OCEAN
Operator-Centred Enhancement of Awareness in Navigation

D1.1 - Identification of navigational accidents' root causes

September 2023

Co-funded by
the European Union

UK participants in Project OCEAN are supported by UKRI grant numbers 10038659 (Lloyds Register) and 10052942 (The Nautical Institute).

Project information

Project acronym:	OCEAN
Full title:	Operator-Centred Enhancement of Awareness in Navigation
Grant agreement:	101076983
Programme and call:	Horizon Europe, CL5-2022-D6-01
Project coordinator:	HVL
Contact:	ocean@hvl.no
Project duration:	36
Project website:	www.ocean-navigation-awareness.eu

Deliverable information

Deliverable number	D1.1
Deliverable title:	Identification of navigational accidents' root causes
Dissemination level:	PU
Deliverable type:	R - Report
License:	CC BY-NC-ND 4.0
Status:	Submitted
Due date:	30/09/2023
Submission date:	30/09/2023
Work Package:	1
Lead Beneficiary:	HVL

Disclaimer

Copyright and license information

Revision History

Date	Version	Author	Comment
02/02/2023	V0.01	ML, HVL	Creation of document outline
27/02/2023	V0.02	ML, HVL	First draft content of Section 1
03/04/2023	V0.03	ML, HVL	Deliverable structure for review
28/07/2023	V0.04	ML, HVL	Final draft for pre-review
07/08/2023	V0.1	ML, HVL	Review submission
23/08/2023	V0.2	ESP, HVL	Review version
31/08/2023	V0.3	ML, HVL	Amended version
20/09/2023	V0.4	ML, HVL	Revised after review comments
22/09/2023	V0.5	ML, HVL	Revisions accepted by reviewers
29/09/2023	V1.0	Solveig Lund Witsø Risk and Quality Manager, HVL	Final check and approval for submission
29/09/2023	V1.0	Erik Styhr Petersen Coordinator, HVL	Final check and approval for submission

Author List

Institution	First name and Name	Contact information
HVL	Margareta Lutzhoft	mhl@hvl.no
LR	Jonathan Earthy	Jonathan.Earthy@lr.org

Abbreviations and acronyms

Abbreviation or acronym used in this document	Explanation
ALARP	As Low As Reasonably Practicable
AMSA	The Australian Maritime Safety Authority
ATSB	The Australian Transport Safety Bureau
BAM	Bridge Alert Management
BNWAS	Bridge Navigational Watch Alarm System
CHIRP	Confidential Human Factors Incident Reporting Programme
CREAM	Cognitive Reliability and Error Analysis Method
DMAIB	Danish Maritime Accident Investigation Board
DSS	Decision Support System
EMCIP	European Marine Casualty Information Platform
EMSA	The European Maritime Safety Agency
GISIS	Global Integrated Shipping Information System
HCD	Human-Centred Design
HF	Human Factors
ICT	Information and Communications Technology
IG P&I	The International Group of Protection and Indemnity Clubs
IMO	The International Maritime Organization
ISM	International Safety Management Code
IT	Information Technology
KPI	Key Performance Indicator
MAIB	The Marine Accident Investigation Branch (UK)
MAIIF	Marine Accident Investigators' International Forum
MARPOL	International Convention for the Prevention of Pollution from Ships
MARS	The Mariners' Alerting and Reporting Scheme
MEPC	The Marine Environment Protection Committee
MSC	The Maritime Safety Committee
MTO	(Hu)man, Technology, Organization
NTSB	The National Transportation Safety Board (USA)
OOW	Officer Of the Watch

OT	Operational Technology
PSC	Port State Control
SA	Situation Awareness
SHIELD	Safety Human Incident & Error Learning Database
SMS	Safety Management System
SOLAS	Safety of Life at Sea
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
TSB	The Transportation Safety Board of Canada
UNCLOS	United Nations Convention on the Law of the Sea
UNCTAD	The United Nations Conference on Trade and Development
UX	User eXperience
WSC	The World Shipping Council

Executive Summary

The aim of this report is to draw from experiences from past accidents – focusing on navigational accidents, in particular collisions and groundings. The pre-project hypothesis is that these accidents often are triggered by human error. However, there are equally often underlying, influencing factors comprising technical or organizational matters, as well as human behaviour. Performing any kind of joint analysis or averaging of data on causes was not possible, mainly because of the diversity and discrepancy of methods, taxonomies and causes. The method applied in task 1.1 being reported here uses several sources: Past accidents re-assessed by experts, follow-up interviews (added due to the taxonomy issue) with accident investigators and other experts, and statistics and literature reviews.

Extracting an overview of the results of the literature review (EMSA, 2022a, EMSA, 2022b, Allianz, 2022, Equasis, 2021) shows us that:

- The EMCIP special investigation reports that 28% of maritime incidents are navigation accidents.
- 70% of navigational accidents around Europe occur in internal waters.
- The relationship between accident event and safety recommendations is unbalanced.
    - Human action/factors 60% vs. recommendations 22%
    - System or equipment failure/ship related 24% vs. recommendations 60%
    - Safety Management System 2% vs. recommendations 51.5%

One main result from the empirical data collection is that not only is human error as a single cause an inappropriate dead-end conclusion to an investigation; there are many underlying factors to an accident. These results are backed up by analysis of all the data collected and provides a set of latent and less recognized causes of accidents and a limited number of interesting quantitative data points.

- The lack of ergonomics, work-oriented design and consistency causes concerns.
- Out of 225 navigational accidents, in almost 60% of the cases, the humans involved did not see the situation developing.
- In 229 accidents, plans were wrong or incomplete.
- Almost half the human action issues concern BRM, coordination and resources.
- Alertness can be impacted by fatigue or poor crewing levels.
- Experience is eroded by new technology but is crucial as a backdrop for interpreting situations.
- Technology both helps and hampers work, for example decision support systems can become disruptive in stressed situations.
- Trusting a system that projects trustworthiness can hide weaknesses in the system.
- Often need to allocate a crew member to managing alarms in critical situations.
- Increasing administrative burden causes workload, frustration on board and tension to the ship-shore relationship.
- There is an expectation that people will comply with rules, but no assessment if it is possible, and procedures and policies do not always match the way work is done.
- Maintenance and IT issues are emerging factors which could be underlying many others.

As part of the findings, there is a critical discussion of how much it is possible to learn from accidents and incidents – which concludes that the accidents we do investigate may not be the ones with the highest potential for learning, and that given the rapid technological change we need predictive methods to be able to address new risks and growing concerns.

Table of Contents

List of Figures

List of Tables

1 Introduction

The OCEAN project as a whole focuses on navigational accidents, in particular collisions and groundings. The overall aim of this task (1.1) is to shortlist the dominant causes identified, including latent or less recognized causes including lack of HCD and systems risks, thus qualifying the project pre-proposal hypotheses, but also to lend itself to continued quantitative and qualitative analysis using results from WP1, providing a solid basis for work in WP2.

