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Learning from failures in cruise ship industry: The blackout of Viking Sky in Hustadvika, Norway

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ABSTRACT

This article brings to attention learning from the failure - blackout, loss of propulsion and near grounding - of Viking Sky cruise ship which occurred in Hustadvika, Norway, in March 2019. Failures and accidents in the cruise ship industry attract the global media and can severely impact reputation and business performance of companies and authorities involved. A system approach investigation and analysis - CAST - was employed with the aim to maximize learning from the Viking Sky's failure through a systematic approach and to contribute to failure reduction in the cruise ship industry. Three main recommendations emerged from this study: an overview of the accident or failure precursors and resilience indicators; safety recommendations for other cruise ships; lessons and strategies of actions for the increased cruise operations in the Arctic and Antarctic areas. It was found that several accident or failure precursors, for example, a low level of lubricating oil, the failure of a turbocharger, an inoperative large diesel generator, lack of functionality for safety equipment due to bad weather, and others precursors contributed to failure and highly critical situation encountered by Viking Sky in Hustadvika. Resilience indicators such as the master's immediate decision to launch mayday, the crew preparedness, and the way how the emergency situation was handled were found to have positive impacts on critical situation of Viking Sky. This article highlights also that adaptations and improvement of standards and regulations for harsh environmental conditions can play an important role in prevention of marine accidents. Furthermore, for a better understanding of correlation between environmental loads and their effects on machinery systems, digital solutions such as digital twin for condition monitoring of cruise ships in the Polar areas are seen as possible innovative solutions yet to be fully implemented in the marine industry.

1. Introduction

The cruise industry can generate important revenues, and for instance, in 2018, the worldwide revenues from the cruise industry reached to the amount of 47 billion US dollars [1]. The cruise industry is among the most regulated industries with many comprehensive standards regarding safety at sea, security, health and protection of crew members, and environmental safeguarding. Furthermore, cruise ships are between the most scrutinized ships at sea which are subject to many announced/unannounced inspections following strict implementation of safety standards and enforcement of international laws and specific requirements [2].

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Nevertheless, since ships are increasingly being operated by investors and banks rather than maritime professionals, a decrease in maritime safety can also occur [3].

Despite efforts for prioritizing the safety and many commitments about ''Never compromise on safety'', safety is compromised in the maritime industry on daily basis and in many parts of the world [4]. The disaster in 2012 of the Costa Concordia, a ship larger than Titanic, is a dramatic example about the major challenges which are faced by the maritime safety in this present century [5]. A blackout situation was encountered by many cruise ship around the world, and few examples are given from the recent years: in 2013 - the Carnival Trimph cruise ship, in 2017 - the Vasco da Gama cruise ship, in 2018 - the Vision of the Sea cruise ship, and in 2019 - the Coral Princess cruise ship [2,5].

According to the Maritime Injury Guide (MIG), a comprehensive and consistent database which to document accidents/incidents of cruise ships is yet to be implemented. Over many years, there have been very few consistent and systematic data gatherings in order to explore and review cruise ship safety and accidents. A problem in obtaining accurate statistics is linked to the fact that many cruise lines are outsourced and the most of ships are incorporated and registered overseas. Moreover, the cruise industry tries to avoid too much publicity around accidents/incidents as it impacts reputation and success in business. The most common safety concerns for cruise ships were identified to be linked with the followings: loss of power and adrift at sea, fire, collision, sinking, running aground or ship grounding, plumbing issues, spread of viruses on ship, improper sanitation, and crimes. More than 448 major cruise ship accidents have been reported since 2015 [6,7].

The failure of machinery was found to be the top cause for the accidents within the maritime industry in the last decade [8]. The risk of failure for the propulsion system was seen as high. Moreover, this risk can be amplified by stormy weather conditions which can impact dynamics of load variation, fatigue behaviour and life time of propulsion shaft [9]. Vizentin et al. [10] analyzed the most common failures of the ship propulsion system and found that the failure for shaft of marine propulsion system is the most common point of fatigue failures within the entire propulsion system. Failures linked to the marine machinery systems and components are defined as sudden events or gradual deterioration that lead to loss of functions as per the DNV GL rules for classification [11]. The study of Nejad et al. [11] discussed the state of the art and development trend for condition monitoring and maintenance for marine propulsion system. As the machinery failure is on top of the accidents in the shipping industry, the condition monitoring has been seen as important in order to improve system reliability and to reduce unexpected shutdowns.

Learning from failures, accidents and disasters can be considered as a valuable and important input to the risk assessment process. Moreover, a dynamic and interdisciplinary learning can contribute to prevention of accidents in the future and can support transfer of lessons to other industries [12–15], 16.

The present study focuses on learning from the failure of the Viking Sky cruise ship. On 23 March 2019, the Viking Sky experienced a blackout and loss of propulsion in the Hustadvika area, Norway, and the ship started to dangerously drift towards shore. Despite a great media attention given to the blackout and loss of propulsion of the Viking Sky, very few research studies have been dedicated to this near disaster.

A study of Dahl [7] focused on the rescue aspects of the Viking Sky cruise ship and drew attention to the dramatic challenges which could have been occurred if the Viking Sky had to encounter a grounding. The urgency to review and update the emergency plans for cruise ships and for coastal emergency services was emphasized [7]. Solberg et al. [4] mentioned about the availability and functionality of the Search and Rescue (SAR) resources which were deployed for the Viking Sky in 2019, in Hustavika. A study by Rufibach [17] discussed the legal aspects which emerged after the near disaster of Viking Sky. Updates and changes are required about the legal framework of the International Code for Ships Operating in the Polar Waters. Rufibach [17] emphasized the accident of Viking Sky has brought under hot spot gaps and shortcomings with regards to the legal aspects of the cruise tourism in the Arctic waters.

Towards contributing to a systematic and comprehensive learning from the failure of the Viking Sky cruise ship, an accident analysis research approach - CAST - was applied. The aim is to bring forward recommendations in order to maximize learning from the Viking Sky failure and to reduce the risk of future failures/accidents.

In following sections the CAST research method is first detailed and then is applied for the analysis of the Viking Sky failure.

2. Research method

The research method used in this study is the CAST accident analysis approach which stands for Causal Analysis based on STAMP (Systems Theoretic Accident Model and Processes). According to Leveson [18,19], CAST is an accident analysis method which supports the improvement of learning from accidents.

According to the latest CAST approach by Leveson [18], five major parts are recommended to be followed, see Fig. 1.

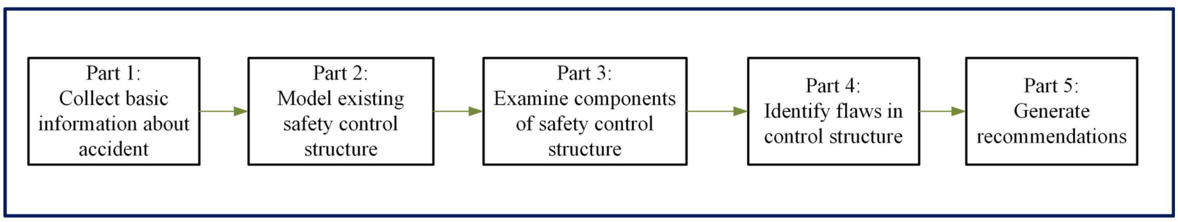

Fig. 1. The five parts of the CAST accident analysis approach, adapted from Leveson [18].

The five components of CAST accident analysis are described by Leveson [18] as follows:

- Part 1. To collect the basic information about accident: to define the involved system and boundary of accident analysis; to identify the hazard and the systems safety constraints required to prevent the hazard; to describe the accident/loss and hazardous state which conducted to it and to try to explain why the events occurred; to analyze the loss at physical level with reference to physical equipment and controls - the design to prevent the hazard, the emergency and safety equipment, failures and unsafe interactions which led to accidents, missing or inadequate physical controls which might have prevent the accident, and to present any other contextual factors which influenced the accident.
- Part 2. To represent the existing safety control structure for this type of hazard/accident. The Safety Management System (SMS) is a more common name for a safety control structure. However, the safety control structure includes components and functions which are not always present in a SMS.
- Part 3. To examine the components of the safety control structure in place; to determine why they were not effective in prevention of accident; to present the role of each component and their mental model and to offer explanations about their actions and reasons.
- Part 4. To identify the flaws in control structure which contributed to accident; flaws related to coordination, communication, safety culture, changes and dynamics over the time, internal and external economical and environmental factors.
- Part 5. To generate recommendations for changes in the safety control structure in order to strengthen it for prevention of accidents in future.

Leveson [18] has highlighted the CAST steps are not necessarily rigid steps or shall follow a straight-line process. Adaptations are possible and recommended to be implemented according to specific accident case studies and type of industries.

Within the following section, the five parts of CAST accident analysis research approach are applied to the failure encountered by the Viking Sky in Hustadvika, Norway.

3. CAST accident analysis applied to failure of Viking Sky

3.1. CAST part 1: to collect the basic information about failure

The Viking Sky ship is the system to be investigated, and its features and technical details are provided in the Table 1 [20,21].

The Viking Sky ship is the third ship in the Viking Star class of cruise ships and was inaugurated on 25 February 2017. Viking Sky was baptized at Prostneset, in Tromsø port, on 22 June 2017. Starting from 2017 until the failure in 2019, the Viking Sky navigated in the Scandinavian waters, in the Baltic Sea, in the Mediterranean sea and in the Caribbean sea [20,22].

On 14 March 2019 Viking Sky started the last of the six Northern Lights or Aurora borealis cruises. The duration of voyage was scheduled for 13 days and the cruise voyage started from Bergen and included the ports of Narvik, Alta, Tromsø, Bodø and Stavanger which are located along the Norwegian coast[20]. In this voyage, the Viking Sky had 1373 people on board - 458 as the crew and 915 as the passengers - the maximum passengers capacity of this ship is 930 people.

The Viking Sky cruise ship is equipped by four MAN engines type 32/44 CR; two of them are MAN model 9L32/44CR (5 MW each) and the other two are MAN model 12V32/44CR (6.7 MW each). These four MAN engines powers the Rolls-Royce Promas propulsion and manoeuvring system. The total installed power of ship provided by the four MAN engines is 23520 kW. The engines were specially designed for use of the heavy fuel oil (HFO) in accordance with the DIN ISO 8217 specifications. Viking Sky had on board around 343 tonnes of HFO and 465 tonnes diesel. The propulsion of ship includes 6-bladed with 4.5 m diameter fixed-pitch mono-block propellers and the Promas system which incorporates both the propeller and rudder into a single unit in order to increase hydrodynamic efficiency. The two Rolls-Royce Promas units are driven by two 7250 kW electric propulsion motors. The Rolls-Royce Hydrodynamic Research Centre in Sweden designed and developed the rudders and propellers, and the model testing of the Promas system was performed by MARIN [20,21,23].

