View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Elsevier - Publisher Connector

Ocean Engineering 109 (2015) 103–112

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

A decision making tool concerning retrofit of shaft generator frequency converter

Halvor Schøyen [*,a], Hussein Sow [b,1]

[a] Buskerud and Vestfold University College, Box 235, N-3603 Kongsberg, Norway
[b] Wagle Chartering AS, Box 230, N-1501 Moss, Norway

ARTICLE INFO

Article history:
Received 8 December 2014
Accepted 1 September 2015
Available online 24 September 2015

Keywords:
Retrofit
Decision making
Fuel saving
Shaft generator
Risk identification

ABSTRACT

This paper considers the area of fuel saving through retrofitting shaft generator frequency converter during a vessel operational phase. This retrofit enables the vessel to slow steam with the shaft generator engaged to the main switch board and still maintaining the proper voltage and frequency. An exploratory case study approach is adopted, to achieve an empirically anchored theoretical insight. By considering the trade-off between a cost-benefit analysis and risk area identification a theoretical framework for decision making of the retrofit is proposed. Data is collected from ship-owners and machinery system suppliers. This study shows: (1) In the case of the multipurpose dry bulk ship, the fuel price is demonstrated to have the strongest impact on profitability, (2) the importance of the cost of retrofitting the system appears to be more significant in the short-term, compared to the long-term perspective, (3) eight risk areas that have an impact on the retrofit profitability are identified and mapped in a risk matrix from acceptable to intolerable, and (4) it is revealed that liner operators - in opposite to ship owners – are the most common customers of the shaft generator conversion.

© 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

This paper addresses the topic of vessel retrofitting with the purpose of saving fuel. Since retrofitting possibilities are numerous, the paper will zero in on one specific type, i.e. shaft generator frequency conversion (SGFC). This retrofit enables ship operators to slow steam with the shaft generator engaged to the main switch board and still maintaining the proper voltage and frequency. Because SGFC technology has existed for decades and is a common energy-saving practice (Basurko et al., 2013), it is not widely considered to be revolutionary. Nonetheless, technological advances have undoubtedly modernized it, bringing it up to standards with the latest technologies. This study investigates the extent to which fuel costs can be reduced by retrofitting with SGFC, and informs on the decision-making process to conduct such vessel upgrading. There are three research questions:

1. To answer this question, a cost benefit analysis (CBA) of a one-vessel case will be performed.
2. What are the main risks areas related to retrofitting with SGFC?
3. What is the nature of most customers of SGFC technology, and what are their common commercial attributes?

To answer these three questions, the experiences of a ship manager, an engine manufacturer and a supplier with the SGFC retrofit are collected and analysed.

Section 2 presents the theoretical framework. Section 3 describes the research method, while Section 4 illustrates the results from the cost benefit assessments, along with those from the risk identification of main threats and those pertaining to the main customers. The findings are discussed in Section 5. Finally, Section 6 presents the conclusions along with recommendations for further research.

2. Theoretical framework

2.1. Shaft generators in four-stroke engine ships with controllable pitch propellers (CPP)

Throughout the latest decades, electrical power demand for vessels has grown significantly, the reason behind this being the development of electrical facilities on board. Consequently, the fuel consumption has also grown. In pursuance of lower fuel costs, installing shaft generators became a practical solution (Xiaoyan et al., 2009). Shaft generators (S/G) are driven by the main engine

---

[*] Corresponding author. Tel.: +47 31009411.
E-mail addresses: hs@hbv.no (H. Schøyen), sowhussein@hotmail.com (H. Sow).
[1] Tel.: +47 97744164.

http://dx.doi.org/10.1016/j.oceaneng.2015.09.003
0029-8018/© 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

(Dokkum, 2011), and have the capacity to supply the ship with electricity (Prousalidis et al., 2005). However, many large actors in the field of marine propulsion manufacturing point out that diesel engines running at constant-RPM to drive shaft generators without frequency converters are operated inefficiently at part load, based upon the fact that, when slow steaming at reduced vessel speed and engine load, an above optimal engine RPM is required (Rolls-Royce, 2010; Sam-Electronics, 2010). The problem lies in the fact that ships' consumers require constant frequency, which is only possible when the S/G is run at constant RPM. The efficiencies of the CPP propeller and M/E are diminished when the load is reduced as the ship is then operated off-design (Stoye, 2011). Thus, by installing a frequency converter, the M/E will run at various RPMs instead of at constant RPM, while simultaneously adjusting the propeller pitch. As a result, fuel savings are enabled at various vessel speeds through the efficient operation of the M/E and S/G in combinator mode, which are optimal combinations of RPM and pitch (Stoye, 2011). The fuel savings deriving from combinator mode are between 7 and 10%, depending on the case (Casal and Würzburg, 2014). The deciding factor seems to be the operational speed of the vessel.

2.2. *Retrofitting of SGFC for M/E fuel savings*

The interest of vessel retrofitting has grown considerably in the past few years, in light of higher fuel costs and environmental restrictions. Lassesson and Andersson (2009), together with Armstrong (2013), point out both technical and operational measures, which can result in fuel savings and lower emissions to air. These include, among others, M/E performance optimization. Baldi and Gabrielii (2015) acknowledge the impact of ship operational profile on vessel power requirement, and find out that two or three operational speeds can be suitable in a techno-economic analysis for ships operating according to fixed sailing schedules. Solla et al. (2012) describe the retrofit of a new variable frequency drive technology called the Shymgen system on a fishing vessel, and compare the results post-retrofit, with the initial evaluation of the retrofit project: The Shymgen system generated a 10 % reduction in fuel consumption, which was in line with their initial forecast. In Fig. 1, the S/G generates electric energy that is transmitted to the frequency converter (FC). The FC corrects the frequency of the electricity, which is then distributed via the switchboard to electric consumers.

Lyridis et al. (2005) deal with a cost-benefit analysis of the installation of new advanced automation technology, which optimizes maritime operational safety on board the icebreaker *Frej*. The authors concluded that the investment was worthwhile, the major part of the savings coming from decreased crewing expenses instead of from reduced fuel consumption. In order to build their analysis, Lyridis et al. (2005) make use of the payback period method, a limitation of which is that it does not take into consideration the time value of money.

2.3. *Cost benefit analysis of the retrofit*

NPV is a measure used to determine the profitability of an investment by looking at the sum of all discounted cash flows coming from the project (Berk and Demarzo, 2013). The NPV represents the equivalent of what one would be endowed with today, if one chose to undertake the investment. Below is the standard NPV formula

$$NPV = \; -C_{0+}\sum_{i=1}^{T}\frac{CF_i}{(1+r)^i}$$

CF is a term that stands for the net cash inflow in period i, and $-C_o$ is the initial investment for the project. The investment's discount rate is denoted r, which is used to discount CF_i. CF_i represents the opportunity cost that the company could invest elsewhere. The NPV investment rule states that the firm should undertake the project if the NPV is positive (Berk and Demarzo, 2013).

