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LITHIUM BATTERIES AS CARGO ON SEA TRANSPORTS

DEGREE PROGRAMME OF SEA CAPTAIN
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Lithium batteries as cargo on sea transports

Degree Programme of Sea Captain

The purpose of this thesis has been to compile general information on the transport of lithium-batteries on sea transports. A large proportion of batteries transported by sea are installed inside electric cars. The importance of the safety of these transports will increase in the coming years, as the sales of electric cars increase all the time. Safety onboard is the main aspect of the work, but the topic is dealt with on a large scale. There is not much experience with transportation of lithium batteries on vessels yet, since there has not been a lot of electric vehicles before what to transport. Therefore, it was important to study the subject. Research data will be useful, especially improving safety aspects.

The nature of the work is to present todays situation in transporting lithium batteries on vessels. The descriptive method was used. The information used in this thesis was gathered mostly from internet sources. The work was done at a general level without paying too much attention to the endless details contained in the topics. The thesis was part of the one-year AlusAkku project.

Results was showing that the growing EV market and future's emission control will be pushing Maritime cluster operators who deal with EV transports, to make investments for safer and more efficient operations. Technological solutions are developing in a fast pace. This means that a lot of adaptation is needed in the years to come, inside the ships and at the port facilities (charging infrastructure) and in the safety solutions. Automation will be increasingly important in ship safety systems integration.

Conclusion was that increasing number of EV transports show, that there is a need for regulatory work, and intensive co-operation is needed to gain proper and unified rules inside the industry.

Keywords:
Sea transport, lithium-battery, batteries, electric vehicle, fire safety onboard.

PREFACE

The main goal of the work is to get more overall information of the carriage of lithium batteries on vessels. Leading idea is focused on the safety aspects. There is not much experience with transportation of lithium batteries on vessels yet, since there has not been a lot of electric vehicles before what to transport. Therefore, it is important to study the subject. Research data will be useful, especially improving safety aspects. The idea of the work is not to go into details, but just to get a review of the subject. Future years will show what kind of development there will be in the battery technologies and ship safety solutions.

CONTENTS

ABBREVIATIONS

BEV	Battery Electric Vehicle / Battery-Powered Electric Vehicle
CCTV	Closed-Circuit Television
CO_2	Carbon Dioxide
CSS code	Code of Safe Practice for Cargo Stowage and Securing
DNV	Det Norske Veritas
EEBD	Emergency Escape Breathing Device
EFTA	European Free Trade Association
EMSA	European Maritime Safety Agency
EU	European Union
EV	Electric Vehicle
ICE	Internal Combustion Engine
IMDG code	International Maritime Dangerous Goods code
IMO	International Maritime Organization
ISC	International Shore Connection
LNG	Liquid Nitrogen Gas
MSC	Maritime Safety Committee
PCC	Pure Car Carrier
PCTC	Pure Car, Truck Carrier
PHEV	Plug-in Hybrid Electric Vehicle
Ro-Ro	Roll-on / Roll-off
SOLAS Convention	International Convention for the Safety of Life at Sea
STA	Swedish Transport Agency
UK	United Kingdom
WMU	World Maritime University

1 THESIS INTRODUCTION

AlusAkku is the project covering my thesis work. It is a one-year project and ends in the beginning of 2022. Funding to the project comes from Ulla Tuominen foundation. The work is a basic study and is not diving deep into the different topics. Main goal is to get overall information and to study the subject from a simple view.

Maritime and shipbuilding are going through a vast change these days. Moving towards carbon neutrality the industry is being transformed by diverse changes and the digitalisation. In a fast pace new ships are being build which contain a lot of new technics with battery systems side by side with traditional engines. Ensuring the safety of the large-scale battery systems is an intricate and challenging task. The systems can be even a hundred times larger than in electric cars.

In Finland and in Satakunta there is knowhow and competence in building challenging passenger vessel projects with high level technology. In a near future there is many new generation newbuilds being made in Satakunta Rauma's maritime industry collaboration (Wasaline – Aurora Botnia, Tallink Silja – MyStar and Squadron 2020) Wasaline Aurora Botnia will be built and fulfils the standards and regulations of Clean Design class. It will be powered with LNG (Liquid Nitrogen Gas)/biofuel/diesel combination and with a lithium battery system. This will introduce a set of challenges for the electrical safety as it is taken in use for the first time internationally. (RMC, 2019; RMC, 2021; Wärtsilä, 2021a.)

On the other hand, there is a lot of sea transports with electric cars in the passenger ferries on the Baltic Sea and all-around world. Electric cars will introduce an increasing risk for the safety aspect on ferries. Ship companies lack the information and studies for handling the malfunction situations of the battery systems and fires onboard vessels.

With this development of the ships there is also a rapid development of the lithium batteries which are transported as cargo onboard vessels. The perspective on this work is focused on the safety matters of the lithium battery cargo transported onboard.

Classification societies provide rules and regulations for the installations whereas there is not yet much of studies in national or in international level concerning the operational electric safety of the battery systems, electric vehicle charging systems, operation in malfunction situations and maintenance procedures. There is very little knowledge or information and studies lacking also from controlling and extinguishing ship fires including lithium batteries and the equipment used with them.

2 ELECTRIC VEHICLES

EVs (Electric Vehicle) can be called also BEV (Battery Electric Vehicle). It doesn't have internal combustion engine; it has an electric motor. Electric vehicles are charged with electric current. There are different solutions for charging, one option is to charge the vehicle from a normal wall socket. Charged electricity is stored in a traction battery pack, which is then used to release power for the vehicles motor. Because electric motor doesn't need liquid fossil fuels, it doesn't spread pollution in form of exhaust fumes in its surroundings when used. (Alternative Fuels Data Center, 2021.)

2.1 History

The first EVs were invented a long time ago. An adoption of a new technology by most of the people, from different reasons can take many years and decades. This has been the case in the history and today. Yet today we can see faster adoption of the new technologies than in the past. When the first electric vehicles were introduced, there were a lack of electrical service availability. When the availability of the electrical service was increased, the adoption of the new technology was not following. The competitor, internal combustion engine was winning the battle due to reasons that were supporting more the use of the ICE (Internal Combustion Engine). (Warner, 2015.)

The future will show whether the electric revolution in vehicles will displace internal combustion engines when the world is seeking more sustainable ways for the transportation of people and goods. There is already change happening, but the change might be slower than we would want to expect. Battery technology is developing all the time, and that is the main reason for EVs possibility to take over the market. (Warner, 2015.)