With regards to the electric power generation, Viking Sky has four diesel generators (DG) which were manufactured by the MAN Diesel and Turbo (MAN) company. Technical details about DGs are provided in the Table 2, [20].

The Viking Sky has two separate engine rooms, and each engine room (ER) accommodates one small DG and one large DG. It can be observed in the Table 2 the forward ER contains the DG1 (small) and the DG2 (large), and the aft ER contains the DG4 (small) and the DG3 (large).

Both engines rooms have their own switchboard which are connected by tie breakers in order to create a single switchboard for

Table 1
The Viking Sky cruise ship - features and technical details.

Technical detail/feature	Description	Technical detail/feature	Description
Ship type	Passenger ship - ferry	IMO number	IMO 9650420
Year of building	2017	Construction material	Steel
Gross tonnage	47842	Length overall	228.37 metres
Draft	6.65 metres	Maximum speed	20 knots (37 km/h)
Width	28.8 metres	Emergency generator	1.230 kW
Propeller	2/each 7.250 kW	Thruster	3/each 1.400 kW
Crew cabins	260	Passenger cabins	465

Table 2
Viking Sky's Diesel Generators (DG) s - technical details.

Type DG	Name	Power	Location Engine Room (ER)
Small - 9L32/44CR	DG1	5040 kW	forward ER
Small - 9L32/44CR	DG4	5040 kW	aft ER
Large - 12V32/44CR	DG2	6720 kW	forward ER
Large - 12V32/44CR	DG3	6720 kW	aft ER

power distribution. Normally, the DGs of Viking Sky can be operated in automatic load-sharing mode, but the DGs can be also operated in manual load-sharing mode or a combination of manual and automatic load-sharing mode. In automatic load-sharing mode, the power management system automatically shares electrical load among all the DGs connected to the main switchboard [20].

A primordial safety constraint for a cruise ship like Viking Sky is to ensure the safety of passengers, crew and ship at sea. Nowadays, the cruise ship design and bridge navigation are believed to be at the most ever advanced stages. Viking Sky cruise ship was built according to the safety regulations for passengers ships and ferry - SOLAS (Safety of Life at Sea). The SOLAS treaty applies to all passenger ships which carry on international voyages with more than 12 passengers [24]. the SOLAS provides comprehensive regulations and standards about procedures for ships and safety of equipment. After the Costa Concordia cruise ship disaster in 2012, it became mandatory to implement safety drills for passengers immediately before or after departure from a port [25].

The SOLAS regulations - the Safe Return to Port (SRtP) applied also to the Viking Sky ship [21]. The SRtP became mandatory in July 2010 and applies to the ships with a length more than 120 m and having three or more vertical fire zones. According to the SRtP regulations, certain ship's systems are required to remain operational and to maintain capabilities after an accident within the threshold. The ship shall be able to return to a safe port by its own power and also to provide a safe place for its passengers. After an accident (fire/flooding), the functional requirements shall provide the following capabilities: to ensure propulsion, steering, manoeuvring and navigation, to ensure required service of safety systems such as fire safety and watertight integrity and to support safe areas for passengers and crew. The systems which are required to remain operational after an accident within a threshold belong to four categories: systems which shall provide propulsion, navigation and steering; systems to ensure watertight integrity and fire safety; systems which support safe areas, and systems which shall remain in operation for a period of three hours in case the ship is abandoned. The ship is required to be its own best lifeboat [21,26].

The failure of the Viking Sky ship occurred in the Norwegian territorial waters, in Hustadvika area, in Fraena municipality, Møre og Romsdal county, Norway, as shown in the Fig. 2. On the afternoon of Saturday, on 23 March 2019, when the Viking Sky was passing through the Hustadvika area in a very challenging weather conditions - gale to storm force conditions - a blackout and a failure of propulsion system occurred [20].

Hustadvika area is situated on the shipping route between Kristiansund and Molde - Bud. From long time ago, the Hustadvika received the fame of a notoriously dangerous place along the Norwegian west coastline during the stormy weather, and is known as a cemetery of countless ships. As per local stories, there are so many shipwrecks near each others in the Hustadvika area. If one day those shipwrecks will be brought to the surface, someone can easily pass from one shipwreck to another without making wet his shoes! [28]. According to the Admiralty Sailing directions and to the Norwegian Pilot book number 4, Hustadvika area, particularly area 11, is a very dangerous maritime area which has extensive shoals offshore and is exposed to strong winds from the south-west and north-west.

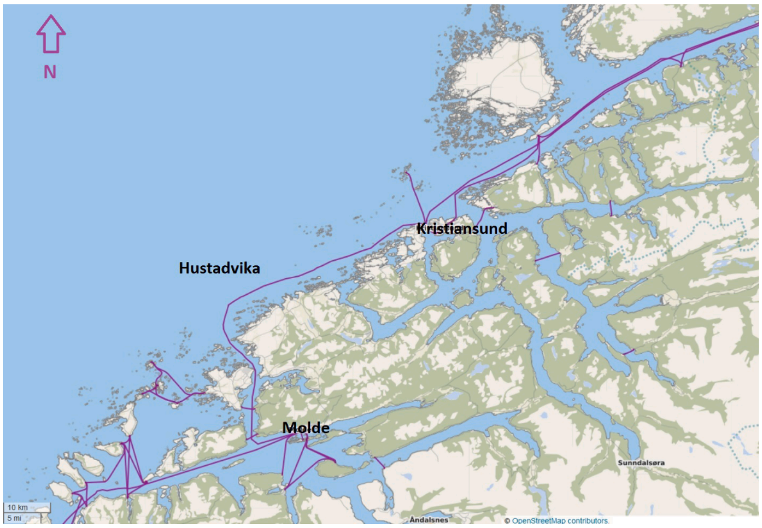

Fig. 2. Location of Hustavika area, on the route between the cities of Kristiansund and Molde, western coast of Norway, map adapted from OpenStreetMap [27].

Strong winds and high waves can become very severe in the Hustavika, particularly in the area of Budadjupet between Bjørnsund and Kolbeinsflua, 5 miles north–northeast [20].

At the day of accident, when the Viking Sky ship passed through Hustadvika area, the main fairway was followed. The wind and sea conditions at Hustadvika were in accordance with forecasted weather conditions: a strong gale to storm wind - Beaufort 9–10 or 22–25 m/s - from the southwest, and total significant waves height over deep water of 9–10 meters from west (with a mean wave period of 12–13 s) [20].

One important matter which brought up many polemics was the reason why the Viking Sky ship was sailing through Hustadvika despite a bad weather forecast. It emerged that no higher organizations/maritime agencies can command to the international cruise lines and cruise ships which time of the year or which area they can sail; the itineraries of cruise ships are taken care by the cruise line management [29].

According to the Norwegian Coastal Administration (NCA), the type of weather in Hustadvika is common to be encountered in this area over the spring time. In case of special circumstances, NCA is sending out warnings, but as per the NCA's narrative "That does not mean that we close the waters like Hustadvika". The belief of NCA was the vessels such as the Viking Sky were built to successfully manage difficult weather conditions even in dangerous places like Hustadvika. Furthermore, a decision about sailing in areas with bad weather like Hustavika needs to be combined with other types of information, to be back up by years of rigorous training, and after conducting an overall assessment of the specific situation. NCA brought also forward that "Ultimately it is up to the captain to decide how to handle a challenging situation " [25]. With regards to the reasons of the failure encountered by Viking Sky, NCA stated "This situation did not happen due to [bad] weather [in Hustavika] but due to machine malfunctions, the cause [of which] is now being investigated" [25].

After the failure encountered by the Viking Sky in Hustadvika, the cruise industry body - Cruise Lines International Association (CLIA) - declared "Cruise ships are designed to withstand extreme weather conditions at sea, and, whenever possible, seek to avoid bad weather" [25]. According to a cruise expert from the Telegraph Travel which often spends a lot of time at sea, "Weather reports now are usually very accurate so the captain must have known a storm was on the cards. Assuming there was a possibility of stormy seas, it would have been better to stay in the previous port until the bad weather passed." Moreover, passengers may get very upset if the voyage suffers changes, but in the particular case of Viking Sky, it was understandable not to sail in the stormy weather, as "One of the selling points of a cruise holiday is that ships can avoid bad weather by changing course" [25].

In addition, on the same day, 23rd March, another ship - the Hagland Captain, a general cargo ship - encountered a failure in the stormy Hustadvika area. The weather forecast indicated the height of waves as 7 until 8 m, but the master ship and the Coast Guard estimated the actual wave height as high as 15 until 18 m. Sea water flushed in the engine room ventilation and burnt fuses, caused damages to shaft generator, and a blackout occurred to the Hagland Captain ship [30].

Regarding the proximate events which led to the blackout of Viking Sky on 23 March, the cruise ship left Tromsø on 21 March at 22.10 and was scheduled to arrive on 22 March in Bodø and on 24 March in Stavanger. The voyage of ship from Tromsø to Bodø was without any events. According to the forecast, wind in Bodø was estimated to increase significantly over afternoon and evening. Therefore, the ship's master as was concerned the Viking Sky might have difficulties in leaving in time Bodø, consulted the cruise management and decided to cancel the visit to Bodø, but instead, to head directly to Stavanger [20]. During the passage through the stormy water of Hustadvika area, a sequence of events took place and led to a blackout, see the Table 3 [20].

It can be observed from the Table 3 that first a small DG collapsed - the DG4 - followed by a large DG - the DG2 - and afterwards, again, a small DG - the DG1 - collapsed; the second large DG - the DG 3 - was out of operation since 16 March. It can be noticed that on the morning of the 23rd March, between 05.00 and 09.04, 18 lubricating oil low level and low volume alarms were registered by the operational DGs. However, each alarm, after it had been accepted, was cleared within few seconds [20]. All the three operational diesel generators shut down and caused a blackout and loss of propulsion at 13.58. Immediately after the blackout, the bridge crew contacted the engine control room, but at early stages, the engineers could not identify the cause/causes of the blackout. The master was called on the bridge and after an quick assessment of the situation, he issued a mayday at 14.00. Moreover, the master instructed the crew to drop both anchors, but anchors were not able to hold the ship which continued to drift at a speed of 6–7 knots towards the shore. The general alarm on ship was activated at 14.15, and the crew and passengers started to gather in the dedicated points [20].

The master of Viking Sky assessed the condition of evacuating passengers via lifeboats, but because of the stormy weather - high waves and strong wind - this type of evacuation was considered highly risky and not possible to be pursued [20]. Furthermore, after receiving the mayday, because of heavy storm, two rescue vessels - operated by the Norwegian Society for Sea Rescue - were unable to

Table 3
Viking Sky ship - sequence of events and blackout in Hustadvika; adapted from the Accident Investigation Board Norway (AIBN) [20].

