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Fire Risk Analysis on eTrailers as Cargo on Roro and Ropax Vessels

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ABSTRACT

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The purpose of the thesis was to identify critical risks related to the maritime transportation of eTrailers from a shipping company viewpoint. The topic was commissioned by Finnlines Plc.

The thesis was conducted as qualitative research. Risk management acted as the fundamental theory directing the research process from risk identification to risk evaluation. The theoretical part was based on literature review and further studies. The empirical part relied on interviews, observation and two open questionnaires. External stakeholders were involved a) regarding the characteristics and safety issues of eTrailers, and b) to gain insights of the future number and the type of eTrailers to be shipped.

The research put emphasis on eTrailers using lithium-ion batteries as power source for refrigeration machinery in thermo-regulated transportation. This was due to such trailers, or reefers, would require electric connection during the sea voyage. Hence, the risks related to battery charging cannot be avoided.

The original assumption of the thesis was that risks do exist in having eTrailers as cargo on the company’s vessels. This was confirmed by identification of several risks. The risks were evaluated in terms of likelihood and the severity of the consequences, in order to find each risks’ location on risk matrix. As an outcome, a list of the most critical risks was presented.

Keywords: transport, road transport, shipping, sea transport, trailers, electric vehicles, ro-ro vessels, car ferries, cargo ships, risk management, lithium-ion batteries, e-trailers

FOREWORD

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CONTENTS

LIST OF TERMS

eTrailer	Heavy cargo trailer equipped with lithium-ion battery pack as a power source for any additional functionality of the trailer.
EV	Electric vehicle, including all types (passenger car, trucks, etc.) of full-electric and hybrid vehicles used to transport people and/or cargo on road.
RoRo	Roll-on/Roll-off vessel, designated to carry wheeled cargo units.
RoPax	Roll-on/Roll-off passenger vessel, as above but along with passenger accommodation.

1 INTRODUCTION

Electrical vehicles (EVs) have become a daily concept in logistics. Not only we transport the raw materials, the batteries, and the finished products around the globe, but applications have been adopted even to international logistics, from e-forklifts in warehouses to heavy trucks. A relatively new concept in the markets is so called eTrailers – trailers using electric battery as a power source for some additional function, i.e., for a refrigeration machine, or a drive axle (Saikkonen, 2024; Schmitz Cargobull). At least one trailer representing the last-mentioned version has already been sailing on the case company’s shipping line between Finland and Sweden.

With new cargo types there are always new risks. EVs and other alternative fuel vehicles that have been on markets for longer have been studied from the viewpoints of users, shipping companies, fire departments, etc. Unfortunately, these studies have shown that fire risks related to EVs require careful consideration. (EV Fire; He et al., 2022; Sutcliffe, 2022.) eTrailers do share some characteristics of EVs, yet the most significant difference, concerning the reefer type, is that those will likely require electric connection during the sea voyage. Thereby, the risks concerned with charging cannot be fully avoided.

The purpose of the thesis is to identify the most critical fire safety risks associated with eTrailers from a shipping company’s viewpoint. The research problem will be studied through literature review, and an empirical study. The latter will consist of interviews with relevant personnel within the case company, and personal observation. Furthermore, external stakeholders will be involved by interviewing a) the eTrailer manufacturers regarding the characteristics and safety issues, and b) the customers to gain insights of the future number of eTrailers to be shipped.

2 PURPOSE OF THE THESIS

2.1 Scope and Objectives

The objective of the research is to identify and analyse fire safety risks related to sea transportation of Li-ion battery powered eTrailers on roro and ropax vessels from a shipping company's viewpoint and to provide a list of most critical risks as the outcome.

From this research problem, I have derived one primary question:

1. What are the most critical risks related to maritime transportation of eTrailers?

Sub-questions directing the research are:

1.1 The current views on safety of EV's in maritime transportation?
1.2 What are the fire safety -related characteristics of lithium-ion battery packs?
1.3 What are the fire safety -related characteristics of eTrailers?
1.4 Is it possible to cost-efficiently detect damaged battery packs on arrival or before loading onboard?
1.5 How to prevent damage during stevedoring operations??
1.6 How is the accessibility in case of fire onboard?
1.7 What is the state of knowledge on eTrailer concept amongst the ships' crew?
1.8 How do the stakeholders see the future of eTrailers in multimodal transportation?

2.2 Background and Limitations

Hybrid and full-electric vehicles are already part of daily operations within the shipping industry. Based on real life occurrences and supported by the results of lithium-ion battery fire experiments implemented by several business and

governmental sectors, Finnlines and many other shipping companies have forbidden battery charging onboard.
eTrailers are a relatively new concept in electric vehicle markets. The first wave of EV’s in cargo transportation seemed to focus on so called last mile transportation, in which electric vehicles have already proven their capabilities and effectiveness. However, long distance and multimodal transportation set more challenges and requirements for electricity as power source. Therefore, it seems highly probable that eTrailer applications could increase their market share faster than electric trucks.

The research will mainly concentrate on eTrailers using lithium-ion batteries as power source for refrigeration machinery in thermo-regulated transportation. This is because such trailers, or reefers, require electric connection during the sea voyage. Hence, the risks related to battery charging cannot be avoided.

Another type of eTrailers is especially designed to use with high-capacity transport (HCT) combinations. These trailers are equipped with electric towing axle to decrease fuel consumption and to enhance safety and performance. In fall 2023, Sweden allowed HCT traffic, which is expected to increase this type of combinations in Finnlines’ Finland – Sweden route. Unlike forementioned thermotrailers, this trailer type does not require charging onboard, but will likely share some of the risks regarding the battery packs.

Lithium-ion batteries, also as contained in an equipment, are classified as hazardous cargo by the IMDG code. However, the code only applies to packaged goods, which makes the classification irrelevant within the scope of this research.

2.3 Case Company

Finnlines Plc is one of the leading cargo shipping companies in the areas of Baltic Sea, North Sea, and the Bay of Biscay. The company operates with 23 self-owned roro and ropax vessels, connecting 21 ports around Europe on a weekly basis. In 2022 Finnlines carried 750 000 cargo units, and nearly 1,5 million tons of non-unitized cargo. Cargo services forms the clear core of Finnlines' business, yet the company has also invested heavily on passenger services on the recent years. In addition to shipping services, the company offers stevedoring services in ports of Vuosaari and Turku, via its subsidiary Finnsteve Oy.

2.4 Conceptual Framework

In figure 1 I have presented the key concepts of the thesis topic, and the interrelations between them. The arrows represent the expected direction of impact.

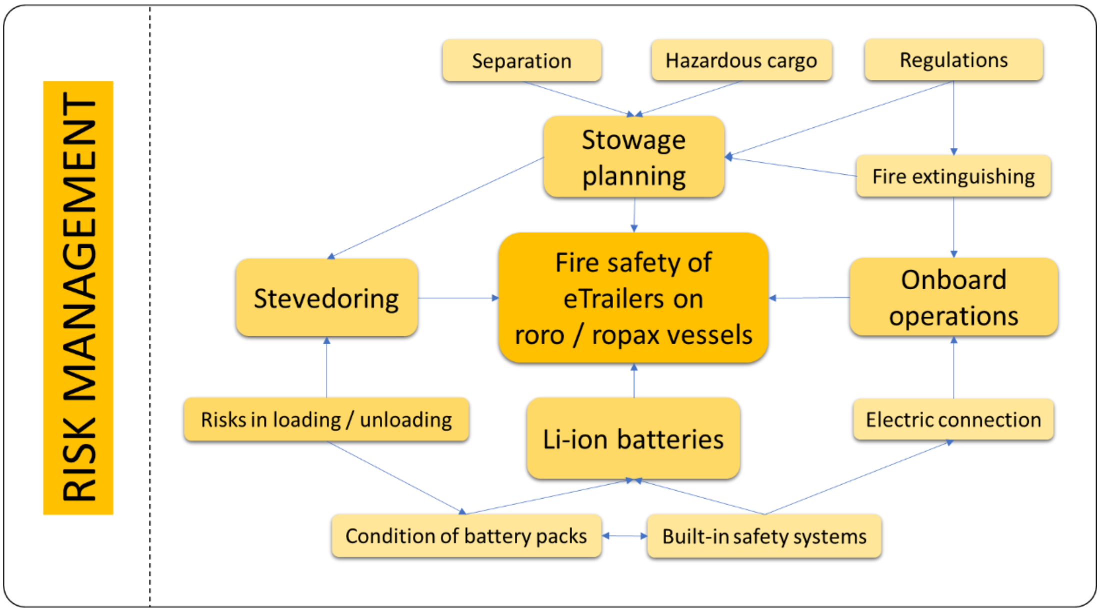

Figure 1. Conceptual framework

Risk management acts as the fundamental theory directing the research process from risk identification to risk evaluation. The research problem is placed in the centre, surrounded by the four operational areas that are estimated to involve most of the risks. Outermost are the operation-specific sub-concepts that have emerged during the initial discussions with the company representatives.

3 RISK MANAGEMENT

Risks are always present in business; basically, business is nothing but taking risks, and it would be fully against the logic of doing business if all risks were to be eliminated (Ilmonen et al., 2022, p.10). Risk management is a set of co-ordinated activities aiming to direct and control an organization regarding its risks. The objective of risk management is to deliver and protect value by improving performance, reducing volatility or uncertainty of outcomes, and by supporting the realization of strategic goals. (Hopkin, 2012, p. 49; ISO 31000:2018, 2018.)

3.1 Concepts of Risk Management

Risks are often considered from a negative viewpoint. For example, Cambridge Dictionary (2024) defines risk as a bad thing that might occur, or the possibility of something bad happening. A broader viewpoint sees risks also as a possibility for positive outcomes. ISO 31000 defines risk as effect of uncertainty on objectives but notifies that the word effect refers only to a deviation from expected, leaving the negative versus positive comparison out of the definition (ISO 31000:2018, 2018).

In operational risk management, the terms accident and hazard are considered as distinct concepts related to risk. Accidents refer to unintended occurrences, such as a car crash in a public road. Furthermore, within the context mentioned, accidents are also defined as undesirable events. Hazard again, may be any object, action, process, or situation that contributes towards the occurrence of an accident. (Pinto et al., 2015, p. 4.)

Risk management is a continuous process, which aims to identify and control deviations and uncertainties that might affect the achievement of organizational objectives. Risk management system should cover all the business functions of an organization, being a natural part of daily operations. (Alftan et al., 2008, p. 80-81.) Risk management is broadly understood as protecting the business activities and company’s profit from unwanted occurrences, negative risks, and from their resulting effects. This viewpoint emphasizes the continuity and reliability of operations, together with safety, efficiency, and quality. This is most often true with operational and accident risks. However, with risk types such as strategic or business risks, there is often a chance to gain positive outcomes. Risk management methods do not differentiate between positive and negative results; hence, the tools can be used to identify and analyse any possible deviations and/or outcomes. By concentrating on negative risks only, an organization cannot fully utilize the possibilities of risk management. (Ilmonen et al., 2022, p.17.)

Risk management can be organized according to generally accepted risk management standards or frameworks, such as ISO 31000 or COSO ERM. The purpose of the standards is to provide a structural approach covering all subareas of risk management. However, the standards and frameworks are advisory in nature and each organization may, and should, implement them as applicable. The biggest advantage of the standards is that they provide a collective terminology and methodology, which enables risk management within the organization to be systematic, understandable, and repeatable. This is especially true in international organizations where common terminology and common understanding of the processes are critical for risk management to be efficient and consistent. (Hopkin, 2012; Ilmonen et al., 2022.)

3.2 The Principles of Risk Management

The principles of risk management can be viewed from two perspectives. Firstly, risk management standards may provide a detailed list of principles describing the features and/or to-dos of efficient and successful risk management. (Hopkin, 2012, p. 49.) Secondly, the top management may, and should, define organizational principles, which may include directions for, for example, responsibilities and authorities, goals and objectives, and procedures and methods of risk management. In some organizations, the principles are seen as regulatory, while others consider them as soft recommendations. (Ilmonen et al., 2022, p.68-69.)

Table 1. PACED principles of risk management (modified from Hopkin, 2012)

Principle	Description
Proportionate	Risk management activities must be proportionate to the level of risk faced by the organization
Aligned	The activities need to be aligned with the other activities in the organization
Comprehensive	In order to be fully effective, the risk management approach must be comprehensive
Embedded	Risk management activities need to be embedded within the organization.
Dynamic	The activities must be dynamic and responsive to emerging and changing risks

Hopkin (2012) states that delivering value is the main principle of risk management. The PACED principles of risk management (Table 1) describe what the risk management should be in practice. According to Hopkin, these five principles are “the foundations of a successful approach to risk management within any organization”. He also suggests that organizations should separate the practicality principles, such as PACED, and the principles describing the expected outcomes, i.e., compliance with laws and regulations, or risk-aware decision making, into two distinct lists.

ISO 31000 standard places value creation and protection as the core of risk management principles, being surrounded by eight characteristics, or elements, to be considered when risk management processes are established (ISO 31000:2018, 2018). Some of the characteristics, i.e. dynamic, or structured and comprehensive, are parallel to PACED principles, while others, such as customized and inclusive, provide a wider vantage point.

Setting up the organizational principles of risk management is one step in communicating the top managements and owners' will for structured and comprehensive risk management. The topic of the document is irrelevant; the principles can be included into company's risk management policy, safety and security policy, or internal control policy. More essentially, the principles should be stated clearly and concisely, and they should answer questions such as who has the responsibility, who is authorized to make decisions, and are there any preconditions or constraints for the decisions. Furthermore, the principles should introduce the basics of risk management processes, the most important requirements, the means of risk management, as well as reporting and monitoring. They can even take a stand on the organizations willingness and ability to take risks. (Ilmonen et al., 2022, p.68-69.)

