Project BLUE BATTERY:
A qualitative study of fire, batteries and risk and safety perceptions in the Danish maritime industry

Safety equipment for the engineers; earmuffs and safety shoes.

DBI FIRE AND SECURITY

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December 2017

Content

1 Introduction: research design and methodology

This qualitative study has sought to investigate how the use of batteries as alternative energy source has impacted the daily practices onboard large passenger hybrid vessels and in what way it has influenced the perceptions of fire, risk and safety in the Danish maritime industry. In Denmark, only a few maritime companies work on a daily basis with battery propulsion in large vessels. Consequently, a qualitative study of this development in the maritime industry seems very relevant, since the goal of qualitative research is to understand the nature of phenomena and not the magnitude or distribution of it (DeWalt & DeWalt 2002).

The number of qualitative interviews carried out in this project is limited to people that have experience with it on a daily basis. The following sections outline the insights from 4 qualitative interviews with 5 participants and two field visits on board large hybrid or electrified passenger vessels, one of which will be fully electrified any time soon. I will name these vessels "Hybrid" and "Electric" respectively during this report. The interviews and participant observations on the vessel were carried out during the summer and autumn of 2017.

The qualitative interviews lasted approximately one hour and were recorded and transcribed verbatim. The interviews were carried out on field location or via Skype as semi-structured interviews, which altered slightly according to what was emphasized as most salient by the interviewees (Spradley 1979; Mikkelsen 2015:169-192). The participants were all male and worked as a chief engineer, naval architect, chief captain and marine superintendent respectively at three relevant stakeholders in the maritime industry, including the Danish maritime authorities. The chief engineer and naval architect were employed at the same ship owner operating "Hybrid" and the other chief engineer and chief captain were both employed at the ship owner operating "Electric".

Onboard "Hybrid" the work of implementing batteries began in 2015 and on "Electric" it started in the very beginning of 2017. The "Hybrid" thus had her batteries installed 2 years before "Electric" and as may become clear during the report, this is reflected in different opinions, experiences and frustrations among the crew concerning the installation and use of batteries, including the communication and cooperation with the authorities.

In order to ensure anonymity of the participants, they are referred to only by their work function. For the sake of comprehensibility, I distinguish between (a) "The Hybrid crew" as a designation for the employees interviewed on "Hybrid"; (b) "The Electric crew" as a designation for the employees interviewed on "Electric"; and (b) "authorities" as a designation for employees at Danish maritime authorities. When speaking in general terms about the crews I will use the term "practitioners".

Topics covered in the conversations included (a) experiences with implementing batteries on the vessel and changes in daily routines; (b) perceptions of risk and safety; (c) fire safety, fire detection technologies and fire emergency evacuation practices; and (d) suggestions for recommendations for a national guideline on the use of batteries on board large vessels.

The field visits at the two passenger vessels (Photo 1) lasted three to four hours and were carried out in order to gain insights into the ways in which the vessel's marine engineers and chief captain made sense of the implementation of the new technologies (i.e. the batteries), how they perceived various risk factors and what concerns they had in terms of fire safety on board. Talks, activities and experiences during the visits were preserved through extensive field notes (Tjørnhøj-Thomsen & Hansen 2013). The same topics as in the interviews were covered in informal conversations during the field visit.

The qualitative findings include rich quotations from the interviews and photos from the field visit taken by the author. Photos are used with permission. All information provided in the following qualitative sections is based on the interviews and reflect the opinions and beliefs of the interviewees.

Photo 1. On the top front deck during a field visit.

2 Executive summary

The ethnographic material from the interviews and field visits resulted in the following insights:

- Overall, batteries are perceived to provide more safety, a more electric rather than mechanic maintenance and less strenuous work compared to diesel engines. In the light of changing weather conditions, geography, routes etc., batteries are perceived to increase the degree of operational reliability and flexibility in combination with diesel engines.
- Batteries are seen as an economically advantageous investment once installed and up and running because of the decreased need for fuel and the increasingly CO_2-neutral (and thus cheaper) form of operation and propulsion.
- According to the authorities, there have been major changes in the fire scenario plans and the safety procedures on board due to the introduction of batteries. However, the practitioners do not feel that much have changed due to the introduction of the batteries. According to the two crews, there have been no changes in terms of evacuation of the passengers and the only actual changes in fire safety have been limited to the technical area of the engineers.
- Technology and digitalization play a vital role in the risk and safety perceptions among practitioners and authorities. Technology is seen to provide an increased level of safety because it limits human interference and mistakes and ensures systematic safety barriers. The practitioners believe that batteries are safer than diesel engines and that thermal runaway is not a real risk but merely a theoretical one. Simultaneously, digitization and in particular hacking is seen as one of the top major threats at sea comparable with fire scenarios because the majority of alarms, detection systems, communication, and now also the battery propulsion systems are controlled digitally and/or via internet connections.
- Automated procedures now run, monitor and control either batteries or diesel engines, which means that the crew's work tasks have changed and their safety and working environment on board have increased. This also means that the responsibility of damage and the ability to define risk and safety is increasingly transferred to the manufacturer.
- There is an ongoing debate in the maritime industry about what the safety level must be concerning batteries as an alternative energy source. This debate has found no answer so far. The lack of specific regulations and guidelines apart from MSC.1/Circ. 1455, and the subsequently thorough, difficult and time consuming risk assessments based on IMO 1455 performed specifically for each new vessel with batteries on board frustrates the industry. It is discussed whether using "risk assessments" as a method in stead of discussing a meaningful "safety level" provides more fruitful insights into potential hazards and accidents concerning the use of batteries in the propulsion system.
- The industry wishes more clear guidelines on the use of batteries and a minimum standard for the safety level. The authorities seek to solve this problem by encouraging the IMO to develop an international battery code.

3 Qualitative findings

In the following sections the key findings and additional insights will be elaborated during four main sections: '*The implementation of batteries*' ; '*Perceptions on risk, safety levels and fire scenarios*' ; '*Reflections on fire emergency evacuations*' and '*The maritime need for guidelines – a case of definitions*'.

3.1 The implementation of batteries

3.1.1 Legal aspects of the implementation

According to the authorities, using batteries onboard large passenger vessels (e.g. ferries) in Denmark is a fairly recent adoption which started back in 2013. As of interviewing the participants, there have not been any drafted rules or regulations specifically on the topic of batteries apart from the IMO standard 14.55[1], which is a legal guideline that can be used as a tool to approve alternative designs on vessels. According to the authorities, it is an approval process which includes all relevant experts, shipyards, owners, researchers, manufacturers and other stakeholders. This team is called the "design team" and is established very early in the IMO 14.55 approval process for the batteries in order to ensure a satisfactory process. For instance, the "Electric" design team consisted of over 20 people participating as specialists from a classification company in risk assessment approaches and fire safety, battery specialist from the manufacturer PBS, shipbuilders, consulting engineers, ABB as the key contractor on the interface and entire system and finally national authorities who did not partake in the design phase itself but rather joined to listen and learn. Thus, all stakeholders involved in assessing the battery technology, implementing it and running it must come together to discuss how this will act out in reality and what the potential risks may be. According to the authorities, it is a new tendency to bring together the ship owners, manufacturers and other relevant experts and stakeholders in order to work together on the best possible solutions that entails expertise and attitudes from all parties in the design process. The entire process is initiated as the ship owner files an application (both for retrofitting and new vessels) to the authorities for implementing the batteries. The marine superintendent employed by the authorities explained the reason for the need of such a process:

> *"The reason why they have to file an application with us is that there is not at the present time any rules concerning batteries, i.e. lithium-ion batteries, neither in terms of hybrid vessels nor 100% electrified vessels. No national or international standards. There are no rules about this. In terms of international regulations there are two openings in that legislation: the one is chapter 2.2. rule 17[2], which is about fire and the other is chapter 1 rule 53, which is about the construction of it. These two make for an*

[1] IMO stands for International Maritime Organization, and the name IMO 14.55 refers to the maritime guideline MSC.1/Circ. 1455 on "Guidelines for the approval of alternatives and equivalents as provided for in various IMO instruments".

[2] This paragraph relates to a chapter in SOLAS concerning large passenger vessels.

opportunity to take a risk based approach to solving the problem. I mean, when there are no regulations on the topic, how are we going to approve of it?"

In order to reach an approval of the battery technology, the design team must come together to draft a qualitative risk analysis of the implementation of the batteries on large vessels. According to the authorities, the reason for demanding a qualitative analysis (rather than a quantitative one) is that it brings facts and solutions to the table. In their opinion, the entire risk assessment process would be very protracted if it was to be made quantitatively because the maritime industry is so complex and the risk scenarios are intertwined and complicated. The result of a quantitative analysis would not necessarily equal safety, because one would be misjudging the numbers along the way as it is based on statistics and historical facts. But since the battery technology is still so new and constantly developing, the authorities do not have any historical facts and only scattered statistics to rely on. Therefore, the authorities have switched to do qualitative analyses where the experts are gathered to share and discuss their experience and knowledge on the topic. The marine superintendent elaborated on the procedure of the design team:

"As a point of departure we'd like a qualitative risk analysis based on IMO 14.55. That includes many things, but it basically means that all risks are a part of the approval process. Because it's a very complicated matter. It's very complicated to approve something which is not in the regulations. Because you must start over every time. But it's the only way we'll be able to get something approved. By doing this risk analysis. Until it's written down somewhere in the rules and we're waiting for that. But it's not something that changes over night, because there must be quite a big demand for this change. We're only just now starting to see this demand. We're now building the 7th vessel in Denmark with batteries on board, ready for approval. It's not much, but it actually means that we have the world's largest "green fleet" when measured by the size of the batteries on board large vessels."

