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# Energy-efficient Operational Training in a Ship Bridge Simulator

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## Abbreviations:

EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
GHG	Greenhouse gas
IMO	International Maritime Organization
MARPOL	International Convention for the Prevention of Pollution from Ships
SEEMP	Ship Energy Efficiency Management Plan
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers

## **Abstract**

Over the recent decades, there has been an increasing focus on energy-efficient operation of vessels. It has become part of the political agenda, where regulation is the main driver, but the maritime industry itself has also been driven towards more energy-efficient operation of the vessels, due to increasing fuel costs.

Improving the energy efficiency on board vessels is not only a technical issue - factors such as awareness of the problem, knowledge skills and motivation are also important parameters that must be considered.

The paper shows how training in energy-efficient operation and awareness can affect the energy consumption of vessels. The study is based on navigational, full-mission simulator tests conducted at the International Maritime Academy SIMAC. A full-mission simulator is an image of the world allowing the students to obtain skills through learning-by-doing in a safe environment. Human factors and technical issues were included and the test sessions consisted of a combination of practical simulator exercises and reflection workshops.

The result of the simulator tests showed that a combination of installing technical equipment and raising awareness - making room for reflections-on and in-action - has a positive effect on energy consumption. The participants, on average, saved approximately 10% in fuel.

**Keywords:** Shipping, Maritime education, STCW, Energy efficiency, Awareness, Simulator training

## **1 Introduction**

The consequences of climate changes are already apparent around the world. This means that society's focus on ways to reduce greenhouse gas emissions are growing. A study of shipping-related greenhouse gas emissions that was performed on behalf of The International Maritime Organization (IMO) states that, from 2007-2012, on average shipping accounted for 3.1% of annual global emissions of CO<sub>2</sub>, and an increase in maritime CO<sub>2</sub> emissions are expected, despite the regulatory actions that have been taken (Smith et al., 2015). Depending on future economic and energy development, this could increase to between 50% and 250%. It is therefore necessary to take further action to mitigate the growth in emissions, in order to ensure continued sustainable development.

As a response to the request to reduce GHG emissions, the International Maritime Organization (IMO) succeeded to make an global binding agreement on reducing CO<sub>2</sub> emissions from international shipping. This was effectuated by an amendment to the MARPOL Annex VI - Prevention of Air Pollution from Ships (IMO, 2011). IMO thereby introduced guidelines for calculating energy efficiency during both the design and operation phases through the Energy Efficiency Design Index (EEDI) (IMO, 2012a), the Ship Energy Efficiency Management Plan (SEEMP) (IMO, 2012b) and the Energy Efficiency Operational Indicator (EEOI) [IMO, 2009]. The amendment sets requirements for the EEDI, making sure that newly built ships are designed to be more energy efficient. The EEOI, which is a voluntary guidance tool, was developed in order

to be able to compare the operation of ships and help to find best practices for fuel-efficient operations. For new and existing vessels, it became mandatory to have an SEEMP on board; the intention of the SEEMP is to improve energy efficiency in daily operations on board in a cost-effective way.

Stakeholders in the maritime industry have identified several methods to improve ships' energy efficiency, and a large number of studies estimating the cost-effective potential have been performed. Many of these measures are related to both operational and technical issues e.g. DNV GL (2014, 2015), Faber et al. (2011). These studies demonstrate how it is possible to increase the energy efficiency of vessels and thereby reduce GHG emissions by modifying ship design, installation or retrofitting energy saving or emission reduction equipment. In addition, daily energy reduction measures directly related to the operation of the ship have been identified to have great potentials for improving energy efficiency. Despite the knowledge of the cost-effectiveness of these energy efficient actions, some areas of the maritime industry are still reluctant to invest. Research has demonstrated that small shipping companies lack the resources to analyse, make decisions and implement energy efficient solutions e.g. work performed by Johnson et al. (2014), Poulsen and Johnson (2016). Energy optimisation has been a focus of research in larger shipping companies for a number of years. Based on the large amount of data and the resources in these companies, performance systems have been developed. In particular, in the case of liner vessels, the comparable routes and more equally designed sister ships represent the opportunities for designing a useful tool for optimisation. However, even though some companies have departments that solely focus on this issue, route optimisation seems to be the primary energy efficiency operational tool. For working vessels, the complex and flexible operation profiles make the use of traditional route optimisation difficult to evaluate and compare in order to maximise savings. This limitation, combined with high levels of uncertainty in future fuel prices, makes it difficult to determine whether investment in new energy efficient equipment will be cost-effective, make energy efficient operation a minor, or even neglected, topic on board many working vessels of today (Maddox Consulting, 2012; Poulsen and Sorn-Friese, 2015; Faber et al., 2011; Rehmatulla and Smith, 2015). These vessels are often operated on a time charter basis, meaning that the operational costs, including the investment in fuel efficiency of the vessel, are borne by the owner, whereas the voyage costs including the fuel are paid for by the charter, which is the so-called split initiative problem (Poulsen and Sorn-Friese, 2015; Rehmatulla and Smith, 2015). Therefore, the companies operating these vessels do not focus on fuel consumption; in contrast their primary focus is on safety issues and optimising the time available for conducting working tasks.