3.3 Risk Management Framework

Literature classifies risk management most often as a process: a sequence of pre-defined actions in time. The process should not be mistaken for risk management framework, though in some publications the distinction between them may be unclear. The purpose of a framework is to clarify the organization-specific context for risk management, and to support integration of risk management into all functions of the organization. ISO 31000 includes a detailed framework with emphasis on internal and external contexts. (Hopkin, 2012, p. 60-62; ISO 31000:2018, 2018.)

Figure 2. RASP Framework (modified from Hopkin, 2012)

Risk Architecture, Strategy, and Protocols (RASP) model is developed to present the scope of risk management framework in a more simplified form. Figure 2 illustrates how the three elements form a supportive structure around the risk management process. Despite of the theory or standard used, an organization should customize the elements of the framework according to their individual needs. (Hopkin, 2012, p. 60-62; ISO 31000:2018, 2018.)

3.4 Risk Management Process

Risk management processes and their representations vary according to industries, disciplines, or professions. Most often the differences occur in the detailed instructions of the process phases, but the basic steps are alike: establish, identify, evaluate, manage (treat), supervise (control), communicate, and develop. Yet some authors, Wolke (2017, p. 4) for example, suggest the scope of risk management process be only from risk identification to risk controlling. Pinto et al. (2015, p.15-16) represent a different viewpoint in that they do not present the process as actions or steps, but through a list of questions directing the process. An interesting idea in their theory is that risks cannot be identified without knowing how things should be. Therefore, their list starts from zero, by questioning what should go right.

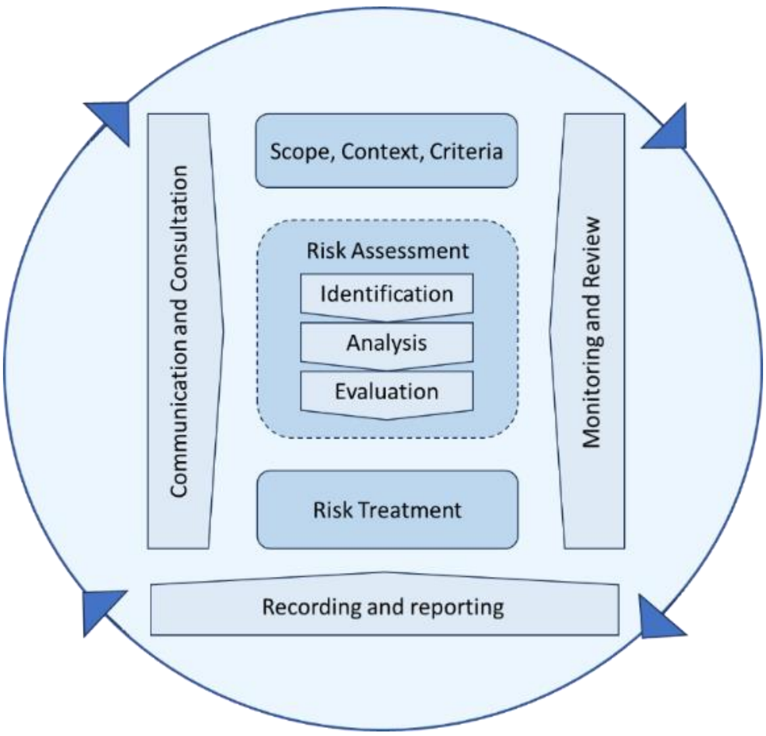

Figure 3. ISO 31000 Risk Management Process (modified from ISO 31000:2018, 2018)

Figure 3 shows the risk management process as it is defined in ISO 31000, which is one of the most used general risk management standards. In this model, the scope, context, and criteria of risk management are the first ones to be determined. Next step is risk assessment, which includes three sub-phases: identification, analysis, and evaluation of risks. In third phase, an appropriate risk treatment method is selected for each identified risk. The three other activities around are continuous, supportive actions that not only use the outputs from the three centric steps, but also produce inputs for them. The surrounding arrowed circle describes the repetitive cycle of the process.

Referring to the scope of the research, I will further examine only the forementioned steps from one to three, as well as Communication and Consultation.

3.4.1 Scope, Context, and Criteria

Risk management process may be applied separately at different organizational levels and the purpose of this first phase is to customize the process for a specific area to be examined (ISO 31000:2018, 2018). A common practice is to classify risks into three of four upper categories: strategic risks, economic risks, operational risks, and accidental risks. In the three-categories model the last two are combined. These categories are further divided into sub-categories, for example, technology risks (strategic), currency risks (economic), project risks (operative) and work health and safety risks (accidental). (Ilmonen et al., 2022, p. 78-79.)

The scope should answer questions such as what the objectives are, what are the expected outcomes, what is included and excluded, what kind of tools and techniques should be used, and what kind of resources are needed (ISO 31000:2018, 2018).

Ilmonen et al. (2022, p. 87) recommend giving consideration also to the participants of the assessment. They state that it is always justified to involve the key people within the scope of the risk management process, yet to keep in mind that the number of participants should be kept as small as possible. The key people are the ones who as a group can form an excellent and comprehensive understanding of the function to be assessed. External consultants, e.g., a fire safety specialist, may be involved when necessary (Ilmonen et al., 2022, p. 87-88). Their idea is well aligned to the communication and consultation phase in the ISO 31000 process.

Examination of both the internal and external environments of the organization is required to defining the context for risk management processes. The external context may include, but is not limited to, factors like social and political issues, financials, laws and regulations, external stakeholders, or contractual commitments. The internal factors may include, for example, the organization's values, strategies and policies, organizational structure and the culture, resources and capabilities, and contractual commitments. (ISO 31000:2018, 2018.)

Risk criteria are the terms of reference against which the significance of risk is evaluated. It should be aligned with the organization's risk management framework yet customized according to the specific process. When applicable, the customized criteria should also take into account the legal and contractual obligations, as well as the views of stakeholders. According to the instructions in ISO 3100 standard, there are several aspects to be considered when setting up the criteria: the nature and type of uncertainties that can affect the outcomes and objectives (both tangible and intangible); how consequences and likelihood will be defined and measured; time-related factors; consistency in the use of measurements; how the level of risk is to be determined; how combinations and sequences of multiple risks will be taken into account; and the organization's capacity. (ISO 31000:2018, 2018.)

3.4.2 Risk Assessment

In ISO 31000 process model, risk assessment is divided into three sub-processes: identification, analysis, and evaluation. Key factors for a successful assessment include systematicity, capitalizing on the views and knowledge of the stakeholders, and utilizing the possible information available. (ISO 31000:2018, 2018.)

Risk identification aims for finding, recognizing, and describing risks. There is a wide range of factors, and their interrelations, to be considered. Those include, e.g., sources of risks within and outside of the organization, consequences and their impact on objectives, and biases, assumptions and beliefs of the members in the assessment group. (ISO 31000:2018, 2018.)

Next step is risk analysis, meaning that the identified risks are further examined. At minimum, this is done in terms of risk sources, consequences, and likelihood. The level of the analysis may vary depending on the purpose of the analysis. Consideration may also be given to complexity and connectivity of the risks, time-related factors, existing controls and their effectiveness, and sensitivity and confidence levels. It is important to acknowledge that risk analysis is sensitive for objectivity, which may be caused by human factors such as opinions, biases and perceptions, or by the reliability of the information, and the available resources. (ISO 31000:2018, 2018.)

ISO 31000 standard does not include specific tools or techniques for risk identification and analysis but notifies that there are several available. A common technique is self-assessment, which can be implemented as a brainstorming workshop, as interviews, and with the help of different questionnaires (Alftan et al., 2008, p. 81). Qualitative tools commonly used to give some structure for brainstorming are SWOT or PESTLE analyses. SWOT is a four-field analysis on possible strengths, weaknesses, opportunities, and threats. PESTLE again, classifies the risks more detailed, into political, economic, social, technological, legal, and ethical (or environmental) risks. Hopkin describes it as a "well-established structure with proven results… in risk assessment workshops". The two most common quantitative techniques again, are hazard and operability studies (HAZOP), and failure mode effect analysis (FMEA). These techniques are best to use when risks are identified in highly dangerous, and/or within complex environments, but have the downsize of requiring a lot of resources in terms of expertise and time. (Hopkin, 2012, p. 141-143.)

The final action in the assessment phase is to evaluate the outcomes of the analysis against the risk criteria established in the beginning of the process. Evaluation aims to determine which risks can be accepted as they are (or with the existing controls), which ones need to be transferred to risk treatment phase, or which are still in need of further analysis. The evaluation should not be done in isolation, but it is recommended that the outcomes are validated at appropriate levels of the organization. (ISO 31000:2018, 2018.)

3.4.3 Risk Matrix

Risk matrix is often mentioned in the risk management literature. It is a relatively simple tool for evaluating the significance of risks based on their likelihood and the severity of consequences. Risk matrixes can be used in many ways: to identify the relative importance of the risks within a pre-defined scope, to identify the type of risk treatment most likely to be employed, or to summarize organization's risk profile (Ilmonen et al., 2022, p. 102; Hopkin, 2012, p. 161.)

Table 2. Example of rating of likelihood and consequences (modified from Hopkin, 2012)

Likelihood	Rating	Severity of consequence(s)	Rating
Veri likely	5	Catastrophic	5
Likely	4	Significant	4
Moderately possible	3	Major	3
Unlikely	2	Minor	2
Very unlikely	1	Negligible	1

In table 2 is an example of rating the likelihood and consequence of a risk. The labels and classifications may vary, depending on the purpose, target area, or organizational level in which the assessment is carried out. Consequences may be labelled as impact, magnitude, or level of risk, and 'likelihood' may be replaced with frequency or chance of occurrence. (Hopkin, 2012, p. 161;

Ilmonen et al., 2022, p. 102; Pinto et al., 2015, p. 21–24.) However, the terminology should be unchangeable throughout a specific process, and aligned with the organizational risk management framework.

Table 3. Risk Matrix (modified from Pinto et al., 2015).

		Consequence				
Likelihood		1	2	3	4	5
	5					
	4					High
	3	Low	Low medium	Medium	Medium high	
	2					
	1					

After the risks have been rated for these two variables, they are placed in the risk matrix, which generally involves four or five categories. For example, in 4Ts' model, used to evaluate the treatment most likely to be employed, the categories are: tolerate, transfer, treat, and terminate (Hopkin, 2012, p. 162-163). When the evaluation is based on the criticality of the risks, the matrix can be divided into five categories between low and high, described in Table 3. Colour coding can be used to better visualize the criticality of risks (Ilmonen et al., 2022, p. 102). Regardless of the categories or terminology, it may be concluded that the higher the scoring in the two variables, the higher is the significance of the risk, and the need to consider its treatment.

3.4.4 Risk Treatment

Risk treatment involves formulating and selecting risk treatment options, planning and implementing the treatment, and assessing its effectiveness by re-evaluating the residual or net risk. The purpose of risk treatment measures is to bring the risk to an acceptable level. The selection of the measure(s) is a choice influenced by a wide range of internal and external factors. One of the most common trade-offs is done between costs and benefits. Furthermore, consideration should be made on several internal and external factors, from organizational values, goals and objectives to contractual and legal obligations, stakeholder views, and potential resistance to change. (Ilmonen et al., 2022, p. 103; ISO 31000:2018, 2018.)

Common options for risk treatment are acceptance, mitigation, removing, avoiding, and sharing. With positive risks (opportunities) it is also possible to take the risk or increase its possibility. In some cases, the acceptable level can be achieved by changing the likelihood or consequences of the risk. (Ilmonen et al., 2022, p. 103; ISO 31000:2018, 2018.)

The issue of varying terminology in the risk management literature becomes visible when it comes to this sub-topic of the risk management process. Hopkin (2012, p. 229) states that "ISO 31000 considers that 'treat risk' is the main heading under which various options exist…". Hopkin himself uses the term risk response, while Wolke's (2017) topic for the same thing is risk control. Hopkin's criticism is understandable as his book involves a chapter on 4Ts of hazard response, in which risk treatment refers to a more specific form of risk management – control and mitigation of risks.

As mentioned in chapter 4.3.2.1, the 4Ts model is an application of the risk matrix in context of responding to risks. Tolerating includes acceptance or retainment, meaning that no (further) actions are made if the exposure is tolerable. Additionally, this response may be appropriate also if the actions against the risks are limited, or the costs are much greater than the potential benefits of the actions. Treatment is stated to be the most common response to risks. While it is decided that the organization will continue with the activity involving the risk, controlling measures are taken to reduce the level of risk so that it becomes acceptable. Third option is to transfer the risk by conventional insurance or with a third-party contract. Terminating refers to avoidance or elimination of the risk. With critical risks, high-rated in both likelihood and consequences, this is sometimes the only option. Elimination of the risk may be done by stopping the process or activity, or by substituting an alternative process. Outsourcing the activity can be either a transfer or termination of the risk, or a combination of them. (Hopkin, 2012, p. 225-231.)

4 ELECTRIC VEHICLE FIRES

As a relatively new technology, EV’s and their safety issues tend to draw attention from the media and public. News headings such as “When the fire fighters arrived, two-meter flames hit the back of the electric bus” (YLE 6.2.2023), or “An electric car being charged exploded in Lahti market park” (YLE 3.6.2023), paint a dangerous looking picture of electric vehicles. At the same time, several studies have concluded that EVs represent only a minor part of all car fires. It should also be noted that an EV fire does not always mean that the fire is initiated from, nor does it involve, the Li-ion battery pack.