On board "Electric", the work of the design team lasted for countless hours and late evenings. The chief captain explained the process and the task of deciding on potential risk factors yet unknown this way: *"There is no key, no database on experiences you can turn to in order to figure out how others did this, because we were the first ones to do this. So we've thrown all the balls high up in the air and been creative and thought: God knows what can go wrong? We've had a great many talented people as a part of this design process. Really, we do!"* He described the work process of the design team which he himself had been a part of as lengthy, slow and frustrating due to the fixed budget and conflicting interests among the involved stakeholders and at the same time very exciting because none of the involved parties had done this before and this kind of installation was built for the first time. "I wouldn't say it was trial and error…we had a plan, haha!" he laughed at me when I asked him about the process.

3.1.2 The maritime industry: slow and conservative?

The maritime industry, including IMO and the Danish Maritime Authority (DMA), is perceived by the "Hybrid" crew to be conservative and somewhat reluctant about changes, i.e. introducing batteries in vessels. The "Electric" crew was not of that impression. The conservative attitude is explained among the "Hybrid" crew by the fact that development moves slowly in the maritime industry when compared to other industries, i.e. the auto industry where the development on hybrid cars moves very fast. The slow pace is said to be caused by a large body of rules and regulations that the ship owners and vessels must follow, which means that the system can be slow and inefficient; it takes a long time to change the system since there are quite a few countries in IMO who all have to agree upon what must be further investigated, evaluated and decided upon[3]. The slow pace also relates to the fact that building a vessel takes quite some time compared to building a car. The chief engineer ("Hybrid") elaborated on the impression of a slow DMA:

> *"We had to decide upon a safety level. And it was quite a complicated affair. The DMA was very perplexed. They weren't…this was new to them. It was a new sort of technology to them. We started in 2015. It was new because the vessel was a new one: on the other vessels the batteries had been installed subsequently, because the rules and regulations are a bit gentler when you retrofit an existing vessel. But when it's a new vessel you always have to build according to the latest rules. There were no formal laws or protocols to follow, only some vague guidelines which were not systematic. So we developed these procedures in cooperation with DMA. Corvus and Siemens were forced to join in the game and provide people to explain the technology […] Remember, everything that we know and have on classifications and rules in this industry have taken a century to build up. What works and what doesn't. And then you come with this brand new system from an area where the development curve is so fast and steep, and then sometimes the law-making process cannot keep up the pace. These good old ground rules that you've known to be true for many years are suddenly challenged by this powerful technological change. Perhaps it's difficult for the authorities to keep up with the development if they constantly have to adjust their laws according to the newest technology. It's a slow process."*

Thus, the "Hybrid" crew believes that the maritime investors and authorities view the implementation of new technology for the use of alternative energy sources such as batteries as a somewhat risky business in an uncharted territory and that the authorities are working too slowly compared to the technological development. The fast development that characterizes battery technology also seems to define the self-image among the practitioners of what they are a part of. The senior captain said that: *"the solution we picked today is based on the equipment and technology we know of today, but tomorrow it will be different and it just develops continuously"*. The quick changes are both a source of excitement because the practitioners feel that they are part of inventing something brand new and practicing innovation. At the same time, this quick speed also results in a feeling of not knowing exactly what one is doing, relying heavily on external experts and manufacturers, and a perceived hopelessly slow administrative and legislative system. The "Hybrid" crew feels that the authorities have been cautious, reluctant to acknowledge the benefits of batteries

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[3] As an example the following four conventions can be mentioned which the crew and ship owners must obey. There are three IMO conventions: Marpol (focus on environmental aspects), STCW (education of the crew) and Solas (concerning safety at sea, which have been converted to message B drafted by the Danish Maritime Authorities). furthermore there is an ILO convention: MLC (crew rights).

even though they were presented with sound data and thorough calculations and technology, and shown a modest reception of proposals to use battery technology.

The authorities perceive the situation differently. They acknowledge that the maritime industry is conservative and works at a slow pace. But the slow development does not stem from reluctance or nervousness. Rather it is because of cautiousness and a strict focus on core values such as "safety" and "growth". The maritime authorities do not believe that they should push the development and innovation forward; the industry must do that, and then the authorities will follow suit with appropriate actions. The marine superintendent at the authorities explained:

> "*It's difficult to keep up with the development. Every day we are trying to keep up with what is going on in these projects and what they [the industry] actually want. It's a challenge because there are so many other tasks that we also have to perform and things to keep track on. So that's why it's difficult, because we're not only dealing with lithium-ion batteries. We have a broad range to deal with. There are so many things that have to come together. But I do think that things are going better and I hope that more state their wishes on these battery installations, because there is a green philosophy in it, too.*"

Some years later, the Electric crew went through the same procedure as "Hybrid" has just gone through. But from the perspective of the Electric drew, the authorities had handled the case and implementation process very swiftly and as helpful as possible. For instance, once when they had come to do a checkup and not all details was ready for them to inspect, they had waited patiently with a cup of coffee for the technicians to finish up their work until they could get started with their part of the task. The Electric crew had the feeling that the authorities acknowledged that this field was new to all of them, and that everybody joined together in the process to learn more.

3.1.3 Technical, practical aspects of the implementation

According to the practitioners on both ferries, the technological transition from diesel engines to batteries have demanded quite a few adjustments and commissioning during the preliminary phases and first periods of operation among the marine engineers. The chief captain ("Hybrid") described the change as a process of *"learning by doing"* since they were getting to know extremely new technology that an extremely limited number of people knew anything about. The change have also demanded some practice among the captains and navigators on "how to operate a hybrid vessel properly", i.e. when to use only batteries, when to shift from battery to generator, how much stored energy should be spent at a given moment etc. Another initial challenge was the task of simply understanding the highly technical details and the complicated technology. However, the shift in general is perceived by the practitioners on both vessels as flawless and very positive, primarily because the crew themselves had been deeply involved in the process of planning, designing and implement the batteries and thus, the new technology seemed easy to handle and get used to.

Once up and running the engineers and their colleagues have been very pleased with the systems. Compared to the earlier conventional methods and "*classic marine engineer mentality*", the practitioners believe that battery technology demands less maintenance, and no crafted skills or specific knowledge about "*nuts, bolts and dimensions*" are needed (Photo 2). Conversely, the battery technology has demanded much more technical and specialized insights which have demanded additional training in the digital systems (Photo 2-4). On board "Hybrid", the engineers have not received any training in the battery system itself, but they have in the Siemens operational system which is their primary user interface (Photo 2). On board "Electric", the engineers got 14 full days of training where they went through a thorough manual describing all the details and alterations which they must take into account such as fire extinguishing, first aid and high voltages. During training both crews scrutinized the safety features, and they were mostly concerned with elements affecting the personal safety such as removing components and moving them around, how they could and could not move the batteries around, what they could and could not touch and change etc. The battery system is only accessible via touch screens placed in front of the battery itself (Photo 3) or on a computer screen in front of the captain on the bridge, showing simplified visuals of red and/or green batteries to signify whether things are running smoothly as planned or not (Photo 5).

Photo 2. Batteries on "Hybrid".

Photo 3. Batteries on "Electric"

With the shift from a mechanical to an increasingly electrical operation and the increased use of computer technology, and as more procedures are run electronically, the daily maintenance and problem-solving has changed. The engineers on both vessels have been forced to acknowledge that problem-solving can now only be done to a certain point and from there specialized experts from the manufacturers have to be called in to help. Both ships have service agreements with their respective providers of the technology and interface systems, and in case they need help they will call these partners, e.g. Corvus, Siemens or ABB. The senior engineer ("Hybrid") said:

> "*All is well as long as the computer operates according to your wishes. But once it starts to give you all these fault reports, you're in uncharted territory. Most people are. So are we. We're not trying to fix the batteries if it has to do with something that we cannot resolve. Previously you could try to see if you could somehow fix the problem. Now our tasks and challenges have changed and we've had to become better at asking the experts for help.*"

These changes in the work tasks of the engineers and an increased dependency on external experts combined with a need for more specialized fire extinguishing methods due to the implementation of batteries is also voiced by the authorities. The battery technology is in many ways more specialized and complicated than the mechanical set up of the diesel engines. The marine superintendent put it this way:

> "*In case of a fire in one diesel generator there are typically three generators left to get home safely. In case of a fire in the battery pack you are left with nothing afterwards. If one of them burns down you only have one to go, and if you burn that on your way back, you don't have anything. Then you cannot get home. So then you'll have to investigate what's wrong. In that way it's different from the traditional vessels, because with one diesel engine down and three to go you'd be able to keep on operating and going. All you'd have to do would be some fixing, and it's possible for you to access the machine and make reparations. But you'd still have those 3 generators to ensure that you're moving forward. In that way it's different with batteries, it demands a different fire philosophy where you might have to reach the shore to evacuate the passengers to await the technicians and the result of their investigations before you can move on.*"

3.1.4 The daily use and handling of batteries on large vessels

Batteries are perceived by the practitioners as easy to handle: they demand less technical and mechanical maintenance than engines do, and you hardly ever have to change the batteries. Furthermore, it improves the work environment of the marine engineers as the use of batteries reduces the amount of strenuous work and level of noise and vibrations usually made by the diesel generators (see the cover photo). However, at the same time it may also change the work environment in a way that new measures must be taken to keep a satisfactory level of safety and a pleasant work environment. The various risks related to the implementation of the batteries are described and discussed further throughout entire section 3.2.

