1 ELBAS – WP1: Human Factors

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1.1 Introduction

The following chapter describes how Human Factors can affect the firefighting capabilities at sea and how the shipboard firefighting crew may be affected by the technology at their disposal and their surrounding environment including passengers.

1.2 Methodology

The following section describes the methodologies used during the research and data gathering phase of the ELBAS project for the Human Factors workshop. DBI acquired the data through a series of interviews with ships' crews held over multiple trips sailing through Danish and Norwegian waters. During these trips, DBI also observed the day-to-day activities of individual crew members and fire drills to understand how the crew trains for a live situation. In addition, DBI conducted a literature review focused on human factors in maritime and electric vehicle accidents.

1.2.1 Literature Review

DBI conducted a literature review at the early stage of the ELBAS project to get insights into previous accidents related to electric vehicle (EV) fires. The review was a typical desk set-up research and included accident reports from the Danish Maritime Accident Investigation Board (DMAIB). The human factor review consisted of two parts, one focusing on EV fires and one focusing on human factors in maritime accidents.

The only accidents studied were related to passenger-carrying vessels, limiting the scope of the review, and focusing on the ship types included in the ELBAS study. Conveniently for this project, an accident report was available on a prior incident onboard the PEARL SEAWAYS which took part in the ELBAS study. This incident involved an EV fire in 2010. Although this fire event occurred 12 years prior to the writing of this report, it provided valuable information on how the crew acted to bring the ship back safely to port.

DBI also reviewed literature released by land-based authorities and actors with experience in dealing with electric vehicles on land. This review proved to be especially useful in understanding how ideal EV firefighting may happen. Additionally, peer-reviewed popular articles on human factors in maritime accidents and risk assessment and control were reviewed for this project. Literature on EV fires and the human and organizational matters surrounding these events were also studied.

1.3 The Ships

Three ships from three Danish ferry companies were visited, and their crews were interviewed for the ELBAS project. The ships vary significantly in age, size, and service different routes of varying distances. The three types of ferries included; an overnight cruise-ferry, a high-speed ferry, and a Ro-pax day ferry.

1.3.1 PEARL SEAWAYS: Overnight Cruise-ferry

PEARL SEAWAYS is an overnight cruise ferry, and was formerly the PEARL OF SCANDINAVIA and was originally delivered as the ATHENA to a finish owner in 1989. Taken over by DFDS in 2001 for their Copenhagen-Oslo route, the ship is Denmark's largest passenger ship. As of June 2020, her route also includes a stop via Frederikshavn, Denmark. In addition to being the largest passenger ferry in Denmark, PEARL SEAWAYS is also one of the largest hotels in Denmark, with 703 cabins and a capacity for 1,832 overnight passengers.

PEARL SEAWAYS was initially built for use in Viking Line's Baltic Sea traffic and was the world's largest car ferry at the time of commissioning. When the shipping company faced bankruptcy in 1993, the ship was sold

to the Malaysian shipping company Star Cruises. Star Cruises converted the ship into a casino cruise ship to sail from Hong Kong and Singapore. During the time in Asia, the ship's new owners extensively upgraded PEARL's camera system for security surveillance purposes. Today this surveillance system provides the crew with an excellent view of potential fires from the bridge.

PEARL SEAWAYS has several restaurants, indoor and outdoor bars, pubs, conference rooms, an auditorium, spas, and cafes. The passengers onboard PEARL SEAWAYS range from cruise passengers going on what DFDS calls a *'Mini-Cruise'* with two nights at sea and a few hours in Oslo to passengers sailing between Norway and Denmark for business and travel. This mix of passengers can provide additional challenges for the crew in the event of a fire. Passengers travelling regularly on PEARL SEAWAYS may be well acquainted with the vessel, while other mini-cruise passengers are less likely to know their way around. Additionally, there is the risk that some passengers may be affected by alcohol, given the cruise vacation atmosphere onboard, which could have an effect on how well the passengers act according to instructions in case of an emergency.

1.3.2 EXPRESS 4: High Speed Ferry

EXPRESS 4 is a catamaran high-speed ferry delivered to Molslinjen in 2019 and has a capacity for 1006 passengers. The ship operates on the route between Aarhus (or Ebeltoft) and Odden, Denmark. As the EXPRESS 4 operates on a shorter crossing, the ship does not have overnight accommodation for passengers sailing onboard. Instead, passengers spend time in the ship's lounges, where food and a large seating area are available.

