Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria

Speeding up the Transition to Partly (Hybrid) or Fully Electric Waterborne Transportation through Education and Skills Upgrading

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Abstract

In response to the current development towards electric waterborne transportation, this paper introduces the consequent gap in maritime education. Although the transition is only slowly progressing, the first crew members have already started operating fully electric vessels, but without any battery-specific training or certification. In this paper, the magnitude and type of information required in the transition is assessed by comparing existing maritime educational standards with battery-specific regulations. From this comparison three focal areas are identified; safety operation behavior, electrical engineering skills and overcoming myths and misunderstandings. The paper analyzes how education can best be composed to speed up the transition to electric waterborne transportation through a case study based on the experiences from the E-ferry project and the educational strategy of the World's first pilot courses offered by a renowned Danish maritime academy. The paper concludes by recommending a range of myths that a course concept should help put to rest.

Keywords: Socio-Economics; Innovation and Policy; Education; Electric Waterborne Transportation; Electric Ferries.

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1. Introduction

In the context of recent major climate agreements, such as the 2020 and 2030 global sustainability goals, a growing trend towards finding environmentally friendly alternatives to conventional solutions is emerging, waterborne transportation being no exception. However, the transition to green technologies in vessels, be it partly (hybrid) or fully electric solutions, is only slowly progressing. A transition involves large time and monetary investments, and the technological development being in its infant stages further requires some degree of versatility towards risk from ship owners. A significant gap is the fact that owners do not have the full overview of what a transition to an electric vessel entails (Hagbarth Mikkelsen, 2015a; Siemens Danmark, 2016). Moreover, the new skill sets that crew members and managers are required to possess pose an additional barrier to a rapid transition to electric vessels (Hagbarth Mikkelsen et al., 2015; Gagatsi et al., 2016).

One of the most significant contributions to this transition is the Horizon 2020 supported E-ferry project, currently in the process of developing, constructing and demonstrating a fully electric ferry. The overarching goal of the E-ferry project is to demonstrate the feasibility of fully electric waterborne vessels travelling up to 10 times the distance between charges compared to the current World record (Gagatsi et al., 2016; Kristensen et al., forth.). The renowned Danish maritime academy, Marstal Navigationsskole (MARNAV), was one of the main-drivers on a preparatory feasibility study, and is currently closely involved in the project. Acknowledging the acute need for skills upgrading in the transition to electric waterborne transportation, MARNAV, as the first in Denmark and its neighboring countries, is developing an educational package to offer crew members, managers and ship owners of electric vessels (MARNAV, 2017).

The objective of this paper is to investigate what a transition to electric waterborne transportation would require in terms of education and skills upgrading of crew members, managers and ship owners. Moreover, we examine how upgrading skills in the maritime sector in Denmark and beyond can contribute to the transition.

In this paper we assess the magnitude and type of information needs required in the transition using the case of the E-ferry project and the challenges and needs that arise during the process of operationalizing the electric vessel. The interpretation of legal frameworks under the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) of the International Maritime Organization (IMO), as well as battery-specific regulations will form the foundation of the analysis. From this foundation, we analyze how education can best be composed to facilitate a transition to electric waterborne transportation through a case study based on the educational strategy of the pilot courses offered by MARNAV. The paper concludes with some recommendations for education and skills upgrading of the maritime sector in Denmark and beyond, including suggested course content, based on the experience at MARNAV, in order to overcome myths and misunderstandings in the maritime society.

2. Gaps in the standards for education and certification of seafarers

Although the number of electric ships is still limited and the growth in this number seems rather slow, the implementation of new technology often tends to follow an exponential growth thus numbers will be low in the beginning although they are doubling or tripling. The development in technology is rapid, pushed forward by recent game-changing projects, i.e. the retrofit of Norled's Ampere and HH Ferries' Tycho Brahe, and the EU supported new-building, Ellen in the E-ferry project. As illustrated in Figure 1 below, Hagbarth Mikkelsen et al. (2015) expects a shift in paradigm for short sea shipping towards electric solutions, and a technological breakthrough is not far out in the future. Some might say that we are already there, especially given the high level of technology readiness of the existing or upcoming fully electric ferries (Hagbarth Mikkelsen, 2015a; Shahan, 2015).