4.1 EV Fires Onboard Ships

The EV fire on MS Pearl of Scandinavia in November 2010 was the first onboard fire confirmed to be initiated from an EV traction battery. The vessel was on its way from Oslo to Copenhagen when a fire alarm system alerted at 5:58 am. Due to efficient responding of the crew, and with the help of Swedish firefighters sent onboard by helicopter, the fire was extinguished in couple of hours. There was no need for evacuation of the people onboard, and the vessel was able to continue its journey after the fire. The exact cause of the battery malfunction and thermal runaway has not been identified. The electrification of the passenger car in question was not industrially produced but the owner himself had converted it into a battery-powered EV. In addition, the cable used to charge the battery onboard was also made by the owner of the car. (Sutcliffe, 2022.)

In February 2022, a Panama-registered PCTC (Pure Car/Truck Carrier) vessel Felicity Ace caught fire while crossing North Atlantic. The crew of 22 people had to abandon the ship and were rescued by a nearby commercial vessel. The fire, initiated in one of the cargo holds, continued for nine days before the rescuers were able to start towing her to safe, but unfortunately, she lost stability and sank on 1 March. The vessel was carrying 3965 vehicles, both new and used, including dozens of EVs. The original cause of the fire is not known, but it has been suspected that the EV batteries did contribute to the intensity and duration of the fire. (DaSilva, 2022; Holderith, 2023; Sutcliffe, 2022.)

The fire on Fremantle Highway, also a PCTC, was at some point claimed to be caused by electric vehicles. However, after the vessel was towed to a nearby port and salvaged, it cleared out that all 498 EVs listed on ship's manifest were in good condition. Unfortunately, this incident resulted in death of one crew member, and several got injured. (Kirby, 2023; The Maritime Executive, 2023.)

4.2 Frequency of EV Fires

Linja-aho's (2020) review on the Finnish national rescue task database (PRONTO) shows that in 2015 – 2019, of the average of 2000 yearly car fires only eleven involved an EV. Australian EV Firesafe collects information on EV fires globally and publishes the results every six months. In their latest review, covering a timeline from January 2010 to June 2023, the total number of verified EV traction battery fires was 393. In addition, there were approximately 100 incidents unverified or under investigation. (EV Fire, n.d.) Mohd Tohir & Martín-Gómez (2023) examined public EV fire statistics of five countries from different years between 2016 - 2022. From the statistics they calculated a weighted average of number of fires per registered EV's to be only 244 fires per million registered EVs. Hassan et al., (2023), on the other hand, calculated the frequency of EV fires between 2010 and 2022 to be 5,29 per million EVs, which is notably lower.

Although the forementioned figures are not directly comparable, they all indicate that the hazard for EV fire to occur is relatively low. In addition, even though the above statistics mainly concern passenger cars, it is unlikely that the figures should significantly differ regarding eTrailers.

It should be noted though, that "electric vehicles with large lithium-ion batteries are relatively new technology and no data is available on how the cars perform when they reach the age of 15–20 years" (Linja-aho, 2020, p. 47 - 48). This is likely to be true with eTrailers as well, those being more recent innovation than EV cars.

4.3 Extinguishing of EV fires

There are several factors contributing to the inconvenience of extinguishing and EV fire. Firstly, EV battery packs are generally large, located in an inaccessible place under the vehicle, and built to be watertight. Furthermore, battery fire is able to feed itself without external source of oxygen, and hence cannot be extinguished by suffocating. Extinguishing and/or cooling may require thousands of litres of water, yet the fire may re-start in hours, days, or even in weeks after. (Linja-aho, 2022, p. 92.)

It is important to note that the majority of EV fires does not involve the battery pack but is initiated in other parts of the vehicle. Generally, a fire initiated from or involving a battery pack can be identified from popping and fluttering sounds (fire proceed from cell to cell), or from grey or black smoke from under the vehicle's skirt. (LASHFIRE, n.d.; Linja-aho, 2022, p. 92 – 93.)

Current practical and scientific research suggests that the best fire-extinguishing agent is water. Linja-aho (2022, p. 96) states that "until now, all EV fires in Finland have been successfully extinguished with water, and without any special equipment". Other equipment and agents usable with EV fires include Co2 or dry powder portable extinguisher, chassis sprinkler, water mist lance, and a collapsible pool that that allows the battery to be immersed in water. Nevertheless, the most essential thing is that the rescue personnel have been trained properly to extinguish an EV fire. (LASHFIRE; Linja-aho, 2022, p. 96 – 97.)

5 LITHIUM-ION BATTERIES IN ELECTRIC VEHICLES

Lithium-ion batteries used in automotive industry may differ in their inner chemistry (i.e. anode / cathode), or in exterior housing types, yet they are similar when it comes to the component levels: a lithium-ion cell, module, and battery pack (Figure 4). In some applications, the battery packs may even be further coupled to form an entire battery system. (Bisschop et al., 2019, p.15 – 29.)

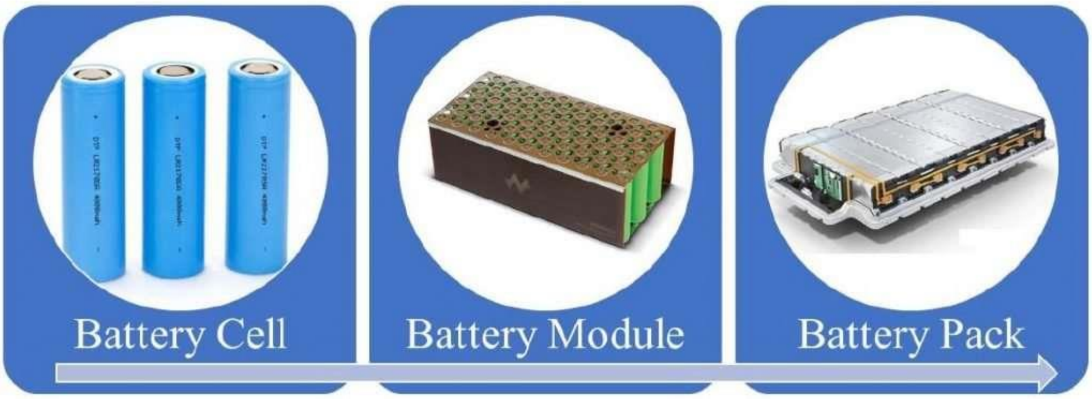

Figure 4. Li-ion battery components. (Ren et al., 2022)

Battery *cell* is the most basic component in a Li-ion battery, which can approximately provide voltage of only 4V. The next level is a battery *module,* consisting of a varying number of cells connected either in series and/or parallel. Generally, the added voltage of the cells in a module is no higher than 60V, due to safety concerns. In the third level, the modules are connected, again either on series or parallel, to form the battery *pack*, which may provide voltages between 300 to 1000V. There is a lot of variation in the energy capacity of the EV battery packs; from 1,56 kWh in a Kia Niro, to 300 kWH in a Volvo FL Electric (heavy truck). (Bisschop et al., 2019, p.15 – 29.)

5.1 Thermal Runaway

A key term related to Li-ion battery fires is *thermal runaway*. Such condition may start from abuse of a single cell of a battery module, leading to the normal electrochemical reactions to be replaced by chemical reactions. Abuse in this context may be, for example, heating, crushing, penetration, or overcharging the battery cell. Consequently, the cell may fail by producing toxic and flammable gases, burn, explode, or become a projectile. First stage in the process leading to thermal runaway is exceeding the onset temperature, after which chain-like thermal decompositions are irreversibly triggered. The second phase involves new chemical reactions that accelerate self-heating of the cell. Thermal runway occurs on the third phase. One definition for it is “the point where a self-heating rate of 10ºC/min or greater is obtained” (Bisschop et al., 2019, p.31). Thermal runaway causes oxygen to be released from the battery cell(s), facilitating the conditions for combustion. In “ideal” circumstances, even an explosion may occur. Although the process may begin from a single cell, the adjacent cells are likely to be affected by the temperature increase, causing the chemical reactions to spread within the module, and later to the whole battery pack (Figure 5). (Bisschop et al., 2019, p. 30 – 32; EV Fire, 2021.)

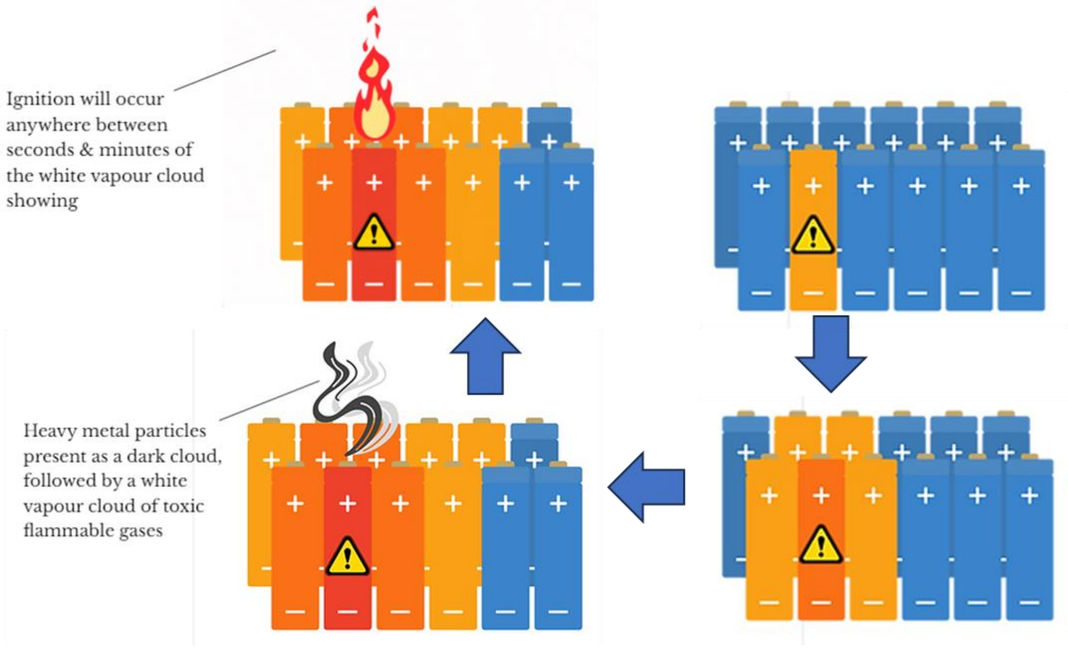

Figure 5. Thermal runaway in a Li-ion battery module. (EV Fire, 2021)

5.2 State of Charge

The effects of state of charge (SOC) on the ignition and burning of Li-ion battery has been examined in several studies. He et al. (2022) investigated how SOC effects on thermal runaway temperature of open-circuit Li-ion batteries.

Their results suggested that no self-ignition occurs when the SOC is less than 30%, and only when the SOC was over 80%, flames could occur. They also state that both the temperature of the middle cell, and the critical ambient temperature decrease when the SOC increases. Another experiment performed by Chen et al. (2019), indicated similar effects of the SOC, though all tested battery configurations did ignite and burned with visible flames. Their conclusion was that 100% SOC batteries present the highest danger in terms of mass loss, peak heat rate release, and total heat release. Similar conclusions have also been made by Daniel Keslar in his report for US Department of Transportation in 2022: "An Analysis of State of Charge in Lithium-ion Batteries", and Fredrik Larsson in his Doctoral Thesis: "Lithium-ion Battery Safety - Assessment by Abuse Testing, Fluoride Gas Emissions and Fire Propagation" from 2017.

5.3 What Causes Battery Failures?

In RISE's (Research Institutes of Sweden) report from 2019, Bisschop et al., (2019) state the causes presented in Table 4 as the main causes for battery failures.

Table 4. Main causes for battery failures (modified from Bisschop et al., 2019)

Cause	Explanation
Internal short circuit	Reasons for an internal short circuit include manufacturing defects, and physical damage. This is stated to be the most hazardous failure as the condition may occur suddenly and without any warning signs, causing severe damage.
Mechanical deformation	May result, i.e., from a (traffic) crash or ground impact, leading to an internal short circuit. Even if only the external cover is damaged, a short circuit risk does exist due to the battery modules' and cells' possible exposure to water.
Failure of BMS	Failure in the BMS (Battery Management System) may result in over-charging of the battery, which may lead to chemical reactions, and thereby to an internal short circuit.
Overdischarging	Equivalent results may occur in the opposite direction as well; in case of overdischarging. Normally this is also prevented by BMS. A long storing time without charging may cause self-discharging of the battery, though the risk for a short circuit arises only when such battery is recharged.
External short circuit	An external short circuit may be caused by extreme mechanical impact, exposure to water immersion, corrosion, or an external electric shock.
Exposure to high temperatures	An external fire in proximity of the battery pack, or any other heat source, causing exposure to high temperatures may initiate the thermal runaway process (described in section 4.2).

The reasons for battery failures include both internal and external causes. Such failure may result from design or manufacturing defects; external shocks caused by thermal, mechanical, or electrical factors; wrong / faulty support equipment (i.e. charging cables); or external heat source. The most critical failures are considered to be internal and external short circuits, which may result in exothermic reactions within the battery. (Bisschop et al., 2019.)

5.4 Fire Risk Management

Compared to other popular battery types, i.e., lead-acid batteries, Li-ion batteries differ in their high risk of fire. In lead-acid batteries and nickel metal hybrid batteries, the electrolyte is water-based, and their overcharging or over-discharging does not lead to faults which cause self-feeding heat rise. Due to the risk of thermal runaway in Li-ion batteries, manufacturers are obligated to design products including such battery to be sufficiently safe in their normal use. (Linja-aho, 2022, p.77-78.)