Timing	Events - details
05.00–09.04	18 alarms gave indications about low levels lubricating oil
13.37	alarms gave indications about low levels lubricating oil to DG4 (small DG)
13.39	alarms gave indications about low levels lubricating oil to DG1 (small DG)
13.45	DG4 shuts down
13.45	DG2 (large DG) shuts down
13.56	DG2 restarts
13.58	DG2 and DG1 shut down; complete blackout and loss of propulsion
14.00	Mayday broadcasted by the master of Viking Sky

reach to Viking Sky and were forced to return[31]. The first tugboat reached in vicinity of Viking Sky around 16.40, but the storm was very strong and a towline could not be secured [20].

The Southern Norway Joint Rescue Coordination Centre (JRCC) launched the rescue operations for Viking Sky and started at once to gather helicopters, crew and other resources. The helicopters were managed to be mobilized very quickly from other areas of Norway, despite high wind and decreased light, a rescue helicopter operation began. After few hours, the helicopter operation for Viking Sky was slow down as a nearby cargo ship, the Hagland Captain, suffered also a blackout and required urgently to evacuate his crew [31,20,32]. The first helicopter reached to Viking Sky around 15.00, and the hoisting operation commenced five minutes later. The evacuation operation continued over the entire afternoon, evening, and night until the next morning. The helicopter operation took 19 h in the air and a total of 30 trips were performed back and forth, from the Viking Sky ship until the emergency center shore, in Fræna, More og Romsdal county, western Norway. The ship was terribly listing, and the passengers were hoisted one by one from the deck of ship more than 30 meters into air [20,29,32].

Some of passengers suffered injuries such as broken bones, bruises, cuts, trauma and around dozen were hospitalized. Fortunately, no fatalities occurred [32,30]. Passengers were sent to the Molde and Kristiansund hospitals which received a total of 26 passengers; 15 were admitted and 12 were treated as outpatients. Three passengers were considered as seriously injured, and one was transferred to the Haukeland University Hospital in Bergen [7].

On Sunday, 24 March, around 05:00, the ship's engines started to work. The three operational DGs were restarted, but engineers

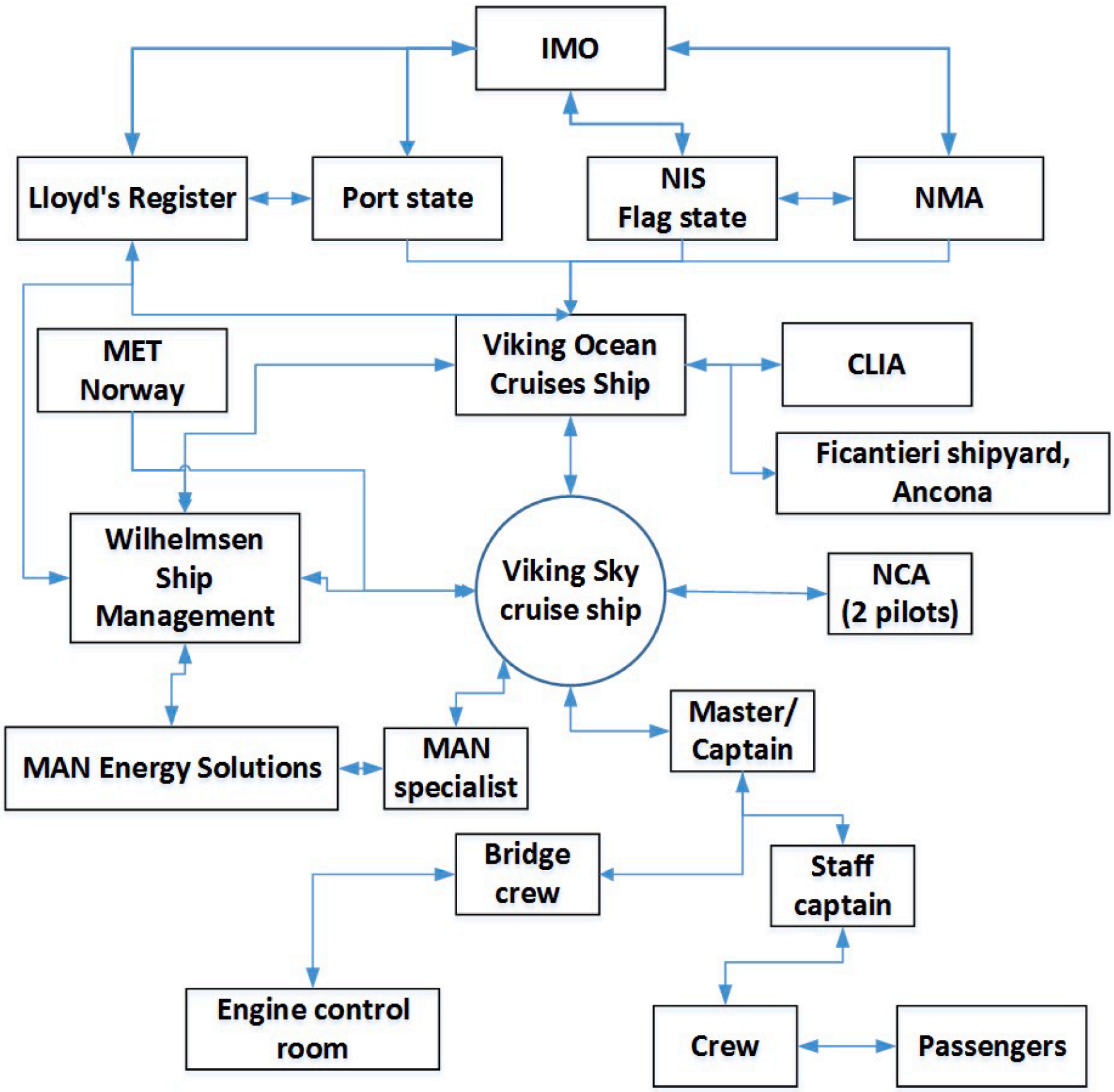

Fig. 3. Safety control structure for the Viking Sky cruise ship. IMO - International Maritime Organization; NMA - Norwegian Maritime Authority; NIS - Norwegian International Ship Register; MET Norway - Norwegian Meteorological Institute; CLIA - Cruise Lines International Association; NCA - Norwegian Coastal Administration.

had to continuously balance manually the electrical load. Furthermore, around 06.30, weather conditions improved and the towlines could be secured fore and aft of Viking Sky, but vessel maintained its own propulsion. At around 09.15, the master of Viking Sky decided to stop the evacuation of passengers as the ship was considered out of danger. At that time, a total of 479 passengers was managed to be evacuated via helicopters [20,29,32].

Viking Sky with a speed of around four knots together with two tugboats reached to the Molde port at around 16.25; it had on board 436 passengers and 458 crew members [20,33,7]. On Tuesday, the 26 March, the Norwegian Maritime Authority (NMA) granted to Viking Cruises a permit to sail on a single voyage to the Kristiansund shipyard in order to have all the required repairs done [34]. Viking Sky was examined by a diver in order to verify for any damages below waterline. Moreover, the inlets for cooling water were also inspected by diver if were clogged or not. No damages to ship's hull were identified, and inlets were confirmed to be open and in order. It was also confirmed the ship did not cause any environmental damages [32,20]. The Viking Ocean Cruises has canceled only the voyage of Viking Sky on the 27 March, and the ship was expected to return to sea, as early as April 2019.

3.2. CAST part 2: to represent the existing safety control structure for this type of failure

The safety control structure which has been in place for the Viking Sky in order to control the hazards and to enforce the safety constraints with regards to passengers, crews and ships is illustrated in the Fig. 3.

In can be observed in the Fig. 3 that a very high level of safety control structure is represented by the IMO, the port state, the flag state, other Norwegian maritime authorities and organizations, and the classification society of the Viking Sky; in this figure, the control - feedback relationships among organizations are represented by double arrows. The components of safety control structure as shown in the Fig. 3 are examined in next subsection.

3.3. CAST part 3: to examine the components of the safety control structure

Within the maritime industry, like many other industries, the decision process is rarely "white and black" as involves many stakeholders which interact in different ways. Moreover, there are many political, economical, socio-cultural considerations involved and which influence the decision process within the industry [35].

With regards to the components of the safety control structure for Viking Sky cruise ship as shown in the Fig. 3, their responsibilities are presented in this subsection.

The International Maritime Organization (IMO) is the regulatory authority which is in charge of maritime safety. the IMO is a specialized agency of the United Nations (UN) for maritime safety, security and environment [24]. The IMO has 172 member states which are represented by their maritime administrations. The IMO is organized within five committees and each committee has several sub-committees. As an example, the SOLAS Convention is administered by the Maritime Safety Committee (MSC) [35]. On regular basis, the IMO updates and reviews maritime regulations through various general sessions, committees and extraordinary sessions which is a time consuming process with various political and national interests [35,2]. The IMO ensures a safety level which is globally considered acceptable, and the IMO requirements are enforced through the flag states and class rules [35].

The country of registration or the flag state is the country where a ship is registered. As per the UN Convention on the Law of the Sea, the flag state has as a duty to ensure safety at sea for its registered ships. The flag state inspects its registered ships on regular basis to assure compliance of ships with both international and national regulations [2,35]. The Viking Sky cruise ship was registered by the shipowner with the Norwegian International Ship Register (NIS) under the IMO number 9650420 [20]. The shipowner of Viking Sky chose to have Norway as the flag state and registered all its ships in the NIS. The NIS has been very interested to have a diverse fleet, particularly, major ships like the Viking Star type - the Viking Sky and his cruise ships sisters. Moreover, since the size of a fleet matters within forums such as the IMO, an increased number of ships registered with a flag country will increase its international maritime influence [36,37].

The Norwegian Maritime Authority (NMA) is administrating the Norwegian maritime registers such as NIS/NOR registers, and is also administrating and enforcing the maritime Norwegian requirements [35]. The NMA is the authority body for safety related issues for all the Norwegian-registered vessels and foreign vessels in the Norwegian ports and waters. The highest safety standards for protection of life, health, environment and property for both Norwegian and foreign ship owners need to be in place. The aim of the NMA is to ensure that Norway is an attractive flag state with high safety standards. Moreover, the NMA ensures the Norwegian Government's maritime strategy is implemented; NMA subordinates to the Ministry of Climate and Environment and to the Ministry of Trade, Industry and Fisheries [36,37].

The port state is the country whose waters and ports are visited by a ship. The port state has full authority to ensure that a cruise ship complies with the international, national and local regulations and requirements [2]. At the time of the blackout in March 2019, the port state for the Viking Sky ship was Norway.

