysis of products to obtain customer-based SWOT factors.

Based on the equipment requirements, review, and technical feasibility study, delivery alternatives were created for new build and retrofit sales purposes. The availability of components for each product as well as the installation location alternatives for the components were presented for both projects. It was shown that both low- and high-tier products as well as the company`s own product can be divided into three delivery scope alternatives, including complete product or partially delivered product, data collection and monitoring equipment including a web-based platform, and individual component(s). The delivery alternatives for new build and retrofit projects followed the same principles, but the most apparent difference between the projects was that the retrofit delivery alternatives are almost always supplemented with supplementary work and components. It was shown that both low- and high-tier products as well as the company`s own product can be used for new build and retrofit sales purposes, but during the process of this master`s thesis, the company decided to proceed with the company`s own product.

9. Summary

In 2018, IMO introduced the initial GhG strategy with the aim of reducing emissions from international shipping compared to the 2008 baseline. The strategy aims for a 50 % reduction in annual GhG emissions by 2050 and a 40 % reduction in carbon intensity by 2030, and strives to achieve a 70 % reduction by 2050. As The Full Report of Fourth IMO GhG Study 2020 shows, although the carbon intensity of international shipping can still be improved, reaching the 2050 reduction targets with technical or operational measures alone will be difficult. Most of the reduction will come from the use of low-carbon and zero-carbon fuels. To reach the 2030 carbon intensity reduction target, IMO constructed short-term measures that entered into force in early 2023.

In 2021, CII was adopted. CII is an operational measure, measuring the transportation efficiency of a ship, and is calculated by dividing the total mass of CO_2 emitted by the total transportation work undertaken during the calendar year. The total mass of CO_2 emitted is calculated from the total consumption of different fuel types, including individual fuel mass to CO_2 mass conversion factors. The calculated total mass of CO_2 emitted is divided by the total distance travelled and the capacity of the ship to determine the attained annual operational CII. The collection and reporting of fuel oil consumption data follows the requirements and methods of DCS. Fuel oil consumption collection and monitoring methods include the use of BDNs, the use of flow meters, and monitoring of bunker fuel oil tanks on board.

In 2021, guidelines for the calculation of the attained annual operational CII were adopted. The guidelines outline the process for determining the attained annual operational CII and the verification process against the required annual operational CII to determine the ship`s CII rating from A to E for a specified year. In 2022, interim correction factors and voyage adjustments were adopted to determine the corrected attained annual operational CII. Despite CII`s intention to reduce carbon emissions, it has been pointed out that the adoption of CII measures could in some cases even increase carbon emissions. It is proposed that more advanced models and calculation methods utilizing real data should be developed to evaluate the functionality of CII measures and the possibility of forming a reformed CII.

This master`s thesis was carried out for a company that supplies fuel oil supply units for ships` fuel oil systems. As short-term measures, including CII, were known to enter into force, the company decided to productize the equipment to be incorporated into the current design of fuel oil supply units to assist ship owners and operators meet the requirements of CII. The objectives, of this master`s thesis, were to review the available equipment and to study the feasibility of the equipment from technical points of view to create a solution for sales purposes. This master`s thesis reviewed the available equipment, determined and described the functions of the equipment, studied the feasibility of the equipment from the points of view of different design departments, conducted SWOT analyses on the equipment, and created different delivery alternatives for new build and retrofit sales purposes.

Based on the equipment review, it was concluded that both low- and high-tier products as well as the company`s own product can be used to assist ship owners and operators to meet the requirements of CII, but further studies on the actual need for the product and the applicability of the products for projects with dual fuel engines should be considered. Based on the technical feasibility study, it was concluded that the inclusion of a low- or high-tier product as well as the company`s own product in the current design of the units can be carried out without major issues. Based on the SWOT analyses, it was concluded that the company`s own product provides more desired factors compared to low- and high-tier products, and the inclusion of the company`s own product in the current design of the units is more feasible. However, an IPA-based SWOT analysis of the products should be considered. Based on the equipment requirements, review, and technical feasibility study, delivery alternatives were created for new build and retrofit sales purposes. It was shown that both low- and high-tier products as well as the company`s own product can be used for new build and retrofit sales purposes. During the process of this master`s thesis, the company decided to proceed with the company`s own product.