Batteries are used on "Hybrid" as a way of optimizing the vessel's engine power and performance. On "Electric", the batteries specifically play a key part in moving the vessels and entire ship owner towards being completely CO_2-neutral. In case of a generator stop it is possible on both vessels to activate the batteries and keep the vessel going. Batteries also give an operational flexibility as the captain can choose when and how he wishes to use either the diesel engines or the batteries (Photo 5). This is much needed at sea where weather conditions, geography, routes etc. influence the maneuverability of the vessel. On a daily, operational level, the use of batteries is about balancing input and output: when there is a surplus of energy in the engine it is possible to recharge the batteries, and when there is a deficit of energy, it is possible to discharge the batteries and use this energy to run the propulsion system. Balancing the energy in this way means that the ship owners will reduce the fuel and energy consumption in total on these vessels. Still, the way you use the batteries and how much fuel and CO_2-emission it will be possible to save depends on the route of the vessel, how the vessels are built and how old they are. Thus, the uses of batteries are very much related to the operational profile of the vessel.

Using batteries then also turns into a question of saving for the practitioners: they spend less fuel, save energy, put less strain on the engines over the years and thereby increase the efficiency of their engines and batteries, and prolong their lifetime. This will eventually save them money, as the ship owner will be able to use the engines – and the batteries – for a longer period of time and thus postpone the date for buying new engines etc. Investing in batteries is thus very much about economic advantages, but just as much about saving for the sake of the environment. Especially the "Electric" crew emphasized the environmental issue as a key motivator to implement batteries as a substitute for diesel engines. During the past 15 years, the ship owner of "Electric" have also initiated the use of catalysts, presorting of waste onboard[4] and substitution of harmful chemicals due to the health and safety of the crew.

Corvus, a manufacturer of batteries used on "Hybrid", has an extensive level of surveillance and safety built in the system (Photo 4). On "Hybrid" there are 4 temperature sensors in each of the 231 battery modules, including monitoring of the voltage. The cells are installed in series. On "Electric" PBS is the manufacturer of the batteries. Here, there are 640 batteries, all installed with similar sensors and monitors. The cells are installed in arrays. In case of missing feedback in the system or a temperature rise above level, the surveillance system will activate an alarm. If nothing is done, more alarms will sound, and so on. Eventually the system will automatically shut down itself if nothing is done. This design of several systematic barriers is perceived positively by the practitioners as an increase of the safety onboard. Thus there are several points where the system can and will shut down in case of risk, which makes the surveillance and automatic shutdown of the batteries quite extensive. This procedure is the same on board both vessels. This automatic surveillance system run by a computer is perceived by both crews as very safe. As soon as the computer loses a connection with any of the sensors it activates an alarm and shuts the battery down. Once an

Photo 4. The Corvus Array Manager monitors the batteries and temperaturen. The only way for the crew to access the batteries is via the touch screen on the front of the box.

[4] This is done according to ISO 14001 on environmental management.

alarm is on, e.g. in case of high temperatures, the reason for this alarm is checked by the engineers on duty. He checks what the alarm means and what must be done to fix the problem. Mostly, the problems can be solved by altering the way the batteries are used in the operation. If needed, they can also detach the specific module from the package or stop it entirely. The naval architect (Hybrid) explained the system and its alarms this way:

> *"There's an ocean of alarms, warnings and critical alarms. Some of the alarms that affects the operation of the vessel are directed at the bridge where the captain and management decide what must be done. They can monitor the battery status on the bridge. The alarms signal right away when something is irregular in the battery packages, which is crucial as the entire setup rests on the capability of the batteries to delivering power in stead of the diesel engines. There is an automated computer which is situated in several places on the vessel, and on this is it possible to see what kind of alarm it is, what causes the alarm, whether the temperature is too high and so on. In case of too high temperatures in the battery modules, the computer will tell the reason. Perhaps the batteries are being used too much, which makes them warm. Perhaps the cooling of the room with the batteries is not sufficient which makes the temperatures rise. Then you have to increase the cooling, sail slower and less harsh, decrease the use of the batteries and perhaps start one more diesel engine in order to give the batteries a break".*

3.1.5 Key insights on the implementation process

- In lack of a definition of safety levels for the use of batteries as an alternative energy source in propulsion systems, the authorities have initiated risk assessment processes performed by specific design teams. This team is made up of the authorities, experts on the field, ship owners and other relevant stakeholders. The design team must asses the various potential and relevant risks through a qualitative risk assessment based on their expertise, experience and individual assessments, and they must also come up with the solutions to the various risks exposed in this assessment and write the guidelines for the daily handling of and safety practices around the batteries on board the vessel.
- Apart from some time of transition and commissioning during startup, the practitioners believe that the daily use and handling of the batteries is easy, less demanding, more or less flawless compared to diesel engines. The battery technology is welcomed due to easy maintenance and increased feelings of safety in terms of risk of fire, personal safety and operational reliability of the vessel despite changing outer conditions such as weather, geography, season etc.
- According to the Hybrid crew, the use of batteries in combination with diesel engines provides operational flexibility and most importantly operational reliability for the vessel. Furthermore, batteries are perceived as an economically advantageous investment once installed and up and running.
- Operating with batteries on board as a part of the propulsion system demands the ability to navigate even more complex decision making processes than before.

3.2 Perceptions on risk, safety levels and fire scenarios

3.2.1 Deciding on risk factors, safety levels and monitoring them digitally

In order to keep a satisfactory safety level at sea, and as a consequence of the risk based approach in the design teams, a number of procedures about the handling of the batteries have been implemented on board the vessels. A range of risk scenarios are discussed by the experts in the design team. The marine superintendent elaborated on the topics often discussed:

> *"Of course the big topic will always be thermal runaway. I mean, fire extinguishing is a imperative part of the risk scenarios on a vessel, it will always be. You know, there's a difference between being on board a vessel compared to being inside a building. You cannot really run anywhere, but a fire can lead to many different scenarios and many additional questions. Evacuation: where do you direct the toxic gasses? Right next to a lifeboat station so the people gathered there to evacuate into the boats will suffocate? Navigation: in case of an "event" will you then completely loose eyes and ears so you cannot communicate with the surroundings? Will your entire safety system together with your emergency system shut down, or how does that work? That's definitely a major factor that we will discuss. And then we also discuss the working environment. In terms of installing batteries it reduces the noise and vibrations because you no longer have those diesel engines hammering through. But then there may be other aspects, which means that it can be less disable for the crew to get near these batteries: perhaps if you haven't taken into consideration what kind of chemicals they contain. Is there any possibility that the batteries can emit something unwanted without a thermal runaway event? It's a very typical question whether there are only cases of thermal runaway. The typical answer for the lithium-ion batteries is yes, but when it comes to traditional batteries you can be dealing with hydrogen, which is enormously explosive. So that's a topic too: old lead batteries versus lithium batteries. That's essential to know, because the systems on the vessel will be built accordingly. Then there's flooding, like inundation. Leakage. It's a vessel! In case the water gets inside then what happens? Does it lead to a huge electric fire or explosion? What does it lead to? That's also something we discuss with them. And many other things. Mostly we discuss the entire installation on a more general level - but sometimes we also discuss the painting of the walls. What happens down there in case of a fire? Is the coating fire-resistant or does it emit additional gasses that are highly toxic? What about working environment? So these risk analyses are not limited by anything at all, except what you can imagine and remember."*

Thus, the primary challenge of the design team is creativity and imagination, understood in the way that when you work with innovative projects it may be a challenge to think of all possible risk scenarios when you seek to map out the risks based on the expertise and experience from the various stakeholders in the design team. In the minds of the authorities, that is the best they can do. Because all regulations in the maritime industry are founded upon previous experiences and historic sea events like Titanic or Estonia, the challenge is to foresee the future, which is what they try to do in the design teams. However, research has questioned this ability to imagine future accidents at sea (Schröder-Hinrichs, Hollnagel & Baldauf 2012).