The classification society is an organization which conducts periodic inspections on behalf of cruise ship owner, flag states, insurers, coastal administration and other maritime organizations in order to ensure that respective ship complies with standards and regulations [2]. The classification society acts also as an objective third party. The classification society for Viking Sky is the Lloyd's Register.

The owner of Viking Sky is the Viking Ocean Cruises Ship II, care of manager Viking River Cruises Inc of Woodland Hills, California, USA [38]. Viking Ocean Cruises is worth 3.4 billion dollars where three quarters are owned by Torstein Hagen who is the founder and chairman of Viking Cruises and a Norwegian-born entrepreneur. The Viking Sky is the third ship in the Viking Star class of cruise ships [38]. Viking Ocean Cruises is a member of the Cruise Lines International Association (CLIA) [2].

The technical management of Viking Sky was provided by the Wilhelmsen Ship Management AS of Lysaker, Norway. The Wilhelmsen supplies to the vessels around the world extensive solutions in terms of crew management, technical management, risk management, vessel accounting, procurement services, dry docking and building supervision. On behalf of the Viking Ocean Cruises Ship II, the Wilhelmsen is part of the Steamship Mutual (Smuab) [39,38]. Vessels operators ensure that safety is provided as per regulators' requirements at the lowest possible cost. On regular basis, the ship owner/operator has to cover expenses associated with regulatory requirements and costs of insurance. Insurance of a ship is valid only if the ship complies with flag state requirements [35].

The Viking Sky ship was built at the Ficantieri shipyard in Ancona, Italy, and was delivered in January 2017. The Ficantieri shipyard declared after the blackout of the Viking Sky that "the Viking units are all built according to the latest navigation regulations and equipped with the most modern safety systems, including safe return to port" [23].

The Norwegian Meteorological Institute (MET Norway) provides meteorological services, and the Norwegian Coastal Administration (NCA) conveys messages/warnings about wave patterns in the Norwegian waters. From 2018, the NCA started to offer a digital route service which automatically advises masters/captains of ships about favoured/disfavored routes. However, at the time of Viking Sky's failure, this system was active just for the southeast Norway, and not for the Hustadvika area. As per a NCA declaration issued on March 2019, many efforts have been in place to have a digital route service available for the rest of Norwegian waters until the end of 2019 [29,25]. Viking Sky cruise ship did not require approval from the Norwegian maritime authorities/organizations for sailing through the Hustavika area during a stormy weather. As per the NCA, never a discussion took place about the sailing of the Viking Sky through the Hustadvika during a stormy weather. Viking Sky was seen as a 203 meters tall ship, only 2 years old, and built as per the highest safety standards. NCA underlined further that it was nothing which required the Viking Sky ship not to sail through Hustavika [40].

Two licensed and experienced Norwegian coastal pilots from NCA were on board of Viking Sky when departed from Tromsø. Pilots were present on board of the Viking Sky as it is mandatory to use pilots in order to assist the ship master for some parts of voyage. Both pilots had experience with Viking Sky ship as they have sailed on the ship several times before, and they were also well familiar with the crew. The pilots together with the Viking Sky's master reviewed the planned route of ship before departure from Tromsø. After the failure encountered in Hustadvika, one of the pilots declared that everything went according to the plan until the ship's engines collapsed, and "That's when the problems began" [20,40,29,25].

According to the Norwegian Maritime Authority, there is the captain decision to sail or not, and no guidelines from other maritime authorities are required. The master/captain has a first hand knowledge about ship situation, and has the final decision about sailing or staying in port [40]. Regarding the master/captain of Viking Sky, on 22 March, at around 13.40, he instructed the staff captain to inform the crew to be prepared as the weather conditions were deteriorating [20]. The captain of Viking Sky has been in this position since 2017. Previously, he was the Staff Captain for the Viking Cruises for a period of six months, and the Vice Captain for the Crystal Cruise Line for a period of one year. For more than eight years, he was master/chief officer for both Aeron Marine and Fred Olsen Cruise Line [29]. The captain of Viking Sky took advice from two Norwegian experienced pilots which were on board of the ship at the time of blackout. The pilots together with the captain assessed that was nothing which required not to navigate through Hustadvika. Furthermore, the pilots declared that the level of adrenaline was high on ship during the blackout situation, but pilots emphasized that all crew on board of Viking Sky displayed an excellent seamanship during the crisis in Hustadvika [29,41,31,42]. The training of ship's officers and crew is defined as per the IMO's International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) which was adopted in 1978 and encountered major revisions in 1995 and 2010 [35].

The company MAN Energy Solutions is the provider for the engines of Viking Sky. At the time of failure, a MAN employee was on board of Viking Sky. Normally, the equipment producers provide the ship owner/operator with the required equipment which fulfils the regulators' requirements, but it is also commercially attractive [35].

The safety of passengers on a cruise ship is part of responsibility of the ship operator and the provided ship. In order to stay competitive and have a profit, ships operators often try to keep the costs related to safety equipment to minimum requirements, but within the levels defined by regulations [35]. One of the passengers of Viking Sky declared that the entire experience of blackout in Hustadvika was "surrealistic": "We were siting in restaurant when the ship started to move violently from one side to another. People were falling down and also the food plates. Many thoughts crossed my mind and at that time, I was thinking to Titanic" [41].

3.4. CAST part 4: to identify the flaws in control structure which contributed to failure

The Viking Sky ship, the crew and the passengers narrowly escaped a disaster. Several critics and questions have been addressed to the decision of Viking Sky and its management to sail through Hustadvika during a stormy time. After the blackout of Viking Sky, a former captain for a rescue ship criticised the decision to sail through Hustadvika: "I can't understand why they did it. There was no need to go out, not least thinking of the passengers" [31].

However, the NCA supported the decision of Viking Sky to sail through Hustadvika. The NCA's argued that "There was nothing to suggest that the Viking Sky shouldn't take this route in the weather conditions" [31]. Moreover, the captain's decision to follow the route through Hustavika was supported by two NCA's experienced Norwegian pilots. They were in charge to assist the captain with navigation in the Norwegian waters [31,42].

The cruise lines plan their voyage itineraries based on weather forecast, navigational aids and known bad weather patterns. At the time Viking Sky decided to adventure through Hustavika, a smaller size Hurtigruten ship - a daily Norwegian coastal ferry service which is transporting passengers around the Norwegian cost since 1893 - decided to stay in port, in Trondheim, during the stormy weather and to send its passengers via air to Bergen. "Based on our previous experience, and the weather forecast, two Hurtigruten captains decided independently and individually to stay in port" [25]. One of the pilots which assisted the captain of Viking Sky argued that in comparison with Norwegian Hurtigruten Cruises ships, the Viking Sky was a ship 10 m larger and has a length of over 200 m [31,42].

The communication department of the Norwegian line Hurtigruten declared that Hurtigruten ship was very well aware about the risk posed by bad weather and Hustavika area: "We pass Hustadvika 700 times a year. There are only a handful of times a year where the conditions are so extreme that we cannot. Every decision to divert due to weather conditions are made by our highly experienced captains." [25]. Another comparison can be applied to the Caribbean waters where many cruise ships are scheduled to sail during the peak of the Atlantic hurricane season, but the ships' captains try to avoid the stormy areas [29].

According to Svein Kristiansen, professor at NTNU Trondheim, Norway [22], the sailing of Viking Sky during a stormy weather in the Hustadvika area had to be considered as a pure gambling act. It was an outrageous action for a cruise ship with 1300 people on board to sail in such stormy weather with high waves and strong wind, and in a dangerous place like Hustadvika, taking in account that it was not possible to use the lifeboats if something was going wrong with the ship. Even somebody with a minimum experience knows that a ship can miss propulsion and control, and when this happens, it shall be a possibility to evacuate the ship at earliest. Moreover, Svein Kristiansen emphasized that in the specific case of Viking Sky, it was not possible to evacuate the ship neither with help from other ships, nor by using lifeboats. The machinery of a ship can be affected by high movements from ship itself, and a blackout can occur also when sea is calm. When the blackout occurred, the Viking Sky was very near to shore and the ship had a marginal possibility to stop drifting before a grounding [22]. The possibility of a blackout during a stormy weather was a possible scenario which was not considered at all during planning of the voyage for Viking Sky [31,42].

During the voyage of the Viking Sky, and before the occurrence of blackout in Hustadvika, on 16 March, the turbocharger of one of the two large generators, the DG3, failed and made DG3 inoperable. On the day of blackout, a technician from MAN company was on board of Viking Sky in order to dismantle the damaged turbocharger of DG3 and to arrange for a replacement to be done in the Stavanger port [20].

During the blackout of Viking Sky, the crew and passengers experienced a very demanding situation [30]. Nevertheless, the competencies and professionalism of crew during the emergency situation played an important role to alleviate that difficult situation [32]. This brings to attention the finding of Rasmussen and Svedung [3] that people should not be seen only as an error source, but also as a very important safety resource. Majority of Viking Sky's passengers praised the crew and the rescuers for their professional attitudes, comforting and calming down actions during a very difficult time [7]. One of the NCA's pilots declared that in Hustadvika, it was a good portion of good luck, in addition to the fact the people done their best at that critical time [40].

The rescue operation of Viking Sky's passengers was a well-organized and effective air operation which had a positive contribution to manage the emergency crisis. An emergency center was established onshore by the Southern Norway Joint Rescue Coordination Centre (JRCC) and many organizations collaborated over the rescue operation as illustrated in the Fig. 4.

Regarding the helicopter rescue operation, the Norwegian Search and Rescue (SAR) contacted the company CHC at 14.00, immediately upon receiving the mayday from Viking Sky. Within 30 min from the call for assistance, the first CHC aircraft which was on contract with the Norwegian Ministry of Justice reached at Viking Sky area and started to hoist passengers, initially, one at a time. Very shortly, another helicopter - on contract with Equinor at Heidrun - arrived at the Viking Sky location. A rescue pattern was established in order to ensure that one helicopter was hoisting passengers all the time. The Fig. 5 shows the hoisting process of a passenger via helicopter during the blackout in Hustadvika.

During each helicopter mission between 15 to 20 passengers were hoisted and transported to the shore [44]. In total, the CHC responded with six teams from its bases in Statfjord, Sola, Floro, and Heidrun and support from the Stavanger operations center. Two helicopters were dispatched also from Kristiansund. The crews from CHC included 12 pilots, six hoist operators, one systems operator, two ground support engineers and seven rescue swimmers. The rescue operation for the passengers of Viking Sky - via helicopters - has been considered as the largest passenger ship rescue. This rescue operation took place during very difficult stormy conditions - waves of about 15 meters and wind up to 23 meter per second over more than 18 h.