In the last ten years there has been rapid increase in numbers of EV growth. Today the trend is to decrease carbon dioxide emissions of transport sector. This is done by trying to move towards zero emission tail pipe solutions. Transport sector's role has been getting bigger in the recent years because of the increase of the demand of transporting goods and commodities. Direct CO_2 (Carbon Dioxide) emissions can be reduced when

EVs are in use of the transport sector. This has most impact in the areas with high population. In the commercial market EV sales has been growing fast also. If the number of electric cars on road are compared between 2010 and 2019, the growth has been vast. (International Energy Agency, 2021.)

As found out from the annual publication of International Energy Agency; The Global EV Outlook, we see that the number of electric vehicles will increase in the future and the need for new solutions and innovative ideas will be needed for the future development of the battery driven vehicles.

2.2 Electric vehicle market today

Electric vehicle market is growing. In the first half of the 2021, 2,65 million new EVs was sold. That is, 168% more compared to 2020 (Irle, 2021). Next quotation from the webpage EV-volumes.com tells a simple story about the rise of EV sales.

> For 2021, all regions and most countries witness strong increases in EV sales, with growth rates 3 to 8 times higher than for total light vehicle markets. The share of BEV+PHEV (Battery-Powered Electric Vehicle + Plug-in Hybrid Electric Vehicle) in global light vehicle sales increased from 3 % in 2020 H1 to 6,3 % this year. Europe (EU+EFTA+UK) (European Union + European Free Trade Association + United Kingdom) leads with 14 % EV share for the first 6 months combined, up from 7 % a year ago. A caveat is that half of Europe's EV sales are PHEVs, compared to 80 % pure electric outside Europe. The tailpipe emissions of PHEVs are completely depending on the charging and driving habits of their users, whatever the catalog value says. To their benefit it can be said that countries with high PHEV market shares usually have high BEV market shares as well. (Irle, 2021.)

As result, there is evidence that the growth is continuing and will rapidly continue in the future. Countries are reshaping the future of the traffic and making more strict rules and regulations for emission control. This has pushed the development of EVs and making car manufacturers to change the path in powering their products.

3 CARGO

Today's trend is to manufacture electric vehicles with zero tailpipe emissions. This means that the new electric vehicles prices are going to come down sooner or later. Many cities already encourage electric vehicle owners by offering benefits from using electric vehicle (Paoli, 2021). The numbers of the growth of sales of electric vehicles are updated upwards all the time (Winton, 2021a). In his article Winton discovers that China is leading the after corona-pandemic recovery in auto sales, United States is second and the Europe is lagging. (Winton, 2021b.)

As it is found out, also the transportation of EVs and particularly electric cars by sea-ways is going to increase all the time. This is so, because people are going to buy more electric cars since the price range is going to be more reachable for most households (Rowlatt, 2021). Many of the ferries which transports vehicles, transport people too. This adds more safety issues to those transports with increasing number of electric vehicles onboard in the future.

Shipping company Wallenius Wilhelmsen advice customers on their Frequently asked questions webpage concerning electric vehicles about the procedures what they include in their EV transport process. They mention that they have extensive experience with transporting EV's. Next quotation from the webpage.

> Over the years, we've invested in specially designed infrastructure and extended our pre-delivery inspection and yard management services to support handling of EVs. These services include battery charging, cooling liquid filling, monitoring the charging levels and movement of disabled units. (Hargreaves, 2019.)

3.1 Loading and unloading

Fast loading and unloading are crucial in today's shipping business. Timetables are tight, and the ports have technological solutions and logistics which will speed up the

loading even more. Ship turnaround times are optimized as much as possible. If possible, ships are carrying cargo all the time. But, during the pandemic, we've also seen more empty holds, decks, and tanks on vessels.

Shipping companies are reacting to transportation needs of the electric vehicles. "South Korea-based Hyundai Glovis has established a dedicated electric vehicles (EV) handling solution for car carriers to meet the demands of the EV shipping market" (Ship Technology & Verdict Media Limited, 2021). Compared to shipping companies which have been on the market a longer time, new car manufacturers don't have that much of experience from logistics.

Hyundai Glovis provides service for the customers which includes all the steps from the logistic point of view. They also provide information from the status of the cargo for the shipper. (Ship Technology & Verdict Media Limited, 2021.)

Wallenius Wilhelmsen requires that the battery level is sufficient before loading the EV's. The charging should be at maximum level of 50%, flat batteries are avoided because it might be indication of defective battery and/or battery management system. They state that a vehicle is acceptable for transport if it is in clean condition, fully functional, self-propelled, safe to drive, damage free and at the correct charging level. (Hargreaves, 2019.)

3.2 Cargo locations onboard

Ship's crew will determine safe planning and loading of the cargo. The cargo what is taken onboard is known beforehand. This makes it possible to plan the loading and, in most cases, make use of preliminary loading plan already existing. Demand for advanced planning tools for loading cargo is crucially important when cargo is consisted of many different items and EVs being one of those.

IMO's CSS code (Code of Safe Practice for Cargo Stowage and Securing) provides standards for safe stowage and securing cargoes. A ship needs to be suitable for purpose what it is used. Cargo must be properly stowed and secured so that the risk for

the ship and its personnel is minimized. It is advising on the stowing and securing cargoes which are hazardous and may cause difficulties. (IMO, 1991.)

One of the biggest risks for the ship and for its crew is created if there is a fire, which cannot be detected in time or a fire which is spreading rapidly. Therefore, different types of cargoes should be categorized and separated on the decks so that the location of a dangerous cargoes is not creating favorable conditions to fire to spread or cause dangerous fumes etc. (IMO, 1991.)

3.3 Other cargo

Planning the stowage of the cargo is important. It is especially important when the cargo doesn't come in standardized forms.

Chapter 5 of the CSS code provides advice for non-standardized stowage and securing of cargoes and especially those cargoes which have been proven to be difficult to stow and secure. Special thought should be exercised when stowing cargoes like this. In the next list from the code (5.3), we can see these cargoes difficult to stow and secure. (IMO, 1991.)

.1 containers when carried on deck of ships which are not specially designed and fitted for the purpose of carrying containers (annex 1);
.2 portable tanks (tank-containers) (annex 2);
.3 portable receptacles (annex 3);
.4 special wheel-based (rolling) cargoes (annex 4);
.5 heavy cargo items such as locomotives, transformers, etc. (annex 5);
.6 coiled sheet steel (annex 6);
.7 heavy metal products (annex 7);
.8 anchor chains (annex 8);
.9 metal scrap in bulk (annex 9);
.10 flexible intermediate bulk containers (FIBCs) (annex 10);
.11 logs in under-deck stow (annex 11); and
.12 unit loads (annex 12).

(IMO, 1991.)

Loosening of any cargo could potentially cause damage for EV cargo. EVs and other lithium battery cargo is potentially dangerous when damaged. It is not necessarily possible to see whether the batteries of the cargo are damaged just by assessing it from outside. It is possible that EV is damaged badly, but the batteries are intact and not damaged at all. In the other hand it might be that there is intangible damage in the batteries due to some factors onboard which may cause short circuit and lead to an evaporation of dangerous fumes or fire.