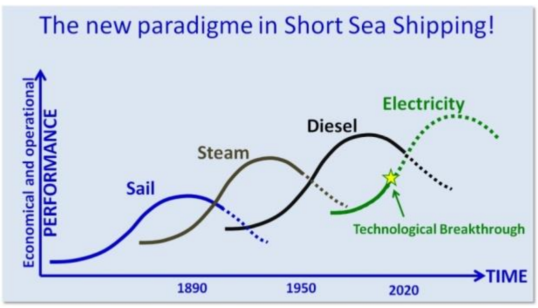

Fig. 1. The innovation S-curves of ship propulsion (Hagbarth Mikkelsen et al., 2015, p. 3)

Such a paradigm shift in maritime technology entails considerable impact on a wide range of parameters, there included the requirements to crew competences and educational needs. This relates especially to new safety requirements, understanding of batteries and battery systems and change in navigational behavior, but also to the overcoming of a number of myth and misinformation about batteries and electrical operation (Hagbarth Mikkelsen et al., 2015; Gagatsi et al., 2016; Mjøs et al., 2016).

Despite the technological development in vessel technology towards electric solutions, educational standards and regulations have not been updated for years. For instance, the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) has not been amended since 2010 (IMO, 2010). National legislation e.g. in local ferry operation is often adjusted faster, but also here no new legislation has been implemented or even planned yet looking at Denmark, Norway and Sweden.

2.1. Existing standards for maritime education and certification

Starting with the mandatory minimum requirements for certification of officers in charge of an engineering watch according to the STCW Convention chapter III the propulsion machinery output will define the appropriate education. Limitations to the certificates are introduced at respectively 750 kW and 3,000 kW propulsion power (IMO, 2010).

Below 750 kW the navigation officer can be in charge of the engine watch. Having two fully separated and redundant engine compartments of 750 kW each the Danish Maritime Authorities (DMA) have allowed the E-ferry to be operated only by a navigation officer up to 1,500 kW propulsion power. The standards for certification are set in section A-II/3 in the STCW Code (IMO, 2010) if the ship at the same time is less than 500 gross tonnage. Then only very little is required apart from basic training and firefighting knowledge and basic understanding of small ship power plants and auxiliaries.

If the electric ship has a propulsion power between 750 and 3,000 kW a certified engineer is needed meeting standards of education in section A-III/3 of the STCW Code (IMO, 2010). For propulsion power above 3,000 kW section A-III/2 will apply instead. In Denmark the certification of an electro-technical officer according to section A-III/6 in the STCW Code has been included in the education for all marine engineers. Hence they will have a good understanding of the electrical drivetrain except for the lithium-ion battery system which would be new territory for all seafarers.

Looking at the mandatory STCW requirements, it is obvious that existing legislation is based on the competences needed to run a fossil fuel engine with relevant auxiliary systems. The distinction between engine size, e.g. 750 kW for different educational requirements, gives only little meaning in the context of an electrical motor with permanent magnets where operation is fully automatic and no ongoing maintenance is needed for the first many thousand hours.

For electric waterborne transport it would be more appropriate to differentiate between AC and DC charging systems, water cooled or air cooled battery systems, high and low voltage inverter systems etc. Alternatively a differentiation by route length giving higher mandatory requirements for vessels sailing outside the range of immediate assistance from air support or similar would be suitable.

2.2. New requirements to the skills of crew members, managers and ship owners

Although this is not yet reflected in the educational standards, the needed skills in personnel on board an electric vessel, especially fully electric solutions, differs substantially from those needed on board a conventional vessel. In the following the most central battery-specific skills requirements in the context of maritime transportation are highlighted.