The EXPRESS 4 is the fastest vessel of the ones examined in ELBAS, capable of reaching speeds of 40.5 knots (75 km/h). The types of passengers sailing onboard EXPRESS 4 are typically persons who need a quick route to go from Jutland to Zealand in Denmark, without passing the longer way over the island of Fyn, saving drivers up to 200 km compared to the journey by road.

1.3.3 COPENHAGEN: Ro-Pax Day Ferry

The COPENHAGEN is a Ro-pax day ferry, delivered to Scandlines in 2016, and sailing on the Gedser - Rostock ferry route between Denmark and Germany together with her sistership, BERLIN, and has a capacity for 1,300 passengers.

Passengers sailing onboard COPENHAGEN usually do so because of travel, either for business or pleasure. A portion of the people sailing onboard COPENHAGEN are also same-day return border shoppers, taking a shopping trip to Germany.

1.4 Qualitative Interviews

The most significant portion of data and insights DBI gathered came from interviews conducted while sailing around Danish and Norwegian waters. Unfortunately, the interview study was met with a problematic start causing it to be delayed by a few months due to the outbreak of COVID-19. These disturbances meant cancellations and postponements during the initial interview stage, resulting in less-than-ideal interview settings in the early phase. Sailing finally began in March of 2022. Members of the project team spent three days onboard the PEARL SEAWAYS conducting interviews with most crew members, including fire watches, hotel staff, restaurant staff, crew, officers, and the captain. These interviews were soon followed up with similar interviews onboard the COPENHAGEN and EXPRESS 4. All the shipping lines involved in the interview

phase, DFDS, Molslinjen, and Scandlines, were constructive and eager to provide helpful input that could aid the firefighting in electric vehicles.

The line of communication formed will continue beyond the conclusion of this project in an active effort to reach out and involve more stakeholders in the industry. Talks with stakeholders in 2023 are scheduled, and DBI hopes these meetings and interviews will provide further insights to continue building the foundation for future projects on this topic.

In addition to these interviews, a large workshop with attendants from land-based authorities, maritime authorities, equipment manufacturers, firefighters and ship crews allowed us to broaden the investigation of electric vehicle fires beyond the sea. The workshop showed how to extinguish fires in cramped conditions, such as a ship's vehicle deck, using different types of equipment.

1.4.1 General Attitude Towards Fire Safety

The crew on all three ships were observed to be well-trained and having a solid dedication to safety. No uncertainty of individuals' roles onboard during an emergency ever came up. The interviewees spoken to by DBI personnel knew their responsibilities well, and their knowledge of firefighting was high. Each of the shipping companies have put great effort towards knowledge sharing and increasing awareness of electric vehicles and battery fires. Due to a lack of easily accessible information on EV fires, the crew asked many questions about the dangers of battery fires. This has led to increased attention to the hazards of batteries onboard.

1.4.2 The Bridge

From the bridge of all three ships, it was easy to get an overview of the ship's fire alarm systems.

The closed-circuit tv (CCTV) camera coverage of the vehicle decks was excellent, and it was easy to get an overview of the vehicles. It might even be possible to identify vehicle types from the bridge via the CCTV system. This monitoring capability may prove helpful in fighting fires in electric vehicles on the vehicle deck.

From the bridge, the following functions can be operated to aid with firefighting:

- Ventilation
- Pumps
- Surveillance
- Fixed fire extinguishing systems (Drencher system (Except for PEARL SEAWAYS)
- Communications

It should be noted that because of the different dates of construction (keel laid dates) of the ships, they are not all expected to have the same functionality. All three ships comply with the minimum requirements for their type and sometimes go beyond that in the form of additional equipment.

1.4.3 The Vehicle Deck

The vehicle deck layout is different from ship to ship. The high-speed ferry is open fore and aft, while the Ro-pax day ferry has one upper vehicle deck which is open at both ends and one fully enclosed vehicle deck. The cruise ferry has one large enclosed vehicle deck, with hanging car deck that can be raised and lowered as required. All three ships are equipped with CCTV cameras to enable the crew to get a good view from the

bridge. The statutory required equipment available for firefighting was the same across all three ships. All the shipping companies are considering additional equipment to aid in firefighting of EV fires, and all three ships had different approaches to fighting EV fires.