Next quotation is retrieved from the webpage of Battery Recyclers of America.

> If moisture or oxygen gets into the defective battery it can cause a dangerous reaction. Improper storage and transportation can lead to fires or even escalate to an explosion. Lithium-ion batteries that are damaged can also release toxins into the air so must be isolated immediately for everyone's safety. (Battery Recyclers of America, 2021.)

IMOs IMDG code chapter 3.2 lists dangerous substances and the following is stated concerning lithium-ion batteries.

> Electrical batteries containing lithium ion encased in a rigid metallic body. Lithium ion batteries may also be shipped in, or packed with, equipment. Electrical lithium batteries may cause fire due to an explosive rupture of the body caused by improper construction or reaction with contaminants. (IMO, 2018.)

From this information we can see that the cargo which is placed next to lithium-ion battery cargo, should be properly stowed, and secured. Also, defected lithium batteries can create a dangerous incident, especially in case if the battery is in state of thermal runaway or already in fire. They can also evaporate dangerous fumes so if stowed under deck, lithium battery cargo should be in a space, which can easily be ventilated in an emergency.

3.4 Charging stations

Some ship companies are offering charging of EVs during the voyage. Some are not. Finnish Eckerö Line does not offer possibility to charge electric vehicles now, nor they offer electricity to camping vans and caravans either (Eckerö Line, 2021). Viking Line states in their webpage that now it is not possible to charge hybrid vehicles on their vessels (Viking Line, 2021).

Lauri Mäenpää (Mäenpää, 2019)has researched the recommendations and guidelines set by STA (Swedish Transport Agency) in his thesis work. He has noted many safety measures in his work that must be implemented during Swedish Ropax vessels.

If a shipping company in Sweden is offering services for electric cars, there are many things to taken into consideration. In the next paragraphs examples from STA's report about transporting EVs in Swedish vessels can be found.

Swedish Transport Agency states that charging of EVs is permitted on Swedish Ropax vessels. Shipping company is responsible to ensure the safety of charging station and actual charging process. Shipping company is also responsible for the further safety measures and for example firefighting procedures during sea voyage. (Mohebbi, 2018.)

Transport Styrelsen (STA) recommends that the company will take responsibility for their services for EVs according to IMO resolution MSC.353(92) (Mohebbi, 2018).

Charging equipment. Only charging equipment what is to be used should be manufactured by following applicable standards, also products which provide equivalent safety level can be used. Enclosure rating minimum standard must be of IP 56. Equipment must be protected from damage when stored or in use. Automatic disconnection of power source during circuit failure or error is mandatory. (Mohebbi, 2018.)

Charging stations. Transport Styrelsen recommends the charging to be conducted on weather deck of the ship. Enclosed areas charging services including the vehicle itself

should be arranged according to requirements of SOLAS II-2/20.3.2.2 (IP 55, T3, 450 mm, 10 cycle air exchange and constant ventilation). Open fires or other equivalent sources of ignition is prohibited within the vicinity of the charging station. Flammable material is also prohibited to be in vicinity of the charging station. Recommendation is also that the charging station should be monitored all the time. For the surveillance purposes, video monitoring is one option. (Mohebbi, 2018.)

Firefighting equipment. Remotely or manually by the crew controllable firefighting water cannons are recommended to be installed on weather deck and on the open ro-ro (roll-on/roll-off) decks. Other option is to use foam extinguishers. (Mohebbi, 2018.)

There are also recommendations for onboard instructions and warning signs, just mention few here. Written risk assessment is to be available for all the crew and recommendation is that it will form a basis for the deck operations with the EV cargo. Charging process must be conducted skilled professionals who are familiarized to the process and know the risks and monitoring procedures concerning the charging process. There must be a clear instructions in case for emergencies and firefighting situations with electric cars. The procedure for rescuing people must be also clearly stated in the instructions. (Mohebbi, 2018.)

3.5 Risks

Transporting EVs seaways creates new kinds of risks. More studies are needed so that in the future safety of vessels, crew and cargo can be improved. Risks are related to charging of the EVs during voyage. Also, the potential of battery system creating a very dangerous fire is something to consider. EVs and their batteries are developing all the time so there will be new challenges in the future to tackle with. There are several subjects what can be damaged or people who can be injured. Even a small accident or incident can cause a bigger problem if not handled correctly and in time.

Securius and Kähler have been studying in 2013 if increasing amount of transporting of electric vehicles creates higher risk of fire and if measures increasing safety are needed in those transport operations. Risks created from the cargo which is onboard

can be divided into different categories. Risk for persons onboard, risk for the ship and risk for the cargo itself. In the summary it is found that most of the fires are limited to the power cable and the crew, nor the passengers are suffered from injuries. It was recommended that only ships own power cables are used and only by the crew members. A battery fire will burn in very high temperatures and before ignition the battery will emit toxic gases. To prevent those battery fires from spreading, the surrounding area must be cooled down efficiently. (Securius & Kähler, 2013.)

In their study, it was noted that any fire poses a special risk for the search and rescue teams, and the crew should be informed of the cargo and its placement on the decks. Transporting EVs and charging their battery-pack at time of the voyage creates a greater risk of fire than transporting them without charging them during the voyage. (Securius & Kähler, 2013.)