2.2.1. Safety operation behavior

Battery installation onboard a vessel is considered as an alternative design arrangement under the International Maritime Organization’s International Convention on the Safety of Life at Sea (SOLAS/IMO) and hence by most flag state approving organizations. While approval under the alternative design guidelines is mainly of concern to the suppliers, the necessary risk assessments of the overall battery system and design require the participation of the navigators and owners (IMO, 2014; Mjøs et al., 2016). Moreover, the evaluation of the system has implications for the practical day-to-day operation of a battery driven vessel, as well as for how crew members should behave in case of emergency (Mjøs et al., 2016).

Given that some emergency procedures differs drastically for battery driven vessels compared to conventional vessels, operators need to make sure that the correct way to behave is ingrained in its crew members, who otherwise risk behaving according to 'normal procedures' (IMO, 2014), e.g. in case of fire below deck. According to normal procedure on a conventional vessel, the crew should shut down the ventilation system in the engine room. Shutting off the equivalent on a battery vessel, i.e. the battery room, should not be done under any circumstances. On the contrary, it is crucial that the room is ventilated at all times, so that any potential explosive gasses can be removed from the room immediately (Mjøs et al., 2016).

Moreover, the crew members and managing officers must be capable of using and understanding a battery management system (BMS) in additional to the power management system (PMS) also used on conventional ferries. The BMS is monitoring and controlling temperatures, stock and usage of the batteries, and is therefore a crucial tool for circumventing potential emergency situations (Hagbarth Mikkelsen, 2015b; Huppunen et al., 2017).

Apart from external factors, the operational behavior of the navigator can influence not only the lifespan of the batteries, but also the battery safety. 'Overdischarging' can occur if the vessel is not conducted sensibly and the batteries are pushed to the limit during operation. Frequent occurrence of such behavior will shorten the lifespan of the batteries and in worst cases cause explosion when recharged if safety systems are circumvented. Such behavior would not have the same consequences on a conventional vessel, and has to be corrected in battery specific training (Mjøs et al., 2016).

2.2.2. Understanding of batteries and battery systems

Traditionally, a conventional vessel of the E-ferry type requires as part of its operating crew a machine engineer for maintaining and monitoring the engines etc. In a fully electric vessel, such competences are not necessary, as the battery system is fully automated and operational from the bridge (Mjøs et al., 2016; Huppunen et al., 2017). For the simple and rather maintenance-free electrical setup of a battery driven vessel, it has been approved that it can be operated without an engineer. In fact it should suffice with a basic certificate of competency in motor operation if the redundant engine system has a propulsion output below 2 x 750 kW. This is a standard certificate that all navigators and the most part of able seamen possess (IMO, 2010; Hagbarth Mikkelsen et al., 2015). Instead it is expected that the main monitoring and maintenance services are land-based performed during port stays, monitored and maintained with software updates and the like, whereas more manual or practical maintenance should be done by electrical engineers or specialized marine engineers (Hagbarth Mikkelsen, 2015b).

Energy management when charging a battery driven vessel is also an aspect of the daily operation where battery and battery system understanding skills become crucial. In the vessel charging during the day and docking over night for instance, different charging modes are required, which the navigator must be familiar with to activate the correct charging connection from the bridge (Mjøs et al., 2016; Huppunen et al., 2017).

2.2.3. Overcoming myths and misunderstandings

A large barrier to a widespread uptake of battery solutions for vessels is based in myths and misunderstandings. Ferry companies operating routes suitable for fully electric battery solutions are reluctant to go 'all the way' due to range anxiety, upfront cost concerns, instability and unreliability of batteries, just to name a few of the reasons based on outdated or downright wrong information. Hence, an important task for maritime education and training is to ensure that crew members, managers and ship owners are correctly informed, in order to accelerate the transition to electric vessels (Gagatsi et al., 2016; Hagbarth Mikkelsen, 2017). More will follow in section 4.

3. Case study: MARNAV – filling the gaps in maritime education

To date, no specific courses or certification have been developed in the maritime educational system, although the first crew members and navigators have started sailing electric ferries. In response to this MARNAV, as the first in the World, have prepared the foundation for a course concept that should become, if not an integrated part of maritime educational standards, a de facto standard among electric ship operators, and more concretely, for ferry companies.