Following the conclusions of the risk analysis, there are implemented strict guidelines as to what the crew can and cannot do when around the batteries. No other crew than those directly involved with the batteries are allowed in the battery rooms, which are now secured, restricted area. Sirens, alarms and yellow signs signaling "no entrance" have been set up outside and inside the battery room. During my five hours visit the deafening alarms goes off 4-5 times and signs that lights up and blinks in accordance with the specific kind of alarm. There have been regulations made concerning the daily work practices when dealing with battery risk factors such as: (a) high voltage; (b) fire; (c) thermal runaway; (d) the development of dangerous gasses; and (e) risk of getting electrical shock. Due to these risk factors, the design team and ship owner have agreed upon a set of procedures and rules about what to do if the batteries are not acting normally, when to stop them and when to shut them down. For instance, due to risk of high temperatures in the batteries and the risk of lethal gasses (in case of thermal runaway), the crew cannot enter the battery room in case of temperatures rising. The authorities are guided by values such as "safety" and "growth" during the entire approval and implementation process of the batteries. The risk analysis is a distinct tool for managing safety onboard, and the discussions often result in a reorganization of the crew where they are removed from the batteries and engines in case of emergencies and are focused on taking measures to save the passengers. This is one example of how the ambition of the risk analysis in the design team is to discuss resources and redistribution of the crew to heighten the safety in general.

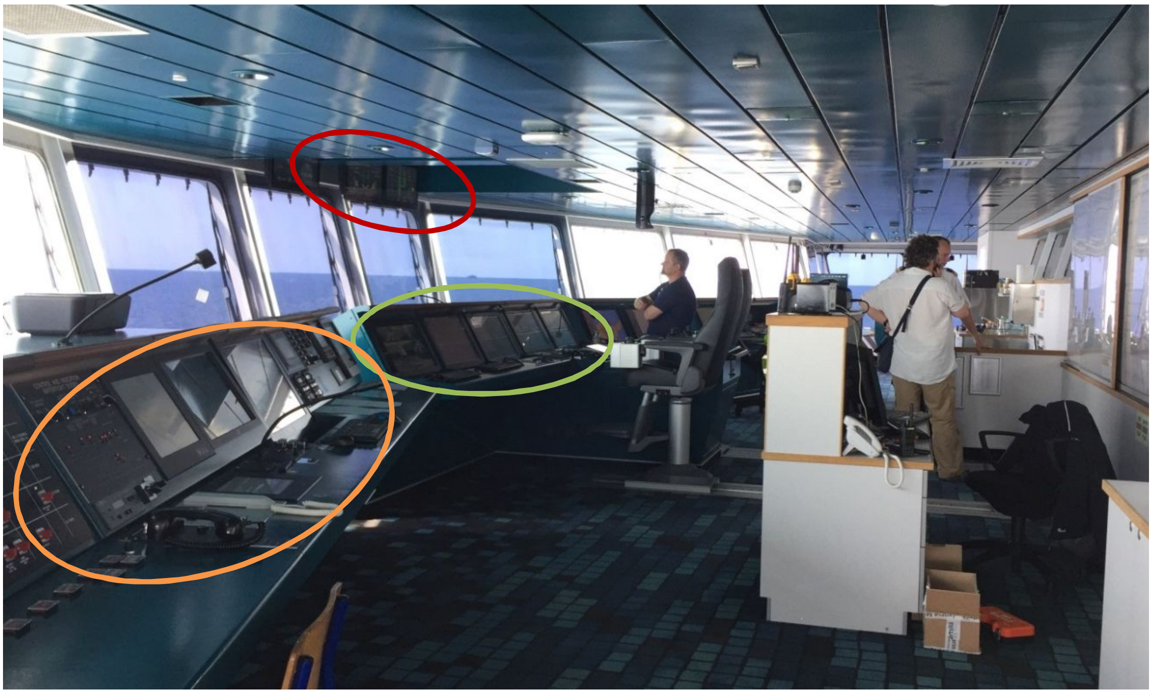

Photo 5. The captain watches over his vessel. He makes the final decision on navigation, operation and evacuation based on information on his control board (green circle). To the left is the control board for fire safety (orange circle) which is operated by the chief engineer on duty. In front of him a board shows the status of the batteries and engines (red circle).

Irrespective of the decisions made in the design team, the daily practice on board the vessel shows that the captain and his officers (and the vast number of computers and alarms) is responsible for evaluating risk and safety and undertakes the decision making process which is related to fire or emergencies (Photo 5). Onboard "Hybrid", three fire safety systems have been implemented to work as substitutes if the other ones fail. The primary alarm system is the digital system controlled via touch screens and linked online to the internet (Photo 6-9). In case this system breaks down or gets hacked, the engineer move on to the next system which is a more traditional, offline hard-wire system with old-fashioned buttons installed throughout the vessel. In case this system also fails there is a third and extremely basic system which is able to start basic commandos and evacuation procedures. The engineer on duty is responsible for monitoring the fire safety related to the batteries whereas the navigator on duty is responsible for fire safety in general. The responsibility for fire safety among the engineers is a change that has come with the implementation of the batteries. However, at the end of the day the captain solely and individually (and more importantly, subjectively) decides the level of safety, potential fire risks or consequences of unwanted battery action and not the experts in the design team, which are also guided by their individual assessments of the risks. This point will be discussed further in section 3.4.

3.2.2 Digital decision making and trust in technology

The engineers and ship owners have agreed upon strict temperature intervals that are monitored by the manufacturer and the interface computer system. The computer system signals (and ultimately also decides) whether a situation is risky or not. The temperature limits have been set in order to prolong the life of the batteries and not because of risk of high temperature. This indicates that battery life span is of a greater concern and more realistic risk factor than e.g. thermal runaway. The optimal operating temperature for the batteries is 15-25 degrees Celsius according to the practitioners. Onboard "Hybrid" the computer is instructed to stop the battery and shut down at 40 degrees Celsius (because of the battery life span). According to the "Hybrid" crew, thermal runaway occurs at 180-200 degrees Celsius, but their system is set to perceive 80 degrees Celsius as a risk temperature causing thermal runaway. Onboard "Electric" the computer initiates the first alarm when the battery temperature reaches 40-45 degrees. This is not perceived by the "Electric" crew as critical as it may merely relate to the water cooling or an error in one of the sensors. At this stage the engineers in duty will start investigating the reason of the alarm and try to fix the error or remove the battery. If they forget to react on the alarm the "system takes over control at 60 degrees Celsius and says: if you do not do anything within one minute I will do it myself. And then it cuts off the battery." In case the temperature reaches 70 degrees the battery management system takes over control and cuts the connection with the entire battery array. A temperature on 120-128 degrees Celsius it is perceived as the maximum temperature allowed onboard "Electric". In case a module unexpectedly reaches this temperature, the computer will stop all battery action, and the vessel will continue its route until it reaches a harbour and then waits here for the temperature to drop satisfactorily.

The manufacturers monitor the batteries meticulously from the other side of the Atlantic Ocean and "*if a battery cell acts suspiciously*", the manufacturer will notice it, contact the vessel and advise the engineers to replace it before anything dangerous happens. This practice of both a daily, practical monitoring on board and a highly skilled overseas technical surveillance adds to the feeling of safety among the practitioners. This feeling of safety also stems from a trust in the numerous systemic barricades which have been put up and because it feels like the digital systems help manage the risks. The "Electric" chief captain said:

> *"We explored what could possibly go wrong and in that case what we would do about it. And eventually which kinds of barriers we would put up to deal with the situation and prevent it from happening. And if this doesn't work, then we'll put up another barrier. And another. We've put up barriers against everything we could imagine"*

According to the Hybrid crew, the procedure for monitoring risk factors is fairly similar for batteries and diesel engines. The monitoring of the diesel engines also focuses on temperature levels and performance. A diesel engine stripped of its temperature surveillance system would also be extremely dangerous as the engine potentially could explode and blow metal pieces out everywhere. The naval architect said: "*Several people have been killed due to explosions of diesel engines. So far, no one has been killed by an overheated battery. So I think that batteries are safer than a diesel engine*". This illustrates the belief among the Hybrid crew that batteries are safer than a diesel engine.

There is little worry that the computer controlling the battery temperatures will fail. Since there is a great deal of surveillance built in to the system and it is meant to shut down in case of a breach in the system, it is believed that the system will shut down by itself in case of emergency. Another reason why batteries are perceived as safer than diesel engines by the "Hybrid" crew is because the "human factor" is removed (Photo 4,6). When delivered, the manufacturers have set the batteries and the computer system in a certain "auto-mode" that "*should be kept on, because it all starts to go wrong once you uninstall the auto-mode. You just have to leave it the way it came, like the systems want to be set. If you start to overrule it, then it becomes dangerous*". Thus, the battery technology is perceived as a fail-safe technology with a low frequency of errors and with a great amount of trust put in the manufacturers. Ultimately this also means that the manufacturer partakes in the daily assessment of risks via the decision on what constitutes the "auto mode". Electronic components and installations are seen as less flawed compared to mechanic components because "*there isn't someone who's adjusted something incorrectly some-*

Photo 6. The work tasks of the engineers on duty are increasingly of an electronic, digital kind rather than a mechanical kind. This makes it more difficult to fix problems at sea and assistance from external experts may be needed.

where". And as mentioned, it is possible to set up digital barriers and limit values with the same standard in the components. This affects the perception of safety and risk greatly: *"Then you have a very clean equation stripped of a range of obscure factors. This is not the case in diesel engines. And that's why I believe you have a substantial level of safety in these batteries".* This aspect makes the trust in the system and technology very high among the engineers and management.