In the DNV GL Energy management study from 2015 (DNV GL, 2015), the question "*What matters to actually increase energy efficiency in ship operation?*" was raised. Based on input from ship managers, owners and operators from 24 countries, the report showed that the companies struggle with the implementation and finally concluded "*that people make the difference*". This conclusion was based on the

fact, pointed out by forty percent of the companies, that lack of education and resistance to change are the primary barriers for improving the energy efficiency of ships.

The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) (IMO, 1978), sets the standards of competence for seafarers internationally. The latest revision of the STCW convention and code was made in 2010 and entered into force on January 1, 2012 (IMO, 2010). One of the amendments highlighted in relation to energy-efficient operation was “*New requirements for marine environment awareness training and training in leadership and teamwork*”. Therefore, it must be expected that future generations of seafarers will not have a lack of education nor resistance to change, as pointed out in the DNV GL Management study (DNV GL, 2015). However, it is unclear in the standards how environmental awareness will be achieved. It is up to the countries' administrations to ensure a way to obtain the goal. A survey from 2011 of Maritime Education and Training of Maritime Personnel in the Ship Energy Efficiency area presented in the PhD Thesis by Banks (Banks, 2015) showed that there were no formalised courses available in 2011. Banks pointed out that the focus areas for improving the energy efficiency on board vessels should include factors such as increasing awareness of the problem, knowledge skills and motivation towards energy efficiency by ensuring the availability of maritime education and training, addressing both technical and human factor topics. In the survey, selected Maritime Education and Training institutes (MET) that were interviewed pointed to simulator training as being a way forward, as they used “try-observe-compare” as awareness training. Furthermore, the mindset “better safe than sorry” is mentioned as being a barrier, as there was a lack of awareness among the institutions about how energy efficiency can be achieved without compromising safety. Therefore, it is important to identify the right balance between safety and energy efficiency.

In 2012, a model for a training course on the efficient operation of ships was published, which was developed by the World Maritime University in Malmö, Sweden, on behalf of the IMO (IMO, 2014). This is a formalised course, focusing on giving an insight on the possibilities and the reasons for why energy-efficient operation is necessary. Unfortunately, awareness training and a way to handle *the better safe than sorry mindset* are lacking in the course. Furthermore, the course has been criticised for not considering seafarers' current levels of awareness, knowledge, skills and motivation towards energy efficiency, (Banks et al. 2014). The higher-ranking officers are not taught and trained in energy awareness; therefore, it is not feasible for them to give onboard training to younger officers. In Banks's survey, the participants were asked to rank methods for effective awareness learning. This showed that practical workshops, simulator training and onboard training are considered to be most effective. Since onboard training is not the best choice, due to a lack of education of the higher-ranking officers on board, which was also pointed out in the DNV GL survey (DNV GL, 2015), a combination of practical workshops and simulator training must be considered. In

a simulator, due to the safe learning environment, it is possible to include energy efficiency as a factor in situation awareness training, without compromising safety and customer requirements.

The potential of energy efficiency training is known from studies of land transport. Research has demonstrated that initial eco-driving training can reduce fuel consumption by private vehicles by up to 5%, and with feedback, this could increase to 10% (Barkenbus J., 2010). Navigating and manoeuvring vessels is more complex and the environmental impacts are probably greater, but it could be compared with the potential of eco-driving, and make vessels not normally subject to performance systems more energy efficient.

The aim of this paper is to examine how training in energy-efficient operation and awareness can affect energy consumption. The conclusions will be based on results from a navigational, full-mission simulator test. The overall question for the simulator tests was *"can the ship bridge simulator that is normally used for training safe navigation, collision avoidance and bridge team management, also be used for training energy-efficient operation, and is it possible to show the effects of the training?"*.

The paper is structured as follows: Section 2 presents the learning theories used for development of the test set-up and the purpose of the bridge simulator training in the master mariner training programme of today. Section 3 describes the test set-up and this includes a description of the simulator, the data collected, the voyage and the people involved. This section ends with a detailed description of the test phases. Section 4 contains the results and an analysis of the tests, which are discussed in Section 5. Section 6 provides the conclusion.

## **2 The idea behind the test**

The basis for the full-mission simulator test in this study is the Dreyfus model of skills acquisition (Dreyfus and Dreyfus, 1980) and the Schön theory on educating the reflective practitioner (Schön, 1983), combined with Wenger's theory on communities of practices (Wenger, 1998). This theory is combined with knowledge of how simulator training is conducted today in the master mariner education and training.

### **2.1 Skills and competences**

Aristotle said that the expert does the appropriate thing, at the appropriate time, in the appropriate way. However, to become an expert requires a certain acquisition of skills. The Dreyfus model is used in this study to understand how skills are acquired. The model posits that one passes through five levels of proficiency, which could be summarised as:

- *The novice* has little situational perception. Actions are rule-based and there is a lack of understanding of the context.

- *The advanced beginner* still has limited situational perception. The performance is governed by guidelines, which the advanced beginner follows accurately. The different aspects of the work are treated separately and with equal importance.
- *The competent* has obtained situational perception and will be able to deal with multiple pieces of information, long-term goals and deliberate planning. There is a sense of emotional investment and an act of conscience.
- *The proficient* has a holistic perception of the situation. He spontaneously recognises the important aspects and notices deviations from the normal pattern. Decisions are made by simple and memorable rules of guidance.
- *The expert's* reactions are intuitive. He uses an analytical approach and has an implied understanding of what is possible in the present situation.