3.1. Defining the scope of a course concept

The needs for new knowledge acquisition and competency development, arising from recently operationalized or upcoming fully or partly electric vessels, are only vaguely identified through operation manuals and product handbooks, such as the DNV GL battery handbook (Mjøs et al., 2016) referred to above. A pivotal task lies in further clarifying the specific scope of activities for education and skills upgrading within the topic of electric waterborne transportation.

According to MARNAV (2017), it is not likely that IMO will amend their existing standards to include mandatory training and certification for electric waterborne transportation in the near future. Therefore the Maritime Academy has looked to the users and the suppliers of the new maritime technology for indications of needs and gaps in the current maritime educational system. Being deeply involved in the E-ferry project, MARNAV had the opportunity to use the stakeholders to the E-ferry operation as a test base. They consulted the suppliers of the electric system and the ferry company about needs for skills, and concluded that a course concept was suitable for this purpose, targeting crew members and operators, as well as owners or potential owners of electric ships. Three segments of electric ships will be target groups of the course concept: pure electric ships, plug-in hybrid ships and hybrid ships.

In terms of market potential of a new course concept, although the current number of fully or partly electric ships in Denmark and beyond is quite limited, a large proportion of existing ferry routes are relevant for electric operation. 65-80% of the local ferry routes in Northern Europe are suitable for battery solutions (Hagbarth Mikkelsen, 2015a), while it is estimated that up to 70% of Danish ferry routes would be profitable if replaced by an electric counterpart (Siemens Danmark, 2016). Based on these assessments, MARNAV (2017) estimates that no less than 22 ferries could be replaced by electric solutions over the coming five years, just within Denmark. This would result in a large number of crew members and navigators in need of behavioral education and competency upgrading, in order to learn how to operate the new technology correctly.

3.2. Course content

With the extensive experience with course provision and maritime technological development, and based on the scope definition, MARNAV has been able to identify three types of courses with three distinct target audiences, two of them, are deemed necessary, if not the bare minimum, in order to prepare the involved stakeholders for the new maritime technology. Although the specific details of the course content is still being finalized, the overall course structure and content are worth looking at, at this point.

3.2.1. Courses for crew members

In order to operate a battery ferry safely, all crew members will need to be familiar with at least the basic principles of the battery technology, which requires a new skills set. Crew members should be divided into two target groups with two different, yet overlapping needs for skills upgrading.

All crew members, including navigators, engineers, technicians and service staff that are in any way involved in the safety and operation of the vessel, must be introduced to basic knowledge of batteries, and concepts and approaches to fully electric operation, as well as being equipped to ensure safety on board and disseminate the acquired knowledge to passengers. Range anxiety and other existing myths on battery operation from passengers is also a central reason to educate all members of the staff so that they can mitigate these misunderstandings.

The knowledge includes basic understanding of the redundancy principles of battery rooms and the electric drive-train system. A crucial component in this basic course package, which should be specially emphasized, is safety. Crew members should understand the risks and necessary procedures in case of fire, electric chock, short-circuiting etc. A number of contingency plans will be defined, discussed and trained. Moreover, to safely and responsibly operate a battery ferry while taking care of the batteries, the crew members must be familiar with the risk of thermal runaway and the role of the BMS (Battery Management System), EMS (Energy Management System) and PMS (Power Management System) including specific navigational and operational characteristics of an electric ferry. Although batteries require a minimum of maintenance, the course should make the crew members aware of life cycle properties of relevant batteries in order to ensure a reasonable lifespan of the batteries, e.g. not being unnecessarily worn out due to rapid discharging or overcharging.

This knowledge will be disseminated through a two-day course and the approximate distribution of hours on the different focus areas will be as outlined in Tables 1 and 2 below.

Table 1. Two-day basic course in electric maritime operation: Content of day 1.