The feeling of safety because of the use of batteries also stems from a conviction that batteries prevent the risk of energy blackout. If something went wrong on older vessels, entire energy storage systems could or would shut down, leaving the vessels to drift away. With batteries on board, the vessel "*stays where it's supposed to"* according to the practitioners. They feel that batteries ensure a higher level of safety than fuel because of reliability, both in terms of operation, navigation and not least human lives. Automated procedures now run, monitor and control either batteries or diesel engines, which means that the crew's work tasks have changed and their safety and working environment on board have increased dramatically. As the superintendent puts it: "*In the old days the marine engineers were left in the engine room when Titanic sank because they tried to get the water out. It's not like that anymore because today most of the systems are automated*." Thus, the authorities also believed that digitalization is "*the future*" and that it increases the feeling of safety and reliability on board.

As already hinted, the increase in applying digitized and automated technologies and systems means that the risk scenarios shift in accordance with the increased digitalization. Hacking and cyber safety is of greater concern and a more immediate risk factor than thermal runaway. As the chief engineer on "Electric" put it: *"The numbers on when it will happen are something like one in a million: I can tell you, it won't happen, not with all the barriers we've made"*. The only actual risk of using batteries perceived by the senior officer on Hybrid is *"getting a cold from standing in shorts in the battery room"* (because of the cooled air system in the room and on the batteries). And yet at the same time, there is great acknowledgement in the dangers of thermal runaway: flammable and toxic gasses which are difficult to predict where and how they act. However, the risk of thermal runaway is not perceived as significant, as the computer and surveillance system will monitor the batteries and shut them down in case of fire. Furthermore, there has been installed a specialized and separate ventilation system to take care of the potential lethal gasses. Fresh air from the outside is pumped into the battery room and thereby pushes the lethal gas out of the room and into the ventilation system, which is also designed to shut off at tactical spots in

Photo 7. The ventilation system.

case of fire (Photo 7). Thus, the risk of the batteries going into thermal runaway is more perceived as a theoretic risk, which they must take into account, rather than an actual risk that may happen, as the computer primarily ensures the level of safety.

Yet again, just because batteries are introduced as a part of the propulsion system, the practitioners stress that the safety levels for batteries must not be higher than for diesel engines: the level of safety must be the same irrespective of batteries or diesel engines. However, the ship owners seek to keep improving the safety of operating with batteries in order to make it safer than operating with diesel engines because a general safety level has not been agreed upon yet and because the authorities demand these high levels of safety. This perspective is discussed in further detail in section 3.4.

One of the reasons why the trust in the systems and batteries is high is that they have been tested over and over again. What became obvious during the interviews was that the perceptions of risk and hazards – and the level of argumentation and research needed for assessing the risk – decreases, as the number of tests of the batteries increases. Put differently, as the number of tests and guidelines increase, the need for safety arguments decreases. Many of the major installations (not just batteries, but generally) have been tested thoroughly by manufacturers and authorities, which have led guidelines of the production, handling and use of them. The "Hybrid" crew believes that when you add up a range of minor safe and field-proven components you will end up with a very safe major component, because the sanctioned standards ensure an agreed level of safety. The trust is put on the numerous tests (entailing agreed risks and levels of safety) and not necessarily than on the batteries. Referring to the above discussion on deciding a given level of safety and risk, it seems that one broadly acknowledged way to talk about a given level of safety in the maritime industry is to refer to test results, certifications and accreditations.

Photo 8. The fire safety control board. There are three systems to back up each other in case of a black out or breach in the technology and communication. To the right are the internet based, digital surveillance system and to the very left is the most basic local wire system.

3.2.3 Fire safety and digital safety

Of course, the biggest safety concern on board the vessels among the crew is the safety of human lives, in particularly through fire prevention. There are no longer concerns about ship wrecks or Titanic-like incidents. All questions about safety concerns fire safety because of the personal risks.

In the battery room on "Hybrid", water mist with fresh water has been installed as a specific means for fire extinguishing. If the mist turns out not to be sufficient, the sprinkling system can be altered into regular sprinkling. Also, the air is cooled and so are the batteries in order to keep the temperatures at a satisfactorily low level. On board "Electric", the batteries are installed inside four freight containers on the top deck due to lack of space next to the diesel engines. An outcome of the work of the design team on "Electric" has been the development of new, elaborate fire safety strategies, mainly to prevent a potential case of thermal runaway. The batteries are cooled internally with water, which enables the crew to best control the temperature in the batteries in the area of 20 degrees Celsius. As long as they stay that way they are *"home safe in terms of safety"*. They have installed constant vacuum and exhaust ventilation on the back of each battery in order to lead away potential lethal gasses caused by the warming of the batteries. According to the "Electric" crew, this means that *"there's nothing in there [inside the freight containers] that will be able to catch fire. There'll just be a thermal decomposing of the battery cell"*. The potential threat of a cell *"running amok"* due to a chain reaction in the cells next to each other is eliminated with water cooling, because the fire can be detained in the one cell. Furthermore there have been installed aerosols[5] inside the freight containers on "Electric" which *"removes the flames and prevent further heating"*. If all goes wrong. There have been installed sprinklers inside the freight containers: *"Then we'll just bloody drown the fire the expensive way!"* In case of fire outside the container or fire/heat from the decks below the batteries, there are also external sprinklers to *"wrap the container in water"* and they have all been painted white in order not to absorb unnecessary heat from the sun.

Fire safety concerns are so predominant among the practitioners that it permeates all everyday activities and it seems evident to everybody on board that fire safety is an imperative (Photo 8-9). And yet, fire safety seems no longer to be a cause of anxiety and stress among the crew, exactly because of the new technologies which are being implemented and improved all the time and ensure barriers of safety several places in the systems. In this way technology ensures control over a potential fire and the ability to manage it. The chief captain ("Electric") said:

"I have total confidence in the safety barriers. If anything should happen, the water will cool it down, and the fire will be small and quiet and there will be no explosion. We evacuate the gasses and we'll be able to control that. There are safety barriers all the time. And should anything happen we'll be able to control it. We can simply control it and say: okay, the fire is within that cell, we'll just leave it there by itself to thermally decompose. And that's it. We can control the process."

[5] This refers to "FirePro condensed aerosol". The discharged condensed aerosol consists of a mixture of inert gases (the carrier gas) and the active agent K_2CO_3. Fire is extinguished through a chemical reaction that inhibits flame free radicals on a molecular level from interacting with oxygen without reducing oxygen levels.

Thus, with the introduction of new and more digitized technologies aboard, the engineers and the authorities have started to reexamine their systems for new safety challenges and loopholes. They are increasingly concerned with digital safety and the risk of hacking, as their systems develop in a digitized, online direction (Photo 8-9). One example of this alertness is that special firewalls have been set up and the battery manufacturers are only allowed to monitor the systems as external partners and cannot change or alter any settings or specifications in the systems unless they are onboard the ship physically. This step has been taken in case the manufacturer's systems were hacked or similar events. This digital risk is a greater concern to the practitioners than "regular" fires or even thermal runaway. The marine superintendent from the authorities shares this digital concern and explains:

> "*We were concerned with cyber safety from the minute we started doing these risk analyses in 2014. That was when we did the first 14.55 procedure*[6]*. And back then we discussed access, because typically the battery manufacturer wants to have a user interface aboard the vessel in order to monitor their batteries properly and it's typically tied to a contract. They have a contractual relationship with their client stating that they operate in a certain way and use the batteries in a certain way in order to outlive the contract and the battery lifetime. But that means that they will need internet access to these batteries. And we discussed this issue of user interface with the owners and the manufacturers. Typically you need some kind of password in order to gain access, and perhaps they are located on the other side of the planet and they log on to a vessel in Denmark in Danish waters. Is it possible that they can access the systems and change the parameters or are they merely logged on to observe? I mean in order to see and track data, but not to change parameters or settings? Because then you'll get scenarios where you should have a master, master, master password and*

Photo 9. A digital overview of all alarms, including fire alarms, on one of the decks. In total there are 8000 various alarms to consider in the "Hybrid" system and 5-6000 in the "Electric" system.