2.4. *The relevance of risk identification for a successful retrofit*

The level of success in a retrofit project is linked to the management of risks. Risk identification is considered as one of the most important steps of risk management (Barati and Mohammadi, 2008; Rolstadås, 2008). The company should focus on answering the questions of whether the expected benefits justify the risk of failure, and how the possibilities of failing can be mitigated in a cost effective fashion. Further, Lozier (2010)

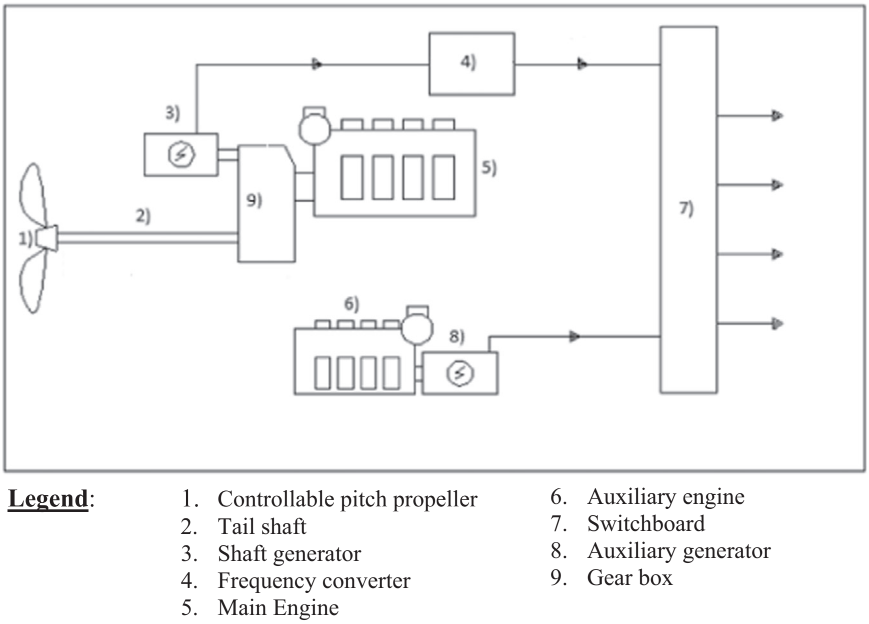


Fig. 1. Illustration of a SGFC arrangement.

develops a framework for identifying and handling risks in companies' quality management systems; the same framework is applied in this paper. As the emphasis is placed on mapping out the key risks, a risk matrix tool (Lozier, 2010) will be used in Section 4 to present risks, along with the severity and probability of their impact.

2.5. Outsourcing management to third parties in shipping

The last decades have seen a rise in outsourcing, often termed "third party ship management" (Panayides and Cullinane, 2002; Mitroussi, 2004); the responsibilities that are referred to in this definition can vary widely, from ship management (encompassing crewing and technical management), to other services such as insurance, chartering, freight management, sale and purchase (Asuquo et al., 2014). In relation to the potential fuel savings derived from SGFC, it must be highlighted that frequently the time charterer (TC) of a vessel is responsible for paying the ship's fuel, depending on the speed and consumption clauses in the TC agreement. As a result, both ship-owners and time charterers, also known as disponent owners, may have incentives in retrofitting their ships: They will then be able to reduce fuel costs, which often constitute the lion's share of voyage costs (Notteboom and Vernimmen, 2009).

3. Methodology and data

3.1. Exploratory case study design

The research design adopted here is the exploratory case study method (Mabry, 2008; Yin, 2009), a choice derived from the need to investigate the contemporary phenomenon of retrofitting for fuel savings and to ascertain whether ship-owners who had retrofitted ships in their fleet could confirm the benefits over the cost. As regards the selection of informants among ship managers, the purposive sampling method was chosen. The motive behind this decision is first and foremost the fact that a majority of ships in the world fleet run with fixed pitch propellers; thus, a probabilistic sampling method would yield results of little relevance to the study, as the fuel savings are only possible on ships endowed with CPPs. Secondly, an additional requirement of the variable frequency drive system was that the ship must be fitted with a shaft generator, which is not the case for many vessels. Therefore, a purposive sampling method was necessary. In addition, it is a well-known fact that ship-owners, and companies belonging to the maritime industry, are generally conservative when it comes to sharing information. This constitutes a certain barrier in getting many parties to participate in this project.

3.2. Ship data for the case

For the purpose of the first research question, one Norwegian ship-owner that possesses a fleet of multipurpose dry bulk (MPP) ships supplied the case vessel's necessary technical specifications, as well as a "Time charter description" that reveals critical information for the calculation of the potential benefits of the SGFC solution, such as M/E power; S/G power; speed and consumption; CPP. For the sake of the cost benefit assessment, the chosen vessel is the MPP "M/V Oslo Bulk 6", with the main particulars as depicted in Table 1.

The fuel consumption shown in Table 1 is estimated for good weather conditions, defined as wind force maximum Force 3 in Beaufort scale and sea-state 2 in Douglas scale.

Table 1
Vessel particulars "MV Oslo Bulk 6". Sources: Oslobulk (2015) and DNV GL (2015).

Flag/Nationality	Singapore
Year of build	2011
Builder	Jiangsu Yangzijiang Shipbuilding Co., Ltd.
Class and notation	DNV GL. 100 A5 E Multi-Purpose Dry Cargo Ship, BWM, Equipped for carriage of containers, DBC, DG, G, Strengthened for heavy cargo
Loa	108.18 m
Beam	18.19 m
Summer draft	7.057 m
Corresponding deadweight	8036.9 mt
Cruising speed	12.0 knots
Corresponding daily fuel consumption	13 mt (IFO 380 cSt)
Main diesel engine	1 × 2998 kW mAK 6M32C
Auxiliary engines	2 × 365 kW mAN D2876
Shaft generator	360 kW, 450 kVA, 60 Hz
Cargo handling	Geared, 2 deck cranes

3.3. Procedure and assumptions to estimate fuel savings

Data related to the vessel's operational profile, i.e. "arrival reports", "departure reports" and "daily reports" , which the ship sends on a regular basis to the management on-shore, were collected for a duration of about 3 months. From this material, in line with Baldi and Gabrielii (2015), we identify two common operational speeds when the ship was underway in situations of fair weather conditions, which serve as operational points and will be crucial inputs to determine the combinatory mode fuel savings. These speeds – 11.0 and 11.5 knots – are taken as the basis for the calculation of the saving potential. Appendix C contains a common daily report in a situation stated by the Captain to be wind Force 3 (gentle breeze) and sea-state 3 (slight): which are fair weather condition, and this vessel experienced negligible involuntary speed reduction (Prpić-Oršić and Faltinsen, 2012).

The calculation of yearly consumption is based on the assumptions that the vessel operates 280 sailing days a year, and consumes 11.5 mt per day. We assume the shaft generator is always operated whilst at sea both before and after the retrofitting of the SGFC. The saving potential presented in this paper assumes a constant ratio of shaft generator running time/auxiliary engines running time, during voyage, before and after the retrofit. Hence, energy pattern for the auxiliary engines is not affected by the retrofit (ceteris paribus), and all fuel savings presented in this paper are for the M/E through the efficient operation of the M/E and S/G in combinator mode. The vessel's general arrangement plan was also collected in order to evaluate spaces where the frequency converter could be installed. The following step was to convey the vessel data to Vicusdt, a specialized R&D maritime company (Solla et al., 2012) who assisted in quoting a representative price for the SGFC retrofit and making an estimate of benefits relating to installing the Shymgen system, including fuel savings. Since the retrofit can be performed while the ship is operating, there will be no off-hire costs, nor service costs related to installing the system. In addition, there are no maintenance costs related to the variable frequency drive; this point will be elaborated further in the risk identification assessment.