4 HARBOURS AND ROUTES

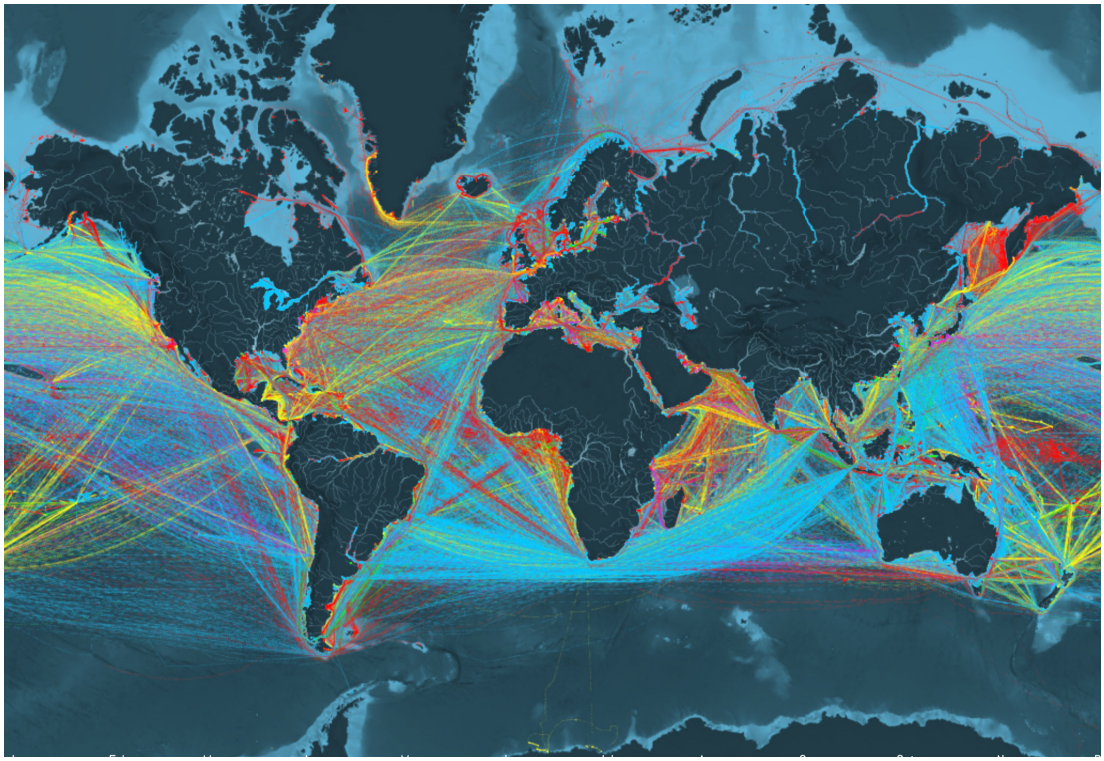
As we know, shipping industry is playing its part all around the world. It is apparent that where there are people there is transportation of passengers, goods, and vehicles. In modern time, shipping routes are reaching all around the world. From the furthest places into the middle of cities through fjords and canals. All kinds of raw materials and commodities are hauled throughout the waterways on open sea, archipelago areas and inland waters. Most of the people, communities and companies are dependent on shipping industry's contribution in worlds economical balance.

Finnish Shipowners' association writes following in their webpage.

> Technology and automation are reshaping seafaring and logistics. Developing data gathering and transmission methods produce better, more comprehensive and more real-time data. This enables the automation of ships and development of autonomy, and therefore promotes the safety and environmental friendliness of seafaring. Digitalization also offers shipowners and other operators in the logistic network tools to develop services and make processes more efficient. (Finnish Shipowners' Association, 2021.)

As the automation and technological development helps shipowners to track and calculate their investments and incomes, there are still uncertainties glooming in the future under the pressure of tightening regulation across different jurisdictions. Shipowners make their investments and transition to cleaner technology without simply clear picture of the future's technological needs and the industry's regulatory changes to come. "A ship ordered in 2025 will still need to be operating in 2050, if the owner is not to face substantial losses," Pyers Tucker, Head of Strategy at Hapag-Lloyd, a German international shipping and container company, told *World Finance"*. (Katsomitros, 2020.)

Here we can see a picture of a map showing ship movements from cross the year 2012 (picture 1). Different colors shown in the maps route lines represent five categories of different vessels and varieties of their cargoes. These include container (yellow), dry bulk (blue), tanker (red), gas bulk (green) and vehicles (purple). The map was created by visualization studio Kiln based on data from the UCL Energy Institute (UCL EI). Website: Duncan Clark & Robin Houston from Kiln. Data: Julia Schaumeier & Tristan Smith from the UCL EI. (Kiln, 2021.)



Picture 1. Movements of the global merchant fleet over the course of 2012 (Kiln, 2021).

4.1 Harbour operations

In the future when the flow of the EVs will increase, the ports will have to facilitate storage areas for EVs flowing through the port and invest in charging infrastructure. This is not a problem with vehicles which are expected to stay at the port terminals just for a short period of time. The vehicle charging cycle is not affected in that situation. EV manufacturers want to keep control of the first complete battery charging cycle. This charging should take place at the dealership after the vehicle has been delivered. EVs will have a minimal charge just enough for the port operations and logistic chain to get the vehicle delivered. The issue concerns the middle term and long-term warehousing of the EVs. Those warehouses act as regulators for the flow of the vehicles through the port. The investments to be done is the charging infrastructure in the vehicle storage areas. "According to the EV sales rates and production, forecasts predict that within ten years it will be necessary to install permanent charging stations to optimise the battery-charging process of vehicles as they go through the terminal". (Martin, 2018.)

4.2 Archipelago and inland waters

Shortest waterways are situated at archipelago areas and inland waters. Vast amounts of cargo are transported every day on these areas in short distances. In the United States the ferry business is growing in the areas where there is a need for transportation of people and goods. All the sustainability requirements and emission control near big cities is pushing ferry operators towards renewable energy solutions onboard. For example, the Washington State Ferries is planning to replace their old ferries with new ones with possibly running with battery power (Parker, 2019).

In Norway the world's largest ferry has been taken into use in the route between Moss and Horten. The 139.2-metre-long and 21-metre-wide Bastø Electric can take 600 passengers and 200 cars or 24 trucks in its accommodation and cargo spaces. Ten-kilometer-long ferry route which Bastø Electric will travel, is Norway's busiest says shipping company Bastø Fosen. It is a route for 3.8 million passengers and 1.8 million

vehicles annually. Across the year 2022 shipping company says the emissions are going to be reduced 75%. (Randall, 2021.)

Whether ferry is powered with electricity or traditional engines, it will be transporting EVs among other cargo and passengers.

Irish Ferries is offering EV charging services for customers with a reservation for the charging space. Charging points are POD Point Type II chargers. A link for the user manual of the chargers can be found from their webpage to ease the use of the chargers. With this way customers are more prepared for charging procedure in the vessel. (Irish Ferries, 2021.)

In Norway there is encouragement for citizens to purchase EVs. The Norwegian EV association represents electric car owners in Norway. They collaborate with the Norwegian government, the electric car industry, and other organizations. They promote Norway being the best place to own electric vehicle. (Norsk elbilforening, 2021a.) Norway's both state and county owned ferries give a rebate of 50 per cent for electric vehicle drivers. In Norway the ferries can many times be the only way to travel from one place to another due to mountains and fjords. Especially northern and western Norway are home for numerous ferries. (Norsk elbilforening, 2021b.)

4.3 Open sea

Car carriers are delivering cars all over the world. The waterways are located near land areas usually, but when transporting cargo from one continent to another, are large vessels in use. The most efficient way of transporting products between continents is to use large capacity vessels because the voyages are long. Basically the bigger the ship is, the more cost-efficient it is.

5 VESSEL CHARACTERISTICS IN SAFETY ASPECT

Certain basic principles are present whether the vessel is a car carrier, ro-pax or ro-ro vessel. There are many basic measures which should be in order to maintain a good level of safety in a vessel. These include for example arranging realistic drills and training, making sure that orientation is done properly for new workers, enable feedback channels to work correctly, inspecting firefighting equipment periodically and monitoring and ensuring cargo securing.