Part of the work then is to validate the pre-project hypotheses: that navigational accidents predominantly are the result of a chain of events that often is triggered by human error. However, in those cases there are often underlying, influencing factors comprising technical or organizational matters, as well as human behaviour. These include but may not be limited to: Inappropriate standards and professional culture; Organizational and operational drivers and pressures; Improper and insufficient training; Lack of correct, timely and relevant information; Inadequate technology and technological design; Lack of situation awareness, including error in mentally processing data from bridge instruments and maintaining a correct mental model of the navigational situation; Poor planning and execution of manoeuvres.

> *It will go well for a long time, seafarers adapt, so they will save the day – until they don't. We cannot foresee every possible combination of things that can happen. But if we are not even trying it's not good enough.*
>
> Former accident investigator

The main outcome of an accident investigation is to determine the contributory factors and issue recommendations to improve the safety of life at sea and to avoid similar future accidents. Not surprisingly, most such reports focus on one case. This may be due to limitations in resources, such as time, funding, personnel (with the right competence) or the mandate that the investigating body has. Even with access to all necessary resources, data collection and analysis is done by humans with the perspectives and the biases (positive as well as negative) that entails. In addition, the narrative of an accident should preferably be reduced to actionable and enforceable conclusions and recommendations, or at the very least challenge the industry.

These factors mean that there is much potentially useful data left outside the investigation and/or the analysis – which could be used to draw a wider picture of hazardous practices that apply to the maritime industry. One notable exception to this is the extensive study performed by MAIB and DMAIB (2021), on the application and usability of ECDIS. The foreword summarises that "Current system shortcomings, compounded by limited bathymetry data, make safe navigation challenging"[1].

There are multiple ways to talk about causality, for example root causes, dominant causes, underlying, latent or contributory factors. It would have been preferable to work with one concept, such as *contributory factors*. In this report, most of the concepts will be used interchangeably. This is not to be interpreted as the project taking a stance on which is the most useful concept, nor about causality or blame.

In summary, the reader should keep in mind that the majority of actors in the maritime domain are compliant, safe and care about their crew. The focus here on accidents and underlying causes may paint a gloomy picture, but this deliverable is dealing with a small part of the industry and the work is intended to help reduce that fraction even further.

[1] Joint statement by Oessur Hilduberg, Head of the DMAIB and Andrew Moll, Chief Inspector of Marine Accidents, MAIB.

1.1 Relevant objectives for WP1

There are 3 objectives for WP1 that are relevant to this deliverable:

1. In-depth reassessment of publicly available navigational accident investigation reports.
2. Assessment of navigation accident probabilities, consequences and risk.
3. Synthesis of findings with experience-based knowledge

The work on achieving these objectives will be performed using a holistic approach and several sources:

- Past accidents re-assessed by senior navigators and other maritime experts,
- Accident investigator and other expert interviews,
- Statistics and literature reviews.

1.2 Intended readership

The readers of this document will be project internal - partners, and project external, including regulators, accident investigators, educators, ship and technology designers, manufacturers, and shipping companies.

1.3 Structure of the document – reading guidance

The document starts with a methods section, followed by an overview of accident statistics, supplemented with information about the world fleet, inspections and detention and accident analysis. This is followed by information about the data collection performed with experts, and reports of the findings. The report ends with a discussion and a summary chapter.

1.4 Relationship to other deliverables

The causes identified here lend themselves to continued analysis, certainly qualitative and to a lesser degree quantitative (further discussed in section 3.6 and chapter 7). The findings will serve as input to task 1.2 - providing a sounding board for the KPIs, and some take home messages/conclusions can work as input to task 1.3 for the continued accident analysis work. It will also provide a basis for work in task 2.1.

2 Research design and procedure

This section briefly introduces the research design, and the details of the procedure and data collection is available in chapter 4.

Statistics and literature have been reviewed and is presented in the background and integrated with results as appropriate. The literature includes material from IMO, EMSA, Allianz, Equasis, UNCTAD and WSC. In addition, in accordance with the task description, past accidents were re-assessed by senior navigators and other maritime experts.

The questions we have asked of the gathered material include:

- What is happening, contributing factors?
- Which ships are most at risk?
- Where is it happening?
- Why is it happening?

As the study progressed, but still quite early on, the realisation grew that there was a very low level of useful detail on navigation accidents and human behaviour in accident reports, especially data that could be used to identify future trends and risks. Therefore, it was decided to include accident investigators in the interviews, to assess what was available in that regard. As the general lack of such data was confirmed, they were also interviewed about what would be needed to address the issue.

The literature search was based on snowballing, starting with EMSA, finding links and references, and following up on suggestions provided by the interviewees. The empirical data collection method was mainly interviews, performed online in Teams, recorded and transcribed. Experts were invited from within the project as well as outside. More detail on the procedure is provided in chapter 4.

3 Accident statistics

This chapter covers the first objective of WP1: In-depth reassessment of publicly available navigational accident investigation reports. Much of the information in this chapter is from the EMSA Annual Overview of Marine Casualties and Incidents 2022. The report presents "statistics on marine casualties and incidents which involved ships flying a flag of one of the EU Member States and occurred within EU Member States' territorial sea or internal waters as defined in UNCLOS or involved substantial interests of EU Member States, as reported by Member States in the EU database for maritime incidents EMCIP (European Marine Casualty Information Platform)".

3.1 What happened?

Maritime accidents, incidents or occurrences are categorised slightly differently across various databases. Here, we present the EMSA statistics relevant to navigation accidents over several years.

- The total number of reported marine casualties and incidents over the period 2014-2021 is 21,173. The total number of reported marine casualties and incidents in 2021 is 2,637 (EMSA, 2022a).
- The most common occurrences with ships are *Collisions*, and *Loss of control - loss of propulsion power*, where the latter has exceeded the former since 2018.

A recent report by EMSA (2022b) studied a subset of the EMCIP data covering navigation accidents (collisions, groundings and contacts) involving passenger ships, cargo vessels and service ships between 2011 and 2021. The incentive was to apply the EMSA methodology to detect safety issues on cases that are horizontal to different types of vessels. During that period, there were over 8,800 occurrences of navigational accidents which is 28% of the total dataset. Around 41% of the events concerns contact, 30% collisions and 29% groundings.

3.2 Where do accidents happen?

This section provides a brief overview of the location of casualties and incidents, both in terms of geography and voyage segment.

3.2.1 Globally

Allianz data shows that the British Isles and surrounding waters have the most casualties/ incidents with total losses included – 679 out of 3032 (
Figure 1). They are closely followed by the East Mediterranean and Black Sea with 584. However South China, Indochina, Indonesia and the Philippines is the main *total loss* hotspot, accounting for one-in-four total losses (10/38). The East Mediterranean and Black Sea region is the location of the most shipping incidents over the past decade (Figure 2), closely followed by the British Isles (Allianz, 2023).