1.4.4 Fire Watch

Each ship has a procedure for having a crew member designated to conduct a fire watch, in order to detect a fire before it develops. This crew member makes their rounds on the ship to ensure that everything is safe. Depending on the ship arrangement, the time of day, and which areas are manned, the route for a fire watch may vary.

During the observation of one of these watches, it became clear that the crewmember had a very good knowledge of the ship, and which areas that could potentially be problematic. This is not only related to fires on the vehicle deck, but also fires in general. When going a night patrol route on a larger vessel, all the main corridors, restaurants, gallies, public areas, vehicle decks and more, will be checked for anything considered *'out of the ordinary'*. If a fire should be discovered on this route it is often discovered so early that a smoke detector would not have set off an alarm yet. This means that the fire watch will often attempt to extinguish a fire if observed before calling for assistance. Whether or not the watch will call for assistance depends on the severity of the identified fire.

1.4.5 The Catering and Hotel personnel

Some of the catering and hotel personnel were also trained maritime firefighters and the permanent staff were very knowledgeable. In case of a fire on the vehicle deck, the catering and hotel personnel were tasked with making sure that the passengers and crew are taken care of and evacuated if need be. If catering and hotel staff were trained as firefighters, then they aid in the extinguishment of fire and may be sent to the vehicle deck.

Onboard all three ships, there was a considerable number of seasonal staff or student workers making up a large portion of the restaurant personnel. This means that seasonal workers may not be as well informed about procedures in case of fire and may not be able to assist in case of an emergency at the same level as an experienced crew member. It should be noted, however, that even though these seasonal and student employees are not as experienced as the permanent crew, they still participate in the weekly fire drills held onboard. These considerations for catering staff also apply to the hotel staff.

1.5 Procedures when a Fire Occurs

The initial procedures for what to do when a fire occurs onboard the three ships are almost identical. Depending on the type of ship and the type of fire, the procedures will then begin to differentiate. On each ship there are different concerns either due to the proximity to the nearest port, the time of day, or the design of the vessel.

1.5.1 Verifying the Fire

A fire on a vehicle deck will often trigger a smoke detector and send an alarm to the bridge. As soon as an alarm goes off the personnel will begin to identify which detector was triggered and verify that there is a fire by using the ships' CCTV cameras. It may be the case that there is no visible smoke or that the fire has not developed far enough to show up on the camera. If that happens the crew must go to the vehicle deck to

verify that there is a fire. Smoke detectors triggering is not uncommon, so it frequently happens that personnel must go to the vehicle decks to verify that a fire has started.

After verification the personnel will report back to the bridge to confirm that a fire has developed, and firefighting must begin. The general order of actions is:

1. A smoke detector gets triggered.
2. The cameras are checked for confirmation that a fire has developed.
3. If the CCTV cameras provide no evidence, personnel are sent to the vehicle deck.
4. Personnel reports back to the bridge and appropriate actions will be taken.

1.5.2 Ventilation

Due to the toxicity of the smoke from a fire, the procedure for how to handle ventilation was discussed internally at the time of this project.

The standard procedure for ships such as the PEARL SEAWAYS has historically been to turn off the ventilation to attempt to smother the fire and assist in the firefighting together with the drencher system. This procedure was discussed during a debrief onboard, due to the potential toxicity of the smoke released from modern car fires.

As for the high-speed ferry and the ro-pax day ferry, ventilation would be turned on and ship would be turned in such a direction that smoke would be led away from the ship keeping the passengers safe.

1.5.3 Fighting the Fire

When fighting a fire on the vehicle deck there are multiple firefighting strategies which can be used, but the shipping lines mostly agree on one thing; the fixed firefighting sprinkler system (drencher or water mist) should be activated as soon as possible. The fixed sprinkler system is the first line of defense, in case of a car fire and enables the crew to fight the fire remotely.

When hours away from the nearest port, such as onboard the PEARL SEAWAYS, considerations are made whether manual firefighting is needed. The PEARL SEAWAYS is the only Danish ferry to have experienced an actual EV fire. When that EV caught fire, the ship’s drencher system was activated, and the fixed system successfully extinguished the fire. Later, the fire crew went to the vehicle deck, to verify that the fire was extinguished and ensure that the fire would not reignite.