Based on experience from training and educating master mariner students, the Dreyfus model is here used in connection with bridge simulator training focusing on navigation and anti-collision. A student moves from one level to another because of experience. One way to obtain experience is learning-by-doing as practised in a simulator. When the students start on the simulator training, they are at the level of the Dreyfus model called the *advanced beginners*. They have been on board a vessel as cadets and they have received classroom theory on navigation and rules of the sea, but it is the first time they are responsible for navigating the ship. The instructor will inform the students about the exercise. The whole job is separated into smaller tasks, where the students will focus on these tasks doing exactly as they have learned, or at least trying to do so. If they are told to plot positions in the chart every 15 minutes and to avoid a collision following the rules of the sea, they will do that. However, when they mark the position they often lose focus on anti-collision. The aspects of the job are treated separately and with equal importance. After each session, the instructors will hold a debriefing meeting, where they will reflect-on-action. For the *advanced beginner*, it is important that the instructor points out the different perspectives of the situation to reflect on. In the beginning, it is often seen at the next simulator session that the student will focus on what the instructor pointed out and is not able to adopt other perspectives. When the student has experienced enough “real” situations, he will move to the level of *competent*. The instructor no longer decomposes the task, and the student is just given an end goal, which could be an arrival position. The student will now be able to include multiple information – the movement of other ships, the influence of wind and current on his own vessel, and requirements for navigation. At this level, it is still seen that the instructor will guide the focus, but the students are now able to reflect-on-action by themselves, and change action if the result was not as planned. As an instructor, it can be noticed that changing from the level of *competent* to the level of *proficient* happens when the student starts recognising deviation from the normal pattern and acts immediately on that. This shows that the

student spontaneously recognises important aspects. On the other hand, the *competent* will do what is planned, and afterwards will reflect on why he did not succeed.

The students rarely move to the *expert* level, as they will not have enough lessons in the simulator to reach this level. The few *experts* seen during the training often have big experience from before they started their education as e.g. fishermen or mastering pleasure boats. The students are able to use this practical training in connection with theory and experience from the education, and their reactions will be much more intuitive when the complexity of the navigation is increased.

## **2.2 Making room for reflection**

The simulator training is a reflective practicum (Schön, 1983), where the students will get the ability to reflect on their actions and thereby be engaged in a process of continuous learning. When students are engaged and reflective, they will analyse the effect of their work and plan for improvement. Reflective practice is an important tool, where people learn from their own practical and professional experience. The reflecting student is not just looking back on similar past events, but is also taking into account earlier experience, actions and responses in order to achieve a higher level of understanding. Schön's theory on the reflective practitioner and the reflective practicum introduces the concepts of learning-by-doing, reflection-on-action and reflection-in-action in order to explain how professionals meet the challenges of their work with a kind of improvisation that is improved through practice. The instructor's debriefing after a practical simulator session is connected to the reflection-on-action and affects the planning before a new session, while the reflection-in-action affects the decisions taken in the simulator.

In this study, the reflective practicum is combined with the establishment of a sort of community of practice (CoP). This community is used for learning and knowledge - sharing among the students / bridge officers participating in the tests. The term "community of practice" is described by Etienne and Beverly Wenger-Trayner (Wenger-Trayner, 2015) as follows: Communities of practice are groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly. The structure of a community of practice can be described by three primary characteristics – the domain, the community and the practice. The domain must give meaning for the participants. The group must have a shared domain of interest and it must inspire the members to participate and make room for learning and knowledge - sharing. When members are interested in the domain, they feel commitment and the community is established. A strong community will engage members to join activities and discussions and will encourage them to be willing to share ideas. The members of the community are all practitioners – they collect and develop information and resources, which can be shared in the community.

Combining the theories on the reflective practitioner and the community of practice will open the way for reflection-on-action in a group, making room for experiencing learning-by-others. These shared experiences supplement the students' own knowledge and become part of the new strategy. When back in the simulator



alone, reflection-in-action will be connected to both the students' own experience and the shared knowledge. The test is based on the Reflective practicum and the community of practice and designed to enhance reflection-on-action in groups, as well as reflection-in-action during the voyage.

### **3 Description of the test**

The crew on board the ship plays a very important part with regard to energy-efficient operation; it is they who make the daily operational decisions, such as route, speed and engine settings - all parameters that influence the energy consumption. The aim of this study is to examine how energy-efficient operation and awareness training can affect the energy consumption. The test was based on simulator learning and training activities using a full-mission navigation simulator. The overall question for the study was: *“Can the ship bridge simulator that is normally used for training safe navigation, collision avoidance and bridge team management also be used for training energy-efficient operation, and is it possible to show an effect of the training?”*

The study took place in the full-mission simulator at Svendborg International Maritime Academy (SIMAC) in the period from April 11<sup>th</sup> to 15<sup>th</sup> 2016.

This section gives a description of the tests performed. Firstly, details about the simulator, the training ship, and the monitored data and output are given. After this, the people involved in the study are presented, followed by a description of the specific route and sailing modes. The section ends with a description of the phases of the test related to the learning programme.