Top 10 regions	Loss	Annual change
British Isles, N.Sea, Eng. Channel and Bay of Biscay	679	+9
East Mediterranean and Black Sea	584	+47
S.China, Indochina, Indonesia and Philippines	242	-34
West Mediterranean	191	+14
Great Lakes	186	+64
North American West Coast	148	+10
Iceland and Northern Norway	138	+33
Baltic	119	-5
Newfoundland	108	+22
Japan, Korea and North China	88	-15
Other	549	
Total	3,032	+32

Figure 1: All casualties/incidents including total losses 2022 by region (Allianz, 2023)

Top 10 regions	Loss
East Mediterranean and Black Sea	4,969
British Isles, N.Sea, Eng. Channel and Bay of Biscay	4,938
S.China, Indochina, Indonesia and Philippines	2,598
Great Lakes	1,529
Baltic	1,433
Japan, Korea and North China	1,255
West Mediterranean	1,208
North American West Coast	1,156
Iceland and Northern Norway	1,136
West African Coast	911
Other	6,344
Total	27,477

Figure 2: All casualties/incidents including total losses 2013 - 2022 by region (Allianz, 2023)

3.2.2 Europe

Half of the total number of casualties and incidents around Europe between 2014-2021 occur in internal waters (Figure 3), with most of the remainder in territorial (25%) or open sea (20%), and only a few percent in inland waters.

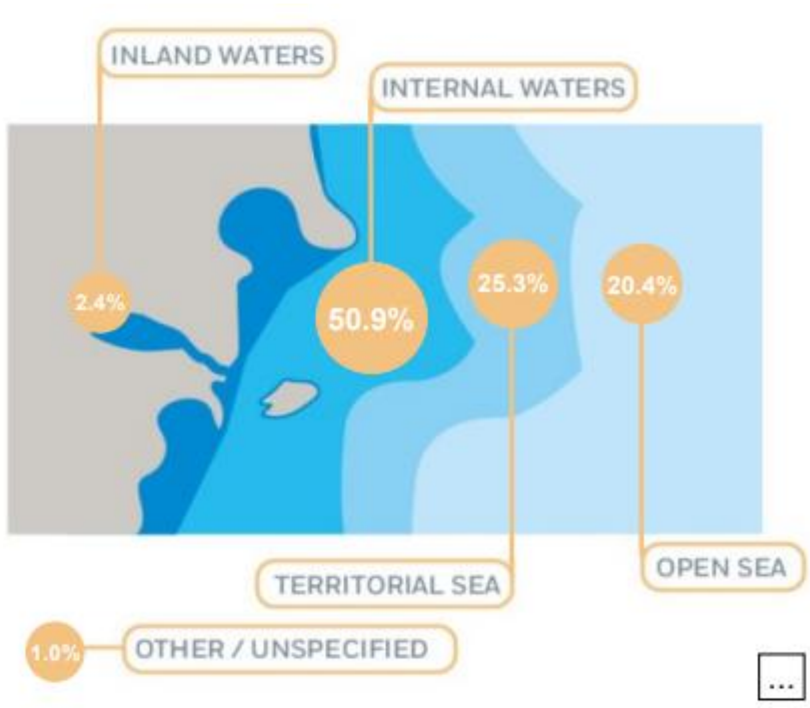

Figure 3: Percentage of marine casualties and incidents for the period 2014-2021, organized by navigational area (EMSA, 2022a)

Looking at navigational accidents only, the picture changes (Figure 4). Internal waters represent 70%, territorial sea 19%, inland waters and open sea only 4% each. This is not surprising given the increased traffic, closeness to land and shallow waters.

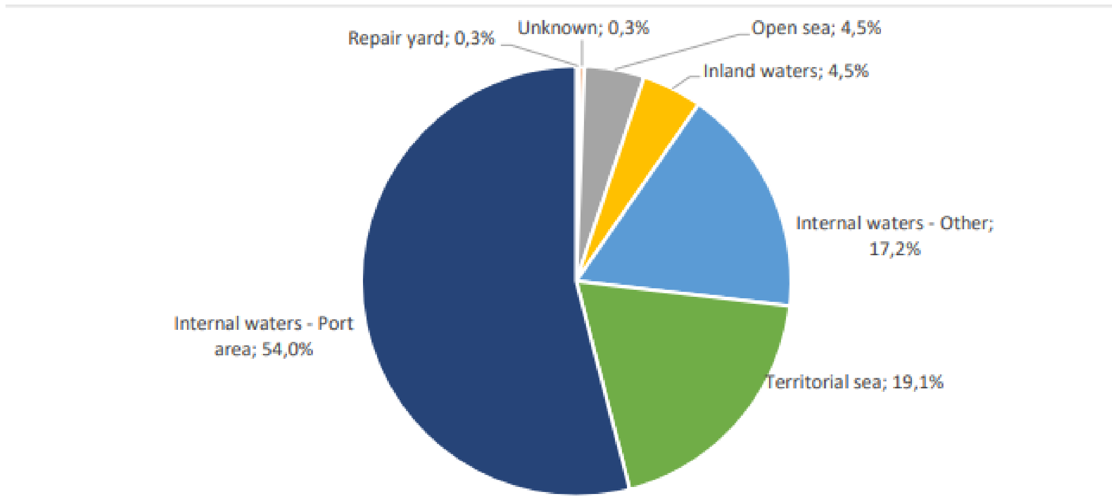

Figure 4: Distribution of casualty by sea area - Navigational accidents only (EMSA, 2022b)