"DNV GL's "Fires on Ro-Ro decks" has examined fires within Ro-Ro spaces on Ro-Pax vessels, vehicle carriers and general Ro-Ro cargo vessels and has identified 35 such fires between 2005 and 2016" (Späth, 2016).

Anders Tosseviken, Principal Approval Engineer Fire Safety & Life-Saving at DNV GL – Maritime says that "In all cases, the fires were caused by the cargo (cars, trucks etc.) or the power connection between the reefer unit and vessel" (Späth, 2016).

Anders Tosseviken recommends that the Ro-Ro space operations should be carefully monitored, and thoughtful decisions made about what kind of cargo and operations are allowed in the ship's cargo spaces. Owners and operators should have clear policies concerning these matters. Tosseviken also says that, if possible, reefer units should be placed on weather decks or other dedicated areas and should be monitored with CCTV. During voyages the access to cargo spaces should be restricted. (Späth, 2016.)

5.1 Passenger vessels

In November-December 2006 at its 82nd session The Maritime Safety Committee (MSC) made a set of amendments to SOLAS. The amendments were made due to vast investigations and review which was started in the year 2000. This review was aiming to determine if the standard regulations were enough for those big passenger vessels being built at the time. Here in the next quotation from IMO's webpage, we can see a short explanation of what the amendments include. (IMO, 2021b.)

- alternative designs and arrangements;
- safe areas and the essential systems to be maintained while a ship proceeds to port after a casualty, which will require redundancy of propulsion and other essential systems;
- on-board safety centres, from where safety systems can be controlled, operated and monitored;
- fixed fire detection and alarm systems, including requirements for fire detectors and manually operated call points to be capable of being remotely and individually identified;
- fire prevention, including amendments aimed at enhancing the fire safety of atriums, the means of escape in case of fire and ventilation systems; and
- time for orderly evacuation and abandonment, including requirements for the essential systems that must remain operational in case any one main vertical zone is unserviceable due to fire. (IMO, 2021b.)

International Safety Management (ISM) Code for passenger ships which came into force 1998 created an international standard for the safe management and operation of ships and for pollution prevention, was an important step towards taking into consideration the "human element" side of the shipping industry. (IMO, 2021b.)

If a fire breaks loose on a passenger vessel, it is important that the crew can get the fire under control as fast as possible. The worst-case scenario is that the vessel must be evacuated. That is not good for anybody. There are numerous things which consist of the safety of passenger vessel. The smallest details should also be considered because in many accident cases, small mistakes lead to a bigger one and so on. As result, there can a major problems or incident which can compromise the safety of crew and passengers. In case of lithium battery fire, the toxic fumes create a major safety issue if spread into the passenger areas. In this case the ventilation is the main solution to get the fumes out.

5.2 Ro-Ro ferries

The big review of the safety of the passenger ships initiated by the IMO in 2000 launched a series of amendments to rules and regulations which will equally concern passenger ro-ro ferries besides the cruise ships.

Some ferries are not in need to comply with SOLAS, this is recognized by IMO and IMO is working on the development of standards for "non-convention" vessels. These vessels are operated only inland or in domestic routes, so they don't have comply with international rules and regulations. There is work done also in improving the safety of the ferries on certain developing countries where the ferries are important transport mode for large populations. (IMO, 2021c.)

Ferry transport is very safe way of transport in many parts of the world. Safety in the ferries is created by many comprehensive and practical regulations with those implemented effectively. Important part of the safety system is to collect all the evidence and information of the accidents thoroughly. All the parties of the process, operators and regulators need to get all available information and understanding from the lessons learned. It is the only way to keep up the good work for future accident prevention. (Interferry, 2021.)

A DNV-GL produced report shows that between the years 2005-2015 there has been 18 fires on Ropax vessels Ro-Ro decks. The report has many recommendations, the next one being one of those.

> Un-authorized charging of electric cars should be banned. Electric sockets should be marked and secured, and fire patrol on RoPax should be instructed to remove charging connections if found. This does not mean that a carefully designed charging arrangement could not be approved for a future design. (DNV-GL, 2016.)

5.3 Car carriers

Here, we talk about PCC (Pure Car Carrier) and PCTC (Pure Car, Truck Carrier) vessels. PCC vessel is for transporting new and secondhand consumer cars for their future owners. With PCTC vessel many kinds of cargo can be transported, for example consumer cars, trucks, construction equipment and other heavy cargo what can be driven to the vessel. Different decks of the vessel accommodate different cargo. (Wärtsilä, 2021.b)

According to the DNV GL report there were nine fires reported on pure car carriers (PCC) and pure car and truck carriers (PCTC) (DNV-GL, 2016).

Car carriers can be tightly packed. If there is a fire, it can be that it is impossible to get to the fire and extinguish it. Only method here is automated fixed fire extinguishing system. Still, it can be that the fire spreads and there is no way out from the situation but only to leave the vessel.

At Port of Jacksonville in Florida there was fire in Höegh Xiamen on June 4th, 2020. The fire didn't injure any of the crew, but eight firefighters got injuries in an explosion. The fire which started from the seventh deck, spread throughout the ships structure, and caused the fire to impossible to extinguish from the inside of the ship. A drone with thermal camera was used to find the hottest spots on the ships outer hull. Water was sprayed on those spots to prevent the ship from sinking in the port. (Holderith, 2020.)

If this kind of fire spreads in the middle of a voyage, it represents immediate danger to the crew of the ship.

6 SAFETY

Safety at sea in merchant shipping consist of a vast variety of different things and is affecting to everybody onboard and in land operations. Everything is linked together

and there are no shortcuts to take if the level of safety is wanted to maintain in a satisfying and acceptable level.

6.1 Crew and passenger safety

Saving human lives at sea is the most important priority onboard ships. The next quotation is from IMO's webpage about the SOLAS (International Convention for the Safety of Life at Sea) convention.

> The main objective of the SOLAS Convention (International Convention for the Safety of Life at Sea (SOLAS), 1974) is to specify minimum standards for the construction, equipment and operation of ships, compatible with their safety. Flag States are responsible for ensuring that ships under their flag comply with its requirements, and a number of certificates are prescribed in the Convention as proof that this has been done. (IMO, 2021a)

It can be mentioned that SOLAS Convention is to be considered one of the most important international treaties concerning the safety of merchant ships. Not only the Convention addresses the safety of human lives at sea, as the name suggests, it also relates to other safety objectives in the maritime industry. SOLAS also includes a variety of amendments by MSC.

Safety of the crew is crucial for the ship to operate in an efficient way and succeed in the delivery of the cargo. In the passenger vessel and ferry business there are more strict regulations, and more safety related things to take into consideration due to the large number of people travelling onboard. There are variety of matters that can go wrong and cause a safety hazard for the crew and passenger.