On the shore, a Norsk Luftambulanse Airbus EC145 transported the injured passengers to the nearest hospitals in the area. Heavy

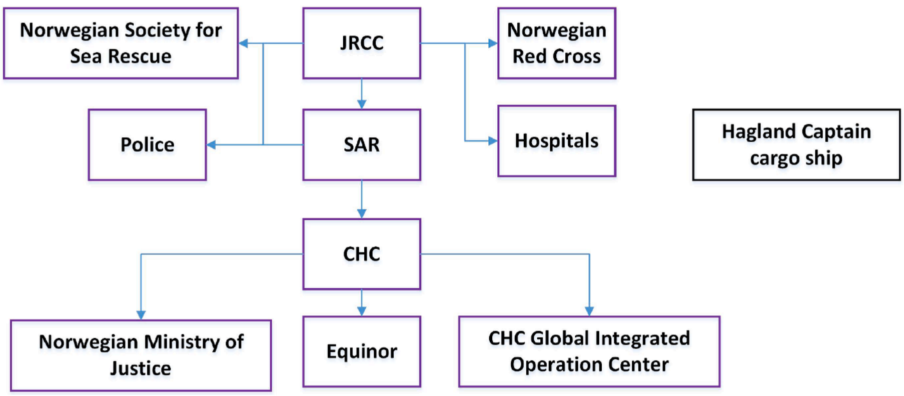

Fig. 4. Rescue operation for Viking Sky cruise ship - overview of the organizations involved; JRCC:Joint Rescue Coordination Centre (Southern Norway); SAR: Norwegian Search and Rescue.

Fig. 5. Evacuation of passengers from the Viking Sky cruise ship via helicopter, adapted from NRK [43] - please note the passenger hoisted by helicopter.

helicopters which included CHC Sikorsky S-92s and Airbus AS332s were also employed. The CHC Norway team airlifted 460 passengers, including 17 injured passengers [44,45].

The Hagland Captain cargo vessel tried to answer to the mayday call from Viking Sky, but encountered itself a blackout [30]. The rescue operation on Viking Sky was slowed down as the helicopter rescue assistance was required to be provided also to the Hagland Captain Cargo ship where nine crew were airlifted [46,30].

The helicopter rescue operation for the Viking Sky was reminiscent to some extent to another helicopter operation which took place in August 1991 when Oceanos - a Greek passenger ship - lost power and listed in a stormy weather in the Coffee Bay in South Africa. The captain and crew abandoned the ship, but 16 rescue helicopters which included 13 South African Defense Force Pumas managed to hoist 225 passengers from a total of 571 on board; a nearby cargo ship manged to save the remaining passengers [44,45].

The Viking Sky's helicopter rescue operation has been appreciated as a large, complex rescue operation where all coordinating aspects were handled very well. Moreover, it was a close collaboration and an outstanding team effort among CHC and different organizations in Norway such as the Joint Rescue Coordination Centre (HRS) and customers of CHC - Equinor, the Norwegian Ministry of Justice, the international military for the safe movement of CHC aircraft, and the CHC Global Integrated Operations Center [44].

The Norwegian Red Cross was informed about emergency of situation on Viking Sky at 14:30 and managed to gather 400 volunteers along the west and central part of Norway [32].

As per estimations of the AIBN [20], the Viking Sky ship came within a ship's length of grounding and passed over or was in the immediate proximity of 10 m shoals before the propulsion could be re-established. The Viking Sky confronted a very critical situation as seemed to be less than 100 meters from the nearest ground and about 900 metres from shore. A near grounding in the stormy waters of Hustadvika was very near to occur, and in a tragic scenario such as the occurrence of a grounding, it was not be possible to evacuate all the passengers and crew in time, and fatalities could occur [20,33]. The owner and operator of Viking Sky denied that the decision of captain to sail through stormy Hustadvika was due to strong financial considerations [38]. After the accident, the chairman of Viking Ocean, Torstein Hagen, travelled personally to Molde and apologized to passengers and acknowledged and thanked the crew and organizations involved in rescue. He offered full support for investigation of the accident. A full refund and a voucher for a complimentary cruise was offered to each passenger on Viking Sky [46].

For the investigation of the Viking Sky's blackout, many authorities/organizations have been involved. The lead investigating authority has been the Accident Investigation Board Norway (AIBN).

Taking in account the nationalities of passengers on Viking Sky during the dramatic voyage such as 602 - United States citizens, 192 - United Kingdom citizens, 69 - Australian citizens and 47 other nations, in accordance with the Norwegian Maritime Code section 474, both the United Kingdom and the United States of America have been considered as Substantially Interested States (SIS). Consequently, the United Kingdom's Marine Accident Investigation Branch (MAIB), the United States Coast Guard (USCG), and the United States' National Transportation Safety Board (NTSB) have worked with the AIBN, as representatives of the SIS. Moreover, the Australian Transport Safety Bureau (ATSB) has also assisted in collecting evidence for investigation. AIBN have worked closely with the Norwegian Maritime Administration, the Norwegian Costal Administration, Viking Ocean Cruises, Wilhelmsen Ship Management, Lloyd's Register, Police and other interested organizations. This close collaboration among organizations has as aim to reveal underlying causes and to identify appropriate measures in order to mitigate future accidents [20].

As a part of focus of investigations, it has been the Viking Sky's machinery and the logs which covered the alarms that went off prior to blackout in Hustadvika [34,32]. According to the NMA [34], the Viking Sky's engine failure was caused by low oil pressure. At the time of passing through Hustavika, the level of lubricating oil was relatively low, but within the set limits. The stormy weather and high waves most probably caused movements in the tanks so large that the supply of oil to pumps stopped. This triggered the level alarms which indicated a low level for lubricating oil and shortly, an automatic shutdown of engines occurred. "The heavy seas in Hustadvika probably caused movements in the tanks so large that the supply to the lubricating oil pumps stopped," and the sensors had detected the shortage and shut off engines to prevent a breakdown [34,42].

The AIBN issued an interim report dated 12 November 2019 about the loss of propulsion and near grounding encountered by Viking Sky on 23 March 2019 [20]. As per this preliminary report, the Viking Sky carried between 28 until 40 percentage lubricating oil in its engines before the blackout in Hustadvika. As per the engines' manufacturer - MAN - the recommended level was 68 to 70 percentage. Low lubricating oil levels combined with pitching and rolling of ship conducted to shut down of engines. The shut down of diesel generators caused the blackout and loss of propulsion. Before the propulsion of ship could be re-established, it was estimated that the ship came within a ship's length of grounding [20].

After the blackout of the Viking Sky questions were raised by shipping community if this accident exceeded the casualty threshold for the IMO's Safe Return to Port regulations. A severe weather condition should not endanger the ability of ships to safely return to port [23].

3.5. CAST part 5: to generate recommendations

The aim of CAST's recommendations is to bring to attention the required changes and necessary improvements in order to maximize learning from current accident, to contribute to prevention of future accidents, to improve the safety control structure and the overall risk management program among others.

Towards further learning from the failure encountered by the Viking Sky in 2019, Hustadvika, Norway, the following aspects are being highlighted:

- The failure encountered by Viking Sky ship - an overview of the accident/failure precursors and resilience indicators;
- Safety recommendations for other cruise ships and vessels;
- Lessons for the cruise operations in the Arctic and Antarctic areas.

These three aspects are being further discussed in the following section.

Table 4
Overview of accident/failure precursors and resilience indicators, AP - accident precursor; FP - failure precursor; RI - resilience indicator.

AP/FP/RI	Safety performance	Potential risk
AP - Strong beliefs about power of Viking Sky and low risk perception about Hustadvika area		
FP - A large DG (DG3) was out of operation long before Hustadvika		
FP -Turbocharger failure and collapse of DG3		
RI - A technician from MAN, on board of Viking Sky, at the time of blackout		
AP/FP - Clearance / non-action with reference to alarms which indicated low level of lubricating oil		
AP - Identification of blackout causes took time		
RI - Restart of DGs and decision to balance manually the electrical load		
RI - Master's immediate decision to launch mayday and general alarm		
RI - Crew preparedness and handling of emergency situation		
RI - Immediate launch of rescue operation; coordination of helicopter rescue operation		
AP - Incapacity to use Viking Sky own lifeboats and to receive help from other ships/boats		
AP - Voyage planning		
AP - Blackout scenario was not considered during a stormy weather		
AP - Emergency evacuation during stormy weather- all scenarios not considered		
AP - High number of passengers and crew on board of Viking Sky		
FP - Low levels of lubricating oil		
FP - Type of lubricant and viscosity		
FP - Possible design errors for lubrication oil tanks and/or placement of lubricating oil transmitter		
FP - Engine control software and faults		
AP - Competition environment within the cruise industry		

4. Discussions

4.1. The failure encountered by Viking Sky ship - An overview of the accident/failure precursors and resilience indicators

The Marine department of the AIBN assessed "the risk to the passengers and the vessel was high" in Hustadvika [38]. The NCA confirmed that Viking Sky confronted a highly risky situation as the ship reached to be 100 m far from rocks under water and 900 m from shore [46]. Viking Sky was clearly near the border of a catastrophe, and it was a large amount of good luck that helped to emerge out of the blackout situation in Hustadvika. As per estimations, if the grounding of the cruise ship has been occurred, the Viking Sky could encounter fatalities near to the death tolls of Estonia and Titanic [47].

Various accident/failure precursors have contributed with a different degree to deterioration of safety and to the high risk situation which was encountered by Viking Sky ship in Hustadvika. The Table 4 offers a non-exhaustive overview of the accident/failure precursors and resilience indicators.

It can be observed from the Table 4 that many accident/failure precursors negatively impacted the safety performance of Viking Sky. Moreover, they can indicate a potential risk for future if no measures for risk reduction are in place. However, the Table 4 shows also resilience indicators which had a positive impact on overcoming the critical situation of Viking Sky in Hustadvika.

One of the accident precursors is represented by the strong beliefs of the Viking Sky's management and operator, ship's master, pilots, and even the Norwegian authorities such as the NCA, that a ship like the Viking Sky can overcome a stormy weather in a place like Hustavika area. This displayed a strong confidence in the power of a ship to overcome a storm and a low risk perception about the dangerous area of Hustadvika which is well-known as the cemetery of ships.

A failure precursor is represented by the technical failure confronted by Viking Sky: one large DG (out of two existing large DGs) - the DG3 - was out of operation for many days - since 16 March - because of a turbocharger failure. Consequently, before the blackout in Hustadvika, there were only three operational DGs - one large and two small ones. Before the blackout, the first DG which shut down was the small DG - the DG4 - which was situated in the aft engine room, the same room where the out of operation large DG3 was located. Turbochargers are seen to be among the high-technological and critical engine components on board of a ship. A turbocharger is a a piece of high-speed machinery which serves continuously in harsh conditions and under high strain. A damage to a turbocharger negatively impacts engine, brings a significant reduction in speed of a ship and can be considered as a significant safety hazard. Furthermore, a turbocharger damage is linked with very costly repairs [48].