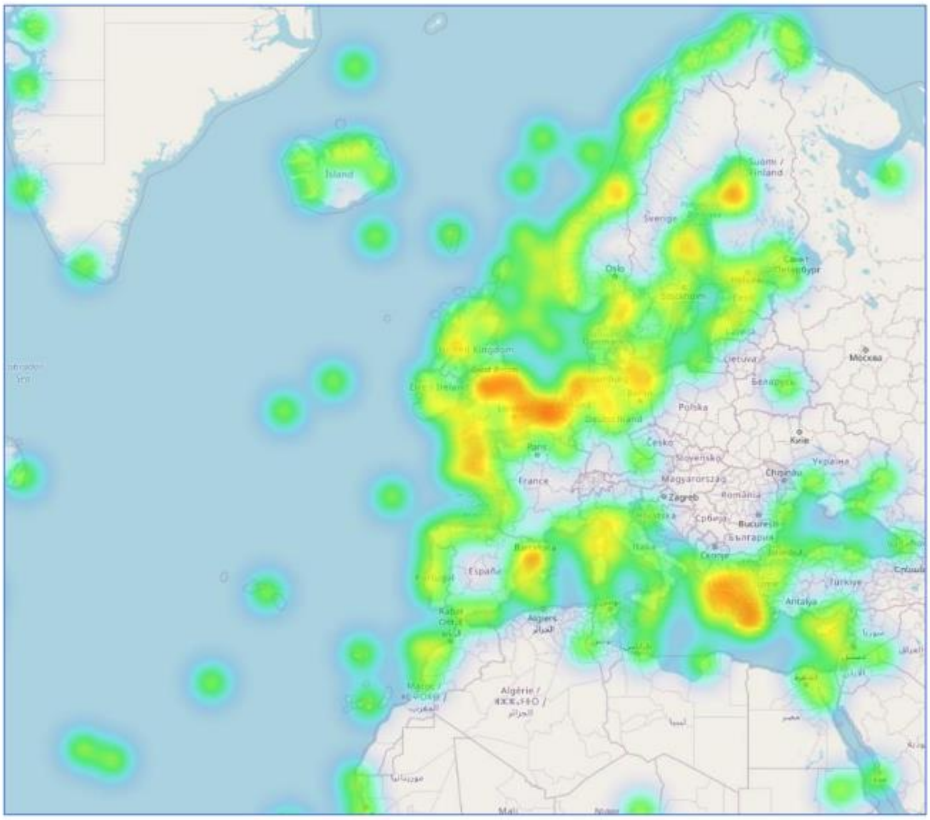

Figure 5: Heatmap of navigation accidents (EMSA, 2022b)

Contextualizing these numbers in EU-EEA waters we see the locations most at risk; UK waters and North Sea, North Baltic and eastern Mediterranean Sea (Figure 5).

3.2.3 Voyage segment

Voyage segment also plays a role – the most common part of a voyage is *en route*, followed by anchored or alongside, arrival and departure (Figure 6).

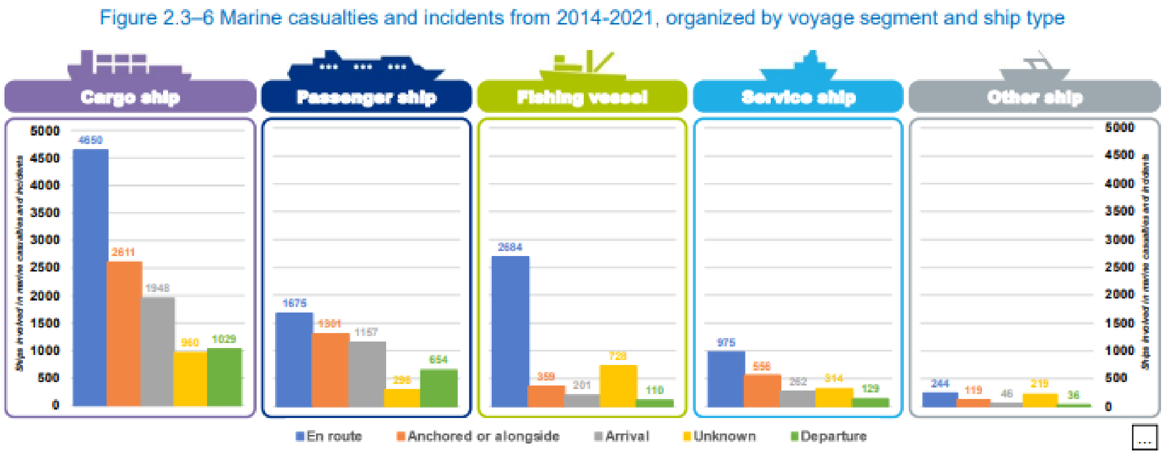

Figure 6: Marine casualties and incidents 2014-2021 by voyage segment (EMSA, 2022a)

3.3 To whom do accidents happen?

On average, accidents happened to old cargo ships under an EU flag.

- The average yearly number of ships involved in reported marine casualties and incidents during the period from 2014 to 2021 is 1,400 for cargo ships, 635 for passenger ships, 510 for fishing vessels, 280 for service ships and 83 for other ships. (EMSA, 2022a).
- On average, during the period from 2014 to 2021, 70.5% of the marine casualties and incidents reported in EMCIP have an EU State as coastal State. In 2021 an EU State is reported as coastal State in 74.8% of the reported marine casualties and incidents (EMSA, 2022a).

Take-home message

- The EMCIP special investigation reports that 28% are navigation accidents.
- British Isles and surrounding waters have the most incidents (including total loss).
- South China, Indochina, Indonesia and the Philippines have the most total losses.
- 70% of navigational accidents around Europe occur in internal waters.

3.4 Accident investigation

The perspectives on causation are different depending on who you talk to, or where you get the data. The Nautical Institute book *Navigation Accidents and their Causes* – written by ship masters – focuses mainly on operations (scenarios) and illustrates an operational focus on how 'accident data' are categorised, interpreted, and put to use. This contrasts with the EMSA-controlled EMCIP database, that year after year reports a high "human error" component. A third approach is taken by MARS[2] (Mariners' Alerting and Reporting Scheme) and CHIRP (Confidential Human Factors Incident Reporting Programme) both of which focus on extracting learning from events, mainly by presenting short narratives of the incidents.

Most reports and publications on maritime accidents highlight that human error is the cause of a majority of the accidents. This appears to be (or is even presented as) an unsolvable and unchanging problem. However, if we change our perspective – perhaps seeing human error as the start of an investigation rather than the conclusion, we might make headway. The traditional view on safety, known as S*afety-I,* has been challenged by researchers proposing the *Safety-II* perspective. *Safety-I* is where as little as possible goes wrong; the absence of accidents is safety. On the other hand, *Safety-II* relates to a system's ability to succeed under varying conditions and moving from ensuring that 'as few things as possible go wrong' to ensuring that 'as many things as possible go right' (Hollnagel, Wears & Brathwaite, 2015). The problem is that we do not collect data on what goes right.

Many existing taxonomies for collecting and analysing accident data are either oversimplified, leading investigators directly towards human error, or imposing hundreds of categories on the analysis work, making it nigh impossible to overview. To make matters even more complex, it is not always clear who is responsible for safety improvement. Some regulators may not be accountable for safety as they do not have responsibility for collecting accident data[3].

Under the Safety of Life at Sea (SOLAS) convention, flag states are required to submit accident reports to the International Maritime Organization (IMO). Under SOLAS regulation I/21 and MARPOL articles 8 and 12, each Administration undertakes to conduct an investigation into

[2] https://www.nautinst.org/technical-resources/mars.html
[3] From interviews.

any casualty occurring to ships under its flag subject to those conventions and to supply the Organization with pertinent information concerning the findings of such investigations if: .1 it judges that such an investigation may assist in determining what changes in the present regulations may be desirable; and/or .2 the casualty has produced a major deleterious effect on the marine environment[4] (MSC MEPC.3/Circ 3). Depending on the seriousness of the casualty, more data and a more detailed investigation is needed.