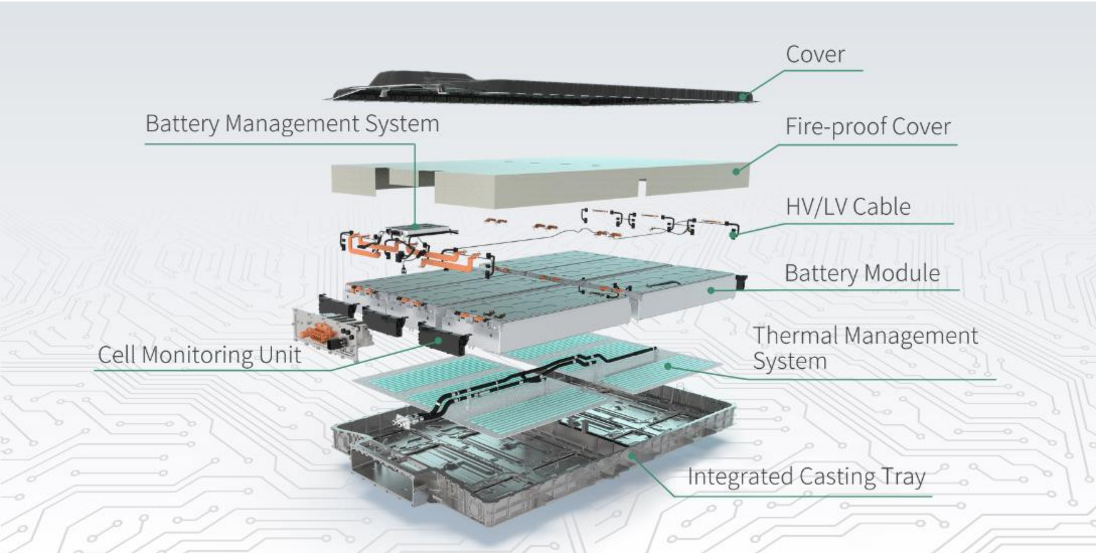

Figure 6. Components of EV batteries. (Morris Garages, 2024)

One technical solution (engineering control) in Li-ion batteries is that the battery packages are so designed, that thermal runaway in one battery cell spreads as slowly as possible, and the fire is limited to the module level by using compartmentation. Small gaps on outer edge of the battery allows fire gases to vent out safely. Administrative safety solutions include instructions on charging the battery given in the user manual. (Linja-aho, 2022, p. 79 – 80.) Figure 5 shows the basic components of an EV battery pack.

5.4.1 Battery Management System

Due to the risks related to battery overcharging and over-discharging, Li-ion battery must involve some type of Battery Management System (BMS). The systems can be classified in many ways, for example, into analogue and digital systems, or into protection and control circuits. (Linja-aho, 2022, p. 62.)

No unique definition exists for BMS, and other terms such as voltage management system (VMS) or protection circuit module (PCM) are used for similar systems. In general, BMS is intended to monitor and protect the battery, to estimate its state, to maximize the performance, and to report to users and/or external devices. (Andrea, 2010, p. 16.)

A Li-ion BMS has several critical functionalities, which may even be set in order by their importance. The most important function is preventing the voltage of any cell from exceeding a limit, by stopping the charging current, or requesting that it be stopped. This safety issue concerns all Li-ion cells. The second most important task is preventing the temperature of any cell from exceeding a limit by a) stopping the battery current directly; b) requesting the battery current to be stopped or c) requesting for cooling. Next comes preventing the voltage of any cell from dropping below a limit by stopping the charging current or requesting it to be stopped. Fourth function is preventing the charging current from exceeding a limit (which varies with cell voltage, cell temperature, and precious level of current) by requesting that the current be reduced or stopped, or by stopping the current directly. And finally, the fifth most important functionality of a BMS system is preventing the discharging current from exceeding a limit, as described in the precious point. (Andrea, 2010, p.16.) Basically, a BMS guards all three factors affecting the safe operating area of a Li-ion battery.

5.5 Cell deterioration and the life cycle of Li-ion batteries

The lifetime of a Li-ion battery is dependent on several factors, for example its capacity, temperatures in which it is used, charging (e.g., charging to 50% vs. to 100%), and the quality of the battery cells. Battery condition deteriorates both for passage of time, and due to charging – discharging cycles. There is a lot of experimental and simulation-based research on both, but no generalizations cannot have been withdrawn, as these studies apply only to certain cell models. A cell of another chemistry, or even of the same chemistry but from a different manufacturer, may act in a significantly different way. Regarding EV battery lifetime, Linja-aho (2022, p.47 – 48) states, that "in 2020 I estimated an EV battery to last for 10 – 15 years and 200 – 300 thousand kilometres". He adds, though, that with the improved 21st century technology the figures are likely to be higher. (Linja-aho, 2022, p. 39 – 51.)

6 E-TRAILERS

Electrification of heavy cargo vehicles has become an emerging trend in transport business, and multiple trailer manufacturers have started to use Li-ion batteries as power supply for different functionalities in trailers. The power supply solutions vary from hybrid to all-electric technology, and from converting the tractor unit's engine power into electric power, to only using shore power to charge the batteries. The following models represent the two eTrailer types expected to be adopted in near future by the case company's customers, hence becoming part of daily operations on Finnlines' cargo operations.

6.1 eThermotrailer / eReefer

According to Kai Mäkinen (2024), S.KOe Cool, an all-electric thermotrailer by Schmitz Cargobull, was the first model to enter Finnish markets. The trailer in Figure 7, is one of the fifteen trailers launched in the pilot phase to gain user experiences for further product development.

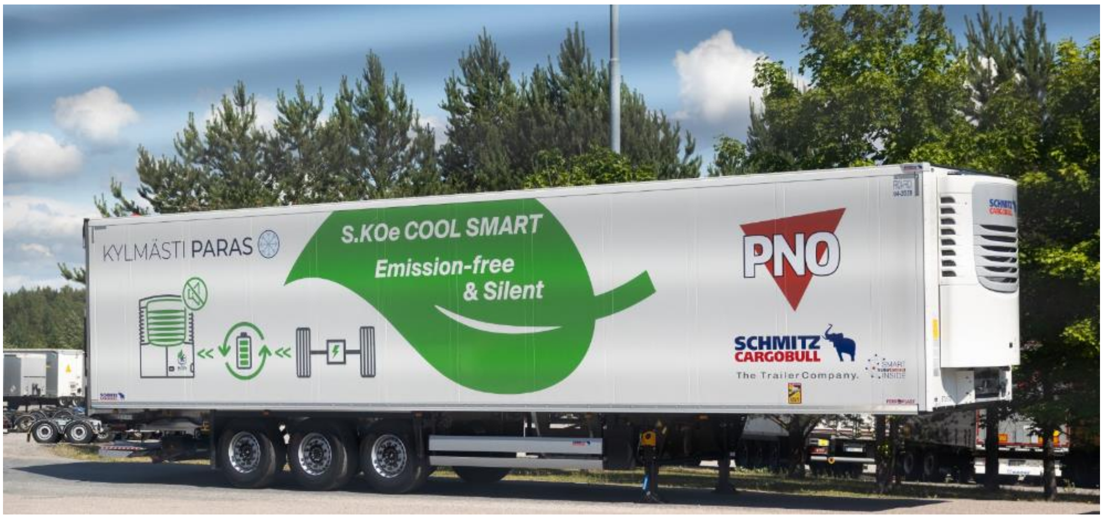

Figure 7. PNO Finland's pilot trailer, manufactured by Schmitz Cargobull. (Mäkinen, 2024)

In S.KOe Cool, the traditional diesel-powered refrigeration machine has been replaced with an electric cooling unit which gets its power from a Lithium-ion battery pack. The capacity of the pack is 32 kWh, which is approximately half of the capacity of a passenger EV battery. The usage of a relatively small battery pack is possible due to the generator axle which allows the recharging of the battery while driving. When the trailer is parked, the batteries can be charged with a CEE plug via a three-phase network (400 V, 32A, 50Hz). Additionally, the trailer is equipped with a small solar panel to protect against deep discharging of the battery pack. The autonomous runtime of the cooling unit is four and a half hours, and it takes approximately two hours to fully charge. (Schmitz Cargobull, n.d.)

As shown in figure 8, the energy flows always via the battery pack. Therefore, it would not be possible to run the engine with network power without charging the battery at the same time.

Figure 8. Energy flow in the system. (Schmitz Cargobull, n.d.)

According to Mäkinen (2024), there has been inquiries regarding the possibility of avoiding the charging while the system is plugged in network. He noted that the battery management system is built so that it always protects the battery, for example from high voltage peaks. Hence, “cutting” the battery from between would likely increase the risks, rather than reduce. He also pointed out that in a perfect scenario, meaning that the battery is fully loaded, and the correct temperature has been reached inside the trailer, the battery capacity is enough for the trailer to travel, for example, from Travemünde to Helsinki. In such case, the onboard charging would not be needed.

6.1.1 eAxle Trailer

This eTrailer type is equipped with an electric drive axle, which provides support for the semitrailer tractor in starting, normal drive, and when tackling inclines. The main purpose of e-axle trailers is to reduce fuel consumption, and thereby the emissions, especially in long-distance transportation. In manufacturer's tests the fuel savings have been significant – from 20% to even 40%. The traction battery can be charged via plug-in, and it also restores energy when braking (recouperation). (KRONE Trailer; Trailer Dynamics.)

The battery capacities seem to vary a lot, as while a Finnish manufacturer VAK uses 15 kWh battery (Saikkonen, 2024), the options provided by Trailer Dynamics (2024) goes from 200 kWh and up to 600 kWh. It must also be noted that both companies use battery chemistries other than Lithium-ion.

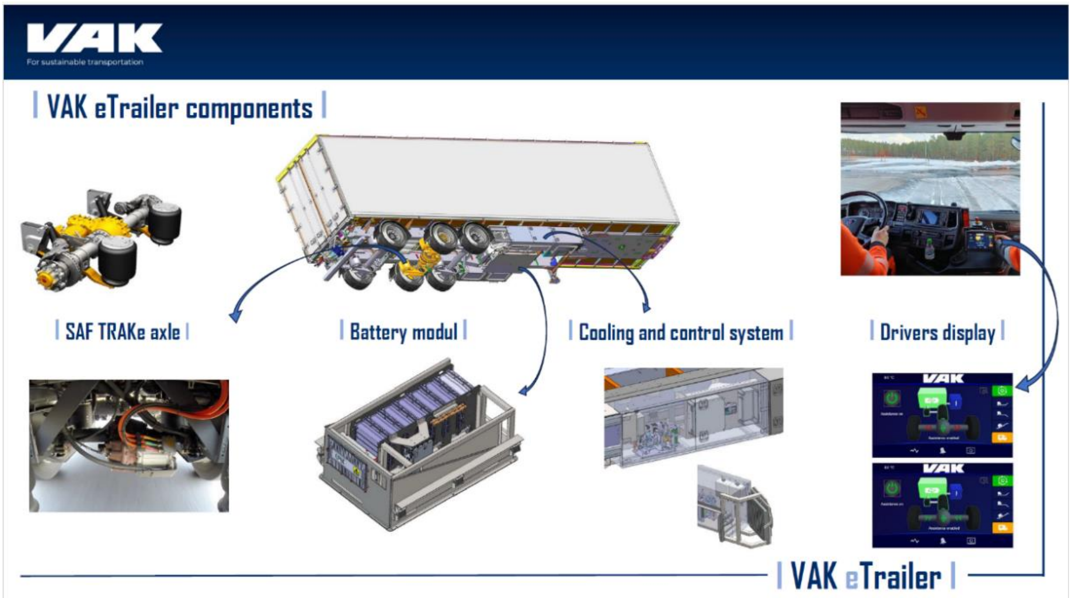

Figure 9. VAK eTrailer components. (Saikkonen, 2024)

Regarding safety aspects, VAK's model has a battery management system which monitors the state of the battery pack and cells, and for example decreases the power if the temperatures rise. The trailer is also equipped with a manual Lithium fire extinguisher, which is directly connected to the module where the battery pack is located. The device is not enough to extinguish the fire, but it does provide additional time for the rescuers. (Saikkonen, 2024.)

6.2 Location of the Battery Packs

In both models the battery packs are located in between the bogie and the landing legs (Figures 9 & 10). The strong landing leg structure protects the battery pack from the front, and collision bumpers from hazards coming from the sides. VAK has added protection from front with a thick baffle plate to avoid, for example, animals from hitting the pack (Saikkonen, 2024).

Figure 10. The location of the battery pack. (Schmitz Cargobull).

The location of the battery pack is relevant for at least two reasons. Firstly, the spot is relatively susceptible for damages, both while driving and during port operations. Though Mäkinen (2024) noted during the interview that the landing legs are more likely to get damaged than the battery pack behind them. Secondly, the location may make it difficult to identify the trailer type, especially if covered from sides, which in a case of a fire could cause unnecessary risks to fire extinguishing team.

7 REGULATIONS

At the moment, the maritime transportation of EV’s is not regulated by any authority or organization. Some governments and regional organizations have introduced safety guidelines. The recent occurrences of onboard fires have turned the interest of many parties towards the issue. Thus, new, and updated regulation, applicable world-wide, may be expected in few years’ times.

7.1 IMO

The International Maritime Organization (IMO) is the top authority of international shipping, setting the standards and regulatory framework for the safety, security, and environmental performance of the industry.

IMO has commissioned its Sub-committee on Ship Systems and Equipment (SSE) to begin the discussions on the EV fire safety in maritime transportation. The committee has already started to work on the issue, and plan to give their proposals to the Maritime Safety Committee (MSC 109) in December 2024. The goal is to “minimize the risk of fire in vehicle spaces, ro-ro spaces, and special category spaces of ships in terms of carrying new energy vehicles, including BEVs” (IMO, 2024). This is to be achieved by identifying the hazards of risks of fire of vehicles using alternative fuels as power sources, and examining whether those are covered by the current legislation. For example, SOLAS chapter II-2 on Construction – fire protection, fire detection and fire extinction, will be evaluated. (IMO, 2024.)

8 LASH FIRE

The LASH FIRE project, coordinated by Research Institutes of Sweden (RISE), and funded by EU's Horizon 2020 research and innovation programme, consists of 27 research institutes and industry partners from 13 EU member states.

