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Energy Efficient Operation of Offshore Supply Vessels – A Framework

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Abstract

Most performance systems in the market have been developed for long distance sailing and cannot be used directly at working vessels having unpredictable and flexible operation profiles. The aim of this paper is to present a framework that describes the overall decision structures in connection with energy optimisation of offshore supply vessels. Modelling a framework like this requires a deep insight into the operation of ships and therefore a high level of crew involvement has taken place.

1. Introduction

For many years, there has been a growing focus on energy efficient operation of vessels. Stakeholders in the maritime industry have identified several methods to improve energy efficiency and a large number of studies estimating ways to improve cost-effectiveness have been performed. The increasing pressures from environmental problems, human health and global climate change have also resulted in new legislation for reduction in greenhouse gas emissions.

Despite the fact that knowledge of ways to improve cost-effectiveness are well understood in the industry, there is only minor emphasis on energy efficient operation on board many offshore vessels of today. Optimising energy efficiency on these vessels can be very difficult; the vessels are known to be involved in many different operations and therefore they have a very complex operation profile, which is difficult to evaluate and to compare. Furthermore, safety issues and optimising the time available for performing offshore work has been a topic of focus for many years. The offshore work is normally very time consuming and well paid compared to the fuel oil costs.

The regulatory framework is also mostly focused on safety issues, and international regulations on energy efficiency are not applicable for offshore supply vessels. The International Maritime Organisation (IMO) has 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 regulation entered into force in January 2013 with the adoption of amendments to MARPOL Annex VI – adding a new chapter on Regulations on energy efficiency for ships, *IMO (2011)*. Where EEDI sets the design limits for new vessels, the intention of the SEEMP is to improve daily operation on-board. The SEEMP is mandatory for all vessels, and also non-transport vessels operating as working vessels, whereas only cargo carrying vessels are included in the EEDI approach of today. The conventional transport vessels operating as container vessels, tankers and bulk carriers are easy to categorise – they are intended for one purpose with a single design point specified with a given cargo load and design speed. The more specialised vessels such as e.g. offshore supply vessels are not covered by the regulations as propulsion type, speed and operations are varying, and it is difficult to define a fixed design point. EEOI is a voluntary guidance tool for existing ships that can help to identify best practices for fuel-efficient operation. The EEOI is based on transport work (cargo transported per nautical mile per ton of fuel), which makes it unusable for most working vessels such as e.g. offshore supply vessels. Lately the European Union has pushed forward an EU-wide legal framework for monitoring, verification and reporting MRV of CO₂ emissions from maritime transport, *EU (2015)*. This regulation, which was adopted on 29th April 2015, applies to larger vessels (over 5000 gross tonnage) calling at EU ports from 1st January 2018 to collect and later publish data on CO₂ emissions; most offshore vessels are below 5000 GT and therefore not included in the regulation.

Guidelines for offshore marine operations, such as *G-OMO (2013)* and regulations like the ISM code, *IMO (2014)* and the safety management system (SMS), which is an important part of the ISM code, are introduced to establish good practice for safe operations, and concerns regarding energy efficiency are not included. These considerations and initiatives must be implemented by the shipping company itself. Furthermore, many offshore vessels are operated on a time charter basis meaning that the capital and the operational costs including the investment in fuel efficiency of the vessel are paid by the owner, whereas the voyage cost including the fuel are paid by the charter. This, which is also called the split incentives problem, does not promote the energy efficiency initiative either.

The number of offshore vessels is increasing; *OECD (2015)* concludes that in the period from 2014 to 2025 there will be a growing demand for energy, which will have an effect on the offshore shipping market. For example, the demand in offshore support vessels engaged as installation supply vessels is expected to grow by 50% and the demand for wind turbine installations vessels by 117%. The numbers are at present challenged by the fall in the oil prices but long-term studies show that there will be a growing demand.

The total CO₂ emissions for offshore and service vessels is estimated to be 6% of the total emissions from ships, *Smith et al. (2015)*. Therefore, there is a need for a special focus on these vessels and on the development of systems that help the crew and ship-owner to optimise operations and to reduce energy consumption.

2. Methods and Framework

The aim of this section is to present a framework that describes the overall structure of a system for energy optimisation of offshore supply vessels. The process of developing the framework is described briefly. Data collected, people involved, analyses and finally the framework connecting the findings from the analysis is presented.