There are also internal investigations of near-misses and sub-reportable accidents for the purpose of organisational or sector learning. These happen but are not reported publicly (not least because of financial, confidentiality and security issues).

3.4.1 IMO and EMSA

The Global Integrated Shipping Information System (GISIS) is managed by the International Maritime Organisation, thus supporting the dissemination of investigation data reported at a global level. The IMO are mainly interested in SOLAS size ships, so near misses or less consequential accidents would not be in GISIS.

The European Marine Casualty Information Platform (EMCIP) is a database and a data distribution system which is operated by EMSA, the European Commission and the EU/EEA Member States. Reporting to EMCIP has been mandatory since June 2011. Most nations report their accidents into EMSA, and if they do not then they will be logged in national systems. For example, the UK used to, pre-Brexit, submit all their accidents[5].

The way data are collected and categorised will impact on what can be found in an analysis. There is a continual trade-off between few categories and ease of sorting, versus many categories and the possibility of a fine-grained analysis. In the EMCIP taxonomy, each marine casualty and incident can have one or more accident events. Contributing Factors are factors that play a part in the cause(s) of the Accident Events, they are always related to an Accident Event and are catalogued in three main types (below) and 21 sub-types:

- External Environment
- Shipboard Operation
- Shore Management

The EMCIP taxonomy also includes third and fourth levels for Contributing Factors. The total number of possible Contributing Factors to choose from are 185 (37 External Environment, 72 Shipboard Operation and 76 Shore management). In appendix 2 of the EMSA annual report (2022) it is commented that such a great taxonomy increases the difficulty of the analysis. Therefore, in the report, the Contributing Factors categories are simplified by structuring them in four categories:

• Human behaviour
• Environment (internal or external)
• Rules, procedures and training
• Tools and equipment

This new categorization of Contributing Factors is said to facilitate the analysis. 'Human behaviour' was the most important contributing factor category, with 50.3% of the contributing factors. It was followed by 'Environment' with 29.2% of the contributing factors. The analysis obtains a similar trend for all the ship types (EMSA, 2022a).

---

[4] https://www.imo.org/en/OurWork/MSAS/Pages/Casualties.aspx (MSC MEPC.3/Circ 3).
[5] From interviews

3.4.2 Other investigation organisations

There are a few different types of maritime/transport accident investigators and/or databases. The first is national investigative boards in for example the UK, USA, Canada and Australia. The second is voluntary schemes such as MARS and CHIRP, thirdly there are national or regional incident reporting systems and company internal incident reporting. It is important to be aware that the datasets will be skewed to the areas who report to them.

- The MAIB in the UK publishes annual reports, Safety Digests with lessons learned and flyers on specific topics. The UK is a small flag compared with others, with national requirements to report. The MAIB is unusual in that they are responsible for collating accident data, often this is a regulator responsibility in most domains.
- DMAIB in Denmark publishes investigation reports, summary reports and safety reports. One notable special report is the one about the application and usability of ECDIS, together with MAIB (UK). https://dmaib.com/reports/2021/application-and-usability-of-ecdis
- The National Transportation Safety Board (NTSB) in the USA conducts accident investigations and safety studies, issue safety recommendations, and conduct transportation safety research studies.
- The Australian Transport Safety Bureau (ATSB) performs independent 'no blame' investigation of transport accidents and safety occurrences, safety data recording, analysis and research. The independence means that they can issue safety recommendations but not police them.
- AMSA has published an annual report for domestic commercial vessels that also includes an analysis of investigation reports using a safety framework that AMSA and ATSB developed which is used as a basis for decision making in relation to where they focus their efforts, given limited resources[6].
- NTSB and ATSB both have a searchable database.
- The Transportation Safety Board of Canada (TSB) conducts independent investigations into transportation occurrences; if necessary, communicates important safety deficiencies to those able to address them right away, before an investigation is complete; reports publicly on the investigation, the factors that caused or contributed to the occurrence, and the safety deficiencies that need to be addressed; makes and follows up on recommendations designed to eliminate or reduce safety deficiencies found in the course of investigations[7].
- Another approach is taken by MARS[8] (Mariners' Alerting and Reporting Scheme), a confidential reporting system run by The Nautical Institute. MARS has a free searchable database and publishes short stories with a focus on extracting learning from events. In a similar vein, CHIRP (Confidential Human Factors Incident Reporting Programme), collects reports from aviation and maritime – making the data available as a learning resource in the form of reports, digests and videos.

3.4.3 Safemode

According to the website for the Safemode project[9], a core element of the project is the Open Data Repository; SHIELD (Safety Human Incident & Error Learning Database). This database and its taxonomy enable systematic analysis and collection of Human Factors elements in safety occurrences (incidents/accidents) in transportation, especially for aviation and maritime operations. Data queries using SHIELD will provide feedback to system and

---

[6] From interviews
[7] https://www.tsb.gc.ca/eng/qui-about/enq-inv.html
[8] https://www.nautinst.org/technical-resources/mars.html
[9] https://www.safemodeproject.eu/shield.aspx#safemode-hf-taxonomy

operation designers, to safety management, and is also claimed to provide quantification of human components in safety risk models.

The taxonomy has 4 levels, where each of the levels have subheadings, that in turn are divided into supporting text/categories. The levels (number of subheadings & categories) are:

- Acts (5 & 18),
- Preconditions (12 & 51),
- Operational leadership (3 & 13) and
- Organisation (4 & 17).

SHIELD has been tested and the testers commented that the SHIELD Taxonomy and tool supported them in considering factors that they would not take into account otherwise. They also found the SHIELD tool very intuitive, with practical descriptions for the taxonomy items, which supports decision making of the investigators, leading to more accurate findings. The taxonomy includes 99 factors in total, and it appears that the number of factors is not the only element that makes a tool hard or easy to use. According to our interviews, it is being discussed whether this taxonomy will replace the CREAM model currently used in EMSA, and that 99 factors is manageable, generally it works for aviation, and fewer categories may make it less useful.