> The Legislative Assessment for Safety Hazards of Fire and Innovations in Ro-ro ship Environment (LASH FIRE) project is dedicated to improving fire safety measures on all types of ro-ro vessels. The project seeks to mitigate fire risks by developing and implementing innovative solutions and impactful strategies for communication, exploitation, and data management. (Karimpour & Riberio, 2023.)

The work was divided into eleven packages, including themes such as cooperation and communication, effective manual operations, ignition prevention, (fire) detection, and extinguishment (Karimpour & Riberio, 2023). The project deliverables are published in the project website lashfire.eu. The following subtopics give a brief overview on the results relevant for the subject of the thesis.

8.1 Cargo Fire Hazards

Cargo fire hazards were listed and evaluated as part of development of a fire hazard database for stowage planning. The data was collected from several sources, such as IMO, RISE and private companies' records, and combined so, that no duplicates of individual accidents exist in the final listing. The project group studied data of incidents occurred during maritime transportation, but also in other relevant areas, including parking lots, roads, and tunnels. (Rylander et al., 2021.)

The figures presented in Table 5 have been derived from three lists of LASH FIRE deliverable 08.1. For the scope of the thesis, I have only included the incidents originated from reefer units and new energy carriers.

Table 5. Fire origin and fire causes, 1995 – 2020.

Unit type	Cause of fire	Number of occurrences
Reefer unit	• Electrical fault in cable or connections • Electrical fault in unit • Mechanical or electrical fault in unit • Overheating of unit / exhaust fumes • Unknown	• 11 • 12 • 2 • 7 • 26
New energy carrier	• Spontaneous ignition	• 17

The report concludes that in general, the most common source of ignition is conventional vehicles, and that the main cause to be electrical faults. Furthermore, it states that reefer units seem to pose a high risk due to poor maintenance causing faults in electric connections in the connectors as well as in the unit. In fact, 80% of the most severe fires on ropax vessels have been caused by such failures in reefer units. (Rylander et al., 2021.)

Despite the relatively small number of EV fires, the overall risk was evaluated to be high, due to the difficulty of extinguishing Li-ion battery fires. As many other sources, this report highlights that incorrect charging by using unsuitable cables or plug connections, enhances the risk of fire. (Rylander et al., 2021.)

8.2 Risks Associated with Charging EVs Onboard

The risks associated with charging EVs onboard can be divided into three categories. One is possible malfunctions of onboard charging infrastructure, for example, short circuits, earth faults, or software problems causing loss of control on the charging process. Poor feeding quality of the vessel's electrical grid, and the possibility of blackouts may cause harm on the EVs. Special attention should also be paid to the condition of cables, as they are often exposed to damages. (Ramachandra, 2023.)

The second category is malfunctions of the electrical systems of an EV. Most often, the risks arise from failure of the control system and vehicle software, or from a failure of the battery. These are the exact risks, that may cause a thermal runaway and lead to self-ignition of the battery. Though, the probability of this type of failures is very low, the chances are increased during charging. (Ramachandra, 2023.)

Other risks are included in the third category. One risk factor is argued to be the state of charge in the battery – the smaller the charge, the less is the amount of energy to be freed in a case of fire. One critical issue are DIY fixes and modifications, which are proven to pose a high risk. Furthermore, the risks related to EV fires are present also when a fire is not initiated from the battery pack, or from the EV at all. (Ramachandra, 2023.)

9 RESEARCH METHODOLOGY

The main goal of the thesis was to identify the most critical safety risks related to the maritime transportation of e-Trailers. The research scope involved the shipping company's processes from unit check-in to discharge of the unit. The research design was strongly based on the general guidelines of risk management process, described in chapter 3.

9.1 Research Approach

The research question or problem is to be solved by implementing an appropriate set of methods of data collecting and analysis. There are two main approaches, quantitative and qualitative, involving different set of tools. The approach should provide right type of data and information in relation to the research problem. In another words, the research problem directs the choice of approach. (Kananen, 2015, p.63.)

Quantitative research involves numerical data; hence it is applicable to phenomena that can be expressed in terms of quantity or amount. Quantitative research is based on existing theories and aims for finding generalizations. Most often, the data is gathered via a survey. This method requires a comprehensive pre-knowledge of the phenomena, so that the questions can be set effectively in relation to the research problem. The data can also be collected from existing statistics, registers, and databases. The problem with those is that the figures are most often collected for a certain purpose and may therefore not be suitable or useful as they are, thus they may require modification, combining etc. In quantitative research conclusions are built on statistical analysis. (Bairagi & Munot, 2019, p.8-9; Kananen, 2015, p.73-74.)

In qualitative research, the goal is to describe and understand a phenomenon, and to provide an interpretation. The research is based on words and phrases: literature, interviews, diaries, articles, etc. Opposite to quantitative research, the process in qualitative research does not follow a linear path. Instead, the collected data is analysed in cycles, and the findings (re-)directs the further study and data collection. In qualitative research, it is often impossible to pre-define the amount and type of data to be collected. Basically, the researcher should analyse and find new data until he/she understands the phenomenon, and the solution is found. (Kananen, 2015, p.18-19.)

Most often, qualitative approach is used for studying processes, and how people experience and view the real-world. The researcher is an active participant, being in direct contact with the subject. Possible research methods include, for example, interviews and observation. The researcher becomes the main instrument of data collection and analysis. Through him/her, the results are filtered into conclusions, and into a solution for the research problem. (Kananen, 2015, p.19.)

This research is conducted using qualitative approach. The research problem was about safety risks in a process, and as described in Chapter 3, effective risk identification requires the stakeholders to be involved in the process. Understanding the problem takes place through experience-based and insightful subjective thoughts of selected persons, directing the study further. Although risk evaluation involves numerical data, no mathematical analysis is used, and therefore I would conclude that no aspects of quantitative approach are present in the research.

9.2 Data Collection

The most used data collection methods of qualitative research include interviews, questionnaires, observation, and literature review. These can be used either alternatively, side by side, or combined in different ways depending on the research problem and available resources.(Tuomi & Sarajärvi, 2018, p.83.)

The data collected can be divided into two categories. *Primary data* is collected fresh by the researcher himself, while *secondary data* is already processed and made available by someone not related to the current research.

Secondary data may provide initial insight into the subject, possibly directing the study further. Other advantages of secondary data include economical and fast access, possibility for data of highest quality, and time saving. The cons are, for example, the questions of reliability, accuracy, suitability, and copyrights. Primary data is generally original and relevant, providing a realistic view about the subject. Such data is said to have higher reliability as it is collected by the researcher, or a concerned, reliable party. On the other hand, acquiring primary data may be time-consuming and expensive. The larger the data coverage, the more resources are required. (Bairagi & Munot, 2019, p.131-132.)

This thesis involves both primary and secondary data. The primary data is collected by interviewing internal and external stakeholders, by using a questionnaire, and by observing the process. The brochures and other written material obtained from trailer manufacturers, documents on earlier research and experiments, and literature review represent secondary data.

9.2.1 Literature Review

Scientific research is always based on existing knowledge. Science advances from knew knowledge produced on the existing information reserve. By studying the literature, and with a comprehensive bibliography, the author can demonstrate familiarity with the subject. Furthermore, familiarizing oneself with the literature of the field also helps to use the correct terms and definitions, which is one of the most important factors of scientific research. (Kananen, 2015, p. 114-115.)

Some criticism of sources is a necessity to maintain the reliability of research. It is good to consider certain factors when choosing the sources to be used: who did it, when it was done, what does it contain, and why was it created? With most topics, there is a variety of views and opinions affecting the individual researchers and authors, and the purpose of the research has its effect as well. In many documents and writings, the author also has the power to choose what is included in the text, what is emphasized, or how the data is analysed.

Therefore, “Why?” is always a relevant question when evaluating the possible references. (Kananen, 2015, p. 116-117.)

There was no existing literature on eTrailers, hence, I chose to focus on literature on EVs as they share many similar characteristics related to fire safety and a lot of research has been done on this field. However, the topic is highly controversial and strongly affected by different viewpoints of the authors, e.g. manufacturer studies vs. authority reports, for which I had to practise strong criticism of sources.

9.2.2 Interview

Interview is a primary data collection method where an interviewer personally communicates with the interviewee, making questions about the research topic (Bairagi & Munot, 2019, p.135). Interview is mainly used when there is no, or only a little, knowledge of the subject, or when the goal is to obtain a deep and comprehensive understanding of the research problem. The forms of interview may vary from a free, informal conversation to strictly following a set of predetermined questions asked in a specific order. (Kananen, 2015, p.143-144.)

An absolute benefit of using this method is its flexibility. The interviewer has the possibility to repeat the question, explain it or re-form it by using another words, correct misunderstandings, and to gain better understanding by asking further questions based on the answers. Interviews aim at obtaining as much information as possible. When suitable, a list of questions or themes can be provided to the interviewee beforehand. It is also considered ethical to inform the interviewee about the research topic. Another benefit is that the researcher may choose the persons who have the best knowledge and most experience on the subject. (Tuomi & Sarajärvi, 2018, p.85.-86.)

Interviews do have their weaknesses as well. Firstly, a possibility for biases, both of interviewer and the respondent, is always present. Another point is that though the researcher can choose who they wish to interview, those people are not always available. This concerns especially persons in high positions or income groups. Interviews, and simply arranging them, may be time-consuming, as is also making of the transcriptions. Moreover, becoming a good interviewer is not a simple task - successful interview requires friendly, safe and open atmosphere; the interviewer should not show any feelings or react to the respondent’s answers; and he/she should always keep the interview on the right track. (Bairagi & Munot, 2019, p.99.)

Theme-centred interview is a form of half-structured interview, in which the phenomenon is discussed through pre-defined themes related to the research problem. The themes can be described as sub-topics for the phenomenon, and their purpose is to give a preliminary framework for the interview. Most often, new issues or questions arise for further discussion. There are no strict rules for whether the researcher shall use same framework and/or questions with all respondents. Rather that is a methodological choice of the researcher much dependent on the research problem. However, one should not ask just anything. The aim of an interview is to gain best possible understanding of the phenomenon; hence the questions should be purposeful and produce meaningful answers. (Kananen, 2015, p. 148; Tuomi & Sarajärvi, 2018, p.87-89.)

Interviews with relevant stakeholders formed the backbone of the data collection – from defining the research question(s) to evaluation of the risks. There was very little information available on the eTrailers, hence, manufacturers and importers were approached by e-mail asking for an interview opportunity. Unfortunately, only a couple of companies were available for cooperation. Interviews, and personal discussions, were also used with internal stakeholders from vessel management, marine organization, customer service and stevedoring, in order to gain insights of possible risks and hazards in loading/unloading operations and onboard the vessels. Interviews and discussions were conducted face-to-face or, in case of long distance or schedule problems, via Teams. Teams is an online video meeting platform, in which the participants can also share visual material and documents.

9.2.3 Observation

In observation the researcher monitors the activity of phenomenon. This data collection method is especially useful in when studying processes related to anthropic activity. There are different forms of observation, and the choice should be based on the phenomenon itself, and whether the presence of the researcher could affect it or not. For example, in secret observation the subject is not aware that they are observed. On the other end is participant observation in which the researcher is physically present in the situation and may take part in the action. Observation can be implemented both in a natural environment, and in an inauthentic, experimental situation. (Kananen, 2015, p.135 – 138.)

In order to fulfil scientific criteria regarding data collection, observation must be planned and documented. Writing about things the researcher has self-experienced “at some point in history” does not meet the forementioned criteria. The documentation can be narrative (unstructured), structured, or evaluative. The situation can also be recorded, or filmed, so that the researcher can return to it later. (Kananen, 2015, p. 135 – 140.)

Observation was used here mainly to study the possibility of damages during loading and discharging, and it was performed during three separate visits on three different ropax vessels. The situations to be observed were pre-defined and therefore documentation was made in structured form. Notes were taken by pen and paper, and videotaping was used to verify the observations. Later, still-frames were taken from the videos to be added to the thesis. Another target of the observations was to identify possible steps in which the personnel had the opportunity to inspect the trailers for damages.

9.2.4 Questionnaire

A questionnaire is basically a set of questions prepared to collect answers from individuals related to the topic. Usually, questionnaires are implemented in printed or electronic form. (Bairagi & Munot, 2019, p. 136.) The questions may be either open or provided with answer options (structured). The quality and profitability of the questions depends on, for example, the respondents' understanding the questions correctly; the respondents have the knowledge required to answer the questions; the respondents willingness to share the information asked; and the questions are unambiguous. (Kananen, 2015, p. 230.)

Mailed questionnaire is a cost-effective instrument for collecting data from a large group of respondents, and when they are located at a long distance. Another advantage is that the respondents can answer at the most convenient time for them, and at their own pace. On the other hand, the response rate may be low for, i.e., lack of interest in the research subject. Same concerns the quality and trustworthiness of the answers. Hence, one key challenge of questionnaires is how to make it interesting and engaging. (Bairagi & Munot, 2019, p. 136.)

A cover letter sent with the questionnaire is a tool to communicate the details of the research to the respondents. At minimum, the cover letter should include the topic, purpose, the author, and the possible principal or supporter of the research. Interest for participation can be improved by personalizing the cover letter, and by explaining (shortly) the possible benefits of the research. Also, the confidentiality, and the anonymity of the respondents should be highlighted. Other information includes the due date for responding, the source of contact details, and the method of sample selection. (Kananen, 2015, p. 251 – 25.2)

Two different questionnaires were used for data collection in this thesis. One concerned the knowledge of ships' crew on eTrailers. The questionnaire (Appendix I) was sent to Masters and Chief Officers of ten Finnlines' roro and ropax vessels via e-mail. The second questionnaire (Appendix II) was sent to representatives of six customers of Finnlines. The selection of the companies based on the traffic volumes, and the type of cargo they ship, with emphasis on thermotrailers (reefers).