3.4. Considerations on fuel price volatility, remaining ship lifetime and discount rate impact on benefits and costs

The assumption for the average fuel price received from the ship-owner is $850 per tonne, which equals €614 (as per April 2014 exchange rate). Furthermore, it is assumed that the vessel will have an expected life span of 25 years. Thus, $i = 21$ as there are

22 periods left from the current age (as of year 2014) of the ship amounting to 3 years. Considering the discount rate, the underlying assumption was made that retrofitting the project is paid in cash; in other words, there are no annual installment costs. The discount rate for this NPV calculation is 7.04%, obtained from Damodaran (2014). In the context of this project, the fuel cost savings represent the opportunity cost. We are looking at scenarios where the fuel price, the discount rate and the system cost may vary from a 50% reduction up to a 100% increase. In this context, the project's NPV was calculated against a percentage change in either variable, holding the remaining ones constant. Freight market volatility is synonymous with the need to modify time perspectives, which means switching from long-term to short-term time horizon. To emphasize the impact of the time horizon, a sensitivity analysis is carried out for two scenarios: The first case will be considered as the long-term perspective (21 years remaining lifetime of the ship), while the second one will depict the short-term horizon (5 year).

3.5. *Data collection on the major risks involved in the retrofit*

The data for answering research questions 2 and 3 was collected in the above stated contacts with the ship-owner, the ship manager and the engine and equipment suppliers. Rowley (1989) and Chapman (2001) emphasize the importance of identifying threats in risk identification; Barati and Mohammadi (2008) elaborate that interviews are an efficient way of gaining first-hand knowledge about benefits and other relevant knowledge pertaining to past projects. Therefore, an extensive interview with a Swedish technical ship manager who had already retrofitted his vessels with SGFC was conducted. The purpose was to reduce the knowledge gap concerning the major risks involved. Moreover, interviews with staff of the sales department at a Danish engine manufacturer and supplier were conducted for the aim of risk identification, with the intention of getting them to share their experiences with such power retrofit. The key risks which were extrapolated from the interviews were based on two retrofitted roll-on/roll-off (Ro–Ro) vessels. An important aspect related to risk is that the customers seek to minimize negative externalities related to this type of installation: If the fuel consumption diminishes, but the maintenance costs increase, the investment’s profitability will then decrease. As there is little public knowledge about the main risks involved with this kind of retrofit, the questions were open-ended, which enabled the gathering of relevant data. The interviews, of a semi-structured nature, contained a standard set of questions key to the task at hand. Prior to the interviews, a set of questions was developed in conjunction with a literature search surrounding variable frequency drive technology. Since the technical manager, from the buyer's perspective, was the party in charge of the retrofit project, his potential concerns were also taken into consideration.

With respect to language, despite the fact that the respondents were all from Scandinavian countries where the languages as a rule are mutually intelligible, it was decided to write and conduct the interview in English: communicating in the same language increases the findings' credibility, as it reduces ambiguities related to language interpretation (Bryman, 2012). The results from the interviews were captured through note-taking and audio recording. In the course of the analysis of the findings, because it was discovered that some points were unclear, further questions needed to be asked in order to achieve complete clarity. This was done through the e-mail, and also through the use of Skype. After the risks were identified, follow-up questions for a risk assessment were asked to the same respondents in order to rank them according to their importance in terms of economic consequence. For this purpose, a risk severity scale from 1 to 4 was created, where 1: Negligible; 2: Marginal; 3: Critical; and 4: Catastrophic, see Appendix B.

3.6. *Consideration on validity and reliability*

Data triangulation (Denzin and Lincoln, 1994) was particularly important in this exploratory case study research, as the limited sample size makes it more imperative to cross-check any information with other sources, to discover whether an occurrence can be regarded as common to all adherents to this retrofit solution. Therefore, the results from the interview with the engine manufacturer and the ship technical manager were communicated to the FC supplier. Despite the fact that the FC supplier and the engine manufacturer deliver a different solution, there are similarities in the technologies they employ, and they both have the same purpose: reducing fuel consumption through the installation of variable frequency drive. Any similarities in their work packages, be it how the work is performed or the use of materials, are therefore significant in terms of risks. Data triangulation was effected mainly through Skype communication. The evidence collected in this way was compared across the interviews by the authors, who did not detect any major difference with regard to the interviewee's perception of the costs, benefits, risks and nature of customers in respect of SGFC retrofits. The answers received in the interviews did not differ significantly from the information obtained from secondary sources. Issues on data quality and data analysis were discussed between the authors and research colleagues, reaching ultimately a common understanding of the interpretation of the data and contributing to investigator triangulation.

4. Limitations

Exploratory case studies are usually accompanied by some limitations. A warning should be expressed here as to the potential limitation of the selected research design and data collection, which may not lend itself to generalization of the magnitude of fuel savings due to SGFC retrofit, as the sample size of one ship during three months of operation is not representative of the world fleet, or of a specific ship type or trade (Baldi and Gabrielii, 2015). The fundamental driving forces behind energy efficiency and fuel savings relate to international and national markets and cost behavior in maritime logistics. Hence, market conditions, including bargaining power as well as physical fundamentals, are important factors behind ship capacity utilization and choice of vessel speed. Speed decisions are dependent on fuel price, cargo inventory costs and surrounding factors, e.g. weather and port congestion, among other factors. Therefore, the estimated fuel savings for “M/V Oslo Bulk 6” presented in this study could be different if the same ship was subject to different trading circumstances. Moreover, an important question in this research was the credibility of the FC supplier’s quotation (Vicusdt, 2014), particularly about the estimated reduced fuel consumption. Vicusdt was the only company to have published a paper (Solla et al., 2012) about their variable frequency drive solution, which strengthens their credibility, as the Shymgen system has been presented to relevant stakeholders in the industry. These include, among others, project partners and classification societies. On these grounds, it was decided to base the cost calculations on the quotation from that company. Nevertheless, the theoretical framework developed in this exploratory case study will be valuable for ship-owners and charterers who need to evaluate energy-saving alternatives and make decisions on improving their fleet’s performance with respect to fuel use.

Table 2
Cost of SGFC on the multipurpose bulk ship.

Cost element	Price (€)
Converter	51,875
Installation	9100
Cabling	8250
Steel works	11,250
Consumables	4219
Others	14,844
Commissioning and start up	32,000
Total	131,538

Adapted from (Vicusdt, 2014).

Table 3
M/E annual fuel savings of retrofit on multipurpose bulk ship.