6.2 Fire safety

Ships fire is dangerous because there is nowhere to escape. Mostly the best possible way to handle a fire is to get it under control as fast as possible. And the best result

from this is that the fire is put off completely. There are three traditional ways to think fire protection, structural fire protection, fire detection and fire extinguishing. The most important is to protect human lives, but it is also important to protect the cargo, the environment, and the ship itself. In the dissertation of WMU (World Maritime University) Zhang has found, that between years 1987 and 1998 there were many total losses due to fires and explosions, compared to all total losses. Total loss meaning that the ship itself and the cargo, or part of the cargo is lost. Other reason for big number of total losses was weather. (Zhang, 2000.)

From these results we can see that fire protection and readiness for firefighting onboard ships is very important. It should be under constant development throughout all the operators on maritime industry. Even the results are from past years, it is that there is a lot of old vessels sailing all around the world still these days. Fire safety begins from ship designer's table. It is in the way of thinking among the crew. It is affecting all around and all the time. In these days and in the future when more EVs are transported onboard ships, the fire safety is staying naturally one of the most important things to consider and examine.

Besides the firefighting readiness onboard a ship, the ship fires as for EV point of view, will be tackled also by developing EV batteries chemistry and quality control. At the Nanyang Technological University Singapore (NTU Singapore) researchers have studied battery chemistry and propose that inside the EV batteries would be inserted so called "anti-short layer". This layer prevents short circuits in EV batteries what cause the fires. Researchers explained that the short circuits are caused by the formation of dendrites, which emerge because of damages to the batteries or if the batteries are not manufactured properly for some reason. The anti-short layer was placed on the separator and this way it prevented the dendrites to reach cathode. The researchers did not try to stop the dendrites from forming, but instead they used the properties of dendrites and created additional layer of conductive material for the dendrites to connect with. This way the growth of the dendrites was stopped. Anti-short layer exchanges lithium-ions with the positive electrode on behalf of the negative electrode. According to the researchers no short-circuits was emerged during the tests and not even with old batteries. The researcher group mentioned that this technique can be easily integrated into the separator manufacturing processes. (Bellini, 2021.)

In car carriers ro-ro and ro-pax vessels there is always possibility for a fire to emerge and spread from the cargo. Continuing development of the battery technology is surely making the situation better in the future, but also ship companies need to improve their systems and standards. Rules and regulations are taking new shapes also and new amendments are added to those.

EMSA (European Maritime Safety Agency) has studied new means for early detection and for quick decision-making of extinguishing system activation in their project "Second study investigating cost-efficient measures for reducing the risk from fires on ro-ro passenger ships (FIRESAFE II)" (Leroux et al., 2018). The study was aimed at open ro-ro spaces, closed ro-ro spaces, weather decks, for both newbuildings and existing ships.

When a fire in a ship occurs, it is essential that the crew has all the possible means to fight the fire and as early as possible. Effective firefighting consists early detection of the fire and quick activation of the fire extinguish system. This is how the damages to the cargo and for the ship are kept in minimum. In a worst-case scenario, there can be injuries for crew or even a loss of life. If the fire emerges in a place where there is no automated firefighting system, then the crew response is important. (Leroux et al., 2018.)

From the report FIRESAFE II here in the quotation is listed mentionable results from the fire detection side.

- The detection system is often deactivated during loading and discharging as well as during maintenance operations. This often implies deactivation of many or all ro-ro spaces;
- It is difficult to detect the fire at its early stage of development if the fire develops inside cargo or a vehicle;
- The environment in ro-ro spaces is quite harsh, and it is not uncommon that dirt, salt, exhaust fumes etc. clog the detectors;

- The detection system alarm panel can be illogical (confusion regarding the detection frame number, detection section, drencher section, Closed-Circuit Television (CCTV) numbering, etc.) which could imply delayed first response and delayed extinguishing system activation;
- No detection system is required for weather deck;
- The frequency of fire patrols is undefined and generally quite low;
- The accessibility within ro-ro spaces is very limited, which makes manual detection and fire
localisation difficult; and
- Many false alarms reduce the motivation of crew to quickly attend to alarms. (Leroux et al., 2018.)

For decision of extinguishing system activation, FIRESAFE II report shows next mentionable results in the next quotation.

- Alarm system management (e.g. information presentation, coherence, noise levels);
- Runner deployment (e.g. speed of deployment);
- Way finding, localisation and relevant support (e.g. familiarity, markings, signage);
- Assembly of key decision-makers (e.g. availability);
- Resource management on the bridge (e.g. competing goals/processes, fire management in relation to regular operations);
- Drencher activation mandate (including hierarchy, blame culture);
- Assessment of fire characteristics, environment and fire spread;
- Ventilation management (smoke removal vs. supply of more oxygen to the fire);
- Maintenance of knowledge and competence (e.g. realism in training); and
- Communication issues (between bridge, fire scene, drencher station, engine room). (Leroux et al., 2018.)

Electrical fires resulted from batteries and connections between the cargo and the ship are very difficult to put off. Those are needing more versatile firefighting techniques

than conventional fires. Companies and industry are putting more and more effort to improve fire safety on ships. (Bush, 2020.)

In his article Declan Bush writes about an interview with shipping company Wallenius Wilhelmsen chief executive Craig Jasienski.

> Mr Jasienski said the company was working with different start-ups on early heat-detection systems, put in "much more stringent" controls on secondhand cargo and on loading and inspection requirements. "I think we're doing a lot and the industry is doing a lot," he said. (Bush, 2020.)

According to Wallenius Wilhelmsen webpages the company carries out standard fire-fighting procedures with EV's, just the same what are used with fires with ICE cars (Hargreaves, 2019).

6.3 Safety solutions in use

A ship safety is a variety of things from ship design to equipment and tools, mentality of the crew to safety management system of the company. There are many layers which form the wholeness of safety, and it all starts from the basics. In this topic we only deal with solutions which are implemented physically onboard the ship.

Basic safety starts with certain preventive measures and appliances. Fire retardant bulkheads, fire doors, fire dampers, fire pumps, fire main piping and valves, fire hose and nozzles, fire hydrants, portable fire extinguishers, fixed fire extinguishing system, inert gas system (tankers), fire detectors and alarms, remote shut and stop system, EEBD (Emergency Escape Breathing Device), fire fighter's outfit, ISC (International Shore Connection), means of escape. (Kaushik, 2021.)

Early fire detection is the key to ensure that the damages from the fire stay in minimum. This also means that crew of the ship must have a good preparedness to carry out the fire fighting and extinguishing.