The operators of ships are required by the classification society, and also by the component manufacturers to assure maintenance of systems on regular basis. The risk of failure, minimization of maintenance costs and time spent in dry docking need to be taken in account among other things [11]. With reference to the machinery planned maintenance and condition monitoring, according to the Lloyd's Register - the classification society for the Viking Sky cruise ship - the condition monitoring is defined in terms of usage of instrumentation for making regular or continuous measurements of various parameters in order to indicate the physical state of a machinery, but without disturbance to its normal operations [11].

The presence of a technician from the MAN company on board of Viking Sky at the time of blackout can be seen as a resilience indicator which positively contributed to overcome the blackout situation in Hustadvika. He was on board of the Viking Sky in order to dismantle the damaged turbocharger and to prepare it for a replacement in Stavanger.

A failure/accident precursor is represented by the warning alarms about the low levels lubricating oil, and which occurred few hours before the blackout. On the morning of 23 March, between 05.00 and 09.04, around 18 alarms indicated the risk of lubricating oil low levels and low volume, but the alarms were accepted and cleared within seconds. No actions were taken about the low levels of lubricating oil until the complete blackout occurred many hours later, in the afternoon, at 14.00.

After the blackout occurred, the bridge crew immediately contacted the engine control room, but the engineers could not immediately identify the cause/causes of blackout. Later on, when the three operational DGs were restarted, the engineers had to continuously balance manually the electrical load [20]. This resilience indicator had a positive impact on overcoming the loss of propulsion, but also indicated that real causes of blackout were not fully cleared until the time of investigation.

An important resilience indicator which positively impacted the emergency situation after the blackout was the quick decision of Viking Sky's master to immediately assess the critical situation and to launch the mayday and to activate the general alarm on ship. The handling of emergency situation by the Viking Sky' crew was definitely a resilience indicator with positive impact. The immediate actions for launching a major rescue operation - a helicopter rescue operation - and the coordination among rescuers/ involved organizations are considered to be resilience indicators with a positive impact.

Incapacity to use the Viking Sky's own lifeboats because of stormy weather and incapacity to make use of help from other ships/ lifeboats - at the time of blackout - is seen to be an accident precursor with a negative impact on a rapid/in-time evacuation of passengers and crew.

With regards to risk assessment of a ship's operations, the voyage planning is seen as a standard prevention action, and a risk assessment needs to be done before and during the voyage. However, many times, a ship's navigation follows just the standard planning procedures and does not require a specific risk assessment. The voyage planning of Viking Sky suffered changes, for instance, the decision not to stop in Bodø because of wind conditions, but to sail through Hustadvika area during a stormy weather. Adaptations during the voyage plays an important role in prevention of marine accidents.

Viking Sky ship was not restricted to leave the port despite a valid bad weather forecast. In this way, the cruise ship operator accepted the high risk associated with lack of functionality of the safety equipment - the safety boats - due to bad weather [4].

A blackout scenario was not considered that could occur during a stormy weather. Furthermore, a back-up emergency evacuation, in case there was no possibility to use own lifeboats or to use help from other ships was also not considered. The helicopter rescue operation was a successful operation. However, the high number of passengers and crew on board of the Viking Sky represents another accident precursor. After the helivac operation carried out over 18 h - from 23 March at 15.00 until 24 March at 09.15 - just 479 passengers were managed to be evacuated. A high number of people - around 900 (436 passengers and the entire crew of 458 people) - were still on board when the Viking Sky was on verge of grounding.

A high risk came from the level of lubricating oil which was within a predetermined safe range, but still at low levels as per manufacturer's recommendations. However, the low-level alarms were not activated until the Viking Sky reached in stormy waters of Hustadvika. At that time, the movements in the tanks were so large that the supply to lubricating oil pumps stopped. This situation triggered alarms which indicated a low level of lubricating oil, and after some hours, an automatic shutdown of engines, blackout and loss of propulsion occurred on Viking Sky [49,20]. The type of lubricant and viscosity emerged also as an failure precursor which can impact the operation of vessels in the coming years [49]. Risk experts have hinted also to possible design/operation errors for the lubrication oil tanks and/or placement of lubricating oil transmitters [50].

As the disaster of Titanic demonstrated more than a century ago, and also the blackout of Viking Sky in 2019, no ship is invincible on sea. It is recommended to always expect the unexpected and never should put too much faith in technological solutions without a back-up [51].

A passenger of Viking Sky - a retired aviation pilot and software test engineer - brought to attention that serious problems are linked with the engine control software of Viking Sky. It seemed that the software was not adequately tested by staff with a maritime experience; critical scenarios such as the blackout situation during a stormy weather were not tested out. Furthermore, the mission critical software should never be given the authority to shut down the engines of Viking Sky ship without the staff's agreement [42]. Critical software issues have also been observed in the aviation industry and have contributed to disasters [15].

Likewise in other industries, the competition within the cruise industry is quite aggressive, and gaining market and financial success implies also operating at the fringe of accepted safety practices. Moreover, it is not uncommon for the cruise industry to take risk and explore by pushing more the boundaries of safe practices [3].

4.2. Safety recommendations for other cruise ships or vessels

The chairman of Viking Ocean cruises - Torstein Hagen - declared after the blackout of Viking Sky that "Something like this shouldn't happen, but it has". After the Viking Sky managed to successfully clear the blackout and to sail to Molde, the owner - the Viking Ocean Cruises - declared that "Yes, we will continue to offer our northern lights itinerary in 2020" [29]. Definitely, a long term learning from the Viking Sky's blackout is recommended for the Viking Sky ship sisters such as the Viking Star, the Viking Sea, the Viking Sun, and other cruise ships around the world.

The accidents and near-disasters in the cruise ship industry get a lot of attention and the cruise industry tries to avoid as much as possible a bad publicity. However, the accidents in the cruise industry require identification and correction of errors in the systems [7].

The AIBN issued an interim report and the owners/operators of all vessels were recommended to carefully ensure the levels of lubricating oil in the tanks are strictly maintained according to instructions of engine manufacturer. In case of a stormy weather

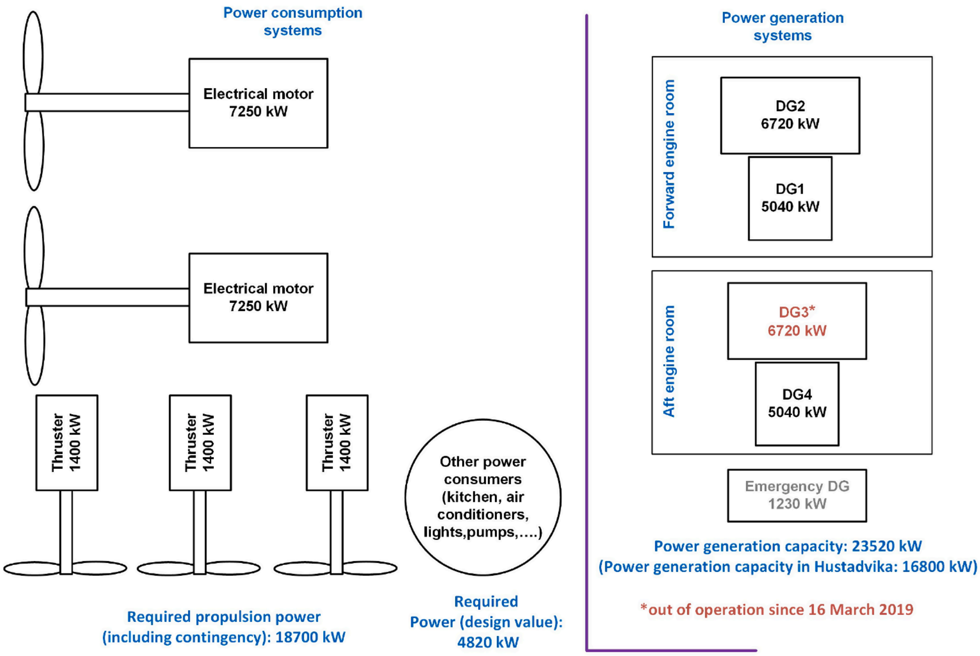

Fig. 6. Power generation and power consumption capacity for Viking Sky cruise ship.

forecast, the engine lubricating oil levels need to be topped up [20]. Furthermore, on 27 March 2019, the Norwegian Maritime Authority has issued a general safety notice - the Safety notice 04/2019 - on risk assessment of critical systems. All shipping companies were asked to ensure a continuous supply of lubricating oil to engines and other critical systems during poor weather conditions. "This should be done in cooperation with the engine supplier and, moreover, be included in the ship's risk assessments in the safety management system" [49,52].

Many studies revealed that commitment, actions, attitudes and behaviour of management toward safety are among the keys towards organizations' safety culture [53]. As per Leveson [54], there are fundamental elements for a successful Safety Management System (SMS): a safety management structure, a safety culture and a safety information system.

The operator and owner of Viking Sky have supported the investigation process of accident [34] and the enhancement of safety process for Viking Sky and its cruise ships sisters. After the blackout of Viking Sky, the Viking Ocean Cruises gave instructions about the lubricating oil levels to be inspected for all its cruise ships [7]. Furthermore, the operator of Viking Sky - the Wilhelmsen Ship Management - issued a safety bulletin with safety recommendations to all their ships. Several actions were identified to be taken with regards to management of recommended lubricating oil levels, preparedness for a stormy weather and blackout recovery procedures. In addition, the Wilhelmsen Ship Management together with the class society - Lloyd's Register - is establishing procedures for sailing with one inoperative engine (or other critical equipment) while maintaining compliance with the SOLAS's Safe Return to Port requirements [20,7].

The AIBN investigation about the Viking Sky is yet to be finalized and targets various matters: lubricating oil management, engine room alarm management, passage planning, decision support, safety management, evacuation and Life Saving Appliance (LSA), safe return to port, local weather conditions and bathymetry. The aim is to ensure identification of required actions in order to reduce the occurrence of similar accidents in the future and to improve the safety at sea [20].

As a critical matter, taking in account the Viking Sky was a newly built ship and with new equipment on board, the early failure of a turbocharger which further caused the failure of a large DG requires to be further investigated. Moreover, the sailing of Viking Sky with an inoperative large DG on board for almost one weak - from 16 March until 23 March (when a complete blackout occurred) needs to bring to attention the high risk for the Viking Sky, its passengers and crew.

The Fig. 6 shows the layout for the power generation and power consumption capacity for Viking Sky cruise ship. It can be observed the Viking Sky's power generation capacity is 23520 kW, and the required propulsion power (including contingency) is 18700 kW. In addition, the design value power for other consumers is 4820 kW. As one large DG was out of operation, the power generation capacity of 16800 KW was under the required propulsion power in Hustadvika.