References

Aquametro. 2020. Fuel Performance System 2.0 (FPS). Performance Monitoring. [Brochure]. [Accessed 19.5.2023]. Available Online: https://www.aquametro-oil-marine.com/files/aquametro/downloads/7300e_fps.pdf

Aquametro. 2018. Fuel Performance System (FPS). Fuel Monitoring Ship / Fleet Management / Fuel Efficiency / CO_2 Reporting (MRV). [Website]. [Accessed 19.5.2023]. Available Online: https://www.aquametro-oil-marine.com/en/products/fuel-performance-system-fps.html

Basu, S. 2019. Plant flow measurement and control handbook: fluid, solid, slurry and multiphase flow. London, United Kingdom: Academic Press.

Basu, S. and Debnath, A. K. 2019. Power Plant Instrumentation and Control Handbook - A Guide to Thermal Power Plants. 2nd Edition. Elsevier.

Boyes, W. 2010. Instrumentation Reference Book. 4th Edition. [Online]. Oxford: Elsevier.

Chu Van, T. et al. 2019. Global impacts of recent IMO regulations on marine fuel oil refining processes and ship emissions. Transportation research. Part D, Transport and environment. [Online]. 70123-134. Elsevier.

DNV. 2022. MEPC 78 in Focus - EEXI, CII, SEEMP ready for implementation. [Webinar]. [Accessed 16.6.2022]. Available Online: https://www.dnv.com/maritime/webinars-and-videos/on-demand-webinars/MEPC-78-in-focus.html

DNV. 2021a. CII - Carbon Intensity Indicator. Overview of the Carbon Intensity Indicator (CII). [Website]. [Accessed 27.1.2022]. Available Online: https://www.dnv.com/maritime/insights/topics/CII-carbon-intensity-indicator/index.html

DNV. 2021b. CII - Carbon Intensity Indicator. Implementation of the CII. [Website]. [Accessed 27.1.2022]. Available Online: https://www.dnv.com/maritime/insights/topics/CII-carbon-intensity-indicator/implementation.html

DNV. 2021c. EEXI - Energy Efficiency Existing Ship Index. EEXI overview. [Website]. [Accessed 9.2.2022]. Available Online: https://www.dnv.com/maritime/insights/topics/eexi/index.html

DNV. 2021d. EEXI - Energy Efficiency Existing Ship Index. EEXI implementation. [Website]. [Accessed 9.2.2022]. Available Online: https://www.dnv.com/maritime/insights/topics/eexi/implementation.html

DNV. 2020. EEXI - Energy Efficiency Existing Ship Index. EEXI calculation. [Website]. [Accessed 19.4.2022]. Available Online: https://www.dnv.com/maritime/insights/topics/eexi/calculation.html

Emerson. 2019. Aperio Software. [Website]. [Accessed 19.5.2023]. Available Online: https://www.emerson.com/en-us/catalog/damcos-aperio-software

Emerson. 2018. Peace of Mind - Compliance Today and Tomorrow. Introducing the Aperio Vessel Emission Reporting Solution from Emerson. [Flyer]. [Accessed 19.5.2023]. Available Online: https://www.emerson.com/documents/automation/flyer-emerson-mrv-solution-aperio-en-1599506.pdf

IEA. 2021. International Shipping. Tracking report - November 2021. [Report]. [Accessed 15.3.2022]. Available Online: https://www.iea.org/reports/international-shipping

IMO. 2022. Consideration of the report to MEPC 78. Report of the 12th meeting of the Intersessional Working Group on Reduction of GHG Emissions from Ships (ISWG-GHG 12). [Report]. [Accessed 4.5.2023]. Available Online: https://www.imokorea.org/upfiles/board/44.%20GHG%2012%C2%F7%20%B0%E1%B0%FA%BA%B8%B0%ED%BC%AD%28%BF%B5%BE%EE%29.pdf

IMO. 2021a. Cutting GHG emissions from shipping - 10 years of mandatory rules. [Press Release]. [Accessed 17.3.2022]. Available Online: https://www.imo.org/en/MediaCentre/PressBriefings/pages/DecadeOfGHGAction.aspx

IMO. 2021b. International Convention for the Prevention of Pollution from Ships (MARPOL). [Website]. [Accessed 16.2.2022]. Available Online: https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx

IMO. 2021c. Prevention of Air Pollution from Ships. [Website]. [Accessed 16.2.2022]. Available Online: https://www.imo.org/en/OurWork/Environment/Pages/Air-Pollution.aspx

IMO. 2021d. Energy Efficiency Measures. [Website]. [Accessed 28.1.2022]. Available Online: https://www.imo.org/en/OurWork/Environment/Pages/Technical-and-Operational-Measures.aspx