Take-home message

- Using existing accident reports or databases for re-analysis is complicated because of:
  - Multiple accident investigation taxonomies
  - Multiple underlying reasons for investigations
  - Data sets are different, and in many cases very hard to query
- New taxonomies have been tried but had to be simplified
- The SHIELD taxonomy and tool may be implemented by EMSA, and is highly regarded

3.5 Why did the accidents happen?

Given the above discussion, and remembering the limitations, the most accessible data set at present is the EMCIP. Therefore, the following sections on 'why' accidents happen will be using that data. Each marine casualty and incident can have one or more accident events. However, when presented in EMCIP, these overlaps disappear as they are shown as single event types. The five accident event types are (percentages for 2014-2021,
Figure 7):

- 'Human action' (59,6%)
- 'System or equipment failure' (24,5%)
- 'Other agent or vessel' (8,6%)
- 'Hazardous material' (5,3%)
- 'Unknown' (2%)

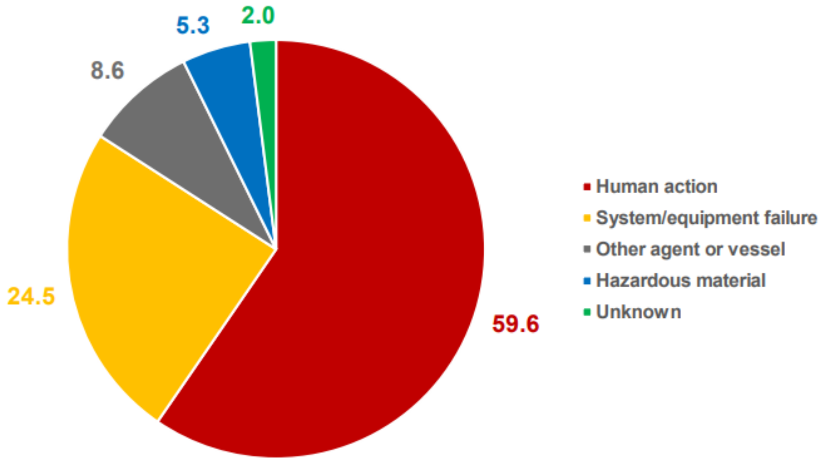

Figure 7: Percentage of accident events for the period 2014-2021, organized by accident event types (EMSA, 2022a)

The percentage of accident events for different ship types is similar across all ship types; 'Human action' is always the main accident event type, and 'System/equipment' failure is higher for passenger ships and fishing vessels and lower for cargo ships. Each accident event can have one or several contributing factors, presented as the following three types: 'External environment', 'Shore management' and 'Shipboard operation' (Figure 8). The most important contributing factor was 'Shipboard operation' was, with 70% of all the contributing factors. 'Human action' was the main accident event type, with 68.3% of all the contributing factors, followed by 'System/equipment failure' with 18.8% of all contributing factors. When this distribution was analysed individually for every ship type for the period from 2014 to 2021, similar trends were found for all ship types.

However, comparing this to Allianz (2023) reveals that half of their 3032 incidents were caused by machinery damage or failure. Their primary data source for total loss and casualty statistics is Lloyd's List Intelligence Casualty Statistics, and illustrates the argument form the beginning of this section on different data sets and categorisation.

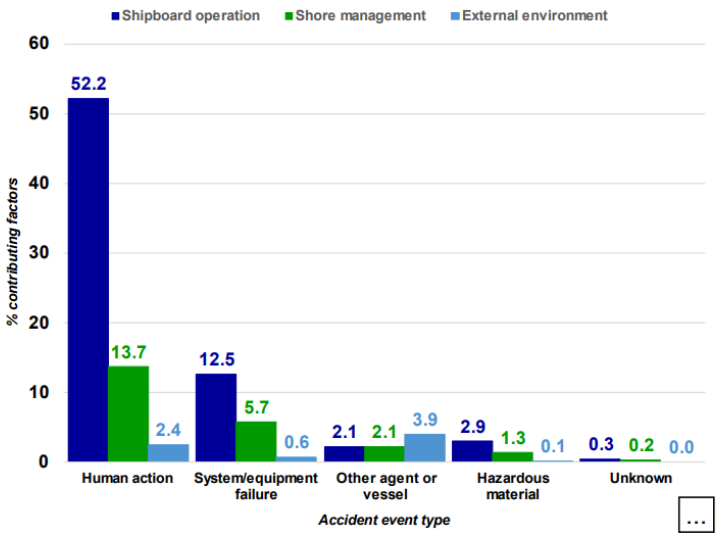

Figure 8: Percentage of contributing factors for the period 2014-2021, organized by contributing factor types and accident event types (EMSA, 2022a)

Safety recommendations and actions taken, as reported by EMSA (2022a), include 45% ship related procedures, 22% human factors, 15% ship structure and equipment and 14% other procedures. The recommendations and actions were addressed to 54% owner/company and 20% maritime administration, and with small percentages port authorities, shipyards, class and PSC.

Take-home message

- An incident can have one or more accident events. Pie charts do not illustrate this.
- An accident event can have one or more contributing factors (ship, shore, external).
- The relationship between accident event and safety recommendations is unbalanced.
  - Human action/factors 60% vs. 22%
  - System or equipment failure/ship related 24% vs. 60%
- Causes vary significantly depending on the basis of the underlying data.

3.5.1 Navigational accidents

A recent meta-analysis was performed on EMCIP data (EMSA, 2022b), on navigation accidents only, as mentioned in Section 3.1. The data comprise collisions, contacts and groundings. An *accident event* indicates significant events leading to the *casualty event*. For example, a failed piece of equipment (accident event) can lead to a grounding (casualty event). In EMCIP, each casualty event can be associated with one or more accident events. The following sections summarise the findings of the two topics human action and safety issues.

Human Action

The analysis considered 351 safety investigations encoded in EMCIP, where 573 accident events were associated to navigation accidents. Human action is the most reported category (447 events). However, the report claims that it is widely accepted by the EU AIB community that human errors alone cannot explain why a marine casualty occurred. The accident event "Human action" is used in reporting human performance in EMCIP, which implements an approach based on the CREAM (Cognitive Reliability and Error Analysis Method) model (Hollnagel, 1998)[10]. One of the ways of structuring data according to the CREAM model is to use the terms analysis and synthesis: "Analysis" is used when a person tries to determine what the situation is, which could mean observation, identification, recognition, diagnosis, etc. Analysis in EMCIP is subdivided into "observation" and "interpretation". These describe aspects of gathering data and information from the devices or the environment, as a reaction to a signal/event or as a result of actively searching for information. "Synthesis" is used when a person decides what to do and how to do it, which typically includes choosing, planning, scheduling, etc[11].

---

[10] Disclaimer (written 2012) by Erik Hollnagel: Although CREAM still appears to be used and referenced, it is only fair to point out that the method from my point of view is obsolete. There are several reasons for that. First, because it focuses on how actions can fail, rather than on the variability of performance, i.e., a Safety-I perspective (q.v.). Second, because it focuses on one part or 'component' of the system only, namely the human(s).

[11] It is possible to carefully map the three CREAM concepts observation, interpretation and planning onto the SA model concepts perception, comprehension and projection (Endsley, 1995):

- **Perception (Level 1 SA)**: The first step involves the processes of monitoring, cue detection, and simple recognition, which lead to an awareness of multiple situational elements and their current states.
- **Comprehension (Level 2 SA)**: Requires integrating this information through pattern recognition, interpretation, and evaluation to develop a picture of that portion of the world of concern to the individual.
- **Projection (Level 3 SA)**: involves the ability to project the future actions of the elements in the environment.