Day 1	Content	Purpose
08:30-10:00	Myths and barriers	Demystifying the concept so that new knowledge can be acquired
10:00-12:00	Batteries and safety	Providing basic understanding of battery properties and risks
Lunch		
13:00-14:30	Operation and systems management	Providing knowledge on the electric systems and normal operation
14:30-16:30	Site visit to the E-ferry	Connecting theory with practice

Table 2. Two-day basic course in electric maritime operation: Content of day 2.

Day 2	Content	Purpose
08:30-10:00	Thermal management of batteries	Providing skills on how to tackle an emergency situation/thermal runaway
10:00-12:00	Other procedures incl. emergency operation	Providing understanding of emergency procedures, e.g. evacuation
Lunch		
13:00-15:00	Simulator part 1	Becoming familiar with a battery driven ship's features and equipment
15:00-16:30	Simulator part 2	Exercises: Practicing reactions to alarms and other unforeseen situations
16:30-17:00	Debriefing and evaluation	Addressing competences gained and course evaluation and development

Managing officers in charge of the electric ferry's operation and maintenance will, in addition to the basic course content, need a more advanced understanding of the operation of battery ferries. Therefore MARNAV suggests building on to the basic knowledge of the first mentioned course, by targeting this segment in a two-day advanced course. Although the course syllabus has not yet been finalized for this add-on course, it is worth looking into the content and objectives.

To properly equip the managing crew members on electric ferries, the course should offer firstly an in-depth review of battery types, benchmarking of pros and cons, as well as insights of the current trends in battery development. Although the managing crew members may not need to be much involved in the maintenance of the batteries, it is necessary that they know how to identify a problem in case of emergency and know how to react to this issue. Moreover, the managing crew members should be able to instruct other crew members in taking care of batteries and personal safety precautions in the daily operation.

Secondly, some of the administrative tasks of the managing officers take a different shape on an electric ferry than on a conventional ferry. For instance, charging is a new factor that must be taken into account in the daily time schedule, just as electricity prices and smart grid connections become central parameters to take into consideration when preparing the charging strategy. Critical speed in case of delays reflects to the peak capacity of the charging station and the battery depth of discharge. These are complex aspects to administrate unless one has been introduced to the logic behind it and the consequences of ignoring it. Therefore, administration of the electric ferry operation and operational behavior becomes a dominant part of the expected course content for managing officers.

Thirdly, the managing officers should be familiar with the specific rules and regulations that concern battery classification and electric ferry approvals. As described in section 2, it is rather difficult to filter out much battery specific from existing maritime regulations and guidelines, as this technology is more or less uncharted territory at this point in time. Still, when operating new technology, all authorities' eyes are naturally on you, making it ever so important not to bypass the system.

On the basic course there are basically no entry requirements, as all crew members and safety staff on board or at shore should be familiar with the fundamentals of batteries and battery systems to ensure safe operation and management of emergency situations. Attending the advanced course will however require an STCW navigator or engineer certification given the complexity and target group of the course. All lecturers of the courses must be specially selected for the course purpose by a certified maritime educational institution. The course coordinator should have a background as a certified navigator or engineer with approved additional training in the maritime education system. In addition, assistant lecturers with an educational background in a specific subject area could be called upon, e.g. battery suppliers.

3.2.2. Full mission ship simulator

As part of the development of a course program for electrically operated vessels, MARNAV has ordered a model of an electric ferry, based on the E-ferry, for their full mission ship simulator. The full mission ship simulator is a unique technology that is attracting a large number of course participants. It is an integrated part of the academy's course program, which allows students and course participants to practice and learn in a completely realistic, however still safe setting, before trying their newly acquired skills in reality.

For these same reasons, the electric ferry model for the simulator is a crucial tool in educating and skills upgrading crew members and managers for electric operation. The course participants will for instance have the opportunity to feel the instant effect of the electric propulsion system before having to navigate out of a narrow harbor. Optimal maneuvering strategies can be tried out and energy consumption compared between different strategies. The participants should also be exposed to different simulated emergency situations where they are introduced to some of the battery specific alarms that require immediate reaction, which they must be completely comfortable with before having to handle such situations in real life.