2.1. Data Collection

Data used for the present study includes a wide range of qualitative data - documentary data, interviews, workshops and observations on board a vessel. Technical data is generated by studying ship drawings, and collecting information from system configurations, technical specifications and layout. Specific company information including policies, operational guidelines and procedures from the Safety Management System (SMS) and other internal documents and HSQE programs etc. were studied. The content of the ship's energy efficiency management plan (SEEMP) together with the use of the plan was also examined in greater detail.

As the study requires a deep insight into the operation of a ship, there has been a high level of involvement of people having operational knowledge during the process of developing a model for the framework. A shipping company, operating an offshore supply vessel, has been involved. 21 interviews, 4 with represents from both technical and HSQE departments and 17 interviews with the crew, have been carried out. The initial model idea was presented and discussed, and the knowledge obtained was used to re-define and update the model. Three workshops with experienced officers have been conducted. The officers were specially invited to assist with development and validation of the framework. Voyage and work descriptions were discussed in detail, and their technical experience and knowledge was used to define technical systems on-board.

2.2. Analysis – Operational Findings

From the initial literature review and during interviews and workshops it was found that an energy management system for these vessels requires a thorough description of the working pattern – the modes, the work done in each mode and a clear description of the transition between modes. Furthermore, it was also found that decisions taken or requirements set by both internal and external actors, including the ship owner, charter, costumer and authorities, have a large influence on the daily

operation of the vessel. Finally, yet importantly, if the system shall be regarded as a support system, it must be meaningful for the crew and fit to the vessel and the technical installations on board.

2.2.1. Modes and Operations

From interviews and workshops with the experienced officers it was found, that the phases of a typical voyage for a working vessel can be described by four main modes. The first three modes, which have been denoted as, harbour, manoeuvring and passage will be equally described for most vessels, whereas the last mode denoted as offshore work will characterise the special purpose of a vessel.

- Harbour: The vessel is alongside the harbour, moored with lines, with the engine and thrusters stopped.
- Manoeuvring: The vessel is manoeuvring in the harbour or in a restricted area. Propulsion and manoeuvring systems including the engine, thrusters and maybe DP (dynamic positioning) are running.
- Passage: The vessel is on passage between fixed positions.
- Offshore work: The vessel can be involved in a number of different types of offshore work depending on the ship's characteristics. The work is described by one or more operations performed in the specific mode. Operations related to offshore work could be cargo transfer, anchor handling, towing, or acting as a standby vessel.

2.2.2. Activity State

One of the main findings from the analysis was the importance of having a clear set of detailed definitions of the transitions between modes and also attaching an activity state to each mode. Three main activity states were defined; namely, active, preparation and waiting.

- Active: The vessel is performing as pre-described. If the involved operation tasks are taken into account, it is possible to compare active modes of the same type. Noticing systems running and the amount of equipment started, together with the load rates and the energy consumption will give a clear picture of the energy efficiency and possible energy saving opportunities.
- Preparation: Preparing the vessel for a mode is a necessary task. To start-up engines, pumps and thrusters takes time. It is un-productive but necessary time used.
- Waiting: Waiting is un-productive time. When, who or what causes these delays – and furthermore, how they can be avoided – must be analysed.

2.2.3. Requirements

Requirements for operating a vessel are laid down by a number of different actors. In the present model, these actors have been separated into three groups: the authorities, the shipping company, and external stakeholders as a possible charter or the customers. The authority group covers regulations from international and national regulators including IMO and national authorities; this could be regulations on minimum requirements to stability, ballast water handling, when and how to conduct drills, or environmental regulations applying to special emission control areas such as ECA. Regulations laid down by authorities are mandatory and must be fulfilled. The other group of requirements is laid down by the shipping company itself. These requirements will always be stricter than requirements set by the authorities. These requirements could include procedures on how to handle the ship in extreme weather e.g. specific requirements for stability and speed, or it could be procedures for start-up of engine equipment in relation to special operations. External stakeholders, mostly the charterer, can have special requirements regarding e.g. readiness, speed or time of arrival. It is important to notice from whom the requirement is set – requirements set by the company or the charterer are not mandatory and can be evaluated, discussed or negotiated, if it is found that they conflict with improved energy efficiency.

2.2.4. Systems and Equipment

In order to establish a model for determining the energy efficiency of a vessel, it is necessary to have knowledge of design and technical systems on-board. Energy consuming systems running in modes such as systems for propulsion, ballast water, manoeuvring and the underlying equipment such as pumps, generators and steering gear must be mapped and described in detail.