#### **3.1 The simulator, the training ship and the monitored data**

Two full-mission simulators at SIMAC were used during the tests. Each simulator has an identical 240° full-mission bridge and engine room part, where the bridge can be interconnected with the engine room so that they jointly constitute a complete ship. The bridge and engine room can be fully manned and operate together in the same exercise, thus constituting a realistic setting.

The ship type chosen for the tests was a working vessel and it was equipped with two medium speed main engines, each connected via a gear to a pitch propeller and a shaft generator. The generators were too small to run both thrusters, and so in a thruster configuration, the use of the shaft generators was required.

As the bridge simulators were connected to a complete engine room simulator, all engine data was available and a total of 54 data points were continuously logged during the tests. Data were saved and presented as diagrams giving information on e.g. speed through water, main engine fuel consumption and rudder positions.

### 3.2 The people Involved in the tests

The participants in the simulator tests were six master mariner students from SIMAC. All students had completed at least 4½ years of maritime education to a qualification level as described in STCW II/2 (IMO, 2010). During their maritime education, all students had accomplished at least 12 months of practical cadet training on board a ship, and furthermore they had conducted several statutory simulator-training courses.

During the training session, four of the six students were assigned as bridge officers and two as helmsmen/lookouts. The students assigned as bridge officers operated the navigation bridge alone. They were given the instruction that the helmsman was available whenever it seemed necessary. The helmsmen were instructed not to interfere in the navigation or the use of equipment.

Three instructors were present during the tests. One instructor manned the engine room. He was instructed to do as the bridge officer ordered – and not to act on his own. One instructor monitored all actions taken by the students during the test. The last instructor was responsible for the monitoring part, and that all data was stored and available after the training session.

### 3.3 Description of route and sailing modes

Energy-efficient ship operation often focuses on long-distance route optimisation. In this study, it was chosen to show what can be done on board working vessels in short sea shipping, where manoeuvring dominates and awareness is required from the officers. A typical voyage for a working vessel can be described by five main modes, see Figure 1. The term *mode* refers to a phase of a voyage characterised by the work performed (Lützen et al. 2017). The first four modes, which are designated *harbour*, *manoeuvring in the inner harbour*, *manoeuvring in confined water* and *passage* will be equal for most vessels, whereas the last mode, referred to as *offshore work*, characterises the special purpose of the vessel. In the *harbour* mode, the vessel is alongside the quay, moored with lines and with engine and thrusters stopped. In the two *manoeuvring* modes, the propulsion and manoeuvring systems, including the engine and thrusters, will be running; the *passage* mode describes a longer passage between two fixed positions.

The voyage used for the simulator test in this study is a trip from the Port of Gothenburg in Sweden to a specific position in the Kattegat, where a platform is positioned. The officer on watch is instructed to arrive at the 500m safety zone off the platform 1.5 hours after departure. This study will cover the three middle modes only, as it is in these modes that the ship is sailing.

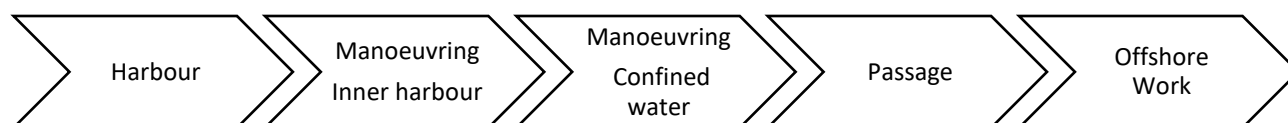


Figure 1. The voyage flow chart – The five modes.

The simulator session starts with the ship alongside – ready to depart, all engines running and thrusters on standby. The change from *harbour* mode to the mode of *manoeuvring in the inner harbour* is here defined as the time when the officer starts manoeuvring the vessel. During *manoeuvring in the inner harbour*, the speed is restricted to 6 knots, but after passing the harbour limit, indicated by a line in the nautical chart, the mode changes to *manoeuvring in confined water*, where no speed restriction is prescribed. Confined water here means an area where the safely navigable waterway is restricted due to the width. During such a passage, the lookout must be available at the bridge and the engine room must be manned. When the vessel passes a prescribed position at the end of the channel, the mode changes from *manoeuvring in confined water* to the mode called *passage*. After the passage, the vessel will arrive at the 500m safety zone off the offshore platform and the mode changes to *offshore work* and the test is stopped.

### 3.4 The phases of the test

The learning programme is divided into eight phases see Figure 2. Each phase is described by learning objectives, and a description of how these objectives are practically achieved during the test sessions. The eight phases consist of one classroom session, two workshops and five simulator sessions. During the practical simulator sessions, a total of nine voyages were conducted by each of the four bridge officers. The first familiarisation voyages were conducted together in groups, in order to establish the same practical basis. During the following voyages, all officers were alone on the bridge, but they all had the same ship, same voyage and same instructors.

The environmental and navigational parameters, such as wind, sea state and current, visibility and traffic density, were kept equal in the first four simulator sessions to insure comparable sailing conditions, and to be able to compare the fuel consumption, the navigation performed and the officers' behaviour. During the last session, the visibility was decreased and traffic density increased, to test the influence of enhanced navigation complexity. Environmental parameters, which influence the resistance of the ship, were not changed because of wanting to be able to compare the energy consumption.