Apart from being of excellent use for educational purposes, the electric ferry model for the full mission ship simulator also provides the opportunity to monitor the behavior of crew members when operating the vessel (Huppunen et al., 2017). It is relevant to monitor their navigational behavior mainly for two reasons:

- Firstly, observing the course participants' behavior can provide insights into additional or differing educational needs, which can help instructors fill individual skills and knowledge gaps. Moreover, when the course participants are actively involved in an exercise it will more easily become evident to which degree they have understood the course content and acquired the necessary skills to, safely and responsibly, operate an electric vessel.
- Secondly, navigational behavioral monitoring is useful for further development of the technology for electric vessels and to optimize operation. An example could be course participants tending to give full speed ahead whenever possible, which would quickly wear out the batteries. If this was the case, a recommendation could be to install a speed management function in the navigational equipment.

3.2.3. Pilot courses to facilitate a transition

Finally, a third course program has been developed targeting authorities, operational managers and ferry/shipping companies who have not yet invested in the transition to electric operation. Apart from providing the basics of battery ferry operation, similar to the two above-mentioned course programs, this course should provide the participants with the necessary background knowledge on how to operationalize an electric vessel. This includes information on battery technology, charging solutions, grid connectivity, redundancy requirements, possible time schedule, life cycle analysis, battery specific rules and regulations and environmental gains. Based on DNV GL's recommendations for performing a feasibility study for the transition to electric operation (Mjøs et al., 2016), the course coordinator will help operators and potential investors work out a case for their specific ferry route in question. These course components should provide the foundation from which a business case and potentially an action plan for an electric vessel can be developed. The lecturers in this course should be selected on the basis of the same criteria as for the basic and advanced courses, though the pilot course would also benefit from a lecturer with business training, e.g. with an MBA from a certified business school.

3.3. Impact assessment

The first test run of the two crew-oriented course packages will take place during Spring of 2018. The course participants will be the crew members of the E-ferry. The impact of the courses on the crew members' abilities and skills will be possible to assess when the E-ferry is in operation in Summer 2018. This group of course participants will constitute a test group from which the concept will be further perfected. Also the introductory course for potential electric ferry investors and authorities will be inaugurated in 2018. The impact of these courses on the transition toward fully electric ferries might not be assessable until further out in the future, but stocktaking would be sensible to perform during 2018, which should give some indication of a trend.

4. Impact on the transition to electric waterborne transport from skills development and education

In short, transition to electric waterborne transport is supported by the urge to reduce greenhouse gas (GHG) emissions but is hampered by the many myths on batteries and misinformation about the sustainability of electrical power production. The E-ferry partners are confronted on a daily basis with such skepticism and myths about electrical and battery operation from both social media but also by renowned professional papers and magazine (Johansen, 2017; Johansen et al., 2017). The debates are usually based on old studies and obsolete technology knowledge. Resistance to change is eminent at all levels from passengers over crew members to ship owner and regulatory authorities. Safety and myths are inherently connected as many myths are fueled by a natural fear towards new technology and uncertainties requiring mitigation measures from safety systems which again need to be trusted at some point.

To accelerate the transition to electric waterborne transport myth busting and updated studies including qualified and peer-reviewed data is vital, besides proper battery-specific education and training. Apart from developing safe and optimal operation in electric waterborne transport, the recommended courses outlined in section 3 should ideally also mitigate these myths and misinformation at relevant levels. In this section a number of myths and misinformation has been identified based on experience in the E-ferry project. The myths necessary to address through education, whether it is the basic or advanced training courses or the pilot courses targeting authorities, operational managers and ferry/shipping companies, is listed in the following subsections.