Both questionnaires were sent by e-mails, which was the best choice considering the time limit and the long distance of the respondents in both groups.

Furthermore, this method provided the respondents with the possibility to answer questions at their convenient time, which I hoped would increase the number of responds. One reminder of the questionnaire was sent two days before due date.

9.3 Data Analysis

It is common for qualitative research to involve several different types of data - observation notes, photographs, voice recordings, etc. Thus, there is no single method for analysis. One option is merely to read, watch, and listen the data, until the common thread is found. Another option is to transcribe the audio and video data, hence creating an integrated data base which can be studied by reading. This option is recommended when the research involves large amounts of data, because text form makes it easier to reduce and organize the information, and thereby to find the key points from the material. Which, at the end, is the purpose of the whole analysis. (Kananen, 2015, p. 159 – 163.)

This research included quite a wide range of material, from brochures to video recordings, and from scientific research to personal discussions. In order to make the analysis, I found it necessary to integrate all data into text form. This allowed focusing on reading only. Other tool of analysis was condensing and thereby categorizing the data. The first goal was to identify the risks within the process, and then the factors affecting their probability and the consequences.

9.4 Reliability, Validity, and Replicability

The reliability of a scientific research is evaluated from the viewpoints of credibility and validity. Credibility refers to the invariance of the results – if it was repeated, would the results be the same? Validity again, asks whether the right things have been researched. The criteria for assessing the reliability of quantitative research are quite established, but the situation is somewhat different for qualitative studies. (Kananen, 2015, p. 343.)

Assessing the credibility of a qualitative research is possible only if the research material, methods, and analysis phases have been properly documented. The results should be so derived from the data in such a consistent manner, that a peer evaluation would end up with the same conclusions. Dependability and repeatability can also be tested with similar evaluation. Moreover, proper documentation is also a key factor for the replicability of a research. The documentation should unequivocally state what was done, how it was done, and why it was done. (Kananen, 2015, p.122, 352-353.)

The simplest way to ensure confirmability, is to ask from the person whom the data and the interpretation concerns. This method, however, has its risks, because the respondent may end up with a different interpretation, or he/she may forbid the publication of the information, especially in cases where the results of the research do not please him/her. Triangulation is another method of ensuring confirmability. Basically, it means that the more supporting evidence from a wide variety of sources, the stronger the interpretation. (Kananen, 2015, p. 354.)

Risks tend to be changing in their nature – situations change, attitudes change, environment changes, knowledge enhances, etc. Therefore, it would be unlikely to achieve the exact same results if similar research was made at another time. On the other hand, it is important in risk management, that the evaluations are carried out in a consistent manner, so that changes can be detected as accurately and correctly as possible. For this reason a high emphasis was put on explaining the research methodology, and the risk management theory the research followed.

The reliability of this thesis may have suffered slightly from the lack of respondents and interviewees willing to participate in the research. Yet, as all answers for both questionnaires were similar, and supported by the short pre-discussions (mail) with the customers; views of the manufacturer and importer of trailers; and discussion with related ship and stevedoring personnel, I would state that the reliability of the final conclusions is at least sufficient.

One risk for the reliability was the commercial aspects of this relatively new product market, as well as of the highly competitive shipping industry. This issue is strongly related to the ethicality of the study and will be discussed further under the next subtopic.

9.5 Ethical Considerations

From one viewpoint, research ethics as a concept can be limited to involve only scientific matters. In this case, i.e. the treatment of research subjects and the relations between science and society are said to belong to the ethics of science, instead of research ethics. Then again, research ethics can be defined as the professional ethics of researchers, which includes e.g. ethical principles, norms, values, and virtues that a researcher should follow. Moral questions in research work can also be ethical in general, but essentially, they concern what is ethically acceptable and recommended in researchers' profession. In this case, research ethics guides the profession and at the same time conveys to other people the values and obligations researchers are committed to. (Kuula, 2011.)

The Finnish National Board of Research Integrity (TENK) guides and monitors the ethics and integrity of research in Finland. According to TENK (2024), research and its results can only be ethically acceptable, reliable, and credible when the research is made in compliance with the Finnish Code of Conduct for Research Integrity. The primary responsibility for RI lies on the author, but also on the research directors, organisations, as well as the whole research community. (Finnish National Board on Research Integrity, 2024.)

The four basic principles of research integrity (RI) are reliability, honesty, respect, and accountability. Good research practices follow these principles and can be described in eight contexts, five of which concern individual researchers: research procedures; safeguards and agreements; data practices and management; authorship, publication, and dissemination; and reviewing and evaluating. (Finnish National Board on Research Integrity TENK, 2023.)

The issue regarding the subject's commercial nature, as mentioned in the previous subtopic, was recognized in early phase of the research. One reason for this issue was that the subject was assigned to the author by her current employer, which is a commercial company in shipping business. Another reason is the involvement of other commercial parties: a manufacturer and an importer of the trailers. The market of eTrailers is new, and certain type of results could have negative impact on the clients operating in international transport sector. From the shipping company's viewpoint again, revealing the internal processes in detail, or publishing the identified risks, could harm the business.

Despite of this issue, and despite that the author has signed a non-disclosure agreement with the case company, strong emphasis was placed on the principles of open science throughout the research. One important reason for this was that the results could thus be utilized by any interest parties: other shipping companies, manufacturers, customers, authorities, etc., and thereby enhance safety of seamen, passengers, and the vessels.

The choice for openness realized for example in that the company behind the research topic, as well as the author's relationship with the company, were clearly communicated to all participants. Another choice was not to re-check the transcriptions and interpretations with the respondents, to avoid changing, or prohibiting publication of the statements. Due to this decision, it was clearly stated during the interviews and in the questionnaires that any question could be left unanswered. A careful consideration was also given to that any publicised information would not be harmful or disrespectful towards the participants.

10 EMPIRICAL STUDY

Finnlines' vessels make calls in dozens of ports around the Europe. The procedures for trailers vary between the ports, and in many cases, they are not performed by the company's own personnel. Considering the resources for the research, especially in terms of time, it was not possible to perform observation in full coverage of the services. The following chapters investigate the processes in two Finnish ports, Vuosaari (Helsinki), and Naantali, and on three vessels: Finnsirius, Finncanopus, and Finnmaid.

10.1 Cargo check-in

In port of Vuosaari, customers (hauliers) may deliver trailers within the opening hours, and the check-in is carried out by the personnel of Finnsteve. The trucks stop at the check-in booths, and a parking spot on the loading field is assigned for the trailer. Each unit is photographed by an automated system.

In port of Naantali, there are two possibilities for delivering the trailers: with a driving permit at all times, or by visiting the check-in office during opening hours. Finnlines cargo customer service is open between 6 – 23 on weekdays, and a few hours in the morning and evening during weekends and most national holidays. There are specialized loading assistants (Traffic Operators) in Naantali, whose tasks include trailer inspections. Due to the nature of the job, those can mainly be carried out outside of vessels' port call times.

10.2 Loading operations

Loading operations in this study covers the discharge and loading of both the un-manned trailers, and manned units (trucks, semis, etc). Special emphasis was put on the risk of battery pack damage, especially on ramps to, and inside of the vessels. Also, the awareness of stevedores about eTrailers was asked from available personnel, and possibilities to check the condition of trailers in different steps was considered.

Regarding the possibility of an eTrailer’s battery pack to be damaged during the stevedoring operations, the results showed that the most critical points are the onboard ramps to/from deck 1 (basement) and to/from deck 7 (weather deck). However, even at those point the risk for a collision is quite low as there is a fair amount of space between the ground and the trailer legs and the side bumper, as can be seen in Figure 11.

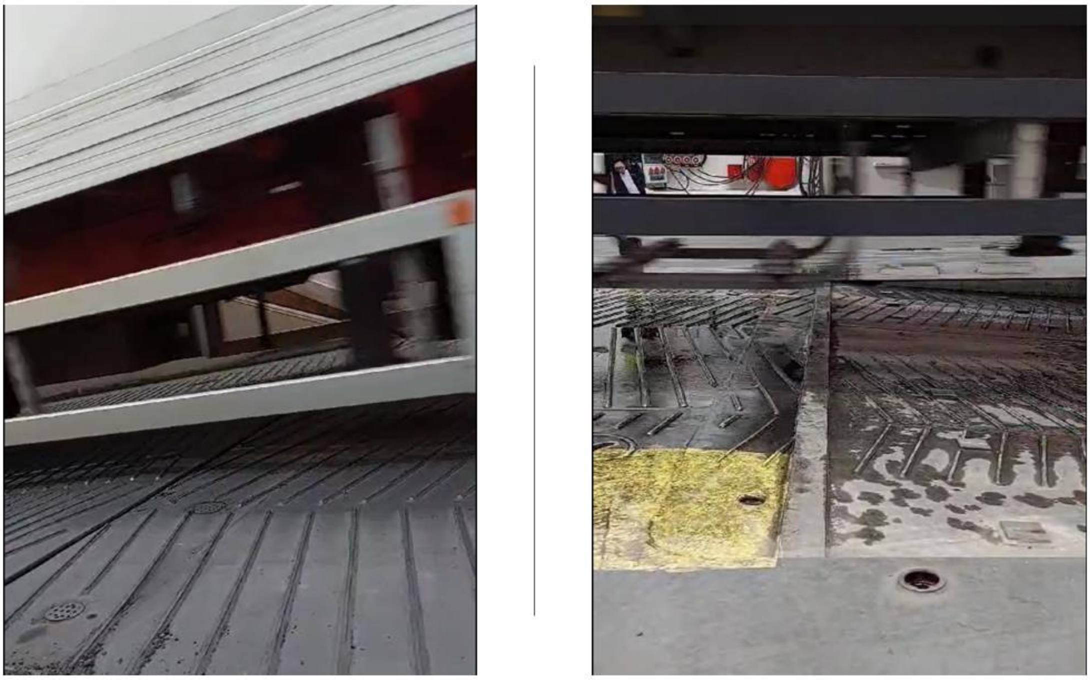

Figure 11. Semitrailer combination going up to deck 7 (left) and a terminal tractor taking a trailer to “basement” (right) on Finncanopus.

The so-called “land ramps” differ to forementioned on that the angles may vary during loading and discharge of the vessels. In Vuosaari, a local Production Director noted that the angle of the upper ramp was quite steep at the observation time. Yet, there was well enough room between the ramp structures and the trailers, hence the risk for damaging the bottom of trailers can be evaluated to be insignificant. During observation, I also took a notice on that the tractors are more likely posed to risk, compared to the trailers. This can be seen in the picture pair in Figure 12.

Another question was whether the stevedores were familiar with the term eTrailers. I had the chance to discuss this only with four persons, of which all were unaware of the concept. But, because this sample is so small, it is not reasonable to draw any major conclusions based on this result.

Figure 12. Comparing the risks for damaging: semitruck versus trailer.

Third issue was the possibility of detecting damaged eTrailers during loading operations. For this, I followed the journey of a couple of trailers from the point when a terminal tractor picked it up to the drop up onboard. This was done both in Naantali and Vuosaari. In both cases, the first possible step for the inspection was when the stevedore stepped out from the tractor to crank the trailer legs up. In Vuosaari, there is one person standing on the stern doors on decks 3 and 5, who supervises the traffic onboard. In both cases, the last possibility was the “guide man” (‘Näyttömies’ in Finnish) who assists the tractor driver in parking the trailer onboard. In addition to visual inspection, the possibility to use a manual IR thermometer was brought up. This idea can be supported by LASHFIRE’s suggestion to utilize IR cameras in detecting EV fires, and for monitoring the batteries (LASHFIRE, n.d.).

10.3 Onboard

The onboard conditions were examined by on-spot observations on three vessels. Videos and photographs were taken, and the topic was discussed with available personnel. Also, a questionnaire (Appendix I) was e-mailed to Masters and Chief Officers of thirteen roro and ropax vessels in Finnlines' fleet. The main themes in the questionnaire were personnels' awareness and knowledge on eTrailers, and capabilities on extinguishing EV fires onboard. A section for free discussion was also involved. During the observations, special attention was paid on the accessibility of the trailers.

10.3.1 Results of the Questionnaire

The response rate was, unfortunately, incredibly low – only four of the twenty-six recipients sent their answers. Three of them work as a Chief Officer, and one respondent as a Chief Engineer, to whom the questionnaire was forwarded by the original recipients. Regarding the vessel type, three respondents worked on roro vessels, and one on a ropax. One of the answers was short, including only couple of sentences, and did not really answer any of the questions. Therefore, I have excluded that one from the results. The other three had answered to questions 1 – 5 with thought and clarity.

The first question was about the respondents' familiarity with the concept of eTrailers, and whether he/she would be able to identify one when loaded onboard. Two out of three respondents replied that this was the first time they heard about the concept, and one of them noted that he would most likely not be able to identify an eTrailer. One respondent did know of eTrailers as he had read about them from articles.

The next question asked whether the respondent was familiar with the risks involved with having EVs onboard. One respondent was well aware of the risks involved and mentioned videos and other material provided by rescue authorities as a source of information. He also told that the issue is regularly discussed in internal trainings. The two other persons said they were aware of some of the risks.

Questions 3 and 4 considered training on EV fire accidents. All three answers included the following key points: 1) the crew has received some guidance on EV fires, 2) further training should be arranged, 3) more information on both EV fires, and eTrailers in specific should be provided.

> "Yes I would = more training and more information how to prevent/check/notice possible fire situations and how to act when facing them. And most important, you should know what kind of cargo you are carrying on."

Above quotation also brings up the question of how the onboard fires could be prevented, as well as the issue of the general awareness about the types of cargo they are handling with.

Question number five on the onboard extinguishing equipment will not be included in the final research for two reasons. Firstly, it did not provide with any significant information for the risk analysis, and secondly, the answers involved information considered to be included under the non-disclosure agreement.