2.2.5. The Framework

The concept model describes the problem based on results from the analysis and findings. The model provides an overview of a whole voyage of the vessel and describes the connection between different actors, requirements, modes, operations, technical systems etc. Fig. 1 depicts the conceptual model, in which the outer boundary – the voyage – indicates that the system covers a complete voyage. The next layer – the vessel – is influenced by the requirements of authorities, the shipping company or external stakeholders and from fixed or variable environmental conditions such as wind, sea, water depth etc. The core of the vessel layer is organised into three main columns, namely “Operational Objectives”, “Technical systems” and “Equipment” – a terminology known by the crew. The two columns “Technical ship systems” and “Equipment” are determined by the ship’s design, whereas the “Operational Objectives” are a combination of the requirements and operations given for each mode in relation to the voyage. Inside the vessel layer is also the crew – it is the crew that, in the end, based on requirements, ship design and environmental conditions, makes the decision how to operate the vessel. By organising the model into columns, it is possible to show the connections and dependencies, which influence the decision processes.

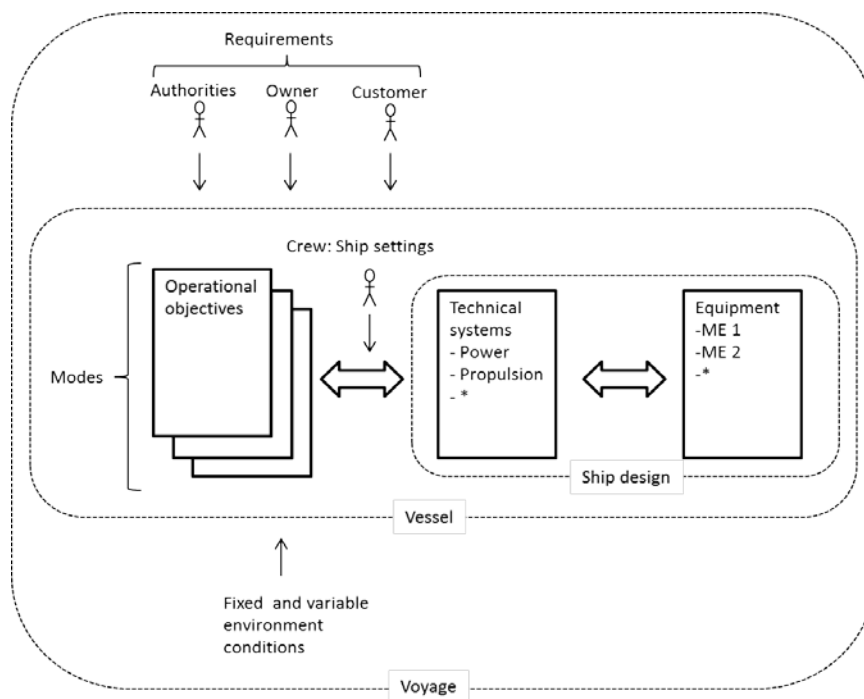


Fig.1: The framework

3. Case Study

The problem of operating and handling vessels having a very flexible working pattern is illustrated by a case describing a voyage for an offshore supply vessel. The section begins by providing a short description of offshore vessels and an introduction to the case. The voyage is described in detail. A clear description of what the vessel is doing during the voyage is given together with comments on the activity state and the transition between different modes. Potential energy savings are mentioned and commented upon.

The term ‘offshore vessels’ covers vessels supporting the industry of energy exploration and production activities offshore. The group consists of a variety of supply and service vessels assisting oil and gas installations and offshore wind farms. These vessels can be employed with towing and anchor handling (AHTS), cable laying, bringing supply (PSV), transferring crew to and from offshore areas, performing maintenance, and acting as standby vessels outfitted with safety and fire-fighting equipment. The vessels can be designed for multiple functions, and often a ship can change purpose, from e.g. AHTS to PSV repeatedly during its lifecycle. The primary purpose of the vessels is the work they perform at sea, and the work has therefore to be taken into account when a model for energy efficiency management is developed. The exploration activities are limited to the continental shelf relatively near to the coast and the sea passages will therefore be of limited length - this is contrary to energy efficient models for transport vessels such as container vessels where the sea passage will be in focus. Safety is an important factor in the offshore industry and special considerations are taken when offshore vessels enter exploration activity areas. Normally, a distance of 500m from the site is considered to be a safety zone, and vessels entering this zone must be extra careful. Offshore vessels working inside the 500m zone are required to follow special procedures, in many cases based on the G-OMO guidelines requiring backup on propulsion and manoeuvring systems.

The offshore vessels have a very complex and flexible working pattern and can, during one trip or voyage, perform many different operations. The detailed planning of a voyage is performed by the crew on-board the vessel, whereas the overall planning is performed by the shipping company or the charter. The time schedule is based on the work to be carried out and therefore, for this kind of vessel, the time schedule will normally be determined by the charter.