	Prior retrofit	Retrofit condition 1 (11.5 knots)	Retrofit condition 2 (11 knots)
Fuel consumption p/y (mt)	3220	3156	3123
Fuel reduction (mt)	0	64.4	96.6
Fuel consumption p/y (€)	1,978,026	1,938,526	1,918,745
Fuel cost reduction (€)	0	39,500	59,281
Fuel cost reduction (%)	0	2	3

Adapted from Vicusdt (2014).

5. Results

5.1. Cost benefit analysis

Table 2 represents the typical costs related to installing the frequency converter on board.

Table 2 informs that $C_o = 131{,}538$€.

With respect to sea trials, since they are performed while the ship is operated in normal conditions, minor costs can arise in relation to technicians' transportation arrangements. This is because they must remain on board the vessel for the duration of the test period; nonetheless, this cost will be incorporated in the “other categories”. Other items under “others” would be expenses for the classification society and other subcontracted work, possible need for modifications on the generators as well as a contingency margin. It should be noted that costs may vary from case to case, due to change in prices for components, labor, location of deliveries and installation, and so on.

Table 3 shows the estimated M/E fuel savings of installing the new technology, due to combinator mode savings.

Table 3's “Prior retrofit” column represents the vessel in the initial state. “Retrofit condition 1” and “Retrofit condition 2” illustrate the situation where the MPP is retrofitted, which then creates two possibilities for the extent of the M/E fuel savings. When steaming at 11.5 knots, which is 0.5 knots slower than the cruising speed as depicted in Table 1, the vessel's – estimated gain after retrofitting is 2% on fuel consumption due to M/E operating in combinator mode. Whenever the vessel sails at 11 knots, it is estimated that the M/E makes a slightly higher gain of a 3% reduction. Possibly additional M/E fuel savings due to vessel slow steaming come in addition to the savings presented in Table 3. As the ship's common speeds in fair weather conditions may vary between 11 and 11.5 knots, the average of the fuel consumption in both scenarios was measured at 3139.5 mt. On average, this equates to €49,390 in estimated annual fuel cost reduction. As a result, $CF_i = €49,390$.

5.1.1. Net present value calculation

By performing the NPV calculation, it was found that the NPV is equal to €375,479. Since the NPV showed a positive value, the owner was encouraged to undertake the investment. Fig. 2 shows the evolution of the investments' NPV, as a function of the remaining lifetime of the vessel.

It can be observed that the NPV turns positive in what seems to be the third year. The importance of this figure is to show that the owner of the MPP does not need to adopt a long-term perspective for the project to become worthwhile: If the owner wishes to sell the vessel in less than 5 years (which can be considered the short-term), the benefits will outweigh the costs from an economic standpoint after 3.5 years. This means that the retrofit is also profitable in the short-term. In order to include this element of change in the analysis, the variation in the NPV due to alterations in factor values is examined in the following section.

5.1.2. Sensitivity analysis

Table 4 shows the results from the long-term sensitivity analysis, and illustrates the change of the profitability of the investment (NPV) if the value of one of the three factors is changed by a certain percentage, while the two other factor values remain constant. For example, if the average fuel price increases by 50%, the NPV of the project increases by 66%. Another example: if the cost of the system increases by a factor of two (100% increase), this causes a 33% reduction of NPV. From Table 4, it is apparent that the fuel price has the strongest impact on profitability, followed by the discount rate and, finally, the cost of the system.

Next, Table 5 shows the results from the short-term sensitivity analysis. It is clear that the fuel price also in the short-term perspective has the strongest impact on profitability, followed by the discount rate and, finally, the cost of the system. The profitability increases by more than 70% when the fuel price increases by 25%.

At the same time, it can be noticed that the NPV becomes negative (a more than 100% reduction) when the cost of the system rises above 50%. In theory, this suggests that the owner has a 50% buffer when it comes to excess costs, before the project becomes unattractive. When we compare the results presented in Table 4 with those in Table 5, we see that the importance of the system's cost is much greater in the short-term, compared to the long-term perspective. Finally, it can be noted that in the short-term perspective the significance of the discount rate is reduced compared to the long-run scenario depicted in the previous subsection. When the discount rate is doubled, the NPV remains positive, albeit diminished by 50%.

5.2. Risk identification

5.2.1. The choice of supplier

Having a supplier in charge of the installation who is not familiar with the existing drive shaft's technical characteristics can lead to problems with the machinery. By selecting a supplier who is the manufacturer of the drive shaft, the customer reduces the risk of misusing the drive shaft's RPM.

5.2.2. The scheduling of work

For both Ro–Ros, the frequency converters were installed while the ships were in the shipyard for their renewal survey. This survey is held every five years from delivery, and includes extensive checks, to ensure that the main and the auxiliary machinery are in satisfactory condition with respect to the relevant rules. The strategic scheduling allowed the charterers to exploit economies of scale by installing the FC and undergoing the survey for the price of one trip to the yard, which is significant, as one trip to the yard implies costs in both lost hire and fuel consumption. Thus,

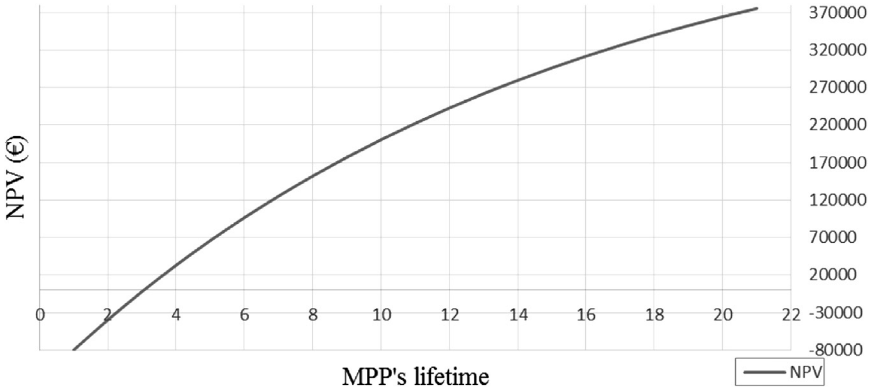


Fig. 2. Net present value evolution over the ship's lifetime.

Table 4
Long-term NPV sensitivity due to change in factor value (fuel price, system cost or discount rate).

	Factor value change				
NPV sensitivity due to factor value change (%)	**−50**	**−25**	**25**	**50**	**100**
NPV sensitivity to fuel price change (%)	−66	−33	33	66	133
NPV sensitivity to system cost change (%)	16	8	−8	−16	−33
NPV sensitivity to discount rate change (%)	53	23	−18	−33	−54

Table 5
Short-term NPV sensitivity due to change in factor value (fuel price, system cost or discount rate).

	Factor value change				
NPV sensitivity due to factor value change (%)	**−50**	**−25**	**25**	**50**	**100**
NPV sensitivity to fuel price change (%)	−143	−71	71	143	286
NPV sensitivity to system cost change (%)	93	46	−46	−93	−186
NPV sensitivity to discount rate change (%)	33	16	−14	−27	−50

avoiding the additional voyage is both a source of savings to the customer and an increase in the profitability of the project.