As an alarming note, few days before Hustavika, the Viking Sky - a cruise ship vessel compliant with the SOLAS's and SOLAS's Safe Return to Port requirements - and his operator agreed to a compromise to maritime safety by sailing with one large DG out of operation and under the required propulsion power.

The Viking Sky accident highlights among others the importance of lubricants and their impact on vessels operation. In Norway, the 0.1 percentage sulphur emission control has been in place for some years. However, very few vessels are fitted with scrubbers and many vessels will continue to use a blended 0.5 percentage sulphur fuel. As per suppliers such as Total, the provided marine fuels will be inconsistent from one batch to another, in terms of cold flow, viscosity, and other properties; fuels will be graded based on sulphur content and no longer based on viscosity. Moreover, according to the marine fuel department of Total, the cost matters will heavily emerged when a minimum viscosity for fuels will be provided, "…but it comes with a cost, because what is not mainstream is bespoke" and "most customers will not be willing to pay for a specific viscosity on top of a specific sulphur content" [49]. Such changes may affect the engine design and lubrication system which must be revisited. Starting from 1 January 2020 the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI, better known as the IMO 2020, has implemented a cutting of sulphur levels to 0.50 percentage in order to allow the shipping industry to contribute to a sustainable environment [55]. The IMO 2020 is seen to bring a lot of benefits, but it will also bring increased costs for ships and ship owners, and possible negative impacts on machinery operations, and an increased damages to the machinery.

The lessons from Viking Sky aim to bring forward for cruise ships, among other matters, the required updates for contingency plans, particularly during a stormy weather and availability of coastal rescue services and resources [7]. A careful and adaptive route planning was another issue which emerged after the Viking Sky accident [29]. In this regard, the NCA launched new digital routes which are available at Routeinfo.No. In the spring of 2020, around 112 new digital routes and way points were available for the Western Norway. The digital route service offers not only sailing routes, but also relevant information about specific routes, such as sailing conditions and local regulations for inbound voyages and arrivals. As per the NCA, this is not a mandatory service for vessels, but it is recommended to be used as reference routes for voyage planning to ports from Haugesund to Stad in Western Norway. This digital system is seen to reduce the time during voyage planning and to reduce the risk of making unfavourable route selections. This service will be extended to cover the county of Møre and Romsdal, the area where the accident of Viking Sky took place. As per estimations, a complete digital route serve has been targeted to be available for the entire Norwegian coast, including Svalbard, and it will include a total of 500 digital routes. This system is free of charge and a part of NCS's efforts to digitize the maritime service [56].

With regards to the Viking Sky, an important question is being asked: would the Viking Sky's blackout could have been prevented if a digital twin condition monitoring platform was in place? As a remark, at the time of writing this article, a multi-national funded project led by Norway is on the way to implement the digital twin for condition monitoring of ships operating in challenging geographical areas [57].

Nejad et al. [11] brought to attention that the focus within the current industrial practices about condition monitoring is mainly on performance monitoring and limited to oil and temperature monitoring, rather than prognosis approach. The digital twin based condition monitoring is seen as an innovative approach in order to implement the condition monitoring in the marine industry.

Furthermore, the advantages and challenges associated with the digital solutions remain to be further explored within the marine industry [15].

A big advantage of having a digital twin based condition monitoring system in place is that such fault scenarios can be possibly seen in simulation, given high fidelity models. Such systems can also reduce unexpected shut downs - like the case of the turbocharger and a large diesel generator.

The condition monitoring is a preventive action and is based on fact that an incipient defect/failure can be detected from changes in the system conditions, see Fig. 7.

There are different methods to identify a developing failure and changes in a machine behavior such as vibration analysis, infrared thermography, ultrasonic measurements, oil analysis. It can be observed in the Fig. 7 that a developing failure/ potential failure is often first visible through vibration measurements. The vibration analysis is seen as the most reliable and cost-effective used method for condition monitoring [58].

4.3. Lessons for the cruise operations in the Arctic and Antarctic areas

The Arctic cruise industry is growing. In early 2020 the owner and chairman of the Viking Ocean Cruises, Torstein Hagen, announced the Viking Ocean Cruises is preparing to launch new expedition voyages and cruise ships such as the Viking Octantis which is planned to sail from Argentina to Antarctic area, and the Viking Polaris which is planned to sail to both Antarctic and Arctic area [59].

There has been a high traffic of cruise ships in the Norwegian Arctic waters. As per a report issued in 2016 [60], a number of 50 until 100 cruise ships visited the mainland harbours in the Norwegian Arctic area, twice or even three times per a season. The main season starts from May until August, but some cruise ships operate until October, and others operate even during the winter months in search for the Northern lights. The city of Tromsøhas been a very popular target of cruise ships with about 100 cruise ship visits per a eight months season. Moreover, the Svalbard archipelago has received also a high interest from many cruise ships; this is a unique place in the world where the cruise ships with thousands of passengers on board can reach the latitude of 80 degrees North. The largest ship which sailed in the Norwegian Arctic waters was the MSC Splendida cruise ship with a total of 5200 people on board (3900 passengers and 1300 crew) [60].

The Arctic and Antarctic travel boom was estimated to occur in the coming years where both the number of cruise ships and the number of passengers has been estimated to increase significantly. In 2018, in the northern parts of Norway around 150000 passengers travelled on cruise ships and made around 478000 port visits; a number of 500000 port visits was estimated for 2019. In addition to Norway, other polar areas have been also targeted by the Arctic cruise industry: Iceland, Greenland, Canada, Alaska and the Russian archipelago, and the Franz Josef Land [61,60]. However, in 2020, the Covid-19 pandemic has terribly impacted the cruise ships operations in the Arctic areas.

The booming of cruise shipping to the Arctic and Antarctic areas brought also to attention the high risk of accidents/major accidents in the polar areas. There is a lot of focus on touristic activities and possible generated revenues for the areas in Arctic, but there is less focus on risk and safety matters involved in touristic activities in the Polar areas [35]. Furthermore, the cruise ships are coming in the Arctic areas very early in the spring and are leaving very late in the autumn, and this situation is similar with "stretching the limits somewhat." [61].

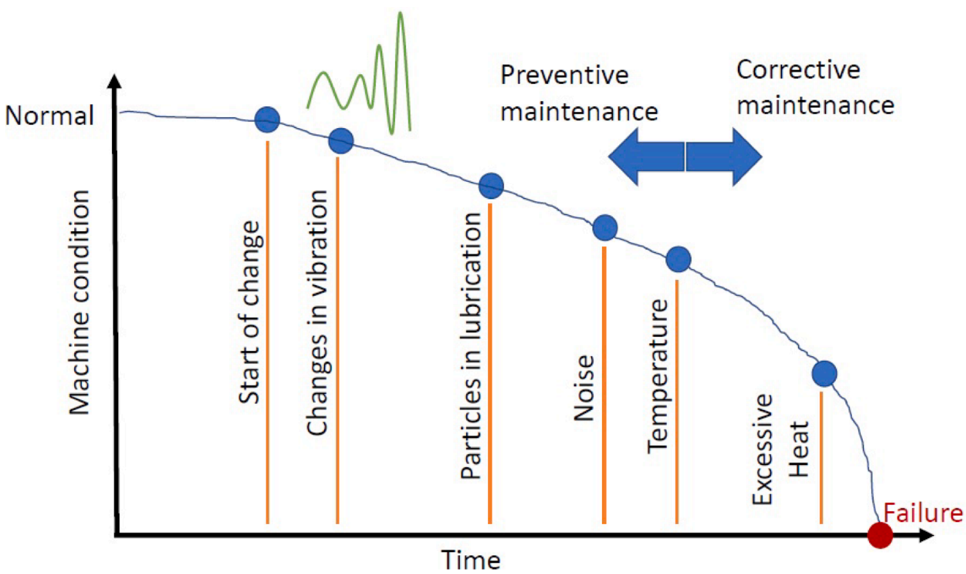

Fig. 7. Condition monitoring and stages of identification of an incipient failure - overview.

Various specialists and researchers have highlighted that the Viking Sky could encounter a very dramatic scenario if the blackout was to occur in the further northern Norwegian regions, after the Arctic Circle, for example, in Finmark or Svalbard. It would most likely transformed into a disaster [61,47,17]. The Viking Sky can be seen as a alarming warning of what could happen in the Arctic areas.

The failure of Viking Sky was called as ”a best case scenario”, as it occurred in an area close to shore where the nearby populated areas were densely populated, and a lot of rescue capabilities and resources were quite close to ship. Nevertheless, ”Had a similar disaster happened in most other places in the Arctic the result would most likely have been catastrophic” as ”No one would have had sufficient resources to react so effectively and promptly in the high North” [17].

A search mission controller of the Norway’s Joint Rescue Coordination Center (JRCC) declared about the rescue operation conducted for the Viking Sky cruise ship: ”This was a bigger incident than even what we’ve trained for”, and ”We were lucky. There were no fatalities ”. Furthermore, ”This was very demanding for everyone”, and ”I can’t tell you how many of our JRCC were involved. It was just everybody. But if this had been in the Arctic? We would not have been able to respond as rapidly. The distances are too big. You can’t get people in as rapidly” [61].

The accident of the Northguider, a shrimps trawl which grounded in December 2018, north to Svalbard area, highlighted difficulty of an emergency operation in a very cold and dark area, particularly, during the winter months. Moreover, the far Nordic areas of Norway are less populated and the communication possibilities are more limited. The emergency operation to save the crew of Northguider - 14 people well trained and accustomed to work at sea in harsh conditions - involved two helicopters and took more than two hours. Usually, on a board of a cruise ship there are a lot of elderly people and many of them are not in a good physical condition. This will further impact length and difficulty of rescue operation. The rescue operation for the Viking Sky took less than 20 h to save 479 people, but if the Viking Sky’s accident was to occur along the coast of Finmark with a more than a thousand people on board, it could have taken more than one week to save all of them as per estimations[47,35].

The Norwegian Red Cross reached to mobilize 240 volunteers to assist the Viking Sky’ rescue operation, but the head of preparedness for the Norwegian Red Cross declared ”The further North you go, it’s less densely populated and that also goes for our Red Cross representation”, and ”Our preparedness is not as good in the far northern part of Norway as it is in the area where this specific event took place ”. An occurrence of an failure similar to the Viking Sky will pose a difficult situation for the Norwegian rescue services and local authorities [61].