One of the main findings from the analysis in Section 2 was the importance of having a clear set of detailed definitions of the transitions between modes, and attaching an activity state to each mode. To reflect the activity state and the transition between modes a flowchart has been developed, see Fig. 2. This figure depicts modes and states. The arrows indicate the transitions between the states inside a mode and between the modes. Modes, states, and transitions need to be clearly defined and known by the crew. In the case description, modes are marked with bold whereas activity states are in italics.

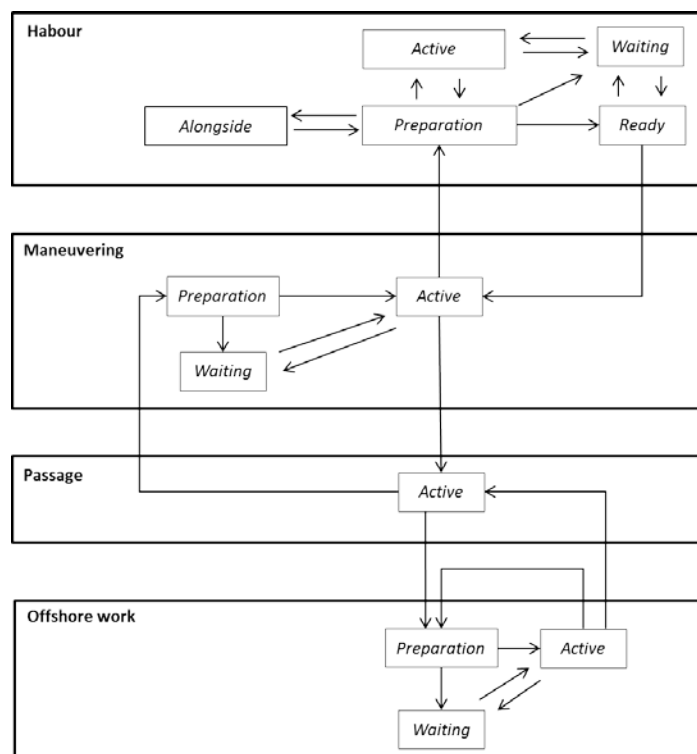


Fig. 2: Mode/state flowchart

Fig. 3 depicts the voyage flowchart with the involved modes. The numbers 1-15 are used to identify the modes in the voyage description, and the dashed lines around mode 4 and 11 indicate that these two modes are unplanned activities at the beginning of the voyage, and are therefore not a part of the voyage planning. The voyage is described in detail in the following description. A clear description of what the vessel is doing in the particular mode is given together with comments on the activity state and the transition between modes. Potential energy saving is also mentioned and commented in each description. If modes are repeated during the voyage, the detailed description is only included the first time the mode is described.

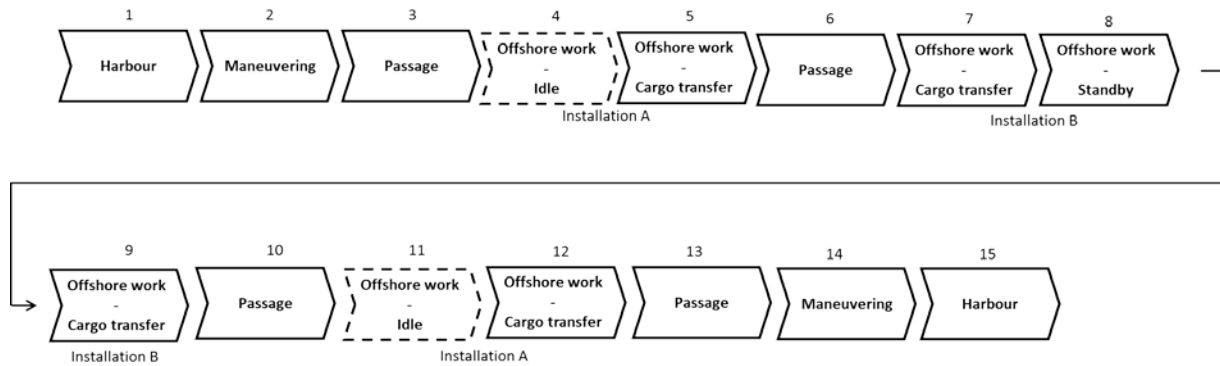


Fig. 3: Voyage flowchart

For each mode, technical systems and the underlying equipment required for running the operation safely and in an energy efficient way must be described. This leads to the introduction of the dependency diagram shown in Fig. 4, where dependencies between operational objectives, technical systems and equipment are modelled. The two columns “Technical ship systems” and “Equipment” are determined by the ship design and technical layout, whereas the “Operational objectives” are a collection of objectives directly related to the given mode and operations. The dashed lines in Fig. 4 indicate the possibility to start up extra equipment i.e. if extra energy is needed.