The following three tables show the number of times the three concepts were applied to the dataset of 351 investigations (in which human action was encoded 447 times). What we can see is that from a data set of 225 events, in more than half, an observation was missed, or a cue overlooked (Table 1). The next data set of 255 events show that more than half of the interpretations or decisions were delayed or incorrect (Table 2). Finally, the planning stage shows 229 cases of incorrect or incomplete plans (Table 3). The information does not allow for analysis of overlap of the observation, interpretation or synthesis – i.e., which accidents or sequences of events included two (and which two) or three of these categories.

On the other hand, we can see that out of the 225 accidents, almost 60% of the people involved never saw it coming. This presents a unique challenge, if the information (if any was indeed available) was not even perceived, part of the solution may lie in something that precedes what is done with existing interfaces. Furthermore, delayed, incomplete, or incorrect interpretation and planning issues have consequences both for training and equipment design which may be slightly easier to address, discussed further in chapter 5.

Table 1: Human action general conditions (Observation) (EMSA, 2022b)

Observation	Nr.	%
Observation missed - Overlook cue / signal / measurement	129	57.3%
Local observation - Incorrect recognition/stimulus	46	20.4%
Local observation - Other	21	9.3%
Local identification - Partial identification	14	6.2%
Local identification - Mistaken cue	12	5.3%
Observation missed - Other	3	1.3%
Total	**225**	**100.0%**

Table 2: Human action general conditions (Interpretation) (EMSA, 2022b)

Interpretation	Nr.	%
Delayed interpretation	70	27.5%
Local diagnosis - Wrong diagnosis	45	17.6%
Decision error - Wrong decision	41	16.1%
Local diagnosis - Incomplete diagnosis	28	11.0%
Local prediction - Unexpected state change	16	6.3%
Local prediction - Process speed misjudged	12	4.7%
Wrong reasoning - Wrong priorities	11	4.3%
Wrong reasoning - Deduction error	9	3.5%
Decision error - Decision paralysis	8	3.1%
Wrong reasoning - Induction error	5	2.0%
Decision error - Partial decision	4	1.6%
Local diagnosis - Other	2	0.8%
Local prediction - Unexpected side	2	0.8%
Decision error - Other	1	0.4%
Local prediction - Other	1	0.4%
Total	**255**	**100.00%**

Table 3: Human action general conditions (Planning) (EMSA, 2022b)

Planning	Nr	%
Local plan - Wrong plan	97	42.4%
Local plan - Incomplete plan	78	34.1%
Priority error - Wrong goal selected	48	21.0%
Priority error	3	1.3%
Local plan	3	1.3%
Total	**229**	**100.00%**

Take-home message

- Out of 225 navigational accidents, in almost 60% of the cases, the humans involved did not see the situation developing. In the rest of the cases something was observed but misinterpreted.
- Out of 255 cases, around a quarter had delays in interpretation, 30% made a wrong or incomplete diagnosis, 30% made the wrong decision and in the rest something changed unexpectedly.
- In 229 accidents, plans were wrong or incomplete.

3.5.2 Contributing factors

The EMSA report on navigation accidents (2022b) also contains a chapter on contributing factors. This section reviews the main discussion and findings regarding *contributing factors*. The three most common safety issues linked to navigation accidents are work operation methods, organizational factors and risk assessment (Table 4), all topics that fall under the remit of the organisation and management.

Table 4: Safety issues (Directly & indirectly linked to navigation accidents) (EMSA, 2022b)

Safety Issues (SI)	CF Nr.	%
Work / Operation Methods	594	36.3%
Organisational Factors	310	18.9%
Risk Assessment	171	10.4%
Environment	139	8.5%
Individual Factors	119	7.3%
Tools & Hardware	117	7.1%
Competence & Skills	69	4.2%
Emergency response	61	3.7%
Operation planning	57	3.5%
Total	**1,637**	**100.0%**

The 594 cases of Work/operation methods were further subdivided into 12 areas of concern (AoC, Table 5) showing several instances related to teamwork, communication and the use of tools and technology.

Table 5: Work / operation methods areas of concern (EMSA, 2022b)

AoC	Nr. CF
BRM (Bridge Resource Management) Coordination	94
Use electronic equipment (navigation devices)	94
Work methods and supervision	63
BRM Resource availability	63
Communications (External)	53
Coordination with 3rd parties	48
Maintenance implementation on board	41
Alarm setup	41
Communications (Internal)	31
Use of equipment	26
Multitasking	26
SMS implementation on board	14
Total	**594**

Around 78% of the investigated navigation accidents were linked to "human action" (EMSA, 2022b). Taking this as a starting point rather than a conclusion, the continued analysis found that the causes were not simply 'human error', and these human actions were consequences of socio-technical interactions. Aspects of the sociotechnical system include humans, organizations, policies, procedures and machines. A qualitative assessment (not further explained) also highlighted several topics that warrant further study, outlined in the below sections.

3.5.2.1 Triggers of "human element" in navigation accidents

Many factors were found to interact in these navigation accidents, such as challenges with the coordination of the bridge team, ergonomic issues, lack of resources, completeness and realistic implementation of the SMS, and the use of technology, as Table 5 shows. Additionally, the crew often felt pressured to get the job done, leading to trade-offs in processes. The qualitative assessment indicated up to 46 areas of concern associated with human action, including the ones listed in Table 5.

3.5.2.2 Coordination of the bridge team, workload and resource availability

Forty-one per cent of safety issues reported in safety investigations were due to coordination and workload of crew, for example having the officer-on-watch alone on the bridge at night. The areas of concern include Bridge Resource Management Coordination, Bridge Resource Management Resource Availability, Fatigue, Multitasking, Resource Availability (Manning) and Cognitive Workload.

3.5.2.3 Shipborne technology

Technology is implemented to increase safety and reduce workload – but it is often found that as it may solve one set of issues, it introduces other effects and new risks. As the report states, technology is often both a trigger and a solution. The areas of concern include Use of electronic equipment (Navigation tools) and Alarm setup.

3.5.2.4 Bridge ergonomics and equipment design

Thirteen per cent of safety issues are related to bridge ergonomics and equipment design. Equipment and controls are installed without much thought to grouping according to how work is done, and different brands have different design strategies – prompting a need for different interaction styles. The areas of concern include Equipment design and Ergonomics bridge.

3.5.2.5 Procedures and working methods

The safety management system (SMS) appears to be similar to technology in that it does provide safety benefits but also introduces new risks. The new risks mainly stem from the establishment of procedures that do not always match the design of the ship or the way work is performed onboard. This leads to crew having to perform trade-offs and bypass procedures when the real world does not match the procedure (EMSA, 2022b). Interestingly enough, although this was the smallest category within 'human action' (2%), accident investigation boards issued most of their safety recommendations to the shipowners and companies (51.5%), mainly addressing operational procedures within the SMS). The areas of concern include all issues labelled procedures.