[6] This refers to the IMO 14.55 or the maritime guideline MSC.1/Circ. 1455.

you can log on from somewhere in Canada and change settings and no one will notice that there's a fire, because it will be possible to change the parameters so it will set on fire. […] With this increased digitization you suddenly have leaks in the vessels in a completely new way than before! […] Cyber safety is the worst enemy. It would be a very unfortunate scenario if a large passenger vessel was hijacked because a company in Canada had been hacked by some potential terrorists and they are drifting about out there somewhere on the ocean. Then what do you do? Can you cut the line? […] The more you put into these systems the more vulnerable they become if one of the systems break down. And this is the way we're moving: digitization creates one major system, and if this crashes you're completely fucked! And then you're left with the old hardcopies and paper manuals and procedures where you go like: UHG, what are we gonna do?!"

The contractual relationship between the ship owner and the manufacturer as described by the superintendent has been set to last 10 years on "Hybrid" and 5 years at "Electric". The increased digitization on the vessels relates not only to the installation of batteries, but also to an increased number of monitors and sensors. However, the only elements obviously signaling that this is a hybrid vessel are two dignified areas on the control boards with special buttons for the battery installations, and that the board in front of the captain showing engine power etc. now also includes indicators for battery status. In total, 8000 alarms are installed on the Hybrid, all of which the captain and his crew on duty must know what to do with (Photo 4-7). On "Electric" there are some 5-6000 alarms and prior to the installation of the batteries they had 3000 alarms. Thus, the amount of alarms that the crew must now consider and know about (due to batteries) has doubled. The growing number of alarms, monitors and digital messages brings about the challenge of navigating the vast amount of information at hand according to the practitioners. The senior engineer ("Hybrid") had this experience to share:

"We've increased the number of alarms due to the installation of the batteries. But it's also much easier to set alarm points today. You set many more alarm points because you have the sensor and measuring technology to do so and which is much more accessible nowadays than 10-15 years ago. Perhaps you set more alarms points than what's doing any good. You just do it because you can. But then you might end up receiving staggering amounts of information. And remember, if you're in an extreme situation of emergency you must remember what kind of information you need and which to pass on. If you have like 20-50 alarms going off at the same time and perhaps only 2 of them are relevant to you while all the others are consequences of some action… the guy standing in this situation…that's very, very difficult. It's very difficult to handle and assess in emergencies. I've tried it myself once where one of the engines blew up. It's very difficult to make safe and sound judgements in situations like that where you have 100 alarms swarming you because of systemic errors and faults and communication breakdown. It's very difficult. Where do you start and where do you stop?"

The chief engineer shares this story with me while we're standing in the engineers' control room at "Hybrid". While we're there an alarm goes off. The engineer on duty (not the one I followed) got out of his chair, approached one of the 6 large computer screens on the wall in front of him. He skillfully navigates the program on the screen and scrutinizes it for 2 seconds. The deafening alarm and blinking sings are still on. He then searches for a specific button, finds it, looks at the screen again to check yet another emergency message and then pushes the button. It all takes 15 seconds. The alarm stops. It was a case of a passenger who was feeling ill. The chief engineer notes that it’s not possible for them to deprioritize an alarm or end it until they attend to it or tell the system that they will attend to it later, no matter if the alarms have to do with batteries or any other part of the ship. Onboard “Electric” they have the same experience of facing the struggle of prioritizing among the alarms in stressed and difficult situations. The chief engineer here tells me that they have 30.000-40.000 monitoring points from which they have to navigate among and select the importance of. This sets high demands on the engineer’s knowledge about the alarms, which ones are useful to them, which ones are not, and what kind of information they (might) need in a dangerous situation.

In situations like these with several alarms going off at one time, it is of paramount importance to reach a comprehensive understanding of the situation via the surveillance cameras and alarms on the vessel (Photo 10). There are automatic fire warning systems on board which immediately tells you the location of the fire. The practitioners place great trust in these fire detection systems. The fire warning signals directly to the captain, who then immediately locates the fire on the cameras placed throughout the vessel. In any case (whether the fire is caught on camera or not) they send a crew member to investigate whether it is a false alarm or there is a real fire and to assess the spread of the fire (Photo 9-10). So when it comes to the well-known fire detection technology the crew double checks, as opposed to the battery technology which the crew place great trust in without double checking.

In case of an actual fire there is a call for all the crew members with specially assigned tasks in fire situation who are supposed to know exactly what to do next. While assessing the fire, the captain and his crew consider the following: (a) what needs to be done; (b) is there a need to start the regular fire safety procedures; (c) should we fight the fire manually; (d) should we evacuate the

Photo 10. The fire detection system with cameras installed throughout the vessel in order to capture fires on camera and evaluate them at a distance before engaging in fire extinguishing and evacuation.

vessel by lifeboats or just a part of the vessel? There is an A60 fire rated construction around the battery room at "Hybrid" which according to the crew ensures that the fire will stay in the room for 60 minutes. Onboard "Electric", the batteries are installed inside four freight containers on the top deck where no passengers except selected crew members are allowed, while the diesel engines are still installed in bottom of the vessel. Both options give the captain enough time to consider the specific plan for fire extinguishing and evacuation and call on the personnel needed.

Curiously, there seems to be more trust in the automatic system connected to the battery packages than the automatic fire warning system. There is no worry that the computers securing the temperatures of the batteries will fail. Since there is a great amount of surveillance built in to the system and it is meant to shut down in case of a breach in the communication or surveillance within the system, it is believed that the system will shut down by itself in case of emergency (Photo 4,7-8). Put differently, if something does not work, the system/the computer shuts it down autonomously. This aspect makes the trust in the system and technology very high as the technology assist in the management of the safety and risks. Here, the battery computer technology becomes an agent of its own that crew members put their faith and trust in to work flawlessly every time. Should something go wrong, it is because someone has changed a mode they should not have, or some other breakdown that the engineer will not be able to fix because they do not have the knowledge to do so. Thus the responsibility of damage and the ability to define risk and safety is increasingly transferred to the manufacturer. This means that when it comes to batteries, the distribution of power changes and is concentrated more in the industry whereas the majority of power in other aspects of the maritime world resides with the authorities.

3.2.4 Key insights on risk and safety perceptions

- The design team designated the specific vessel being built develops strict guidelines about how to install, handle and maintain the batteries on board the vessels. They base their risk assessments on their experience in the field. The only challenges of the design team lies in the ability to imagine and foresee all potential risks.
- In the case of the batteries, there is a practice of both a daily, technical surveillance on board and a highly skilled overseas surveillance. There is little worry that the computer monitoring the battery temperatures will fail. Since there is a great deal of surveillance built in to the system and it is meant to shut down in case of a breach or fault it seen as very safe. Another reason why batteries are perceived as safer than diesel engines by the practitioners is because the "human factor" is limited to a minimum of interference. So far, the practitioners have had no experiences with deaths caused by batteries but numerous accounts exist in the industry on exploding diesel engines with hazardous outcomes. Thus, the practitioners believe that batteries are safer than a diesel engine. All these elements together add up to a heightened feeling of safety among the practitioners and trust in the digital technologies related to the batteries.
- The risk of the batteries going into thermal runaway is more perceived as a theoretic risk, which they must take into account, rather than an actual risk that may happen, as the computer primarily ensures the level of safety. A primary risk factor (if not the most preva-

lent risk factor at the moment) is the case of hacking since an increasing number of systems, communication and surveillance is run automatically, digitally and via the internet.

- Automated procedures now run, monitor and control either batteries or diesel engines, which means that the crew's work tasks have changed and their safety and working environment on board have increased. This also means that the responsibility of damage and the ability to define risk and safety is increasingly transferred to the manufacturer. In this way, technology ensures a perceived control over potential risks and the ability to manage them with the help of systematic safety barriers in the programs and surveillance systems.

3.3 Reflections on fire emergency evacuations

According to the Hybrid crew, there are no distinctive fire evacuation procedures specifically related to a battery fire scenario. And yet, they show me the flow charts for the implemented IMS safety management system for emergency evacuation in case of a thermal runaway. According to the "Electric" crew, there has been made no changes in the fire safety strategies or evacuation plans concerning the passengers due to the implementation of batteries. The changes have been about the crew and in particular the engineering, operational and navigational staff. There are specific rules implemented that the crew cannot be anywhere near the batteries in an emergency and all must be tracked. This is seen as the primary change that has been done due to the installation of the batteries. The maritime engineers fully acknowledge that there are technical considerations to make in relation to the batteries, but apart from the specific technical aspects, fire risk scenarios aboard have not changed dramatically in their minds due to the implementation of batteries, but have rather been adapted to fit the new technology aboard. According to both crews, minor changes have been made, but the overall picture and fire emergency rescue plans remain the same, especially for the passengers (Photo 11). The way they get people into the lifeboats is the same, but it is not possible to foresee the chain of actions in an emergency. It seems that at sea, fire safety evacuations are very hard to predefine according to the "Hybrid" crew. Variations in vessels, routes, machines, technology, weather conditions and staff make it difficult to generalize in practice. The naval architect ("Hybrid") put it this way:

Photo 11. The four different standard emergency evacuation signals. They have not been altered with the implementation of batteries.