IMO. 2021e. Marine Environment Protection Committee (MEPC 76), 10 to 17 June 2021 (remote session). [Press Release]. [Accessed 13.2.2022]. Available Online: https://www.imo.org/en/MediaCe While the EEXI is a one-time certification targeting design parameters, the CII addresses the actual emissions in operation.ntre/MeetingSummaries/Pages/MEPC76meetingsummary.aspx

IMO. 2021f. Fourth Imo GhG Study 2020. Full Report. [Report]. [Accessed 30.10.2022]. Available Online: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%202020%20-%20Full%20report%20and%20annexes.pdf

IMO. 2020a. Data collection system for fuel oil consumption of ships. [Website]. [Accessed 28.1.2022]. Available Online: https://www.imo.org/en/OurWork/Environment/Pages/Data-Collection-System.aspx

IMO. 2020b. Marine Environment Protection Committee (MEPC). [Press Release]. [Accessed 16.2.2022]. Available Online: https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MEPC-default.aspx

IMO. 2015a. Introduction to IMO. [Website]. [Accessed 27.1.2022]. Available Online: https://www.imo.org/en/About/Pages/Default.aspx

IMO. 2015b. Module 2: Ship Energy Efficiency Regulations and Related Guidelines. [Presentation]. [Accessed 30.1.2022]. Available Online: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/M2%20Energy%20Efficiency%20Regulations%20-%20IMO%20TTT%20course%20presentation%20final1.pdf

Kampichler, G., Bülte, H., Koch, F. and Heim, K. 2010. Industrial and Marine Engines. Mollenhauer, K. and Tschöke, H. 2010. Handbook of Diesel Engines. [Online]. Berlin, Heidelberg: Springer Berlin Heidelberg.

Latarche, M. 2021. Pounder's marine diesel engines and gas turbines. 10th Edition. Oxford, England: Butterworth-Heinemann.

MAN. 2021. MAN B&W G70ME-C10.5 Project Guide. [Document]. [Accessed 2.8.2022]. Available Online: https://man-es.com/applications/projectguides/2stroke/content/printed/G70ME-C10_5.pdf

MEPC. 2022a. Annex 15. Resolution MEPC.353(78). 2022 Guidelines on the Reference Lines for Use with Operational Carbon Intensity Indicators (CII Reference Lines Guidelines, G2). [Document]. [Accessed 12.10.2022]. Available Online: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.353(78).pdf

MEPC. 2022b. Annex 16. Resolution MEPC.354(78). 2022 Guidelines on the Operational Carbon Intensity Rating of Ships (CII Rating Guidelines, G4). [Document]. [Accessed 12.10.2022]. Available Online: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.354(78).pdf

MEPC. 2022c. Annex 17. Resolution MEPC.355(78). 2022 Interim Guidelines on Correction Factors and Voyage Adjustments for CII Calculations (CII Guidelines, G5). [Document]. [Accessed 17.10.2022]. Available Online: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.355(78).pdf

MEPC. 2021a. Annex 1. Resolution MEPC.328(76). Amendments to the Annex of the Protocol of 1997 to Amend the International Convention for the Prevention of Pollution from Ships, 1973, as Modified by the Protocol of 1978 Relating Thereto. 2021 Revised MARPOL Annex VI. [Document]. [Accessed 13.2.2022]. Available Online: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.328(76).pdf

MEPC. 2021b. Annex 10. Resolution MEPC.336(76). 2021 Guidelines on Operational Carbon Intensity Indicators and the Calculation Methods (CII Guidelines, G1). [Document]. [Accessed 21.3.2022]. Available Online: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.336(76).pdf

MEPC. 2021c. Annex 11. Resolution MEPC.337(76). 2021 Guidelines on the Reference Lines for Use with Operational Carbon Intensity Indicators (CII Reference Lines Guidelines, G2). [Document]. [Accessed 10.5.2022]. Available Online: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.337(76).pdf

MEPC. 2021d. Annex 12. Resolution MEPC.338(76). 2021 Guidelines on the Operational Carbon Intensity Reduction Factors Relative to Reference Lines (CII Reduction Factors Guidelines, G3). [Document]. [Accessed 10.5.2022]. Available Online: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.338(76).pdf

MEPC. 2021e. Annex 13. Resolution MEPC.339(76). 2021 Guidelines on the Operational Carbon Intensity Rating of Ships (CII Rating Guidelines, G4). [Document]. [Accessed 10.5.2022]. Available Online: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.339(76).pdf