4.1. Range anxiety

The operational range between charging is rising exponentially in this early adaption of pure electric operation. The E-ferry for example expands the known ranges by a factor of ten between charging (Huppunen et al., 2017; MARNAV, 2017). Plug-in hybrids are using their fossil fuel engines as a range extender but also as an insurance against unexpected changes in the operational pattern, e.g. breakdowns of systems or emergency operations, whereas hybrids are solely using the battery system for optimizing the specific oil consumption running the engines at optimal revolutions. The trade-off for using plug-in hybrid instead of pure electric ferries would be a more complicated system and a less efficient drivetrain with a worse carbon footprint. Thus the range extender paid is rather expensive when operation is possible solely using pure electric solutions.

Education of both crews and shipping/ferry companies is needed in order to be able to assess the operation correctly. This is further complicated by the lack of legislation explaining the minimum requirements for reserve energy capacity in fully electric vessels in a clear manner.

Range anxiety exists in all target groups both at passenger level, crew level, shipping/ferry company level and the level of authorities. The demonstration projects and birth of new pure electrical ferry routes is needed to overcome this anxiety like it is happening right now in the electric vehicle (EV) industry getting cars with appropriate ranges of up to 2-300 miles (Lambert, 2016). Education needs to focus on the superior redundancy of the fully electrical drivetrain. A better understanding of needed reserves in different operational contexts is essential. Using the full mission ship simulator to test and gain experience without putting the actual ferry into peril would be an important part of reducing range anxiety for the professionals operating the ferry, managers in shipping/ferry companies as well as authorities. For passengers, education is not always a possibility. The attitude of service staff is vital here thus putting emphasis to their education and understanding of the electrical operation. Also time will be a factor here, especially in the virgin years of operation where a smooth and uneventful record could be hoped for. If not this would be extremely adverse to the time to overcome range anxiety in public opinion.

4.2. Battery life cycle

In an electrical ferry the battery pack constitutes a major part of the investment. Electrical ferry operation is a typical business case of higher investment cost against lower running cost. Thus time of breakeven is much dependent on the battery life and the price for replacing the battery pack. Battery prices are decreasing exponentially. Over the course of the last six years, the battery price on EV batteries has been reduced 16% annually (Seba, 2016). At the same time battery life is a logarithmic function of depth of discharge (DoD).

This means that the operational behavior has a significant impact on battery lifetime. The BMS will impose some limitations but the EMS and/or PMS need to be integrated closely into the operational strategy to avoid excessive wearing out of the battery bank during lengthy operation. Moreover, understanding the energy-balance and power profile of the route is necessary and crews need some guidance to calculate optimal speed and critical speed in case of delays. The peak charging capacity will influence on this speed. In a smart grid solution also variations in electricity prices will influence the operational strategy and choices.

More research is needed preferably based on real data from the demonstration phase of the E-ferry and, prior to this, the simulated exercises in the full mission ship simulator at MARNAV. The findings from these experiments will feed directly into the training courses for crews and shipping/ferry companies and will also be discussed with the battery suppliers. However, theoretical models already show battery lifetimes of more than 10 years e.g. for the E-ferry in the planned operation. Thus the myth of short-lived and unstable battery packs could already be attacked through theoretical education of the stakeholders.

4.3. Thermal instability in batteries

The energy density in modern lithium-ion batteries is still only one tenth of the energy density in fossil fuels. Hence the severity of fires or explosions in batteries is not necessarily higher than for conventional internal combustion engine drivetrains. On the contrary, early research from the EV industry in Norway indicates that car fires are less likely to happen in an electrical drivetrain (Norsk elbilforening, 2017).

Still, battery chemistry constitutes a safety hazard if not managed by thermal control during charging and discharging at high C-rates. Chain reactions between cells or modules can in worst case scenarios lead to a so-called thermal runaway. Also, physical damage to the battery cells can lead to short-circuiting. When the battery cell ages formation of dendrites at the electrodes will also increase the risk of internal short-circuiting. However, risk of overheating and thermal runaway is mitigated by several levels of safety features. In the BMS both mechanic and electronic measures will kick in if battery limits are abused. In the EMS or PMS operational limits are introduced primarily in order to ensure a long battery life but the same limits will also prevent overheating of battery systems.