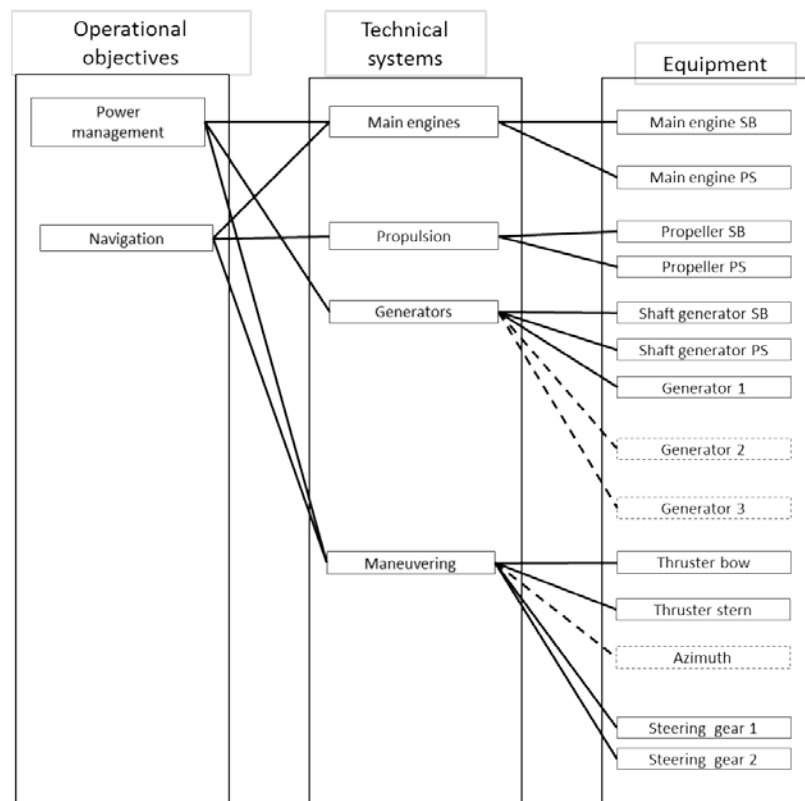


Fig. 4: Dependency diagram – Operational objectives, technical system and equipment on-board

3.1 The Case

The problem of operating and handling working vessels is illustrated by a case describing a single voyage for an offshore supply vessel. The vessel is on a time charter contract covering voyages between the shore base in a harbour and a number of fixed offshore oil and gas production installations. The voyage starts alongside the harbour, the ship is fully loaded and ready to let go of the mooring lines.

The planned tasks for the voyage are as follows: Cargo transfer from the harbour to installation A, cargo transfer from installation A to installation B, be standby vessel at installation B for a shorter period, cargo transfer from installation B to installation A and then returning to port with empty containers and garbage. An unplanned activity occurs during the voyage where a broken pump from installation A is sent ashore for repair.

3.1.1. Harbour (1)

The vessel is *alongside*, fully loaded and *preparation* for departure begins. During the *preparation* state, the bridge and the engine room are made ready for departure, following company procedures and checklists from the safety management system (SMS); this preparation takes approximately half an hour. Bridge and engine systems including radar, engines, and thrusters are made ready for operation. When all preparations are completed and checklists are filled out, the vessel is *ready* for departure and the port control is advised. The transition from **Harbour** mode to **Manoeuvring** mode occurs when the crew start to let go of the mooring lines.

Energy saving – comments: The vessel can be delayed after the preparations are finished, due to late arrival of cargo, delayed paperwork, waiting for other vessels leaving or entering port etc. This causes non-productive *waiting* time and extra energy consumption as equipment such as the main engines are running.

3.1.2. Manoeuvring (2)

The vessel is in the *active* state and the crew starts manoeuvring the vessel, which will bring it from the quay to a specific position outside the harbour area. In the present case, the vessel leaves the port without *waiting*. In the **Manoeuvring** mode, the engine room will be manned and there will normally be an extra officer at the bridge; the manning demand is described by procedures in the SMS system. Propulsion and manoeuvring systems such as engines, thrusters, and steering gear are running. The navigation must normally be performed with caution as the ratio between draft and water depth is often low, the opportunity for deviating from course is therefore limited.