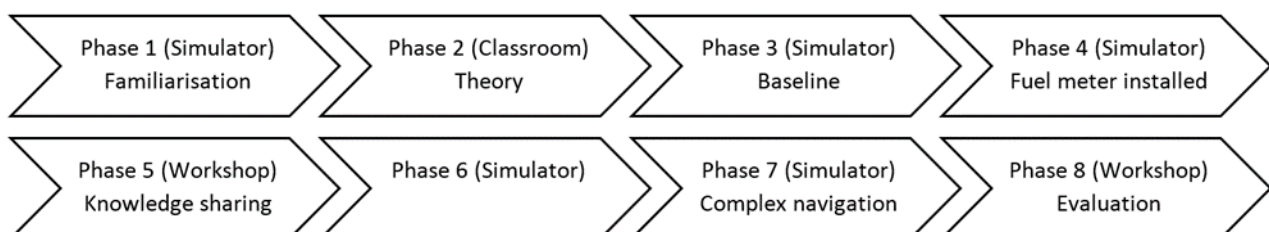


Figure 2. The phases of the test.

**Phase 1: Simulator - Familiarisation**

Firstly, the participants had to know the route and be familiar with the vessel and its manoeuvrability. The goal here was to make the simulator training realistic, and make the participants confident about handling the vessel and the navigation for the following training sessions. In this phase, there were two officers together on the bridge – the helmsman was not part of the familiarisation training. Due to their education level in navigation skills, the students could be designated as *advanced beginners* after the Dreyfus model, see Section 2.2.

**Phase 2: Classroom – Theory**

A lecture of 30 minutes on the topic “Ship energy efficiency management”. The lecture is inspired by the IMO model for energy-efficient operation (IMO, 2014). All students were familiar with energy efficiency from earlier lectures during their education. This lecture was to ensure the same theoretical background from the start.

**Phase 3: Simulator – Baseline (Two voyages)**

In order to establish a baseline for the energy consumption, the route was sailed twice. In this phase, the bridge was manned by one officer on watch and one helmsman.

**Phase 4: Simulator – Instrumentation (Three voyages)**

A fuel monitor was installed on the bridge. A short introduction to the fuel indicator was given to the students and they were free to use it. The “reflection-in-action” (try-observe-compare) concept was introduced during this session. The effect of installing technology on the bridge could be tested, and the effect could be evaluated by comparing with the baseline consumption.

**Phase 5: Workshop – Knowledge sharing**

Meeting between the participants. The participants were presented with the energy consumption for the first five voyages performed during phases 3 and 4. The information was given as diagrams, as described in Section 3.1. The purpose of the session was knowledge sharing, and the students were encouraged to compare, reflect and discuss with each other their way of conducting the voyage. The intention was to make a room for reflection-on-action in a group in order to improve the learning by knowledge sharing, see Section 2.2. The researchers and instructors that were present at the meeting were just observing and did not participate in the discussion.

**Phase 6: Simulator (Two voyages)**

After the discussions during the workshop in phase 5, the voyage was conducted two times to study the effect of the meeting and in that connection the benefit from the exchange of experience between the participants. This phase was conducted to show the effect of the officers meeting a combination of technology and knowledge sharing - using the reflection-on-action for reflection-in-action.

**Phase 7: Simulator - Complex navigation (Two voyages)**

The voyage was conducted twice with increased complexity. The visibility was reduced and the traffic

intensity was increased. During this phase, it was observed how increased navigational complexity affected the energy-efficient way of sailing the vessel. The intention was to observe how deeply the learning and experience about energy-efficient operation was rooted – would it be possible to see if the simulator training and workshops had moved the student from *advanced beginner* to a proficient officer who considered energy efficiency as an aspect of navigating a vessel.

#### **Phase 8: Workshop - Evaluation**

After the training sessions, the participants were invited to an evaluation meeting together with the researchers. The intention of the talk was to reflect on the tests and the different way of learning.

### **4 Results from the simulator sessions**

This section is separated into four. Firstly, the monitored data of the fuel consumption from each voyage is presented; this is followed by a section that contain output from the practical workshop in phase 5, where the students were encouraged to compare and discuss with each other their way of conducting the voyage. The instructors' general observations and comments on the tests is given followed by an analysis of each of the four officers, with comments on the energy consumption and the way the officers performed their individual voyages.

#### **4.1 Monitored data - Fuel consumption**

The total energy consumption used during the voyages was separated into the modes described in Section 3.3. Only the three middle modes were considered – the two *manoeuvring* modes and the *passage*. No energy consumption was registered in the first mode “*harbour*”, when the vessel was alongside, and in the last mode “*offshore work*”; here the test was stopped when entering the mode.

The fuel consumption for the three modes can be seen in Table 1. In the Table, data are given for each of the nine sailing sessions for all officers. A few data are missing in the table – one baseline voyage for officer 1 and 4 respectively. The ship arrived too late at the platform and so it was decided not to include the figures from those voyages. Also data are missing for the first voyage with indicator installed for officer 1. Unfortunately, an engine failure took place during the passage and therefore only the two manoeuvring modes are include for this voyage.