The choice of battery chemistry especially with regards to the anode and the mix of additives in the electrolyte have improved inherent battery safety dramatically within recent years. In a worst case thermal runaway the process is not unstoppable and should not be associated with the melt down of a nuclear power plant. In the E-ferry several firefighting systems are installed including a new foam type capable of fighting lithium fires. However the first line of defense is simply the water cooling system between cells designed with a reserve cooling capacity in case of temperature incidents. For managing officers and shipping/ferry companies an understanding of above mentioned features is essential to make the right choices and to combat the myths of easily exploding battery packs.

4.4. Charging from a fossil powered grid will not cut emissions

This was true a few decades ago and could be true for a few countries with very inefficient and coal powered electrical grids. However, power and drivetrain efficiency of a pure electrical ferry is extremely high and from a well-to-propel comparison with conventional fossil fuel ferries the carbon footprint is found to be less than half of the fossil fuel ferry using the electrical mix in the Danish grid as per 2016 (Johansen, 2017).

Economies of scale and the increasing share of sustainable energy sources in the electrical grid in most countries, make electric waterborne transport an increasingly environmentally advantageous case. The option of buying green certificates, and in this way documenting that the electricity consumed comes from e.g. wind turbines of no more than two years of age, will mitigate the carbon footprint further and one could argue that it becomes close to zero (Hagbarth Mikkelsen, 2017). One could even argue that emissions from a battery ferry are negative if smart grid solutions are applied. Using the enormous battery bank in the ferry to balance the grid when moored in port could make so-called “peaker plants” redundant thus giving room for more wind and solar production in the grid.

Understanding the carbon footprint of ferry operation with batteries would require some education of authorities, shipping/ferry companies and managing officers in charge of deciding on the daily schedule of the local route. Informing the passengers and users of ferries about the reduction in GHG emissions from electric waterborne transport is both a task for the society in general but could also be obtained from shipping/ferry companies trying to brand their operations over conventional operated companies.

5. Conclusion

In existing standards and regulations for maritime education, training and certification, skills requirements for operating battery driven vessels is not specified and are unlikely to do so in the near future. Still, operating a battery-driven vessel requires some distinctive competences and skills compared to conventional operation. This becomes apparent when investigating user manuals and guidelines from the producers of the different components, using the case of the E-ferry project. In this paper we found that the gaps can be divided into three main groups: safety operation behavior, battery and battery system understanding skills and overcoming myths and misunderstandings.

In response to this evident gap in knowledge and skills upgrading in the maritime educational system and based on experience from the E-ferry project and in-depth knowledge of the newest maritime technological development, MARNAV has composed a course concept, designed to fill the gaps identified. In addition to the regular class room training, the academy has had an E-ferry model created for their full mission ship simulator. This gives the opportunity for course participants to try out challenging situations in a completely realistic setting, while it is recommended to make use of this educational tool to monitor behavior in order to develop the course content as well as the maritime technology further.

In addition to providing the crew members, managers and ship owners with the right skill sets, the maritime education and skills upgrading should put the countless myths and misunderstandings stemming from outdated or incorrect information to rest. The myths constitute a large barrier to accelerating the transition to sustainable and emissions-free battery-driven vessels. The paper concludes that by educating crew members, managers, engineers, ship owners and authorities in the background of electric maritime operation, these stakeholders will understand the many advantages with this new technology, making new-buildings more feasible and thereby also more likely, with correctly skilled staff onboard to safely operate these vessels.

5.1. Scope for further research

Since the course concept by MARNAV is yet to be tested, empirical data on the impact of this program should be collected upon the certification of the first batch of course participants. Moreover, it would be necessary to further monitor the course participants' behavior and operation skills when operating the E-ferry after taking the described courses. This data cannot be collected until mid-/late-2018, but would be relevant to follow up on. Finally, it would be interesting to investigate the possibilities and needed actions to influence current educational standards and regulations at a national and international level.

Acknowledgements

The E-ferry project, presented in this paper has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 636027.

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