Energy saving – comments: It is, from an energy efficiency perspective, always important to consider the amount of equipment needed for a particular task. Here, a number of objectives must be taken into account, such as the requirements from the owner or charter, weather conditions, complexity of the harbour area, competences of the crew etc. For some vessels, the amount of equipment that is running will be controlled by pre-described SMS procedures determined by the shipping company, as an example, the number of running thrusters in many cases is based on a worst-case scenario set for reasons of safety.

3.1.3. Passage (3)

When the vessel is outside the harbour area, thrusters are stopped and engines transferred to bridge control, this is the transition between the modes **Manoeuvring** and **Passage**, and the vessel is now *active* in the passage mode. Arrival time at the offshore installation A is set by the charter for the next morning at 7 a.m. The crew on board calculates and proceeds at the lowest necessary speed. Upon arrival at installation A, it turns out that the installation is not ready to receive cargo before 10 a.m. The charter's representative at the installation informs the vessel to wait until further information is

given. This leads to an additional unplanned mode, here denoted as the **Offshore Work - Idle** mode.

Energy saving – comments: If the charter had sent an updated time for arrival, the speed could have been adjusted accordingly and thereby energy could have been saved.

3.1.4. Offshore work – Idle (4)

The waiting will be done outside the 500m safety zone, so the only *preparation* is reducing speed and changing course to compensate for wind and sea.

Energy saving – comments: If the weather is calm, the main engines can be stopped and the installed azimuth propeller can be used to keep the vessel outside the 500m safety zone. Using the azimuth instead of the main engines will reduce energy consumption.

3.1.5. Offshore Work – Cargo Transfer (5)

Transferring cargo to the offshore installation requires entering the 500m safety zone of the installation. Before entering the zone, the crew will perform the preparation procedure and fill out the checklists, the vessel goes from *active* in the **Offshore Work – Idle** mode to *preparation* for the **Offshore Work - Cargo Transfer** mode. Depending on owner or charters requirements, the configuration of the vessel can differ due to weather conditions and e.g. crane reach out at the installation. In some cases, an active DP system (Dynamic Positioning) is required before entering the safety zone. Building up the DP model takes about half an hour, which is considered to be a part of the *preparation*. Inside the safety zone, it is a requirement that the engine room is manned and two officers are present at the bridge. When the preparation checklist for entering the 500m safety zone is completed and the DP system is started, the vessel is ready for the *active* state under the crane. Unfortunately, it turns out that installation A is not ready for cargo transfer, and the vessel enters the *waiting* state.

Energy saving – comments: *Waiting* alongside the installation due to interruptions in crane operations is unproductive time and must be avoided by better planning at the installation. In this particular case, the active DP system is not required and the half hour used for initialising the system can be saved. Being inside the 500m safety zone, procedure guidelines require backup on propulsion and manoeuvring systems, meaning that extra equipment is running. Time used inside the zone must be minimised as energy costs are increased; advantageously the vessel should stay outside the zone as long as possible.

3.1.6. Passage (6)

After the cargo transfer at installation A is completed, the next task will be cargo transfer at 9 a.m. the next day at installation B. The passage to installation B is short which allow ultra-slow steaming.

Energy saving – comments: The vessel is equipped with two main engines, but also with an azimuth propeller, which can be used for ultra-slow steaming in calm weather; this will reduce the energy consumption.

3.1.7. Offshore Work – Cargo Transfer (7)

As the ETA was estimated correct, the vessel went directly from **Passage active** state to *preparation* state in the **Offshore Work – Cargo Transfer**. Installation B is normally unmanned and the embarking of people is, due to safety reasons, done by helicopter. The schedule for the helicopter gives the required time of arrival for the vessel. The crew transferred to the installation will, during the day, handle the cargo transfer and perform other maintenance tasks at the installation. The crew at the vessel have to perform the same preparations for transition to the **Offshore Work – Cargo Transfer** mode as described in mode 5. When alongside the offshore installation the cargo, i.e. tools

and equipment for today's work, is transferred, before the vessel leaves the 500m safety zone again. The vessel is now standby vessel at the installation.

3.1.8. Offshore Work – Standby (8)

Even though the vessel now is in a waiting position, the state for **Offshore Work– Standby** is *active*, as this is a part of the requested work. Here, the standby mode is split into two – work outside and inside the 500m safety zone, respectively. The first part is done outside the safety zone; the vessel is then called inside the zone for being standby due to outboard work at the installation. Before entering the 500m safety zone the vessel has to perform the same preparations as described in mode 5.