New technologies are adopted to fight ship fires. MSC Gűlsűn class of ultra large container ships received enhanced fire safety notation from classification society DNV GL with new means to fight fires with built-in design. These include large capacity fire hoses on towers which can spray water around 100 meters and turn so that they cover the whole ship. The vessel is also equipped with a system which floods the holds individually. Thermal imaging cameras are also used to detect fires in early stage. (Savvides, 2020.)

Thermal imaging would work most likely on ro-ro decks of ships. Thermal imaging cameras situated inside the ship to cover all or some of the decks could detect a heat source and give an audible or other kind of signal and warning which would alert the crew to investigate the incident more closely.

Kongsberg Maritime offers K-safe system which has manual or automatic fire and gas detection system. This system can for example alert personnel, release fire fighting systems, control emergency ventilation, isolate electrical equipment, and close water-tight and fire doors. (Kongsberg Maritime, 2021.)

As technological progress continues, automation can solve safety related issues in the future. Automation is already managing many processes efficiently. Most likely it will continue to be increasingly important part of ship safety systems in the years to come.

7 INSURANCES AND LIABILITIES

Insurances can be divided in two categories, shipowner insurances and cargo insurances. Cargo insurance can mean different types of transportation, for example ship, rail, or airplane. In many cases cargo insurance is commissioned by a seller or a purchaser of the goods. It can also be taken into use where there is no actual sale. Example of this kind of situation could be following. Owner of the goods transports the goods within the company itself from one storage facility to another. The cargo insurance is the most important insurance for the owner of the goods if the goods become a total loss, are damaged, or shortage occurs. (Falkanger et al., 2004.)

Wallenius Wilhelmsen does not require insurance adjustments for EV shipments (Hargreaves, 2019).

8 CONCLUSIONS

Technological solutions in the field of EV's is just started to take leaps forward for becoming majority/one of the majority transport means for consumers everyday life. This means that a lot of adaptation is needed in the years to come, inside the ships and at the port facilities (charging infrastructure) and in the safety solutions.

Automation will be increasingly important in ship safety systems integration.

Increasing number of EV transports means that there is a need for proper and unified rules and regulations when EVs are allowed to be charged at the time of ferry crossing.

The growing EV market and future's emission control will be pushing Maritime cluster operators who deal with EV transports, to make investments for safer and more efficient operations. These investments are partly made without a clear knowledge of the future's technological needs and regulatory framework.
Despite there are political obstacles, the proactive approach what IMO has in its working principle is certainly today's way of doing thing because of the fast pace of technological development. This same proactiveness is also suitable for shipping companies and other operators in the maritime business, but no collective or corporation can do the work by themselves. For this reason, co-operation between different parties is needed for the future development and profitable business operations of the industry.

9 REFLECTION

As the work progressed, I started to see that there are a lot of improvements being made in the shipping industry towards more safer and sustainable transportations. In this situation it would be beneficial that the more co-operation and information exchange are done the more it benefits everyone in the industry. Industry is facing big changes in the future years coming to transform towards more safer, sustainable and climate friendly operations. These changes should be made possible for those countries and operators also with a smaller amount of assets and capabilities. As the EV transports increase yet more, eventually the timeline will show what kind of directives, instructions and rules will be implemented.

10 THE LIST OF REFERENCES

Alternative Fuels Data Center, U.S. Department of Energy. (2021). How Do All-Electric Cars Work? A webpage of Alternative Fuels Data Center. Accessed 11.12.2021. https://afdc.energy.gov/vehicles/how-do-all-electric-cars-work

Battery Recyclers of America. (2021). Damaged Lithium-Ion Battery Disposal: An (easy) how-to guide. Accessed 5.10.2021. https://www.batteryrecyclersofamerica.com/blog/damaged-lithium-ion-battery-disposal/

Bellini, E. (2021). Novel technique to prevent fires in lithium-ion batteries. PV-Magazine. Accessed 2.11.2021. https://www.pv-magazine.com/2021/09/22/novel-technique-to-prevent-fires-in-lithium-ion-batteries/

Bush D. (2020). Höegh Xiamen highlights PCTC fire risks. *Lloyd's List*. https://lloydslist.maritimeintelligence.informa.com/LL1132742/Hegh--Xiamen-highlights-PCTC-fire-risks

DNV-GL. (2016). Fires on Ro-Ro decks. A report. Accessed 9.10.2012. file:///Users/michaelromana/Downloads/RoRo-fire-on-deck_2016-04_web.pdf

Eckerö Line. (2021). Travelling with car. A webpage of Eckerö Line. Accessed 28.7.2021. https://www.eckeroline.fi/auto-mukana-matkalla

EMSA European Maritime Safety Agency. (2018). Leroux J, Mindykowski P, Bram S, Gustin L, Willstrand O, Evegren F, Aubert A, Cassez A, Degerman H, Frösing M, Li Ying Z, Lottkärr J, Ukaj K, & Vicard B. *FIRESAFE II Detection and Decision Final Report*. PDF-document. http://www.emsa.europa.eu/firesafe.html

Falkanger, T., Bull, H J. & Brautaset, L. (2004). Scandinavian maritime law The Norwegian perspective 2nd ed. Universitetsforlaget AS.

Finnish Shipowners' Association. (2021). Digitalization and automation. A webpage of Finnish Shipowners' Association. Accessed 6.10.2021. https://shipowners.fi/en/digitalization-and-automation/

Hargreaves, B. (2019). Electric vehicles 101: Frequently asked questions. A webpage of Wallenius Wilhelmsen. Accessed 21.10.2021. https://www.walleniuswilhelmsen.com/insights/electric-vehicles-101-frequently-asked-questions

Holderith, P. (2020). Thousands of Used Cars Are 'Melting' in Ongoing Cargo Ship Fire in Florida. A webpage of The Drive. Accessed 19.10.2021. https://www.thedrive.com/news/34041/thousands-of-used-cars-are-melting-in-ongoing-cargo-ship-fire-in-florida

IMO. (1991). Code of Safe Practice for Cargo Stowage and Securing (CSS Code). London. IMO.

IMO. (2018). International Maritime Dangerous Goods (IMDG) Code. London. IMO.