5.2.3. *The division of work*

The majority of small jobs (cabling, reinforcements, etc.) were carried out during the ship's stay in port. Instead of doing the whole installation from scratch in the shipyard, and consequently increasing the opportunity cost of the ship, the work was divided, which permitted smaller tasks to be carried out while the vessel was still on-hire. As such, from its daily operations the vessel can still generate earnings for the customer of the retrofit. At the same time, the ship avoids any off-hire and saves valuable time and money. During the period of the installation, the off-hire for one of the ship technical manager vessels would have cost the charterers 15,000 €/day. As the duration of the installation work is 12 days, the total would have come down to 180,000€. According to the ship technical manager, this represented a substantial cost, which will affect the result of CBA presented in Section 4, and is a situation which has to be avoided.

5.2.4. *Reinforcement of work and space*

As the weight of the FC varies with its size, this can lead to the necessity of strengthening the deck on which it is fitted, as was the case for the first ship technical manager's vessel. In turn, this leads to higher costs than what was initially budgeted. Here, the importance of evaluating the foundation needs and thoroughly checking the space in which the FC is placed is emphasized.

5.2.5. *Creating an interphase between the software and the control system*

A cost that turned out to be higher than budget of the first ship was the creation of an interphase between the software and the control system on board. Nevertheless, a key objective during the installation was to keep the system as user-friendly as possible. It was therefore decided to have the suppliers of the control system software make the interphase between both systems. Having the suppliers of the control system on board played an important role to incentivize the engineers (ship's crew) to use the system, and the risk of engineers not using the system because of its unfamiliarity was thus reduced.

5.2.6. *Having a sufficient cooling system*

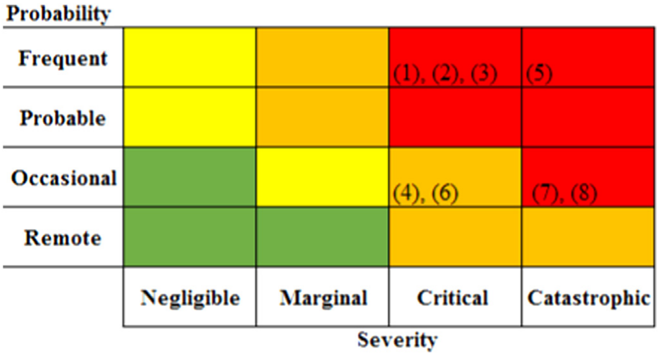
As the aim of such a retrofit is to have an installation that is user-friendly, as well as avoiding future unwanted repair costs, it is important to have a cooling system that satisfies the cooling demand of the FC. This is due to the decreased output of the FC when ventilation is insufficient. In fact, the Ship technical manager experienced a short blackout in the case of their first ship, due to the lack of adequate cooling. However, it is worth noting that the FC itself is not harmed when the ventilation is low. A way of mitigating this risk is by placing the FC in an area with a large degree of ventilation, such as the auxiliary engine room. This factor is quite dependent on the ship type, thus the optimal placement of the FC system might vary.

5.2.7. *Engineers' reluctance to use the system*

As the engineers on board are the users of the new system, it is of pivotal importance to motivate and incentivize them to welcome and adopt it. It is therefore crucial for the relevant personnel to know how to operate the new system, as default settings are still available. Further, due to safety concerns, they may prefer to rely on what they already know rather than on new technology.

5.2.8. *Delayed instruction manuals*

The ship technical manager of the first vessel that was retrofitted experienced delays in the delivery of instruction manuals. This led to a difficult situation as charterers were exercising pressure on the ship to start operating the new system, in spite of delayed instruction manuals. Such a predicament has the potential to lead towards damages, as failures of the system to work can cause blackouts or, in the worst case, breakdowns that are expensive to repair.



Probability				
Frequent	🟨	🟧	🟥 (1), (2), (3)	🟥 (5)
Probable	🟨	🟧	🟥	🟥
Occasional	🟩	🟨	🟧 (4), (6)	🟥 (7), (8)
Remote	🟩	🟩	🟧	🟧
	Negligible	Marginal	Critical	Catastrophic

Severity

Fig. 3. SGFC risk matrix.

5.3. *Mapping the categories of risk from acceptable to intolerable*

Fig. 3 represents Lozier's (2010) matrix (cf. Section 2), in which the risks are plotted in. The different colors show various levels of acceptance towards risk, ranging from acceptable (green) to intolerable (red). Labels (1)–(8) in Fig. 3 refer to the eight risk areas explained in Section 4. The purpose of the matrix is to easily raise awareness towards the most important risks, which in turn will enable the decision maker to better assess costs in relation to the benefits for this type of retrofit. Illustrating the risks in such a diagram also facilitates the task of identifying threats of SGFC for potential customers.

This matrix makes it evident in which categories of risk level the risks identified in the previous page fit. From this matrix, it is observable that the most severe risks are (1)–(3), (5), (7), and (8). The main implication is that ship-owners or operators who are looking to retrofit must give higher considerations to these points, as they present a barrier to having a successful installation of the retrofit. This advice is also valid for parties who are undergoing the project. For instance, the risk level may be altered by both minimizing the lead-time of instruction manuals and motivating the engineers and personnel on board to learn how to master the new system. This can cause the level of risk to switch from intolerable to acceptable.

5.4. *Time charterers as key customers for retrofitting SGFC*

First and foremost, most actors who finance the retrofitting of ships with respect to SGFC are charterers, and the installations are regarded as a common project between the charterers and the technical manager. This is quite interesting because neither the charterers nor the technical manager usually have financial stake in the vessel; in principle, when the time charter reaches its redelivery date, the ship owner will be in possession of a vessel with greater value, as its performance will be improved due to the installation of the frequency converter. However, it is important to highlight that every charter party is unique, and there might be clauses and terms in the contract giving the charterers the opportunity to take out the frequency converter, as they are its owner. Vessels that are retrofitted with SGFC are often traded on long-term time charters. There is mainly one reason why they trade on long-period contracts, i.e. the length of the project's payback period. For the customer to fully reap the benefits of the fuel savings, he must be in possession of the vessel for a long enough time. Even though the technology is available to all ships that have CPP and S/G, most ships that are retrofitted with this technology belong to the liner trade: liner ships trade on the spot market to a smaller extent compared with tramp ships, which implies that liner ships, to a larger extent than tramps, can be regarded as the target customers of this type of technology.

6. Discussion

6.1. *The trade-offs of frequency conversion*

6.1.1. *Ship-owner fleet decision: new vs. old*

The production of modern eco-ships, meaning new vessels that are more fuel-efficient to operate compared to existing similar-size ships, has triggered a fear of divided charter markets among ship-owners and charterers (Nieswandt and Loges, 2013). These worries are motivated by the possibilities that eco-vessels might attract higher rates, while existing vessels could earn lower rates, due to their reduced competitiveness. Consequently, many ship-owners will be confronted with the following scenarios: (1) Fleet renewal: selling existing ships, with a view to purchasing modern fuel-efficient ships. (2) Retrofitting, i.e. the act of adding a supplementary component to an object which was not present when the object was manufactured. In this case, the purpose would be to become more competitive in the freight market. (3) In the case of older vessels: scrapping. It is quite apparent that ship-owners and ship operators are being forced to rethink the energy consumption of their fleets, as stricter requirements may cause higher fuel oil prices, rooted in the fact that is it more costly to produce cleaner than “dirty” fuels (Kalli et al., 2009).