"You cannot make a specific procedure where one size fits all, because there are so many different scenarios that can play out once there is a fire. It is the captain and his

crew who'll assess the fire and decide what needs to be done about it and how to secure people on board. And of course they have fire drills where they try out different scenarios and simulate one incident after another. So they do it a lot on the vessels, the fire emergency evacuations. […] Of course there are special considerations to take when it comes to batteries, and that is of course also a part of the drills. But aside from that we still do the evacuations the same way as we always have."

The senior engineer on "Hybrid" elaborated on the naval architect's point about not being able to make general procedures across many vessels on fire safety. He explained that it is difficult to come up with a clear-cut procedure on how to act in case of fire or other emergency situations. Compared to e.g. the aviation industry where all parts and bolts are placed at the same spots and there is a common design strategy for all planes, vessels are custom made according to the ship owners' whishes. He explained:

"That means that it's difficult to make fire drills on vessels. It's easier to decide what's best if you have 1000 Airbuses, because then you can figure out the best practice. But in a very difficult situation it's hard to say which practices or options are the best. You can make fire drills, but in such a complex organism like this vessel you'll never reach a stage where you can say: this is the right way and this is the wrong way. You can make limiting initiatives and decide to secure the systems you know are actually functioning. You can isolate those systems. And you can start focusing on those systems and make sure they are maintained. But you'll never be able to say if that was the best to do or not."

Contrary to this, the authorities believe that the introduction of the batteries have caused major changes to the maritime philosophy of fire safety. The marine superintendent at the authorities explained the change in fire emergency strategies this way:

"*Of course they will have to change their procedures when they get something aboard the vessel which is not a diesel engine. You'll have to adapt new kinds of initiatives and there are new things to beware of. It's a different kind of philosophy that I will not go into detail with because it will become too specific. But it's obvious that the procedures will change. The general picture of fire emergency evacuations is the same, but the philosophy has changed. It will have to when you install something new on board. Or perhaps is has not changed dramatically, but it has definitely been adapted to the new technology. […] I'll give you an example. The information you'll have to provide when you have to go to the shore, that's a bit characteristic. You change the information for those on land about what we bring along. It's a part of the changed fire philosophy. Perhaps it's also a more general thing that I can explain without being too specific. So if you come into the harbor with something that has been on fire like a lithium-ion battery then you'll have to stay put until some technicians arrive and fix it. It's the manufacturer's technicians who'll come and help remove the damaged batteries. And these are some of the things we found in the risk analysis which have to be implemented onboard. The changed sort of information needed also goes for the fire brigade. The* *vessel have to call them before they arrive and tell them that there is a fire on the vessel, the position they have, and that they are carrying lithium-ion batteries onboard. Because then the fire brigade knows what they bring along and that it's a different kind of fire than a usual fire on a traditional vessel with diesel engines*."

3.3.1 Key insights on evacuations

- There is a slight misfit between the practitioners' and the authorities' perception of whether the fire safety evacuation procedures and the like have changed due to the implementation of batteries. The practitioners believe that are no distinctive evacuation procedures specifically related to a battery fire scenario apart from specific technical aspects which have been changed. Thus, fire risk scenarios have not changed dramatically in their minds due to the implementation of batteries because the passengers are not affected by it, but the scenarios have rather been adapted to fit the new technology aboard. This is opposite to the authorities who believe that the evacuation plans have changed dramatically, but then again say that they have not. Thus, there seems to be some level of confusion to this matter.

3.4 The maritime need for guidelines - a case of definitions

Currently there are no official or general regulations in Denmark or in IMO on the topic of battery propulsion on large vessels. The only available tool according to the practitioners is the 14.55 guideline for "*alternative designs".* However, there is a demand among the practitioners for a definition of the level of safety and risks when it comes to the use of batteries in the maritime industry. As explained previously, design teams are being created as a response to this demand and as a way to try and decide upon a safety level until batteries enter the regulations. According to the practitioners, this approach gathers all the various risk factors in relation to the implementation of batteries. Afterwards the ship owner will consider the risk factors, discuss them and come up with solutions and ways of handlings the assessed risks. The risk based approach has been practiced in the maritime industry in Denmark since 2014, and therefore it is still a new exercise with a need for deciding upon an agreed risk level.

According to the naval architect ("Hybrid"), choosing a risk based approach makes it crucial to consider what level of risk you will accept on board, because if you do not know this level, you will not know what it takes to reach this level and fulfil the demands that go with it. As mentioned, the ship owner of "Hybrid" was not able to find any agreed upon level in Denmark and the Hybrid crew blame this lacking definition on the conservative attitude within the maritime industry and authorities. They believe that the authorities found it is difficult to agree upon a safety level, so they would rather not, especially out of fear of stating something wrong. So when it comes to battery packages, the maritime industry struggles with a definition of the level of safety and risk, because batteries are still perceived by the regulations as "alternative" and not yet big enough in the market to demand administrative and legal changes. According to the "Hybrid" crew it is fairly easy to define a certain safety level, but it has not been done yet because of political reasons. The authorities believe that this lacking defining a safety level is justified:

> *"When you say that there must be "this level of safety", what does that mean? It's really difficult to explain, because it can mean many things. So I cannot just explain what it means in one sentence, because there are many factors. I mean, it's difficult to make generalizations about because these projects are very specific. […] And the solutions that the design team comes up with are not regulated. So if we didn't do the check ups and do it the way we do with the risk assessment process and approval then they'd just be sailing without any. That means we wouldn't be able to ensure safety and growth. So it's the only way there is to approve the technology and ensure the safety of the Danish citizens."*

But according to the "Hybrid" crew, they feel that the demands for the safety of the battery technology were set unrealistically high in comparison with the diesel engines. In the words of the naval architect, a package of battery modules should not be safer or more secure than a diesel engine; it should be the same: *"At it is now, because of the lack of experience, guidelines and knowledge, the battery packages are far more safe than the diesel engines, and it should not be like that, because that means you have spent too much energy and time on this particular technology at the expense of other parts of the vessel which should be just as safe and secure. The safety level of battery package ought to fit with the level onboard the rest of the vessel."*

The authorities agree with the naval architect that the safety levels should be the same. They do not wish to increase the requirements but aim at ensuring an equivalent safety level for the batteries that corresponds to the regulation on diesel engines. However, this is not the impression that the industry is left with. Thus, there seems to be an ongoing yet inadequately debated discussion in the maritime industry on what the safety level for battery packages on large vessels could look like. The naval architect ("Hybrid") explained:

> *"If you're going to follow the risk based approach when building vessels, it will take you at least 500 years to build, because it takes such a long time to make these base line studies on the potential risks. […] I think we should move in that direction in terms of batteries so that you'll have some rules and regulations on what makes sense and what should you do. In this way, you avoid starting over again and again with doing a lot of research, assessing risks and dangers and a whole lot of other stuff. It does seem like we have already started moving in that direction [in the industry]. "*

Thus, the ship owners requests a thorough decision making base line for batteries so they will not have to start over again and again with a new risk assessment each time because it is perceived as a extremely time consuming. Conversely, the authorities believe that it is of utmost important that the risk assessments are being made from scratch each time because every vessel is so different and specific.

The "Hybrid" crew's experiences are not shared by the "Electric" crew, supposedly because they have gone though the same process a few years later and thus have not met the same suspicion, skepticism and lack of knowledge and guidelines. The "Electric" crew feels that the authorities have been much more helpful, alert and keen op cooperation and resolving any difficulties together than they could or would have ever expected from an authority. The senior captain said:

> *"In my opinion the Danish Maritime Authorities have been amazing throughout this process. They have been taking very much part in the process and they have been super enthusiastic. And they've had a good acknowledgement of the fact that this is new to all of us and that we're all still learning. They have been available to us at almost all times, perhaps even more that you could expect or ask for. Those inspectors who were associated with this project have really gotten down to the work!"*

Contrary to the experiences onboard "Electric", the "Hybrid" crew's cooperation with the authorities in developing guidelines for batteries left them with an impression of the authority as being somewhat resistant to facts and much too focused on risks related to thermal runaway (which is, as pointed out, not believed by the practitioners to be a realistic risk but a potential risk). According to the practitioners, the authorities believed more in the notion that thermal runaway would and could happen and that it was dangerous, than they believed in the data and documentation presented to them by the industry and manufacturers which showed that it would most likely not happen. It appeared to the Hybrid crew that the authorities tried to make the use of batteries more dangerous that it seems to them. Among the engineers this reluctance to approve the batteries is explained by the impression that DMA may be afraid to approve something that they might regret later on in case an accident happens. Also, the authorities were perceived to be unable to get access to the needed information or competencies in order to evaluate and assess the technology and situation properly which made them overreact to the situation. In the minds of the practitioners, no authorities dared to sign the acceptance in case the bar had been set too low resulting in a situation where the safety demands for battery packages and technology are now extremely high compared to fuel engines.