The last question encouraged the respondents to share any thoughts they had on the topic. The only comment was that more material on the occurred accidents would be appreciated, with an emphasis on possible mistakes done during the fire fighting, so that everyone could learn from those, instead of repeating the same blunders.

10.3.2 Onboard Observation

During the onboard observations I had the chance to discuss the topic with crew members representing various positions from Deckhand to Master. None of them knew the term eTrailer, nor did they know what those are. After explaining them the basics, all did agree that the risks of damaging do exist, and that the charging may be in issue. In addition, everyone addressed their concerns regarding fire safety, and the accessibility of any EV in a case of fire.

When it comes to the accessibility of the trailers, I find it very limited. As can be seen in Figure 13, the gap between the trailers in longitudinal direction is sufficient, but the sides are practically inaccessible. This seems to be the case especially when automatic trestles, connected to each other in order to speed up lashing of the cargo. The downfall is that they form an obstacle between the trailers, preventing access from one end of a trailer row.

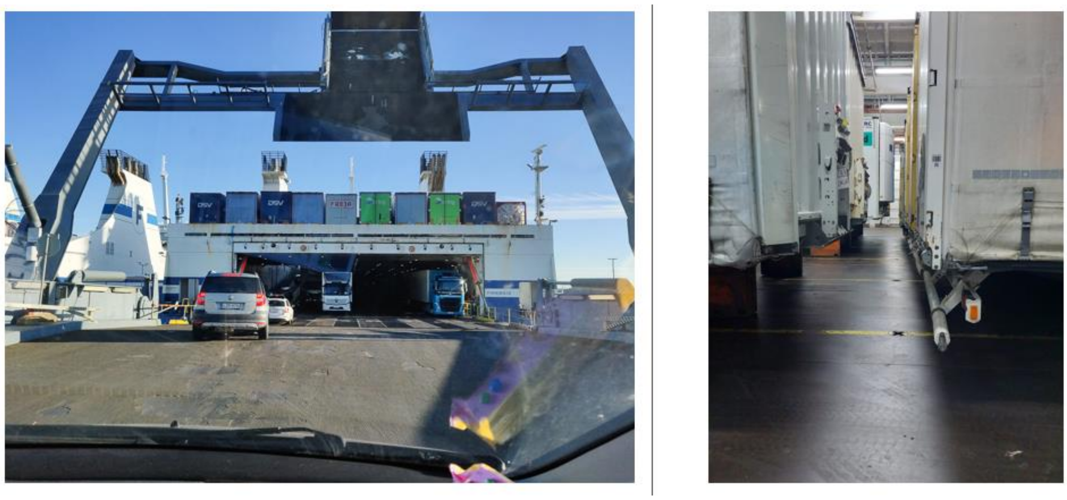

Figure 13. Accessibility of loaded trailers.

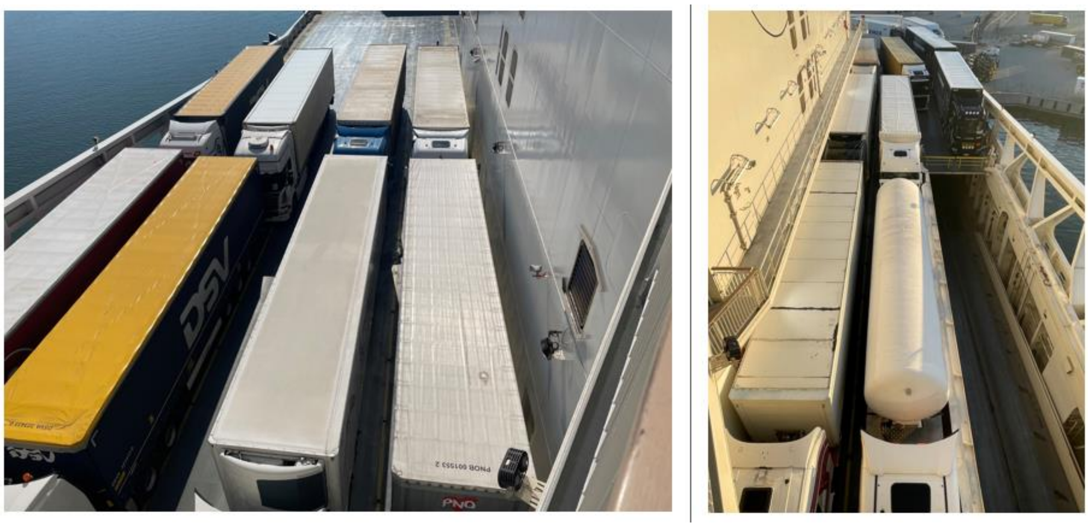

Figure 14. Accessibility of ropax cargo units.

The situation is similar in case of manned units, meaning trucks and vehicle combinations booked with a driver. Though, as seen in picture pair in Figure 14, the situation may vary. Nonetheless, it is clear that locating a possible fire on any cargo deck manually, not to mention identifying whether it involves an eTrailer, would be extremely difficult. Also, carrying the equipment, or moving with heavy smoke diving equipment between the cargo units would be highly difficult as well.

10.4 Future Insights

Future insights were to be researched in order to estimate the schedule for further actions, and to evaluate the significance of the risks today. This topic was asked in the interviews with the representatives of VAK (manufacturer) and PNO Finland (importer / trailer rental), as well as in the questionnaire sent to six key customers of Finnlines.

Unfortunately, the questionnaire did not produce the expected result – only one customer replied. The transport company in question did not have any eTrailers on their fleet at the moment but confirmed that they are planning to acquire those within the next two years. The lines they are planning to use are FinnLink (FI – SE – FI) and HansaLink (FI – DE – FI), and the trailers will be shipped both as loose trailers, and as a truck + trailer combinations. They also revealed that the first step in their eTrailer acquisition project will involve thermotrailers (reefers) powered by solar panels and e-axles.

When it comes to the forementioned interviews, both respondents said that no exact figures can be given, but “the interest has been significant” and “At last year's XX Fair, there was a constant flow of people getting to know eTrailer”. The ETS2 (Emission Trading System) which is expected to become fully operational in 2027, was seen as a factor accelerating the interest to eTrailers, due to their fuel-saving potential. Kai Mäkinen, Key Account Manager of PNO

Finland, also noted that in the Continental Europe, the development and market of eTrailers is considerably ahead of Finland.

Both interviewees also pointed out couple of aspects that might hinder the market development in Finland. One was the ongoing worldwide lack of components, which may impede manufacturing. The other point was that because most of the existing models have been designed in different climate areas, compared to Finland, there have been certain issues especially in cold and snowy weather conditions.

11 RECOMMENDATIONS AND ANALYSIS ON THE RESEARCH QUESTIONS

In this chapter I will first analyse the results in relation to the sub-questions, and then discuss the main research question as its own chapter. I will also provide with a list of the most critical risks identified during the research, and give recommendations based on the analysis.

11.1 Analysis on the sub-questions

Question 1.1 was covered by literature review and empirical research. The results indicate that even though the number of EV fires is low, the fire risks related to Li-ion batteries is seen extremely high, especially in spaces like ship’s cargo deck, underground car parks, etc. At the moment, three onboard fires have been confirmed to have involved electric vehicles. Of these, only the one occurred on MS Pearl of Scandinavia is proven to have initiated from the Li-ion battery of the vehicle. It is important to note that a) the vehicle in question was not industrially manufactured, and b) the fire was successfully extinguished onboard. Another key finding is that the two other accidents happened in PCTC vessels, in which the cargo decks are extremely tightly loaded and inaccessible during the sea voyage, which enables fire to spread fast.

Establishment of large, international projects and studies, i.e. LASH FIRE, suggests that the issues concerning maritime transportation of electrical vehicles are seen critical and of high importance by many stakeholders. The observation and questionnaires also indicated that there is a real need for trustworthy and truthful information among the seafarers.

From a shipping company's point of view, the most critical points seem to be related to identification of electric vehicles, the issues of onboard charging, EVs' accessibility onboard, and the personnel's ability to identify whether an EV battery is involved in a fire accident, and to extinguish the fire in a safe and efficient manner.

Maritime transport of EVs as roro and ropax cargo has not yet been regulated by any authority but, for example the International Maritime Organization has already set a committee to work on this matter.

Question 1.2 on the properties of Li-ion batteries was covered by literature review. The most critical characteristic of Li-ion batteries is thermal runaway – a condition in which the battery may self-ignite, after which it can burn even without external source of oxygen. Thermal runaway may occur from both internal and external causes. If there are no external damages on the battery pack, the risk for thermal runaway cannot be detected by human eye. IR thermometer or thermal cameras can be used for detecting temperature rise.

The effect of SOC (state of charge) on the ignition and burning of Li-ion batteries is studied by practical experiences, which have confirmed the correlation between the two. The results suggest that the higher the SOC, the stronger is the burn reaction and its duration.

A battery management system is a safety application required for any Li-ion battery powered equipment. Its purpose is to protect the battery pack from internal and external electrical defaults, hence preventing the pre-conditions of thermal runaway.

Question 1.3 on the safety -related characteristics of eTrailers was covered by the interviews with the representatives of a manufacturer, and of an importing company, and the documents provided by them. The results indicate that the most critical hazards seem to arise from the Li-ion batteries. The battery packs located under the trailer do expose to the risk of external damage in some degree, but the issue has been acknowledged by the manufacturers and the packs have been protected against such occurrences.

Question 1.4 regarding the possibility to cost-efficiently detect damaged battery packs was answered by the results of observations. Trailer check-in could be one point for the inspection, but because the trailers can be delivered to certain ports outside of opening hours, it seems better to consider the parts of the process that takes place in all ports. Based on the observation of stevedoring operations, visual inspections would be possible at least in two steps: when a terminal tractor picks up a trailer from the parking field, and by the “guide man” when the trailer is parked onboard. In Vuosaari, the third option was that the supervisor could inspect the trailers. In addition, the possibility of the using an IR thermometer to measure the temperature of a battery pack was brought up.

Question 1.5 was also covered by observation. The results indicate that even though there is a theoretical possibility for the battery packs to be damaged during the loading, the risk would not become significant. However, caution should be exercised especially when moving the trailers up or down on ramps, both onboard and on the land ramp.

Question 1.6 was examined during the onboard observations. The results prove undeniably that the cargo units are not easily accessible when loaded onboard. Especially the use of automated trestles under loose trailers prevents approaching from one direction effectively.

The question 1.7 on the state of knowledge on eTrailer concept among the crew members was covered by the questionnaire sent to crew members. No absolute conclusion could be drawn due to the small sample size, but the results do suggest that most of the personnel is not aware of the concept. The personal discussions with crew members during the observations support this.

On the other hand, one respondent seemed to have notable awareness on the concept, as well as on EVs, EV fires, and the related risks. This could suggest that personal interest and activity play a vital role for the state of knowledge.

The issue of how the stakeholders see the future of eTrailers in multimodal transportation (question 1.8) was discussed in the interviews and included in the questionnaire sent to customers. Again, the sample size was unfortunately small, which does affect on the reliability of the results. However, all respondents did agree on that the eTrailers are likely to be widely adopted in the transport industry within few years. There are certain issues that might hinder the market development in Finland, but in Continental Europe the situation is already much ahead. The EU ETS was mentioned as a key factor for the future of eTrailers, especially for the eAxle trailers, which offer significant potential for fuel savings.

11.2 What are the most critical risks related to maritime transportation of eTrailers?

The primary goal of the thesis was to identify the most critical risks related to maritime transportation of eTrailers. This question was covered with literature review and the empirical research. The research plan was based on the risk management principles and the ISO31000 process described in Chapter three.

Referring to the first step of the process, the scope and objectives of the risk assessment were defined in Chapter 2 of the thesis. The risk management theory was also utilized in choosing the research methods, and the people to be involved in the research. Creation of risk criteria was excluded, because that should be organization-specific, and though the topic was commissioned by a single company, the author wanted the results to be more general in nature, so that they could be utilized by other stakeholders as well.

Risk assessment is divided into three sub-processes of identification, analysis, and evaluation of the risks. Based on the literature review and the empirical research I have compiled a list of risks related to maritime transportation of eTrailers (Table 5). It should be noted that risk identification and evaluation is always a time-specific process, meaning that the assessment I have now made may not be true after some time. In addition, this evaluation is made without considering the possible risk management methods already existing, or to be implemented in the future.

Table 6. Risks related to maritime transportation of eTrailers.

Risk		Likeli-hood	Conse-quences	Overall risk
A	Ship's crew is unaware of having an eTrailer as cargo	3	3	3
B	Crew is unaware of the firefighting procedures in case of Li-ion battery fire	3	3	3
C	Crew is unaware of how to identify if a Li-ion battery is involved in a vehicle fire	3	4	4
D	eTrailer fire accident involving a Li-ion battery	2	5	4
E	Risk of loading an eTrailer with a damaged battery pack	3	4	4
F	Inaccessibility of the cargo units onboard	5	5	5
G	Enhanced risks due to self-made modifications or non-authorized maintenance of eTrailers	2	5	4
H	eTrailer battery pack is damaged during loading / discharge	1	2	1
I	Enhanced risks due to aging of the battery / battery cells	1	2	1
J	Fire risk of eThermotrailer being charged onboard	3	5	4
K	Fire risk of eThermotrailer running on battery power onboard	3	5	4

The first three risks are related to training of the onboard personnel. The likelihood in all three is estimated to be moderately possible. This is based on the results of the questionnaire sent to crew members. Regarding the consequences I would state that for the first two the level would be major. One factor for this is that several sources have stated that water is the best agent to extinguish and to control a Li-ion battery fire, and the crew is regularly trained for fire accidents in general. However, the processes for all fires are not the best for those involving a Li-ion battery. With the third risk I took the health and safety of the firefighting crew a little more into consideration, referring to the toxic gas and possibility of small explosions in Li-ion fires. Therefore, I evaluated the consequences here as significant. Thereby the overall risk of the first two are on medium level (3), and for the third one the level is medium high (4).