In Figure 3, the fuel consumption is shown for each of the officers. The figure shows the average consumption for the different voyage types – the baseline, after instrumentation and after the workshop. Plots for both voyages with increased complexity are also shown in the Figure.

Table 1. Fuel consumption - unit [litre].

	Baseline		After Instrumentation			After workshop		Complex navigation	
	1	2	1	2	3	1	2	1	2
<b>Officer 1</b>									
Man inner harbour	699		737	717	730	725	704	693	668
Man confined water	860		980	871	811	820	819	794	799
Passage	1460			1444	1259	1335	1335	1373	1339
Total	3019			3032	2800	2880	2858	2860	2806
<b>Officer 2</b>									
Man inner harbour	762	827	808	790	760	760	733	811	724
Man confined water	896	863	936	934	908	792	836	905	798
Passage	1570	1633	1491	1508	1574	1365	1316	1406	1313
Total	3228	3323	3235	3232	3242	2917	2885	3122	2835
<b>Officer 3</b>									
Man inner harbour	1014	850	840	856	826	736	737	852	756
Man confined water	741	965	723	920	927	845	851	789	817
Passage	1490	1537	1439	1433	1376	1346	1340	1349	1321
Total	3245	3352	3002	3210	3130	2927	2928	2990	2894
<b>Officer 4</b>									
Man inner harbour		847	837	868	927	750	733	726	738
Man confined water		962	913	910	862	777	755	807	768
Passage		1434	1543	1465	1446	1260	1263	1214	1227
Total		3242	3293	3243	3236	2787	2787	2747	2733

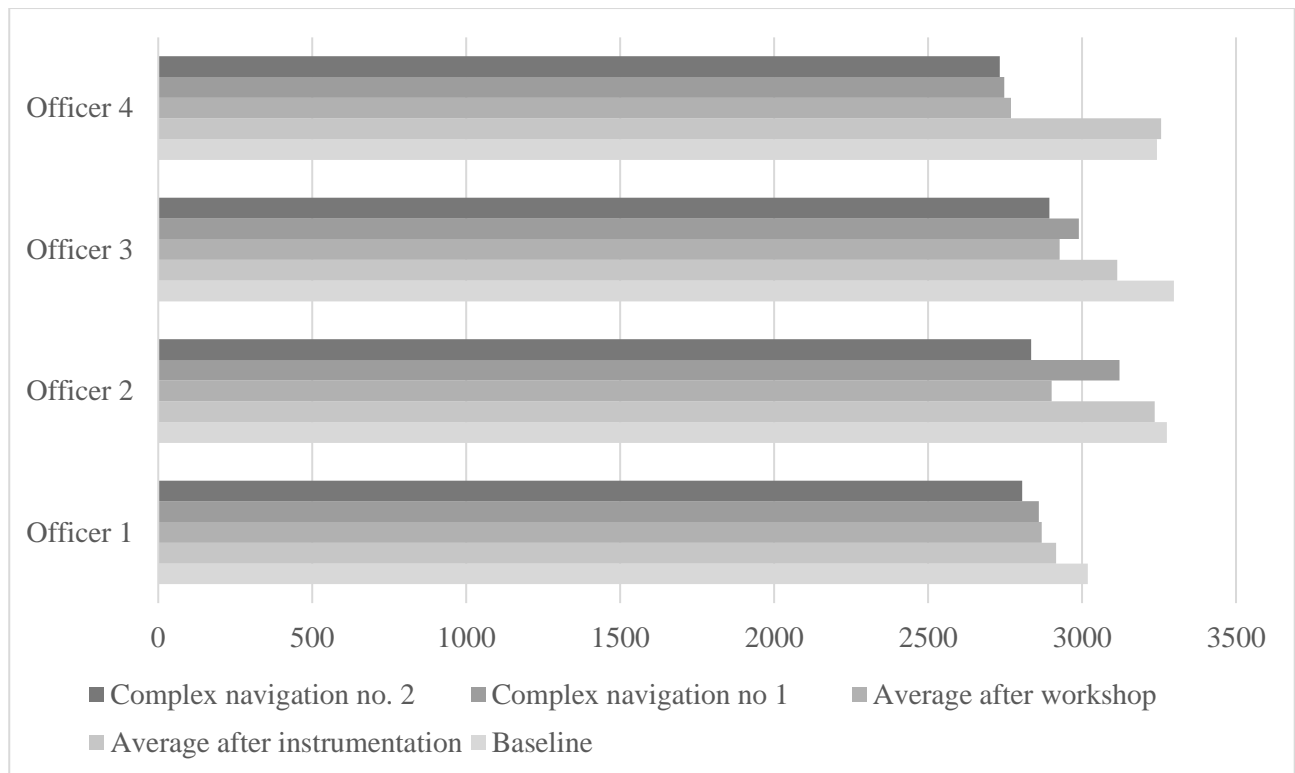


Figure 3. Fuel consumption - unit [litre].

## 4.2 Topics discussed during the practical workshop – Reflection-on-actions

After the first five sailing sessions, the officers were invited to meet each other in a workshop. During this meeting, they were presented with the logged data for each of their voyages. They were able to see the energy consumption in each mode and also had information about the equipment that was running.