Energy saving – comments: The time the vessel is inside the 500m safety zone must be limited, as extra machinery equipment is required. The vessel has to run the procedure for preparation for entering the 500m zone twice. In situations like this, the crew must carefully consider whether they shall leave or stay inside the zone.

3.1.9. Offshore Work – Cargo Transfer (9)

After the work at the platform is finished, the cargo and crew is returned to the vessel. No *preparation* is needed as the vessel is already inside the zone. After the work has been performed, the vessel leaves the safety zone; non-necessary equipment and DP is stopped and engines are transferred to bridge control. This is the transition between the **Offshore Work** and **Passage** modes; the vessel is now *active* in the passage mode.

3.1.10. Passage (10)

At the **Passage** from installation B to A the vessel is requested by charter to use normal cruise speed. Unfortunately, the installation cannot receive cargo transfer before the next day, which results in unplanned waiting for the vessel. The installation plans are not forwarded to the ship, meaning that the vessels will enter the **Offshore work – Idle** mode upon arrival.

Energy saving – comments: Ultra-slow steaming on azimuth propellers could have been used if the vessel had been informed about the work plan of the installation. The energy consumption would have been reduced.

3.1.11. Offshore Work – Idle (11)

The vessel will be waiting outside the safety zone at the installation. Due to calm weather conditions, it is decided to stop the main engines and start the azimuth propeller.

Energy saving – comments: Using azimuth propellers instead of the main engines saves energy.

3.1.12. Offshore Work – Cargo Transfer (12)

The next day the vessel will be prepared for the cargo transfer at installation A. Before entering the 500m safety zone, the preparations described in mode 5 are performed. Alongside the installation, the vessel is loaded with empty containers and a broken pump. The pump is important for production and the vessel is requested by the charter to sail to port as fast as possible with the pump for repair.

3.1.13. Passage (13)

The request from the charter results in steaming at maximum speed.

Energy saving – comments: Maximum speed does not leave room for energy saving, but it is

important for the vessel to observe states of wind and wave and the ratio between draft and water depth in order to adjust the speed and course to avoid using energy without gaining speed.

3.1.14. Manoeuvring (14)

Outside the harbour area, the vessel goes into the **Manoeuvring preparation** state. The engine room is manned and there is an extra officer at the bridge. Thrusters are started and everything is made ready for manoeuvring – procedures described in the SMS system are followed and checklists are filled out. When all preparations on the bridge and in the engine room are performed, the vessel enters the *active* state and manoeuvring into the harbour and the quay can start.

3.1.15. Harbour (15)

The vessel is now alongside, mooring lines are fastened and engines stopped. The vessel is ready for unloading.

4. Discussions

Despite the fact that knowledge of cost-effective improvements are well known in the industry, energy efficient operation is only a minor or even neglected topic on board many working vessels of today. In the present section, the case study from Section 3 will be used as basis for discussing the problem. The case, which describes the problem of operating and handling vessels with a very flexible working pattern, is a simple example but the problems related to energy efficient operation are well known across the industry.

The case, which is built upon statements and comments from the crew on-board a supply vessel and discussions with experienced officers invited for workshops (see Section 2), shows that the reasons for not running a ship in the most energy efficient way can generally be separated into two main reasons, namely un-productive time and unnecessary equipment running. These two topics will be discussed in the following discussion. The sections end with a short summary and an introduction to possible ways forward.

4.1. Un-productive Time

The main reasons for un-productive time (waiting) are related to ineffective planning or poor communication. Waiting relates mostly to external factors such as requests from charter, and the crew on-board the vessel has often no influence. A very common situation may occur when a vessel arrives on time to the specified destination to discover that the harbour or installation is not ready. This situation has been experienced many times by both crew and officers interviewed in Section 2. This demonstrates the same problem as seen in the case study described in Section 3. A non-productive waiting at arrival to the destination may occur when the vessel is forced to go from the **Passage** mode to **Offshore work – Idle**; because the installation is not ready, see mode 4 and 11 in the case study. Time spent in this mode can be seen as time wasted due to poor planning or bad communication. The too early arrival request from the installation will cause the vessel to proceed at high speed with unnecessary extra fuel consumption during the passage. It could be argued that **Offshore - Idle** should be part of the mode **Offshore work - cargo transfer** in mode 5 and not be given a separate mode, but this would conceal the time wasted due to planning errors. Mode 4 and 11 could both have been avoided with better planning; introducing the extra mode makes the problem more visible for charter and owner.