If it were the case that it was impossible for the drencher system alone to extinguish the fire, given the battery pack can sustain a fire by itself even when the drencher system is activated, then manual firefighting may begin. Depending on the conditions on the vehicle deck, the drencher system may be turned off, to avoid personal injury to firefighter from hot steam when entering the space.

For ships which are closer to a suitable port of refuge, manual firefighting can be avoided. This is due to the high reliance on the fixed sprinkler system as well as the shorter time it takes to get back to a suitable port where support can be had from professional shoreside firefighters.

The general rule in this scenario is to only enter the vehicle deck, in case need for evacuations of persons. The general order of actions is:

1. Turn on the fixed firefighting sprinkler system.
2. Send in shipboard firefighters to evacuate any persons on the vehicle deck.
3. Await to see the effect of the sprinkler system in controlling the fire.
4. Send in shipboard firefighters to control the fire after it has come under control.

1.5.4 Passengers

The passengers will be informed as the event unfolds to the extent needed. This is to maintain a good level of trust in the ship and crew, and to prepare the passengers for eventual further action needing to be taken.

If a vehicle fire is identified on the vehicle deck, then all passengers will be required to go to their muster point and await further instructions. This process is largely handled by restaurant and hotel staff.

1.5.5 Evacuating the Ship

If the fire cannot be brought under control, or the nearest suitable port cannot be reached, then evacuation of the ship may be required. In this scenario all ships will use their standard evacuation procedure and perform the action in as safe and controlled a manner as possible.

All the ships confirm that evacuation is considered an absolute last resort, and that the ship itself is its own best lifeboat.

1.6 Authorities

1.6.1 Land-based Firefighters

Regular contact with the authorities and land-based firefighters has provided a good insight into how EV fires are viewed. Just like at sea there are varying opinions on how to deal with EVs but there are some key points that all agree on being a challenge when a fire erupts. These points are:

- Heat generated from the fire
- Fire spread
- Toxic gasses released from burning vehicles

Going through the documentation released by the Danish Emergency Management Agency (DEMA) and hearing what they have to say about electric vehicle fires, it becomes clear that battery fires give rise to multiple dilemmas that differ considerably from responses to non-electric car fires.

In particular, the effort is different if it takes place in a closed environment, such as vehicle decks or parking basements. Due to the nature of a battery fire considerably larger amounts of water are required to cool the battery pack than what is otherwise required for non-electric car fires. As opposed to on land, at sea you have unlimited water, but it requires that the pumps must be kept running for longer to effectively fight the fire and considerations must be made for the surrounding environment.

DEMA lists the amount of water required to extinguish an electric vehicle battery fire to be up to 400 l/m. They also recommend a significantly larger number of firefighters for fighting the fire because the time of exposure should be kept at around 10 minutes.

With toxic gases being released from modern vehicles combined with the risk of re-ignition, extra caution must be taken to ensure the safety of passengers at sea.

1.6.2 Understanding Risks related to Li-Ion batteries

When dealing with a fire in EV, the recommendation from the side of the DEMA at the time of writing is that smoke diving should be carried out in the shortest possible time or not at all. The reason for this is that ordinary clothing for firefighting provided at sea may not provide optimal protection against substances found in the event of a fire in li-ion batteries. This concern may also be valid for other modern non-electric vehicles since the amount of plastic has increased gradually over the course of the last decades.

Any smoke emitted during a fire on the vehicle deck of a ship should be considered contaminated with particles harmful to health, especially if li-ion batteries from electric or hybrid cars are involved.

On a ship it is also essential to identify where smoke can spread to. Since most ferries have vehicles stowed on the lower decks below passenger accommodation, there is a risk that smoke and harmful particles can spread upwards to the passengers. The areas where smoke can spread must be identified quickly and efforts should be made to evacuate these areas.

1.6.3 Understanding risk in Relation to Smoke Diving on vehicle decks

With large spaces such as vehicle decks, there is also the risk that the shipboard firefighters may not have an overview of the progress of the fire in the entire extent of the space. Consideration should therefore be given to planning the smoke diving operation, so that all deployed personnel have clear and safe retreat routes and an understanding of any risks and restrictions.

It is understood that the Danish Maritime Authority takes the same approach to as the Danish Emergency Management Agency.

1.6.4 Firefighters – Experience and guidance from land-based emergency services

In the event of a risk of or ascertained fire/thermal runaway in an EVs, there are two types of interventions that normally are used according to the guidance from land-based emergency services. The choice of method used will be situational.