The topics that were discussed during the meeting can be separated into four categories

- Technical issues – use of equipment
  - o Rudder: Autopilot / use of helmsman / rate of turn
  - o The effect of changing RPM and/or pitch
  - o The use of bow thrusters – effect, on/off
  - o The use of generators after sea passage
  - o The use of redundant equipment
- The communication between bridge and engine room
  - o The importance of knowledge about the response time from ordering equipment to be started until it is running
  - o The same understanding of orders
- The shallow water effect.
  - o The shift from shallow water to deeper depth.
  - o Effect on speed
- Time planning. Arrival just in time is discussed.

## 4.3 Instructors' general comments

General comments about the voyages after the instrumentation:

- The officers had their attention on the indicator – considering how the indicator could be used. What would happen if I did this?

After the workshop

- The instructors experienced that the officers still had their own individual way of navigating the vessel - a special signature, which was normally seen in both real navigation and simulator training. However, all officers considered the topics that were discussed during the meeting. Habits and practices were changed where they fit into the navigational pattern of the officer; they challenged their better-safe-than-sorry mindset without compromising their sense of safe navigation.
- After the discussion, the officers were more focussed on saving energy. It could be seen that a degree of self-competition had been introduced; they now had an idea of the factors that might influence the energy-efficient way of sailing the vessel.

The increased complexity of navigation

- The officers were more focussed on the navigation, especially on the first voyage with more complex navigation. However, the energy efficiency experience they picked up was not forgotten and the navigation was still better than before the meeting. The individual navigation signature could still be identified, but in the first complex voyage, all officers experienced an increased comfort-zone affecting the balance between safety and energy efficiency.
- In the second voyage with complex navigation, they did not have the same need for a large comfort-zone and they again acted as in a non-complex situation.

#### **4.4 Analysis of the test**

In the analysis of the test result, the term “comfort zone” will be used. A comfort zone is a psychological state and the term is defined as “a behavioural state where people operate in an anxiety-neutral position” (White, 2009). Stepping out of the comfort zone will result in feeling a loss of control. The better-safe-than-sorry mindset can be translated into the need for a wider comfort zone, where the zone is widened by the use of redundant equipment, even though external requirements or weather conditions not require this. The comfort zone is a psychological state, which is why a decrease in the comfort zone has to be a personal choice; otherwise, it could result in an increase in anxiety and cause stress reactions. The comfort zone for the *novice* and *advanced beginner* will be regulated by procedures and regulations, creating a feeling that if these are met, he will be inside the comfort zone. For the *competent*, it is possible to challenge this; the problem is to cope with multiple options and therefore he will need instruction on ways to challenge the comfort zone. The reflection-on-action in a group offers this – here different options and actions can be discussed with other students. Using the simulator, the comfort zone can be challenged in a safe environment, the correct balance between safety and energy efficiency could be explored and the experience could affect the proficient recognition of important aspects.

Officer 1: This officer had the same navigational pattern in all his voyages – he was using nearly the same time and fuel in the individual modes. He had the best performance of all four participants from the beginning, and he had an almost even learning curve during the tests. Unfortunately, he experienced some challenges due to engine failure in his first voyages; his reflection-on-action therefore had a negative effect on his desire to experiment in the later voyages. During the first baseline voyage, he decided to stop one of the steering engines, but as he arrived too late in the next voyage and also experienced engine failure in his third voyage, he decided to keep both steering engines running in the remaining tests. He was using the fuel indicator effectively – testing different engine settings - making reflections-on actions. The engine failure in the third voyage was simulator-related and was not his fault – but even though this was explained to him, he did not stop the second steering engine again. His navigation was not affected when the complexity was increased and it seemed as though his comfort zone was not affected and he operated in an anxiety-neutral



mode. This could indicate that he had moved to a proficient level of acquiring skills and that he recognised the difference in the situation, but this reflection-in-action was that the way he conducted the voyage was safe, even though visibility was reduced and the traffic increased.

Officer 2: The improvement in performance after installation of the indicator on the bridge was very small. The officer used the indicator for adjustments to the engine settings reflecting on the response. Unfortunately, the effect of his attempt was small, but the discussion with the other officers - the reflection-on-action in a group - had a large effect on the energy-efficient way of sailing the vessel. This gave him other perspectives on how to obtain energy savings, techniques that he would not have come up with himself. The change was significant in all three modes - during *manoeuvring in the harbour, in the confined water* and in the *passage* mode. When the navigational complexity was increased, the energy consumption rose – safety was in focus, and there was a need to increase the comfort zone by running redundant equipment. However, in the following voyage, which was also complex, the officer's comfort-zone was decreased and he returned to the same pattern as in the non-complex situation – his reflection-in-action was that the redundant equipment was not needed.

Officer 3: The instrumentation of the bridge had a relatively large impact on the fuel consumption in all three modes. The officer was experimenting - he definitely reflected-on-action – but the best result was the first. The discussion in the workshop (reflection-on-action in the group) had a great impact on the fuel consumption for this officer, as for officer 2. The reduction was mainly obtained in the two *manoeuvring* modes, and in the *passage* mode only a slight reduction could be observed. The reduction was mainly achieved by shutting down redundant equipment and reducing the speed during manoeuvring in confined water. Before the discussion, this officer had a relatively large comfort-zone, but discussions during the workshop on respite time for starting up equipment had an impact on this. When the complexity of navigation was increased, the need for increasing the comfort-zone again occurred, and therefore redundant equipment was kept running for a longer time, increasing the consumption in the two *manoeuvring* modes. In the second complex voyage, a reduction was seen again, as the officer's reflection-on-action result in the decreased visibility and the increase in traffic did not require redundant equipment.