In some cases, it might be necessary for the vessel to wait, and entering the mode **Offshore work–idle** could be a good choice. This is illustrated in the case in mode 5 where the vessel starts preparation for **Offshore work - cargo transfer**. The installation is not ready which results in unnecessary waiting time with all engines running, resulting in an increased energy consumption. In other situations it might be better that the vessel is ready and waiting with engines running, but it is only if the waste of time and energy is identified that it is possible to make a well-founded choice. State-

ments from experienced officers working in companies where installation and vessel are part of the same company shows that there has been a movement towards a situation where installations have to be ready when the vessel arrives, otherwise the supply transferee has to wait until the next time the vessel arrives at the installation. This will probably lead to more careful planning and communication. If the time spent in **Offshore work – Idle** mode was visible to owner and charter they could discuss this issue and probably find a solution. Fuel costs are paid by the charter, which in most cases is the owner of the installation - knowing that fuel could be saved with a more precise arrival would probably facilitate communication and cooperation between the ship and the installation.

4.2. Unnecessarily Start-up of Equipment

The appraisal of what equipment is necessary in a certain situation is done by the crew on-board the vessel, and often it is a decision made only by the captain. In some situations, the safety management system will provide guidance to the crew and captain as to what the owner sees as necessary equipment. This guidance is often based on fleet experiences and near-miss reports. The interviews performed in relation to the present study have shown that the captain on-board the vessel tends to have more engines and other equipment running than necessary, so if one engine sets out, the redundant one can take over. The modes **Manoeuvring** and **Offshore work** are the two modes where this reflection between safety, or the need for redundancy, and energy efficiency are most pronounced. *Bonavita et al. (2008)* uses the concept of a comfort zone in the context of oil and gas production. The comfort zones are the bands between production constraints and the actual production values. In the oil and gas production industry the operators should strive to minimise the comfort zones and thereby increase production and at the same time reduce energy consumption. The concept of a comfort zone can also be used in this context i.e. if unnecessary equipment is running during operation where neither external requirements nor weather conditions requires it, the comfort zone is too wide. A number of factors incite the crew for the increased comfort zone and procedures and regulations tend to promote safety behaviour ignoring the energy efficient operation of the vessel. Many procedures are built on worst-case scenarios and the main purpose of the SMS is to make sure that the vessel is running in a safe manner i.e. guidelines for navigating a supply vessel in the 500m safety zone only focus on safety. Furthermore, many offshore vessels are operated on a time charter basis meaning that fuel is paid by the charter, which does not promote energy efficiency initiatives, the extra fuel cost is not taken into account.

4.3. The Way Forward

To increase awareness of the energy efficiency of supply vessels it is important to focus on the above-mentioned topics. The problems must be visible and presented for the crew, owner and charter and it must be possible to analyse a given situation.

If the vessel goes into waiting, when, who and what that causes it must be analysed - and furthermore, how this can be avoided. Running equipment must be registered together with practical need in the present situation. If more equipment than necessary is running, it must be possible to gain information about the reason. Is it due to regulations from authorities that are mandatory and therefore must be followed, procedures from owner or charter that may be evaluated for the given situation or is it the captain that runs more equipment because external factors such as wind and sea demand it for safety reasons.

To support the crew, charter and owner, the introduction of a decision support system must be introduced. The system should provide all parties with a transparent decision process and show the consequences to ensure that the crew only starts up necessary equipment and the owner and charter focuses on precise planning to avoid un-productive time. The system should also show the impact on the present situation caused by procedures set by charter and owner.

5. Conclusions

A framework that describes the overall decision structure in connection with energy efficient operation offshore supply vessels has been presented. The framework provides an overview of a whole voyage and describes the connections between different actors, requirements, modes and technical systems on-board. Modelling a framework like this requires a deep insight into the operation of a vessel, therefore a high involvement of people having operational knowledge has taken place. Workshops with experienced officers and 21 interviews with crew and office employees from a shipping company have been conducted.

From interviews and workshops, it was found that a typical voyage for working vessels can be separated into four modes, the first three apply to all kinds of vessels whereas the last mode denoted offshore work characterises the special purpose of a working vessel. One of the main findings from the analysis was the importance of having a detailed description of the transition between modes and attaching an activity state to each mode, as this allows monitoring of the vessels' operational patterns and identification of waiting time. Analysis of statements and comments from crew and officers shows that main reasons for not running a ship in the most energy efficient manner can generally be separated into two main topics, namely un-productive time and unnecessary equipment running.

The findings from the present analysis can be used for the development of a decision support system. The system should provide all parties, i.e. the crew, the owner and the charter, with a transparent decision process and show the consequences of this, to ensure that the crew only starts up necessary equipment and the owner and charter focuses on precise planning to avoid un-productive time.

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