As shown in Section 3, the scenario of retrofitting becomes therefore more affordable and interesting for many ship-owners and charterers.

6.1.2. *Forecasted versus actual fuel savings*

Table 3 illustrates an estimate of fuel saving of 2–3% due to the retrofit of the SGFC, which is substantially less that the savings potentials reported by Casal and Würzburg (2014) and Solla et al. (2012). This difference might be rooted in several ship and trade specific external and internal factors. Examples of internal factors are various crews' practices on one ship and variations in deadweight capacity utilization and trim. Moreover, underwater hull roughness and frictional resistance may change over time for one ship, influenced among other factors by the hull surface maintenance conducted during dry-dockings. Examples of external factors are wind and sea-state, current, possible icy waters, port and terminal congestion, waiting time, impact on speed and consumption.

6.1.3. *The impact of cyclical shipping markets on the feasibility of the retrofit*

Despite the many positive sides of frequency conversion technology, limitations that raise question marks surrounding its sustainability can be pointed out. One limitation relates to the state of shipping markets. The practice of slow steaming saw its emergence during the slowdown of the shipping industry, caused by the 2008–2010 global financial crisis (Meyer et al., 2012). During this period, shipping segments saw historic falls in both freight rates and newbuilding prices (Asariotis et al., 2009). Simultaneously, bunker prices increased, making day-to-day operations very costly for most ship owners and operators. These hard market conditions forced ship owners and operators to reduce costs. This was made possible through slow-steaming, thereby reducing bunker costs. Additionally, environmental requirements in relation to SO_x emissions coming into force might also force ship-owners to consider the abovementioned alternatives (IMO, 2010).

However, if freight markets tomorrow were to climb to high levels, where the revenue gained by chartering out the ship exceeds the cost reduction from slow steaming, the retrofit would lose its purpose. In order to profit from the strong freight market situation, ship owners and operators may become more interested in increasing their vessels' speed. The problem with increasing ship speed is that the variable frequency drive realizes no savings. The fuel consumption increases at higher speed, and the ship is run in the same way as prior to the retrofit. In this sense, the profitability of the retrofit depends on the future situation of the market in which the ship belongs. Based on this logic, before they invest in SGFC, ship owners and operators should take into consideration how they believe markets will develop in the future.

6.2. *Monitoring ship energy performance*

The development of the mandatory (IMO, 2014) Ship Energy Efficiency Management Plan (SEEMP) for both existing vessels and new buildings takes into consideration best practices for energy – (mostly fuel) efficient ship operations. This regulation is of significance to the case study presented in this paper as it offers an appropriate framework, which supports the choice of considering SGFC. When it comes to monitoring energy efficiency, the participants in this study have not experienced any difficulties. This might seem surprising, as Johnson et al. (2014) explain that there are barriers which need to be addressed in order to successfully manage energy efficiency, including difficulties in achieving energy performance due to fragmented responsibilities, possible conflicting interests and unclear division of labour between shipowners and third parties.

With respect to the SEEMP offering a supporting framework for retrofits, it was found that it played a role in the frequency conversion retrofit of the Norwegian ship manager's RoRos. The SEEMP was regarded as a tool that simplified the process of retrofitting. This finding shows that the SEEMP not only has a positive impact on the environment, but also may provide ship owners with added value. However, the combination of the fact that most ships undergoing the retrofit are chartered on longer periods, and the reality that charterers are the largest group of customers who pay for the retrofit, facilitates the monitoring of energy performance.

Despite the fact that all ships with CPP and S/G are target candidates for SGFC, this study also explores whether there is an effect of the nature of the trade in which ships retrofitted with the technology belong. Liner ships are characterized by trading on fixed routes and schedules, whereas tramp ships have a tendency to operate in spot markets (Anyanwu, 2013; Köhn and Thanopoulou, 2011). Charterers have incentives to monitor the fuel consumption closely, because they have invested in the retrofit. In addition, having fewer counterparties to deal with makes it easier to track the fuel consumption. The ships in this study do not trade on short voyage charters, but rather on long-term charter parties, on fixed routes and schedules. Consequently, the relationship between ship owners or operators and third parties becomes longer, and problems related to information sharing are less likely to occur, as the same party is in charge of bunkering the ship for long periods of time.

6.3. *Mitigating the risks in the retrofit*

SGFC technology is still relatively unknown to many ship owners and operators in the shipping industry, which suggests that the suppliers are more informed about the risks stemming from the variable frequency drive retrofit than their last-mentioned counterparts. However, as this study has identified risk areas related to power conversion of the shaft generator, one could argue that parties seeking to retrofit their ships are now in possess of more information regarding the “do's and don'ts” of this type of project. From a strategic standpoint, this suggests that these actors are now in a position with more symmetric than asymmetric information, which affords them the possibility to make more informed decisions.

6.3.1. *Customer perspective*

Greater knowledge surrounding the risks of SGFC could promote favorable contract negotiation conditions for those who are interested in retrofitting with this technology. As a result, customers can seek to include clauses and terms in the contract for the retrofit, stating that they are entitled to price reductions in the event that terms are not met, as is the norm in newbuilding contracts. Examples of what these kinds of clauses could deal with are price reductions in the event of delayed instruction manuals, insufficient cooling systems, and so forth. These kinds of provisions in the contracts can transfer risk from the customers to the suppliers of the technology, which makes it more attractive for the customers. This is also beneficial for the suppliers, who may acquire more customers, since the lower element of risk makes the technology more interesting. Although this might not always be positive for suppliers, one can argue that it promotes the commercialization of the retrofit.

6.3.2. *Supplier perspective*

From the point of view of the suppliers, the identification of important risk areas can translate into indicators of concern, whereupon they can improve their system. If the risk of engineers not using the system is considered, suppliers can evaluate the state of their tutorials on how to use the new system, and thereby ponder the needs to improve their methods for instructing the crews. Suppliers can also use the risk matrix as a tool for assessing their quality management system, by keeping track of the different risks that occur in SGFC projects, and developing efficient ways to mitigate them. What this means is that the risk matrix can serve as a tool in the three-step risk framework by (Rowley, 1989), that was presented in Section 4.

7. Conclusions

The CBA analysis for the one-vessel case shows that the benefits from frequency conversion outweigh the costs. The sensitivity indicates that the short-term scenario presents the greatest challenges to the profitability of the retrofit. Factors such as the evolution of the fuel price, along with the cost of the system, are vital elements of the investment's profitability.

This study distinguishes 8 separate risks that customers and potential customers normally take into consideration. Identifying these risks provides additional information for parties interested in retrofitting ships with SGFC, which has the potential to increase the degree of profitability of their retrofits. This also suggests that the suppliers of SGFC are more informed about the risks stemming from the variable frequency drive retrofit than their above-mentioned counterparts. From a strategic standpoint, this indicates that these actors are now in a position with more symmetric than asymmetric information, which affords them the possibility to take more informed decisions. The most frequent customers of the retrofit of the SGFC are charterers with no financial stake in the ships, and not ship-owners.