As the battery technologies have had time for development before it has been applied to eTrailers, and because all eTrailers are not powered by Li-ion batteries (but some other type), I have estimated the risk of the eTrailer fires involving a Li-ion battery to be merely unlikely. The consequences though, are on the other extreme of being catastrophic. This is due the absolute fact that a fire onboard any vessel always has the potential to become life-threatening. Not to even mention that Li-ion battery fires have the ability to burn without external source of oxygen, thus being extremely difficult to extinguish. Thereby, the overall risk is classified as medium high (4).

The risk of loading an eTrailer with a damaged battery pack was found to be moderately possible, and its consequences to be significant. Thereby, the overall risk is evaluated to be four (medium high). Firstly, the stevedores seemed not to have knowledge of the whole concept of eTrailers, and there are no existing procedures on how such trailer could be identified, or how it should be inspected in order to prevent loading of faulty units. Secondly, even though a bump on the battery pack does not necessarily mean the battery would ignite during the sea voyage, external impacts have been identified as a significant cause of EV fire accidents. Additionally, inspecting the units before loading could be one of the cheapest and most effective ways to prevent onboard fires of eTrailers.

When it comes to the accessibility of the vehicles onboard, the research shows undeniably that it would be extremely difficult to move across a fully loaded cargo deck. Hence, locating and identifying a burning unit, as well as getting the rescue crew and the firefighting equipment in proximity of the correct vehicle, would be time-consuming and hard. Therefore, both the likelihood and the consequences got the highest scores, giving the overall grade of five (high).

The next identified risk was about enhanced hazards due to self-made modifications or non-authorized maintenance of eTrailers. According to current information available, only one onboard fire has been confirmed to be initiated from an EV. The vehicle in question was converted into electric vehicle by a private person. Also, the charging cable was self-made. This issue was also brough up in the reports of the LASH FIRE project. Regarding the eTrailers, it was not easy to evaluate the likelihood, but the consequences were clearly in" top class". The overall risk evaluation ended up being of medium high (4).

During the observations the possibility of damaging the trailers during stevedoring operations was carefully considered, and videos and still-photos were taken in order to verify the findings. It soon became clear that the risks were mainly theoretical. Hence, the likelihood was estimated as very unlikely. As there was well enough space between the ramps or cargo decks and the bottom parts of the trailers, it seems likely that a possible hit would not cause severe damage. Therefore, the consequences were evaluated to be minor, which gives the overall risk class of 1 (low).

Aging of the eTrailers and the battery packs was one of the pre-defined subjects of the research. The technology is still relatively young, especially in the application on electric vehicles. The literature review indicated though, that even with the older technology the lifetime of Li-ion battery cells would be approximately ten to fifteen years, and recent development has been fast. As the risk assessment should consider the current state, the likelihood was evaluated as unlikely. The effects of the aging are not fully known, but as long as the battery management system works as it should, the consequences of aging should not be significant. Based on this assumption, the rate given was two (minor), and the overall risk rating was hence one (low).

One of the most critical issues regarding any EVs is whether those can be charged during the sea voyages, or not. To start, let's examine the findings that support "yes" to charging. Those include the small percentage of EV fires compared to combustion engine vehicles and the Battery Management system that protects the battery cells during charging. In the opposite corner we have the disastrous accidents already happened, the statement of LASH FIRE project that the characteristics of onboard electricity systems may increase the risk of malfunction in the battery or the BMS, as well as the surprisingly high number of fires occurred by electric faults in conventional reefers. Here, the fundamental idea that risk assessment ought to be time-bound has affected the evaluation. There was no proof on that the BMS would fail often, and as the eTrailers will likely be new and in good condition in the next few years, I have evaluated the risk of onboard charging of eThermotrailers to cause a fire as unlikely. The consequences would most likely be catastrophic, as discussed earlier in this chapter. Hence, the overall risk would be medium high (4).

The same considerations are valid also for the fire risk of eThermotrailer running on battery power onboard. The main difference is that this solution would prevent the faults caused by the instability of the ship's power grid. On the other hand, the possibility for overdischarging, leading to short circuit and thereby to thermal runaway, is theoretically more likely. The assessment was similar as with the previously mentioned.

Table 7. Risk matrix

Risk matrix						
		Consequence				
		1	2	3	4	5
Likelihood	5					F
	4					
	3			A, B	C, E	J, K
	2					D, G
	1		H, I			

The identified risks can be places on risk matrix (Table 7) based on their overall risk category. The five-category risk matrix is especially usable when the criticality of the risks is evaluated. Here, the range goes from low (1) to high (5). Colour coding is used to support the visualization of the results.

The next step in the risk management process would be risk treatment. The risks to be transferred into this process depends on several organisation-specific factors such as values, goals, objectives, environmental aspects, etc. The same applies to the treatment methods chosen.

11.3 Recommendations for the case company

It seems likely that eTrailers will represent a significant part of the cargo mix transported on Finnlines' roro and ropax vessels within the next few years. The results of this thesis show that there are several considerable risks involved, especially with the eThermotrailers. As it is unlikely that the risks could be fully avoided, i.e. by prohibiting eTrailers from boarding the company vessels, I would suggest the company to consider risk treatment options for all the identified risks in risk matrix categories from medium (3) to high (5).

12 CONCLUSIONS AND DISCUSSION

The purpose of the thesis was to identify critical risks related to the maritime transportation of eTrailers. The topic was commissioned by Finnlines Plc, which is also my current employer. The thesis was conducted as qualitative research, and the research methods included literature review, interviews, observation and two open questionnaires sent to different stakeholders. In this section I will present the conclusions and discuss the research in general.

12.1 Discussion

As a safety-oriented person, I found the topic interesting, which did contribute to my motivation to conduct the research well. The planning phase of the thesis project was probably the most difficult, as no specific guidelines were given by the commissioner. During the Research Communication course, I received good guidance on how to develop the topic further, and especially on how to limit the topic, hence, setting a clear focus for the study.

The commercial aspect of the subject, and the fact that I have signed a non-disclosure agreement with the company meant that the research work had to be carried out with special discretion and sensitivity. Also, when writing the results, I had to carefully consider the tone, and which information did really contribute to the research and needed thus be published. Still, I had a strong emphasis on following the values and ethics of Research Integrity. In the end, my personal goal was to make the research public, so that it would truly benefit not only my employer, but also the key stakeholders, such as Finnlines' cargo customers, and the importers and manufacturers of eTrailers.

When it comes to my professional development, I would say that the research work deepened my understanding of risk management activities, and improved my capabilities, and my courage, to cooperate with both internal and external stakeholders. I also learned self-leadership and self-disciplinary skills, as the whole project from planning and scheduling to finalization was basically in my own hands. For my disappointment, I did not stay in the original schedule because the political strikes in spring 2024 hit the industry quite hard. At that point I had to admit, mostly to myself, that I just cannot do everything at the same time and decided to set my focus fully on my job for the necessary time. Now I know it was the only sensible choice in terms of my own well-being, and I think it provided me with an important lesson for future, both for work and private life.

If I was to repeat the research, I would put more time and effort on the questionnaires, and on the cooperation with the external stakeholders. Otherwise, I am quite happy with my contributions to the research.

12.2 Conclusions

The number of EV fires in maritime transportation seems to be extremely low, but considerable weight should be put to the disastrous nature of the possible consequences of such accidents. As the research considered the conditions in roro and ropax vessels, it should be noted that the most catastrophic events have occurred on PCTC (Pure Car/Truck Carrier) vessels, in which the cars have been loaded in low spaces, in proximity of only 10-30 centimetres, causing the fire extinguishing to be extremely difficult, or even impossible.

The overall number of EV fires is also relatively low. However, there is only a little information available on the number of fires that were initiated from the battery system. In many cases the original cause of ignition could not be verified. Thereby, the statistics may give a distorted picture of the situation.

When it comes to the eTrailers, the concept has not yet made a breakthrough, though based on the stakeholder insights, they are likely to take their share of the trailer markets within the next few years. Understandably, there was very little information available on this new technology, due to which I had to utilize the theories and statistics related to passenger EVs. From this viewpoint, I would state that the timing of this research was good, as its results can be utilized already now when the company is first preparing for this issue.

Regarding the Li-ion batteries, I had the impression that those would be impossible to extinguish or control in ship-like conditions. The results of the literature review, however, indicate that water, together with equipment designed specifically for Li-ion battery fires can be an effective combination. If not to extinguish the fire completely, at least to cool down the battery and to keep the fire under control for significantly long time.

The results also showed the issue of the accessibility of the trailers onboard being of major importance. A solution for this could be, for example, locating eTrailers on the sides of the trailers rows, or in other spots that can be accessed more easily during the sea voyage.

The validity of the results does suffer from the poor outcomes of the interview requests and questionnaires. The decision to follow absolute confidentiality when presenting the results, did also affect the quality and validity. On the other hand, that was the only possibility when the goal was to publish the results for everyone to read the whole report, hence, hopefully providing useful viewpoints to any stakeholders.

The original assumption of the thesis was that risks do exist in having eTrailers as cargo on the company's vessels. This hypothesis was confirmed by identification of several risks. These were evaluated in terms of likelihood and the severity of the consequences, in order to identify each risks' location on risk matrix. As an outcome, a list of the most critical risks was presented. Thereby, I would conclude that the research did meet it objectives.

12.3 Suggestions for further research

A natural continuum for risk assessment would be investigating the best possible risk treatment methods for the critical risks, and to create a plan and deadlines for their implementation. In this regard, a comprehensive analysis on suitable treatment methods, and possibly a cost and impact assessment of those would be useful topics.

Another topic could be the creation of a company-specific, or a vessel-type-specific training material, guide, or procedures to be followed in a case of an eTrailer (or EV) fire.

Regarding the accessibility, as well as for preventing one battery fire from initiating another eTrailer (or other type of EV) next to the fire, research could be conducted on how to ensure safest possible locating of e-units in stowage planning.

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APPENDIX I

QUESTIONNAIRE ON eTRAILERS
Onboard Personnel

Hello,

I am a Cargo Customer Representative in Finnlink, Naantali, studying Bachelor Degree of Engineering in Logistics in SAMK, Rauma. I am currently writing a thesis on eTrailers as cargo on roro and ropax vessels. The purpose of my thesis is to identify the safety risks associated with eTrailers from a shipping company's viewpoint. The main research question is how to ensure the highest possible fire safety of eTrailers in maritime transportation.

eTrailers included in the scope of my work are:

a) Thermotrailers using lithium-ion batteries as power source.
b) Trailers equipped with an e-axle, powered again by a Li-ion battery pack.

An important part of the thesis is to study the conditions on board, and the crew's awareness on the topic, and I would much appreciate your thoughts for the questions below.

Your answers may be cited in the thesis, but <u>your identity will not be shared with anyone inside or outside Finnlines Plc</u>. The e-mails will be permanently deleted within 3 months of receiving. The thesis will be published in Theseus.fi, at the latest in June 2024.

You may leave questions, or part of them, un-answered. Any info is more info!
Please note that you may answer in English, Finnish, or Swedish.

1. Are you familiar with the concept of eTrailers? Would you be able to identify an eTrailer loaded onboard?
2. Are you familiar with the risks involved with electrical vehicles as cargo on roro/ropax vessels?
3. Would you consider it important for the crew to have (more) training in the aforementioned? What kind of training?
4. Has the crew on the vessel you work on been trained for EV fire accidents? Do you think that the current training would be enough to cover eTrailer fires, or would further training be required?
5. Do you think the vessel's fire-fighting equipment is suitable and sufficient for extinguishing an eTrailer fire? If not, what kind of equipment would you add?
6. Feel free to share any additional thoughts and ideas on the topic!

The response time is, unfortunately, quite short, only until 26/05.

Finally, many thanks for Your time in advance.

With kind regards,

APPENDIX II

QUESTIONNAIRE ON eTRAILERS
Customers

Dear Customer,

I am a Cargo Customer Representative of Finnlines Plc, studying Bachelor Degree of Engineering in Logistics in SAMK, Rauma (Finland). I am currently writing a thesis on eTrailers as cargo on roro and ropax vessels. The purpose of my thesis is to identify the safety risks associated with eTrailers from a shipping company's viewpoint. The main research question is how to ensure the highest possible fire safety of eTrailers in maritime transportation.

eTrailers included in the scope of my work are:

a) Thermotrailers using lithium-ion batteries as power source.
b) Trailers equipped with an e-axle, powered again by a Li-ion battery pack.

Future insights of the trailer types as roro/ropax cargo are an important part of the study, and I would much appreciate it if you had the time to answer the following questions.

For further research purposes, we are also interested in other types of eTrailers. Please do mention if your answer concerns other than the above-mentioned types.

Your answers may be cited in the thesis, but your identity will not be further shared to anyone inside or outside Finnlines Plc. The e-mails will be permanently deleted within 3 months of receiving. The thesis will be published in Theseus.fi, at the latest in June 2024.

You may leave questions, or part of them, un-answered. Any info is more info!
Please note that you may answer in English, Finnish, or Swedish.

1. Does your company's fleet include eTrailers? If yes, what type of?
2. Does your company intend to acquire (more) eTrailers in the next 2 years?
3. In which of Finnlines' traffic area(s) your company ships / is planning to ship eTrailers?
4. Does your company ship / is planning to ship eTrailers as
    a. Trailer
    b. Truck + trailer
    c. Both?
5. Feel free to share any additional thoughts and ideas on the topic!

The response time is, unfortunately, quite short, only until 26/05.

Finally, many thanks for Your time in advance.

With kind regards,