- Fire in electric car traction battery with offensive approach: Direct shutdown and cooling of battery.
- Fire in electric car traction battery with defensive approach: Let the electric car burn out or place it in an electric car container or equivalent with cooling.

In addition to the above, it will be possible to implement combination efforts, where an offensive approach is first used and then a defensive approach, e.g., in the event of a fire in an electric car in a building.

Defining the boundary of the fire incident scene and danger area - It is important to ensure that the danger area is large enough, so that emergency personnel who have not put on full respiratory protection are not exposed to smoke from the fire.

The same applies to the location of firefighting equipment and vehicles, regardless of whether the burning EV is located outdoors or in a building (/on a ferry vehicle deck).

In the event of a fire in an electric car traction battery, there are always several factors that the technical manager (on-scene commander), early in the response process, must make decisions about:

- Need for additional personnel, as the effort may risk being prolonged

- Fixed or continuous water supply
- Logistics around fire suits, compressed air devices, etc.

Furthermore, the technical manager (on-scene commander) must be aware of the risk of the effort developing, as the smoke generated from an electric car traction battery fire can create large amounts of HF gas.

The technical manager (on-scene commander) must include these elements in his considerations when the internal boundary is established and the structure of the incident site with its facilities is placed.

1.6.5 Precautions in the Event of a Fire in an Electric Vehicle

Common to both deployment methods are that, in most deployments, there is no immediate danger of the crew receiving an electric shock from the vehicle's high-voltage system. The battery and the electrical components are a closed system, which functions independently and is separated from the rest of the vehicle's construction. It is significant that the main switch in the electric car is switched off if this has not happened automatically.

The risk of electric shock only arises if the high-voltage electrical components have been damaged or a fire has occurred in the battery and direct intervention with these systems is undertaken as part of the firefighting strategy.

To minimize the risk of damage to personnel and equipment, it is important that the deployed personnel continuously assess the situation in relation to the development of damage and the current risks.

1.7 Summary of Insights

The following section is a summary of the insights presented in the chapter.

- The challenge of fighting fires in EVs and modern vehicles is a socio-technical problem, meaning that both people-oriented and technology-oriented aspects need to be considered, and which requires broad solutions beyond what can be delivered through technical solutions alone.
- The task of identifying the origin of the fire (battery or non-battery fire) is very difficult and should not be attempted until the fire is under control. It is better to assume the battery is ignited than not.
- Detection, combined with a good CCTV system is key to identifying and verifying a fire on a vehicle deck early.
- Having the ability to control all the ship’s firefighting systems including the vehicle deck drencher system directly from the bridge can make a difference when having to react fast.
- There is a lot of uncertainty and worries concerning battery fires that need to be addressed to make people at sea comfortable by knowing and understanding what they are dealing with.
- Additional efforts should be put towards education and training for fires at sea. This includes both a practical understanding of the fire, as well as a theoretical understanding for those not directly involved in firefighting.
- Knowing the number of electric vehicles and the placement of these could be an advantage to firefighting in the short run. In the long run, EV sales predictions indicate that most vehicles at sea will be electrified.

- Decisions in relation to use of the ventilation systems are currently taken according to procedure or individual assessments on the bridge. An overview of predicted effects of smoke movement and ventilation behavior in case of a fire would be a good tool to aid in this decision-making process.
- Training on how to handle vehicles post fire is going to play a large role due to the risk of reignition in EVs.
- Added focus on the assistants to firefighters is important to the assistant's health. Correct disrobing procedures should be implemented to avoid contamination.
- Increase understanding of the various toxic gases to aid with awareness of potentially dangerous situations.
- Communication can at times be difficult to hear and or understand. Investment in modern communications equipment could help this issue.

1.7.1 Recommendations for Future Work

The following section focuses on recommendations for future work within the realm of human and organizational factors and their respective roles in EV fire incidents.

Interview more and a wider range of stakeholders – this is already ongoing and should continue after the end of the ELBAS project but should also be a feature of any future projects. The recommendation here would be to broaden the scope and include topics such as alternative fuels and other modern vehicles.

Future work and collaboration with selected industry partners, including ship-owners – this is also ongoing and will continue after the project. This will help with a greater understanding of the problem, getting more concrete with certain issues and solutions with selected partners.