IMO. (2021a). International Convention for the Safety of Life at Sea (SOLAS), 1974. A webpage of IMO. Accessed 7.10.2021. https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx

IMO. (2021b). Passenger ships. A webpage of IMO. Accessed 7.10.2021. https://www.imo.org/es/OurWork/Safety/Paginas/PassengerShips.aspx

IMO. (2021c). Safety of ro-ro ferries. A webpage of IMO. Accessed 7.10.2021. https://www.imo.org/en/OurWork/Safety/Pages/RO-ROFerries.aspx

Interferry. (2021). Ferry Industry Facts. A webpage of Interferry. Accessed 7.10.2021. https://interferry.com/ferry-industry-facts/

International Energy Agency. (2021). Global EV Outlook 2020 Entering the decade of electric drive? PDF-document. https://iea.blob.core.windows.net/assets/af46e012-18c2-44d6-becd-bad21fa844fd/Global_EV_Outlook_2020.pdf

Irish Ferries. (2021). A webpage of Irish Ferries. Accessed 1.10.2021. https://www.irishferries.com/uk-en/frequently-asked-questions/general-information/electric-cars/

Katsomitros, A. (2020). The shipping industry must adapt if it is to survive in the modern world. A webpage of World Finance. Accessed 10.11.2021. https://www.worldfinance.com/markets/the-shipping-industry-must-adapt-if-it-to-survive-in-the-modern-world

Kaushik, M. (2021). 16 Fire Fighting Appliances and Preventive Measures Onboard Ships. A webpage of Marine Insight. Accessed 1.11.2021. https://www.marineinsight.com/marine-safety/16-fire-fighting-appliances-and-preventive-measures-present-onboard-ship/

Kiln. (2021). A picture of an interactive map. A webpage of ShipMap. Accessed 29.9.2021. https://www.shipmap.org/

Kongsberg Maritime. (2021). Fire And Gas Detection System. A webpage of Kongsberg Maritime. Accessed 1.11.2021. https://www.kongsberg.com/maritime/products/engines-engine-room-and-automation-systems/automation-safety-and-control/safety-systems-k-safe/fire-and-gas-detection-system/

Martin, C. (2018). How Can Port Terminals Be Adapted To Electric Vehicles? A webpage (PierNext) of Port of Barcelona. Accessed 7.10.2021. https://piernext.portdebarcelona.cat/en/environment/how-can-port-terminals-be-adapted-to-electric-vehicles/

Mohebbi, S. (2018). Charging electric vehicles on board Swedish Ropax vessels. PDF-document. https://transportstyrelsen.se/globalassets/global/publikationer/sjofart/charging-of-electric-vehicles-onboard-swedish-ropax-vessels-20180711.pdf

Mäenpää, L. (2019). Sähkö-, Hybridi- Ja Kaasukäyttöisten Henkilöautojen Paloturvallisuus Matkustaja-Autolautalla [Bachelor's thesis, Satakunta University of Applied Sciences]. http://www.urn.fi/URN:NBN:fi:amk-2019110920874

Norsk elbilforening. (2021). (a). The Norwegian Electric Vehicle Association. A webpage of The Norwegian Electric Vehicle Association. Accessed 1.10.2021. https://elbil.no/english/about-norwegian-ev-association/

Norsk elbilforening. (2018). (b). The ultimate EV tourist guide to Norway. A webpage of The Norwegian Electric Vehicle Association. Accessed 1.10.2021. https://elbil.no/the-ultimate-ev-tourist-guide-to-norway/

Parker, B. (2019). *Inside the World's Top Ferry Lines*. Website of Marine Link. Accessed 26.7.2021. https://www.marinelink.com/news/inside-worlds-top-ferry-lines-462991

Paoli, L. (2021). International Energy Agency - How global electric car sales defied Covid-19 in 2020. IEA. Paris. https://www.iea.org/commentaries/how-global-electric-car-sales-defied-covid-19-in-2020

Randall, C. (2021). World's largest electric ferry launches in Norway. A webpage of news service Electrive. https://www.electrive.com/2021/03/02/worlds-largest-electric-ferry-yet-goes-into-service-in-norway/

RMC, Rauma Marine Constructions. (2019). Cooperation between Rauma Marine Constructions and Meyer Turku extends further – the new Tallink Shuttle will be planned with support from Turku shipyard. A webpage of RMC. Accessed 11.12.2021. https://rmcfinland.fi/cooperation-between-rauma-marine-constructions-and-meyer-turku-extends-further-the-new-tallink-shuttle-will-be-planned-with-support-from-turku-shipyard/

RMC, Rauma Marine Constructions. (2021). News. A webpage of RMC. Accessed 11.21.2021. https://rmcfinland.fi/

Rowlatt, J. (2021). Why electric cars will take over sooner than you think. A webpage of BBC business news. https://www.bbc.com/news/business-57253947

Savvides, N. (2020). DNV GL and MSC promote better fire safety by design. A webpage of Container News. Accessed 1.11.2021. https://container-news.com/dnv-gl-and-msc-promote-better-fire-safety-by-design/

Securius, P., Kähler, N. (2013). Study. Study on fire safety in connection with the transport of vehicles with electric generators or electrically powered vehicles on ro-ro and ro-pax ships. https://www.bmvi.de/SharedDocs/DE/Anlage/WS/brandschutz-roro-schiffen-englisch.pdf?__blob=publicationFile

Späth, N. (2016). Enhancing fire safety on Ro-Ro decks. A webpage of DNV (Det Norske Veritas). Accessed 9.10.2021. https://www.dnv.com/news/enhancing-fire-safety-on-ro-ro-decks-69059

Verdict Media Limited. (2021). Hyundai Glovis establishes EV-optimised shipping solution. Ship Technology, Accessed 26.7.2021. https://www.ship-technology.com/news/hyundai-glovis-ev-optimised-solution/

Viking Line. (2021). Driver and vehicles. A webpage of Viking Line. Accessed 28.7.2021. https://www.vikingline.fi/valitse-matka/hyva-tietaa/autoilijat-ja-ajoneuvot/

Warner, JT. (2015). The Handbook of Lithium-Ion Battery Pack Design: Chemistry, Components, Types and Terminology. Amsterdam: Elsevier Science & Technology.

Winton, N. (2021 b). China, U.S. Lead Global Auto Sales Recovery; Lagging Europe Steers Electric Charge Forbes. 2021. https://www.forbes.com/sites/neilwinton/2021/05/11/china-us-lead-global-auto-sales-recovery-lagging-europe-steers-electric-charge/?sh=1b8d707b7aab

Winton, N. (2021 a). Electric Cars Are Coming and If You Don't Like It, Tough. Forbes. 2021. https://www.forbes.com/sites/neilwinton/2021/03/09/electric-cars-are-coming-and-if-you-dont-like-it-tough/?sh=1aa57434698f

Wärtsilä. (2021a). A Floating Test Lab. A webpage of Wärtsilä – Smart Technology Hub. Accessed 11.12.2021. https://www.smarttechnologyhub.com/floatinglab/

Wärtsilä. (2021a). Pure car, truck carrier (PCTC). A webpage of Wärtsilä – Encyclopedia of Marine and Energy Technology. Accessed 9.10.2021. https://www.wartsila.com/encyclopedia/term/pure-car-truck-carrier-(pctc)

Zhang, S. (2000). Fire Protection Onboard: Enhance Fire Safety By Design. World Maritime University Dissertations. 56. http://commons.wmu.se/all_dissertations/56