Officer 4: The instrumentation of the bridge had no effect for this officer. He was not using the indicator systematically and the fuel consumption during the baseline voyages and the consumption after instrumentation was very much the same. He was not experimenting and not reflecting, but following the plan given by the instructor - he stayed as an *advance beginner*, maybe competent but with limited perspectives for planning making. However, after the discussion - reflection-on-action in the group - a significant reduction in the fuel consumption could be observed in all three modes. This reduction was

obtained by shutting down redundant equipment and adjusting the speed settings. This officer learned a lot from the others' experience and the common reflection. A slight improvement could be observed in the remaining voyages, as he was beginning to experiment, mainly driven by competition, but he needed to reflect in-group, otherwise it had a limited effect on him. His navigation was not affected when the complexity was increased; he did not see the complexity changes as aspects that affected safe navigation, or at least, they did not change his comfort zone.

All four officers reduced their energy consumption, and so an effect of the indicator was obtained, but the impact and the ability to use it as feedback in a reflection-on-action done by the officer alone depended on the skill the officer had achieved in earlier situations. The discussion in the workshop had most impact on the energy consumption, leading to operation that was more efficient. The officers learned from each other, their identities were still intact, but the discussion – reflection-on-action in a group - had offered new perspectives, which were used for optimisation. Their awareness was more holistic – like it was seen for the *proficient*.

## **5 Discussion**

Education is often mentioned as an essential factor to gain more energy-efficient operation (DNV GL, 2015, Ballou, 2013). The way safety is an integral part of the education today can be used as inspiration. This study shows that it is possible, using only a few resources, to integrate energy efficiency management into the simulator training. In today's ship handling simulator training, the students normally take turns, and the social learning praxis as performed in the reflection-on-action in a group will then be a part of the training from the beginning.

It has to be acknowledged that ships of today are operated more and more efficiently, and that the few people on board are not likely to be able to take on further work. If energy-efficient operation creates an extra workload, it is likely to end in failure (Ballou, 2013). Therefore, energy awareness and energy-efficient operation have to be part of an intuitive decision-making process, and therefore have to be part of the education. When the seafarer later acts as *expert* in complex situations, it is not something the seafarer will have to consider, but it is a way of doing, as is seen with safety issues today.

The test results in this study showed that installing technical equipment does not work alone; a combination of technical equipment like in this test, a fuel monitor and awareness training like reflection-on-action in a group has by far the best result.

After the tests, all the officers were invited for a talk, with the intention of reflecting on what they had learned and the effectiveness of using simulator training for learning energy-efficient ship operation. The officers found that they had learned a lot during the tests and they felt that it was relevant to test the theories

on energy-efficient operation in practice. They had had the lectures on energy efficiency during their previous education, which had mostly focussed on aspects such as law and management. They expressed the need to use their skills in practice in order to achieve the competence to operate the ship more energy efficiently. This is supported by the learning theories and the survey from Banks (Banks, 2015) that learning-by-doing is an effective tool.

During the discussion, the officers were encouraged to share their thoughts on how the experience gained during the simulator sessions could be used in their future working life as officers. Unfortunately, their answers revealed that they had very little influence on the energy consumption on board. When manoeuvring a vessel, the Master of the ship is in command and he alone takes the decisions on how the equipment is run. The officers all made negative remarks about that – saying that if they were not allowed to use the acquired skills before they became masters, they believed they would forget them, and therefore it was important to train the older and more experienced officers as well. They expressed their concerns about the long time effect of the training. If they were not allowed to use the acquired skills before they became masters, they believed they would not recognise energy consumption as an important aspect. This was also mentioned in the article by Banks (Banks et al, 2014), where the possibility for onboard training was rejected, which was due to the lack of competence of the more experienced officers of today. It is therefore important that future training in energy-efficient operation and awareness should focus both on cadet training and also on the further education of experienced officers.

## **6 Conclusion**

The results of the simulator tests in this study show that a combination of installing technical equipment and raising the awareness - making room for reflections-on and in-action - can have an effect on the energy consumption. On average, the participants saved approximately 10% fuel. At the beginning, the officers were all focussed on the safety issue, but during the exercises, they found a suitable balance between safety and managing the energy efficiency. The study was performed in a protected environment, which a simulator offers, and the savings cannot be directly transferred to a situation at sea, but a positive effect can be identified. Some bigger shipping companies have simulators for their vessels in order to be able to practice manoeuvring in a protected environment, and for these companies it will be possible to copy this experiment and in that way support the awareness training.

The test described in this study gives an answer to how full-mission navigation simulators can be used to establish a learning process where the reflections- in and on -actions will make room for more energy-efficient operation of vessels. But the analysis also points to barriers to the long-term effect and that it is important not to create a sheltered learning process at the schools, but also make room for the further education of experienced officers. If this is done, the students will be able to include energy consumption as an important aspect in the future when they act as competent officers.

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