The Viking Sky near disaster case has revealed an unacceptable risk level for the cruise traffic along the Norwegian coast and particularly, further north, in the Svalbard and in other High Arctic areas. As there is a growing number of cruise ships through the Arctic areas, an Arctic emergency response has been considered to present many challenges as the number of passengers and crew involves several hundreds or even thousand of people. Moreover, the weather is very harsh in the Arctic areas (presence of ice and icing, icebergs, low temperatures, cold waters, total darkness during the winter, reduced visibility, seasonal changes and unpredictable weather), and emergency services can be located several hours away.

Furthermore, the Arctic areas are sparsely populated areas and have a minimal infrastructure. Lack of experience with these Arctic areas, and other human-related risk factors such as navigational competence and crew fatigue can increase the risk of operations, particularly, during winter and autumn months [61,35,62,60]. The Prime Minister of Norway during a Parliament session in 2019 confirmed that a large scale rescue operation similar to the emergency operation conducted for the Viking Sky will not be feasible in the northern parts of Norway and Svalbard [7].

Solberg et al. [4] brought to attention that with regards to the risk assessments required by the IMO Polar Code, the majority of vessels operators target the minimum five days requirement as the expected time to rescue. Nevertheless, the rescue operations which are targeted to be deployed within a defined timeframe for vessels having on board hundreds of people require enormous functional Search and Rescue (SAR) resources in place and favourable metocean conditions. Therefore, the availability and functionality of SAR teams for different geographical areas needs to be assured and communicated in time by the authorities. The probability of a bad weather should be highly considered, as high wave and wind can negatively impact or even prohibit launching of lifeboats or life rafts and evacuation of a vessel in distress [4].

Since the cruise traffic is increasing in Arctic areas, solutions need to be identified at the earliest in order to reduce the risk of accidents [7]. One the proposed measures was not to allow the cruise ships to sail in the Arctic areas, if there is not possible to ensure appropriate measures for accident risk mitigation, or at best, the cruise ships should be allowed to sail only during the summer months. A possible measure to reduce the risk along the Norwegian coast has brought to attention that the Norwegian maritime authorities need to have the authority to ask cruise ships to stay in ports during a stormy weather [7,35,47].

Furthermore, experienced personnel with the polar areas and intensive training for staff working in the Arctic are required. The northern emergency preparedness needs to be discussed and arranged with the local authorities. Moreover, a close collaboration with neighbouring countries is required in the Arctic areas [61].

As a response to the increased shipping traffic in the polar areas - both the Arctic and Antarctic - the IMO’s Polar Code came into force in January 2018. It covers ship design and equipment, operations, training of staff, search and rescue matters and environmental protection. For instance, it requires a ship to carry equipment which enables survival on land/ice and equipment which enables a minimum of five days survival time. The IMO’s Polar Code is known also as the International Code for Ships Operating in Polar Waters and utilizes a risk-based approach; risks have to be identified, assessed and mitigated through a holistic approach. Nevertheless, currently, there is no common understanding with regards to interpretation of the Polar Code and there are many variations among flag states and classification societies about achieving compliance with this code.

The Viking Sky near disaster case study brought to attention the Polar Code’s jurisdiction needs to be extended to more Arctic area, as according to Professor Odd Jarl Borch, ”Most of the Polar code is related to vessels going into the ice, but most of these cruise vessels do not go into the ice, they only go very close to the ice". Furthermore, the focus needs to be more on fishing boats, yachts and cruise ships as they are getting larger and are operating more through the polar areas. Updates are required to be done to the Polar Code, and initiatives and involvement of the Arctic coastal states are required [61,17] [35].

The accident of the Viking Sky cruise ship determined the appointment of the Norwegian Government's Cruise Committee which is to make recommendations to the Norwegian Government on 19 December 2021. The committee is chaired by the Svalbard Governor and comprises a total of 10 members. The committee is to investigate challenges related to an increased cruise traffic along the Norwegian coast and in the Svalbard area. Among the goals of committee is to perform an assessment about the Norway's ability to manage an accident/serious incident which involves a cruise ship and an assessment about the capacity to manage a high number of injured/non-injured passengers evacuated on the land. Furthermore, a particular emphasis needs to be done on the required risk reduction measures and on how the cruise industry can improve its accident preparedness. A comprehensive overview about incidents/accidents related to cruise traffic in the recent years needs to be prepared together with a map related to challenges and preparedness of cruise shipping along the Norwegian coast and in the Svalbard area. The committee needs also to be aware about the preventive measures taken by other Arctic coastal states and to assess the learning opportunities [63]. The Arctic states can benefit a lot from sharing experiences, best practices and resources [17].

Some technical innovative solutions aiming to increase operational safety in harsh environmental conditions have already been initiated - for example the "Life Prediction and Health Monitoring of Marine Propulsion System under Ice Impact" [57]. Important projects such as the Maritime Preparedness and International Partnership in the High North (MARPART)[62,60] brought to attention that in the Arctic regions there are limited capacities in order to mitigate the severe consequences which can emerge from larger vessels such as oil rigs and cruise ships. In comparison with the oil and gas industry which is obliged to do risk assessments and to have prepared his own Search and Rescue (SAR) and an oil spill response capacity, there is no such an obligation yet for the cruise industry. Consequently, the governmental institutions need to take in consideration the emergency capacity and to perform various risk assessments for Arctic areas where cruise ships has become more frequent. The cruise traffic has been seen to grow in terms of number of cruise ships, size of ships and number of passengers and crew on board.

The Emergency Prevention, Preparedness and Response Working Group of the Arctic Council, in April 2020, issued a Guideline for the Arctic Marine Risk Assessment. This document refers to the best practice method and data sources in order to conduct regional and area-wide risk assessments about ship operations and traffic in the Arctic areas [64].

As an awareness remark, the cruise ships in Arctic areas are linked with an increased environmental risk as they have on board large amount of fuel. Furthermore, the capabilities, resources and time of response require also adequate attention. The maritime emergency preparedness system in the High North is quite complex and requires also a stronger cross-border cooperation [62,60].

5. Conclusions

In this study the failure - blackout, loss of propulsion and near grounding situation in stormy water of Hustadvika encountered by the Viking Sky cruise ship in March 2019 - was investigated and analyzed through a system investigation and analysis approach (CAST) in order to contribute to a systematic and comprehensive learning.

The application of CAST has brought forward the followings recommendations in order to maximize learning from Viking Sky failure and to reduce the risk of future failures/accidents/disasters: an non-exhaustive overview of accident/failure precursors and resilience indicators, safety recommendations for other cruise ships, and lessons for the growing cruise operations in the Arctic and Antarctic areas.

It was observed that many accident or failure precursors contributed to the highly critical situation of the Viking Sky in Hustadvika. The low level of lubricating oil, possible errors for design of tanks and/or operational errors, dismissal/rapid clearance of alarms about low oil levels, failure of a turbocharger and an out of operation large DG, the high number of passengers and crew on board, non-risk assessment and voyage planning, possibility of errors with the engine control software, incapacity to use the lifeboats and help from other ships are among those precursors with a high negative impact on safety and risk. A particular accident precursor is represented by a low risk perception about Hustadvika area, even during a stormy situation. Strong beliefs about the Viking Sky as a new, large and strong ship on sea supported sailing of the cruise ship in the perilous area of Hustadvika. It seems like the fatal beliefs about unsinkable and invincible ships on sea, even dramatically shaken by the tragic fate of Titanic in 1912 are still very much alive even nowadays.

With regards to the resilience indicators with a positive impact on overcoming the blackout of Viking Sky in Hustadvika, the followings have been brought to attention: the master's immediate decision to launch mayday and general alarm, crew preparedness and handling of emergency situation, immediate launch of the rescue operation, successful coordination of helicopter rescue operation, presence of a MAN technician on board of ship, and capacity to balance manually the electrical load.

Towards contributing to the enhancement of safety process, the following safety recommendations for cruise ships emerged: the level of lubricating oil in tanks shall be maintained as per engine manufacturer and a continuous supply of lubricating oil needs to be ensured for engines and other critical systems, particularly, during stormy conditions. The necessity to improve the risk management for ships' critical systems also emerged.

A highly critical matter drew attention to the required propulsion power and the power generation capacity of a ship, in normal conditions and during stormy weather. It requires to be highlighted that for almost one week - from 16 March until 23 March when the blackout in Hustavika occurred - because of a failure of a turbocharger and consequently, of a large generator, the power generation capacity of Viking Sky was under the design propulsion power. As an alarming note, days before Hustavika, the Viking Sky - a cruise ship vessel compliant with the SOLAS's and SOLAS's Safe Return to Port requirements - and his operator have agreed to a compromise to maritime safety by sailing with one large DG out of operation and under the required propulsion power.

Moreover, the safety recommendations for cruise ships brought to attention the followings: the impact of early failure of turbochargers, importance of lubricants and their impact on vessels operation, required preparedness improvements for stormy conditions and blackout recovery procedures, the potential usage of digital twin, and the importance of a condition monitoring and a preventive/predictive maintenance. With regards to a careful and adaptive route planning, the Norwegian Coastal Administration launched new digital routes which aim to reduce time during voyage planning and to reduce the risk of unfavourable routes selection.

The cruise shipping activities and traffic in the Arctic and Antarctic areas are estimated to increase in the coming years. The blackout of the Viking Sky cruise ship in March 2019, Hustadvika, Norway, has indicated the vulnerability of ships in harsh environmental conditions, the far reaching potential safety implications, and tremendous challenges linked with an Arctic emergency response.

The IMO codes and standards such as SOLAS, Safe Return to Port (SRtP), the International Code for Ships Operating in Polar Waters or Polar Code are the best available codes and standards at this time, but do not necessarily set the maximum requirements for the maritime safety. Consequently, changes and continuous improvements, preparedness for uncertainty and accountable actions are all required in order to ensure safety at sea. The near to disaster 2019 Viking Sky requires stricter and more effective maritime safety regulations to be adapted and implemented at the earliest.

Among the lessons for the cruise operations in the Arctic and Antarctic areas, updates to the Polar Code are required together with initiatives and close collaborations among the Arctic coastal states. The failure encountered by the Viking Sky in the Norwegian waters determined the appointment of the Norwegian Government's Cruise Committee which is to make recommendations to the Norwegian Government.

Among the technological solutions which aim to increase the safety in the Arctic and Antarctic areas and to improve the system reliability, a digital twin solution for monitoring, maintenance and life prediction of ship propulsion systems in ice is on the way to be implemented. The digital twin based condition monitoring can be seen as an innovative approach in order to implement and develop further the condition monitoring in the marine industry.

As a practical recommendation, the classification society, and the component manufacturers need to support and require the operators of ships to further implement and develop the condition monitoring towards a prognosis approach.

Learning from failure of Viking Sky can bring insightful empirical grounds for specialists, cruise operations and cruise risk assessment. Moreover, it supports a dynamic learning within the cruise industry through improvements of safety control structures, enhancement of risk management and maritime safety culture, and reduction of risk from future accidents.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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