7.1. *Recommendations for further research*

We strongly emphasize the importance of the ship operational profile on SGFC retrofit feasibility. Many factors, both internal and external, will impact energy consumption that was not controlled for in this exploratory case study. Possible differences in voluntary and involuntary speed losses due to for example wind, current, seaway, ice, congestion, waiting, etc. are neither discussed nor taken into account in the case. The impacts of these factors should be discussed, and the way in which they affect the interpretation of benefits and costs for conducting the retrofit should be assessed. A more thorough inclusion of the complexity of the ship operational profile (Banks et al., 2013), impacting the evaluation of the SGFC's potential, is a topic for further research.

Another area which was not covered in this paper relates to the value brought to the ship by the frequency converter, i.e. the effect of shaft generator frequency conversion on the ship price. In other words, it remains to be assessed how much the value of a ship changes in the sale and purchase market when a variable frequency drive is installed.

Further, as decisions on machinery system through the operational phase and design phase are mutually dependent (Balland et al., 2014), separating these two domains may lead to sub-optimal solutions. Therefore, investigating how the option for retrofitting variable frequency drive technology in the operational phase impacts vessel newbuilding design criteria would be of considerable interest for the abovementioned parties.

Finally, concerning the limitations of the study, increasing the sample size could provide interesting results for both suppliers and customers of the technology: On the one hand, a higher number of potential risks can be included in the risk matrix, yielding a more complete picture of the full range of threats related to the retrofit; on the other hand, drawing on the experiences of other retrofitted vessels can also determine the validity of the risk identification analysis. The rationale is that the number of retrofitted ships with more or less the same risks as those identified in the analysis can dictate the accuracy of the findings. By pursuing this line of research, the paper's limitations with respect to statistical generalizability can be overcome.

Acknowledgments

We wish to acknowledge the help of Mr. Sarasquete (Vicusdt) and the participation of Mr. Carlsson from Ellingsen Ship Management and Mr. Sørensen from MAN Diesel. The views expressed in this paper are those of the authors and not necessarily those of the abovementioned companies. We also wish to acknowledge the valuable comments and advice on earlier versions of this paper by colleagues and four anonymous referees, as well as thank Alice Tonzig for her proofreading of the English language, which led to a number of corrections which improved this article. Any errors are our responsibility.

Appendix A. : Risk identification questions

Questions Ship manager

Background information

- What type of vessel(s) did you retrofit?
- How old were the vessel(s)?
- When did the installation take place?
- What type of SG did you have onboard?
- What were the specifications of SG in terms of Voltage/Frequency and Power/kVA?
- Which Company(ies) did you use for the installation?
- Why did you choose that Company (Reason: so many competing companies who deliver more or less the same product, at similar cost)?
- Where did the installation take place and why?
- Was the frequency conversion the only retrofit, or were there others?
- As there are a large variety of retrofit products available, why did you select this one?

Installation

- Was the installation performed according to budget?
- Have you experienced any technical difficulties related to the converters?
- Was it necessary to educate captains, chief engineers, and officers about the converters, and how they affect the running of the ship?
- How long was/were the vessel(s) off-hire for the installation?
- How long did you estimate the vessel(s) would be off-hire?
- Approximately how much was the cost for the off-hire period?
- How did you schedule the installation?
- It is said that generators are a bit downgraded when frequency converters are installed. This in theory can be a problem when operating the electric driven bowthrusters when maneuvering in and out of ports. How did you take care of that problem?

Operational performance

- How do the frequency converters perform during winter season?
- Prior to the installation, how large fuel savings did you estimate you would realize?
- Are the fuel savings lower, equal to or higher than your estimates?
- How do the actual maintenance costs compare with your estimate prior to installation?
- How large are the yearly maintenance costs of the converters?
- It is said that Variable frequency drive systems can experience overheating, due to reduced cooling at lower speeds. Have you experienced this?
- It is also said that Variable frequency drive systems have higher noise levels than fixed frequency systems. Have the crews informed you about increased noise levels?
- According to your Company's practice, how long should the investment's payback period be?
- If the project was financed through bankloan, what was the bank's position regarding this type of project?
- What type of charter contracts have the vessels been chartered on? Long/Short term?
- Is it difficult to monitor the ship's bunker consumption?
- Many actors in the industry imply that eco-ships and retrofitted vessels can earn premiums in freight markets. How can you comment on this statement with regards to your experience(s)?
- Do you have anything to add about the retrofits, which hasn't been addressed in the previous questions?

Questions supplier

- Generally, charterers are the parties who pay for bunkers. Does it mean that most Owners who retrofit their vessels trade their ships on a voyage charter basis? Probe and discuss
- On average, what is the cost for installing frequency converters? (if doesn't have average, if a range can be given…)
- Which is the most common shiptype that uses this retrofit solution?
- What are the companies' greatest concerns when they decide to install the frequency converters?
- How do most of your clients raise the funds for this kind of installation?
- Where do Banks stand when it comes to financing this type of projects?
- How long has your company offered a shaft generator frequency converter solution?
- How long is the guarantee period, and what type of events are covered?
- Do you have anything else to add about the SGFC?

Appendix B. : Risk matrix guide

Below are the main risks that I have identified from our interview.I intend to rank them according to their importance in terms of economic consequence.

For this purpose, I have created a scale from 1 to 4, where 1: Negligible; 2: Marginal; 3: Critical; and 4: Catastrophic.

Could you kindly help me in this process, by rating each risk using the above scale?

(You can simply write the digit next to the risk).

- Choosing a Supplier who is the manufacturer of drive shaft.
- Scheduling of the work (Special Survey).
- Dividing the work (getting as much done as possible while vessel is in port).
- Reinforcement work.
- Create interphase between Software and Control system.
- Having a sufficient cooling system.
- Engineers not using the system (due to lack of motivation to learn new equipment).
- Delayed instruction manuals.

Appendix C.: Common daily report at sea for “M/V Oslo Bulk 6”

- DT: 010414/1900
- LP: ARICA
- NP: GUAYAQUIL
- ETAPS: 020414/1000
- POS: 0514S08129W
- WND: 3S
- SEA: 3SSW
- SPD: 11.5
- PITCH: 73
- VSPD: 11.3
- ELP: 90
- DIS: 276
- VDIS: 1059/169
- ROBIFO: 135.7/48.6
- CONIFO: 09.8/0.0
- SFCNM: 35.51
- ROBMDO: –/16.7
- CONMDO: –/0.0
- ROBLO: 7600
- CONLO: 0.0
- ROBFW: 48
- ROBSLU: 13.6
- CARGO: 6200/SBM
- DRAFT: 5.9/6.6

References

Anyanwu, J.O., 2013. Analysis of the interrelationships between the various shipping markets. Ind. Eng. Lett. 3 (10), 29–41.

Armstrong, V.N., 2013. Vessel optimisation for low carbon shipping. J. Ocean Eng. 73, 195–207.