MEPC. 2019. Annex 5. Resolution MEPC.308(73). 2018 Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index (EEDI) for New Ships. [Document]. [Accessed 8.5.2022]. Available Online: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.308(73).pdf

MEPC. 2016a. Annex 10. Resolution MEPC.282(70). 2016 Guidelines for the Development of a Ship Energy Efficiency System Plan (SEEMP). [Document]. [Accessed 24.3.2022]. Available Online: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.282(70).pdf

MEPC. 2016b. Annex 3. Resolution MEPC.278(70). Amendments to the Annex of the Protocol of 1997 to Amend the International Convention for the Prevention of Pollution from Ships, 1973, as Modified by the Protocol of 1978 Relating Thereto. Amendments to MARPOL Annex VI. Data collection system for fuel oil consumption of ships. [Document]. [Accessed 13.2.2022]. Available Online: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/278(70).pdf

MEPC. 2011. Resolution MEPC.203(62). Amendments to the Annex of the Protocol of 1997 to Amend the International Convention for the Prevention of Pollution from Ships, 1973, as Modified by the Protocol of 1978 Relating Thereto. Inclusion of regulations on energy efficiency for ships in MARPOL Annex VI. [Document]. [Accessed 13.2.2022]. Available Online: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.203(62).pdf

O`Banion, T. 2013. Coriolis: The Direct Approach to Mass Flow Measurement. Emerson Process Management, Micro Motion Div. [Article]. [Accessed 7.9.2022]. Available Online: https://www.emerson.com/documents/automation/article-direct-approach-to-mass-flow-measurement-micro-motion-en-64236.pdf

Phadermrod, B. et al. 2019. Importance-Performance Analysis based SWOT analysis. International journal of information management. [Online]. 44194-203. Elsevier.

Spitzer, D. W. 2005. Industrial Flow Measurement. 3rd Edition. International Society of Automation (ISA).

UNCTAD. 2021. Review of Maritime Transport. [Report]. [Accessed 15.3.2022]. Available Online: https://unctad.org/system/files/official-document/rmt2021_en_0.pdf

VAF. 2021. Technical Manual. 667. PEM4+SPU3 System. For T-Sense, TT-Sense and PT2 Flowmeters. [Manual]. [Accessed 19.5.2023]. Available Online: https://www.vaf.nl/media/1446/tib-667-gb-1121-pem4spu3.pdf?type=Manual

VAF. 2017. IVY. [Website]. [Accessed 19.5.2023]. Available Online: https://www.vaf.nl/products-solutions/overview/ivy-propulsion-performance-management/

Vermeire, M. B. 2021. Everything you need to know about marine fuels. Chevron. [Publication]. [Accessed 23.2.2022]. Available Online: https://www.chevronmarineproducts.com/content/dam/chevron-marine/fuels-brochure/Chevron_Everything%20You%20Need%20To%20Know%20About%20Marine%20Fuels_v8-21_DESKTOP.pdf

Wang, S., Psarafitis, H. N. and Qi, J. 2021. Paradox of international maritime organization's carbon intensity indicator. Communications in Transportation Research. Vol. 1. 2021. 10005. Elsevier Ltd on behalf of Tsinghua University Press. [Article]. [Accessed 18.10.2022]. Available Online: https://www.sciencedirect.com/science/article/pii/S2772424721000056#section-cited-by

Wang, T. and Baker, R. 2014. Coriolis flowmeters: a review of developments over the past 20 years, and an assessment of the state of the art and likely future directions. Flow measurement and instrumentation. [Online]. 4099-123. Elsevier.

Wärtsilä. 2021. Wärtsilä 32 Product Guide. [Document]. [Accessed 2.8.2022]. Available Online: https://www.wartsila.com/docs/default-source/product-files/engines/ms-engine/product-guide-o-e-w32.pdf?utm_source=engines&utm_medium=dieselengines&utm_term=w32&utm_content=productguide&utm_campaign=msleadscoring

Wärtsilä. 2017. LNG as a marine fuel boosts profitability while ensuring compliance. Business White Paper. [Publication]. [Accessed 11.5.2023]. Available Online: https://cdn.wartsila.com/docs/default-source/services-documents/white-papers/wartsila---bwp-lng-as-a-marine-fuel-boosts-profitability-while-ensuring-compliance.pdf?sfvrsn=26f78b45_10

Wärtsilä. 2016. Encyclopedia of Marine and Energy Technology. [Website]. [Accessed 7.5.2022]. Available Online: https://www.wartsila.com/encyclopedia/term/bunker-delivery-note-(bdn)