What is interesting is that none of the interviewees were able give examples on what the "safety level" means or entails, but all said that it is difficult to define and agree upon, and that it depends on specific characteristics of the vessel, sailing route, geography, crew and so on. The most precise definition that came up was that it relates to "*fire, working environment and many other things*". The challenge is that all parties in the maritime industry seemingly agree that the safety level is difficult to define and all wants to come closer to a common understanding. Yet no one seems to try to discuss what it may actually entails. In stead, risk assessments are initiated as a response to the lacking definitions and agreements. According to anthropological research, risk assessments are highly individual, social and cultural and shaped by personal experiences (Boholm 2010; Garsten & Hasselström 2003). Risk is observer-dependent in the way that it is dependent on the observer's knowledge and understandings, and only rarely does society, specialists or experts agree upon what is "risky" or not (Boholm 2015).

In the risk based approach advanced by the authorities and adapted by the practitioners in order to evaluate potential risks and fire hazards, there is an underlying assumption that risks are objective as factors that can be pointed at and agreed upon. Through the discussion in the design teams, all possible risks will be foreseen and the only challenge is "just" the limits of the creativity and imagination of the experts. The question then becomes: what about those risks that does not come to their attention and which the experts are not capable to foresee or imagine? During the talk with the “Electric” crew they told me:

> *“1,5 years ago we were somewhere up north in Sweden for this test of a thermal run-away. The whole thing blew up in the air! Big time! And there was the guy from Lloyds and they had already come up with some rules and guidelines. But when ha saw that he tucked all his stuff away and said: ‘I think I’ll have to go home and make up some new rules’. So he just hadn’t imagined it would happen!”*

What is interesting about this story is that the crew did not perceive this mistake by the engineer or missing a risk factor as an expression of lack of competencies or as an example of the fact that risks perceptions are very much dependent in individual experiences etc. In stead it underlined the fact that more data on experience with the field is needed and that they are all still learning. With this story as an example, it seems relevant to question the ability to list all possible risk scenarios, and thus to further investigate how emergency situations and (un)likely risk-scenarios are being ranked, judged, evaluated and deemed risky or nor in the design team process. By uncovering this process and delve into it, it may be possible to help avoid situations or accidents where recurring and yet unrecognized and unexplored social, human and organizational factors and relationships in the maritime industry seems to play a crucial role in operational safety (Schröder-Hinrichs, Hollnagel & Baldauf 2012). The issue at hand is not that the risk assessments made by both the design teams and the captains are culturally, socially and individually shaped. The issue is that this seems to be unacknowledged, and that the maritime industry have replaced one term defined by individual factors (safety) with an other term defined by individual factors (risk), while believing that risk assessments are more thorough and objective rather than a given “safety level”. This may eventually leave the industry just as confused about the demanded minimum safety level for batteries, because the risk term promises better knowledge on the risk and safety on board, but will end up being just as undefinable as the safety term.

The authorities also wish to reach a more common guideline or base line for decision making when it comes to installing batteries on large vessels. They suggest the drafting of an international battery code. The superintendent explained:

> *“We have a general objective. We want an international regulation on batteries, but not just batteries. We call it energy storage systems, and that can be a lot of different things, not just batteries. But in the long term we aim to get a battery code, just like the FSS code for fire. At the moment there’s no battery code, but the fire code is a systems explanation on how the various systems must be built. So the battery code would state like: you must have a battery management system in order to ensure that your batteries don’t go into thermal runaway when they charge or discharge. Alright, battery code, rule number two: in case of fire there must be something that ensures that the fire can be detected and extinguished. So more specific in that way, that would be a battery code. And there would also be some definitions of what the different terms mean and how you interpret them. That would be nice, because the knowledge is worldwide; it’s not gathered in one place. With a battery code it would be relevant to define the terms to ensure that we agree on what we’re talking about. So thermal run-*

away, what do we mean by that? And BMS; battery management system. It depends who you are talking to. The definition of thermal runaway varies depending on which battery manufacturer you talk to. They may have different perceptions about their batteries and might want to use a different term than thermal runaway, because it sounds like everything is gonna burn to the ground."

The "Hybrid" crew has a different suggestion than a legal code. They stress the importance of developing a common experience based data bank and perceive the gathering of experiences across different cases as a good thing. They expect that the development of this experience based data bank will develop over time as more ships are built or retrofitted with batteries as a part of the propulsion system. As it is now, the "Hybrid" believes that Lloyds have created one for themselves and that the authorities have as well. *"Everybody tries to absorb everything they can in order to learn about this area,"* said the chief engineer onboard "Electric". However, in case different stakeholders have different experiences it may be very fruitful in future work to merge these experiences and make them accessible across interests and levels of experiences.

3.4.1 Key insights on the need for guidelines

- Ideas for recommendations on guidelines concerning batteries center around three aspects: 1) the need for an agreed safety level on batteries; 2) the need for a battery code related to international IMO regulations; and 3) the need to develop experience based data banks.
- The maritime industry struggles with a definition of the level of safety and risk, and according to the practitioners this is because batteries are still perceived as so-called "alternative" and not yet significant enough in the market to demand administrative and legal changes.
- The authorities believe that the risk assessment process is completely justifiable in order to secure a satisfactory safety level on board, and stress the need for making specific, individual risk assessments for each new vessel that implement batteries. On the other hand, the practitioners feel that the demands for the safety level of the battery technology are set unrealistically high in comparison with diesel engines. In their opinion, the batteries should not be safer than a diesel engine; it should be the same. However, they believe that the safety levels are not matching.
- The challenge in deciding an agreed-upon safety level for batteries is a core challenge in the maritime industry when it comes to batteries. The lacking guidelines and consequently the thorough and time consuming risk assessments performed separately and specifically for each new vessel with batteries on board frustrates the industry, and in particular the ship owners. It is discussed whether using risk assessments as a method in stead of discussing a relevant safety level provides better understandings of potential hazards due to the use of batteries in the propulsion system.
- The cooperation between the practitioners and the authorities in making the risk assessments left the Hybrid crew with an impression of the authorities as being somewhat resistant to facts and much too focused on risks such as thermal runaway, which to the practitioners is more a theoretical risk than an actual risk.
- What the parties do agree about, is that one of the major risks that the maritime industry is facing at the moment is the risk of hacking, cyber attacks and cyber terrorism.

4 Conclusions

- The introduction of battery technology has impacted the daily workflow and activities of the crew. There is less (yet very different!) maintenance to do, a better working environment and less strenuous work to be done by the engineers on board. With the installation of the batteries, the daily, practical challenges have changed from being mechanical to electronic and the engineers have had to get used to calling for help from external experts in case of problems with the batteries.

- The introduction of batteries has been followed by an increased digitization on board. This has altered the practitioners' ways of perceiving risks and there is a great degree of trust in the technology. However, the more digital the systems are, the more complex the operation and technical maintenance become. As it is now, shipping is already an industry marked by both high degrees of complexity on the one hand and very specific conditions on the other. Digitalization and increased amounts of technologies and automated systems does not help to harmonize the complexities but instead supports the specificities and complexities in an industry (Turk 2016). Technologies demand specialization and highly skilled experts. Thus, the marine engineers no longer possess all the skills needed at sea for fixing the various problems related to operating the vessel. Now they will need to call experts from the manufacturer for help. This means that the introduction of batteries also introduces new players in the field of negotiating power balances, risks, safety and responsibility. Operating with batteries on board as a part of the propulsion system demands the ability to navigate even more complex decision making processes than before.

- Technology and digitalization play a vital role in the risk and safety perceptions among practitioners and authorities. Technology is seen to provide an increased level of safety because it limits human interference and mistakes and because it ensures standardized and systematic safety barriers. The practitioners believe that batteries are safer than diesel engines. Simultaneously, digitization and in particular hacking is seen as one of the top major threats at sea comparable with major fire scenarios because the majority of alarms, detection systems, communication, and now also the battery propulsion systems are controlled digitally and/or via internet connections. The traditional divide between land and sea which permeates thoughts, practices and legislation in the maritime industry diminishes and changes with the increased application and use of internet and digitization onboard, and this poses new risk scenarios according to the practitioners. Thus, with an increase in the digital interfaces new potential leaks become present and cyber safety must be considered as an equally hazardous sea event as a fire. The authorities and the practitioners agree on this primary risk issue.

- There is a misfit between the practitioners' and the authorities' perception of whether the fire safety evacuation procedures and the like have changed due to the implementation of batteries. The practitioners believe that are no distinctive evacuation procedures specifically related to a battery fire scenario apart from specific technical aspects. Fire risk scenarios have not changed dramatically in their minds due to the implementation of batteries, but have rather been adapted to fit the new technology aboard. This is opposite to the authorities who believe that the evacuation plans have changed dramatically, but then again say that they have not. Thus there seem to be some level of confusion to this matter.

- The continuum of specificity and complexity characterizes the entire industry and is also at the core of the issue with deciding upon a given safety level. There is an ongoing debate in the industry about what the safety level must be concerning batteries as an alternative energy source. Yet this debate has found no answer so far. The lack of regulations and guidelines, and the subsequently thorough and time consuming risk assessments performed specifically for each new vessel with batteries on board frustrates the industry. It is questioned whether using "risk assessments" as a method in stead of discussing a given "safety level" provides more and new insight into potential hazards and accidents concerning the use of batteries in the propulsion system.

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