Asariotis, R., Benamara, H., Hoffmann, J., Núñez, E., Premti, A., Valentine, V., 2009. Review of Maritime Transport 2009. UNCTAD, New York and Geneva.

Asuquo, M., Coward, I., Yang, Z., 2014. Modeling selection of third party ship management services. Case Stud. Transp. Policy 2 (1), 28–35.

Baldi, F., Gabrielii, C., 2015. A feasibility analysis of waste heat recovery systems for marine applications. Energy 80, 654–665.

Balland, O., Erikstad, S.O., Fagerholt, K., 2014. Concurrent design of vessel machinery system and air emission controls to meet future air emissions regulations. J. Ocean Eng. 84, 283–292.

Banks, C., Turan, O., Incecik, A., Theotokatos, G., Izkan, S., Shewell, C., Tian, X., 2013. Understanding ship operating profiles with an aim to improve energy efficient ship operations. In: Proceedings of the Low Carbon Shipping Conference, vol. 33. London, UK, pp. 51–52.

Barati, S., Mohammadi, S., 2008. Enhancing risk management with an efficient risk identification approach. In: Proceedings of the 4th IEEE International Conference on the Management of Innovation and Technology, pp. 1181–1186.

Basurko, O.C., Gabiña, G., Uriondo, Z., 2013. Energy performance of fishing vessels and potential savings. J. Clean. Prod. 54, 30–40.

Berk, J., Demarzo, P., 2013. Corporate Finance, third ed. Pearson, UK.

Bryman, A., 2012. Social Research Methods. Oxford University Press, UK.

Casal, A., Würzburg, K., 2014. Report on how achieving emissions reductions with lower cost, Seventh Framework Programme, p. 67. Retrieved from: 〈www.tefles.eu〉 (23.10.14).

Chapman, R.J., 2001. The controlling influences on effective risk identification and assessment for construction design management. I. J. Proj. Manag. 19 (3), 147–160.

Damodaran, A., 2014. Cost of capital by sector. Retrieved from: 〈www.pages.stern.nyu.edu〉 (16.04.14).

Denzin, N.K., Lincoln, Y.S., 1994. Handbook of Qualitative Research. Stage, California.

DNV G.L., 2015. Portal. Oslo Bulk 6 – Registry. Retrieved from: 〈www.exchange.dnv.com/Exchange/〉 (03.08.15).

Dokkum, K., 2011. Ship Knowledge. Dokmar Maritime Publishers, The Netherlands.

IMO, 2010. Sulphur oxides (SOx) – Regulation 14. Retrieved from: 〈www.imo.org〉 (23.02.15).

IMO, 2014. Ship Energy Efficiency Management Plan and Energy Efficiency Operational Indicator. Retrieved from: 〈www.imo.org〉 (16.02.14).

Johnson, H., Johansson, M., Andersson, K., 2014. Barriers to improving energy efficiency in short sea shipping: an action research case study. J. Clean. Prod. 66 (0), 317–327.

Kalli, J., Karvonen, T., Makkonen, T., 2009. Sulphur content in ships bunker fuel in 2015: a study on the impacts of the new IMO regulations and transportation costs. vol. 31. Ministry of Transport and Communications, Helsinki, Finland.

Köhn, S., Thanopoulou, H., 2011. A gam assessment of quality premia in the dry bulk time-charter market. Trans. Res. Part E: Logist. Transp. Rev. 47 (5), 709–721.

Lassesson, H., Andersson, K., 2009. Energy efficiency in shipping – review and evaluation of the state of knowledge. Chalmers University of Technology, Sweden.

Lozier, T., 2010. Streamline your CAPA process: use risk assessment to improve quality and compliance. Qual. Assur. J. 13 (1–2), 37–40.

Lyridis, D.V., Psaraftis, H.N., Ventikos, N., Zacharioudakis, P., Dilzas, K., 2005. Cost-benefit analysis for ship automation retrofit: the case of icebreaker Frej. Mar. Technol. 42 (2), 113–124.

Mabry, L., 2008. Case study in social research. In: Alasuutari, P., Bickman, L., Brannen, J. (Eds.), Social Research Methods. Sage, California, pp. 214–225.

Meyer, J., Stahlbock, R., Voß, S., 2012. Slow steaming in container shipping. In: Paper Presented at the 45th Hawaii International Conference on System Science (HICSS), pp. 1306–1314.

Mitroussi, K., 2004. The role of organisational characteristics of ship owning firms in the use of third party ship management. Mar. Policy 28 (4), 325–333.

Nieswandt, C., Loges, I., 2013. Expert Market Survey: Eco-shipping 2013. HSH Nordbank AG, Hamburg, Germany.

Notteboom, T.E., Vernimmen, B., 2009. The effect of high fuel costs on liner service configuration in container shipping. J. Trans. Geogr. 17 (5), 325–337.

Oslobulk, 2015. Vessel and fleet data. Retrieved from: 〈http://www.oslobulk.com/fleet〉 (03.08.15).

Panayides, P.M., Cullinane, K.P.B., 2002. The vertical disintegration of ship management: choice criteria for third party selection and evaluation. Marit. Policy Manag. 29 (1), 45–64.

Prousalidis, J., Hatzilau, I.K., Michalopoulos, P., Pavlou, I., Muthumuni, D., 2005. Studying ship electric energy systems with shaft generator. In: Paper Presented at the Electric Ship Technology Symposium. IEEE, Philadelphia, USA, p. 156.

Prpić-Oršić, J., Faltinsen, O.M., 2012. Estimation of ship speed loss and associated CO_2 emissions in a seaway. J. Ocean Eng. 44, 1–10.

Rolls-Royce, 2010. The HSG (Hybrid Shaft Generator) concept. Retrieved from: 〈http://www.rolls-royce.com〉 (22.10.14).

Rolstadås, A., 2008. Applied Project Management – How to Organize, Plan, and Control Projects. Tapir Academic Press, Trondheim, Norway.

Rowley, I., 1989. Managing in an uncertain world: risk analysis and the bottom line. IEE Colloquium on Systems Engineering Contribution to Increased Profitability, IET, pp. 3/1–3/8.

Sam-Electronics, 2010. Shaft alternator systems with PWM frequency converter. Retrieved from: 〈www.rolls-royce.com/〉 (02.05.14).

Solla, M., Coache, S., Sarasquete, A., 2012. Shymgen system: optimizing the performance of shaft generator and drive train on fishing vessels. In: Proceedings of the Second International Symposium on Fishing Vessel Energy Efficiency E-Fishing. Vigo, Spain.

Stoye, T., 2011. Propeller design and propulsion concepts for ship operation in off-design conditions. In: Proceedings of The Second Int Symposium on Marine Propulsors, Hamburg, Germany.

Vicusdt, 2014. M/V Oslo Bulk 6. Shymgen quotation for SGFC.

Xiaoyan, X., Yinzhong, Y. Chen, C.L.P., 2009. On control of power supply process of marine shaft generator. In: Systems, Man, and Cybernetics (SMC). IEEE, pp. 4776–4779.

Yin, R.K., 2009. Case Study Research: Design and Methods. Sage, California.