Take-home message

- Careful analysis will reveal the underlying factors to so-called human error
- Almost half the human action issues were about BRM, coordination and resource availability.
- Technology both helps and hampers work
- The lack of ergonomics, work-oriented design and consistency causes concerns
- Procedures and policies do not always match the way work is done

3.6 Conclusion of chapter 3

This chapter has reviewed accident statistics to extract information relevant to the first two objectives – the *reassessment of navigational accident investigation reports*, and the *assessment of navigation accident probabilities, consequences and risk*. It was assumed that the first objective, the reassessment, would provide data for the second, the probability, consequences and risk. To cover the third objective: *synthesis of findings with experience-based knowledge*, interviews with maritime experts were performed. These three objectives are the basis of the overall aim of the work; to shortlist the dominant causes identified, including latent or less recognized causes.

Is the existing data and material as complete as we hoped for? Not really. Even though only a limited number of major databases and summary reports were reviewed, there is a considerable diversity and discrepancy of methods, taxonomies and causes. The major issue with the existing data is that when the final cause has been established, the investigation often stops. There is insufficient analysis of the biggest number (human error/action) and of the second biggest number (equipment failure). This is probably due to the investigation toolset (questions, competence, analytic categories) and the problem (impossibility?) of simplifying a complex event without losing important context and detail.

For example, the EMSA analysis – using a simplified categorization of Contributing Factors to facilitate the analysis – ended up with 50% human behaviour. The simplification of categories was made because the existing framework was too complicated, but then it reduces granularity and possible learning. Even EMSA themselves say "human error alone cannot explain why a marine casualty occurred" (EMSA, 2022b).

All this makes it very difficult, if not impossible, to compare across databases, and even comparing reports and summaries from within the same database. This, in turn, makes it unfeasible to produce probabilities and risk as normally defined (quantitative). It could have been possible to extract some information about consequences, but also here several ways of categorising consequences are used, and furthermore, without the underlying 'root case' having data on consequences alone is of questionable use. However, information based on accident investigations in and of itself is not enough. Even considering other sources, the picture is not clear enough. For these reasons, it was decided to perform additional interviews with accident investigators, to attempt to uncover dominant and latent causes of navigational accidents and find out more about the status quo and the best-case scenario.

However, the statistics review was not completely unsuccessful, as it provided some interesting trends, for example the growing number of machinery-related causes and the high number of accidents in which the crew was unaware of the risk. More information is provided in the take-home points and the summary chapter. A shift towards new and more human-centred taxonomies and investigations was also evident, and a clear decrease in the use of 'human error' and increased efforts in probing accidents that would previously have been assigned that label. There are trends and indications that things are getting better, and that investigations and analyses are becoming more sensitive to the complexity of human and system behaviour.

4 Method - Interviews

This section covers the methods used to study objective 2 and 3 of the work performed in task 1.1, the assessment of navigation accident probabilities, consequences and risk, and the synthesis of findings with experience-based knowledge. Maritime experts were initially interviewed with the intention of re-assessing accident reports. As it became clear that the data review and the expert interviews would not suffice to reach the objectives, a series of interviews with accident investigators were performed. The findings are not presented separately for the different interviews, but as a whole, in chapter 5 and Annex 4, as described below.

4.1 Group interview 1 – maritime experts

Participants
Eight experts participated: 6 from within the project and 2 external experts. As a group, they represented researchers, former and current seafarers, engineers, maritime administration, accident investigation, and classification.

Procedure
Three accident reports[12] were selected based on the quality of the narrative and the accident type (two collisions – Helge Ingstad/TS Sola, McCain/Alnic MC and one grounding – Jambo). The reports were sent out in beforehand, and the experts were asked to prepare a 10-minute presentation, based on their own interpretation of what happened, mainly focusing on the narrative, and not the conclusions. The meeting was held on Teams (recorded), where everyone presented their findings which was followed by an open discussion.

4.2 Group interview 2 – accident investigators

Participants
3 experts participated, with professional experience of accident investigation (3), maritime administration (2), seafaring (2) and comprehensive education in Human Factors (1).

Procedure
The experts were invited by email and provided with a few themes to prepare for the meeting, including what they would ideally like accident investigation to be like, what was missing from current practice, the role of regulation and compliance.

The meeting was held on Teams (recorded) and was in the form of an open (but moderated) discussion. A clean version (removed repetitions and insignificant content) of the transcript was sent to the experts for checking.

4.3 Individual interviews

To complement the existing data on the trends that we were seeing from preliminary analysis, especially regarding the increasing numbers of machinery incidents and the growing suspicion that IT and OT are silent, emerging risks in the background, it was decided to make additional interviews.

Participants
Several individual experts and professionals were contacted. The interviewees together represented the following areas: classification, marine superintendent, ship electronics, naval architecture, accident investigation, maritime human factors, maritime IT management and technology for vessel monitoring and remote assistance. In total five experts were interviewed.

[12] https://havarikommisjonen.no/Sjofart/Avgitte-rapporter/2021-05-eng
https://www.ntsb.gov/investigations/accidentreports/reports/mar1901.pdf
https://www.gov.uk/maib-reports/grounding-and-sinking-of-general-cargo-vessel-jambo-off-the-summer-islands-scotland

Procedure
The experts were invited by email which included the following text: 'We would like to invite you to discuss, for an hour or so, how OT and IT actually works and how accident reports may not get the real story about the involvement of complex computer-based technology in accident causation or exacerbation'. The meetings were held on Teams (recorded) and was in the form of an open (but moderated) discussion. A clean version (removed repetitions and insignificant content) of the transcript was sent to the experts for checking.

4.4 Ethics and analysis

The study procedure has been reviewed by Sikt (Norwegian Agency for Shared Services in Education and Research). All participants signed an informed consent form.

The analysis was based on personal notes and the transcripts of the recordings. During early analysis the data were grouped according to the objectives and aim of the task, to arrive at a shortlist of dominant causes, including latent or less recognized causes, and to provide insight into why this could not be done by reviewing accident reports alone. In the majority of cases the excerpts consisted of interviewee statements which where were direct and clear. Very little interpretation has been done on the data. The results are presented in chapter 5, providing input to design and a section on emerging and contributory causes.

The findings of group interview 1 were variable and showed how difficult it is to move beyond a given conclusion. This can be an effect of the selection of experts and the choice of accident reports, and of the moderation of the interviews. However, analysed together with the larger dataset, there were useful points. These insights have been included in chapter 5, relating to the current state of accident investigation, input to design and the emerging and contributory factors.

The findings from group interview 2, with accident investigators were forward-looking and reflective. They are presented mainly in Annex 4, providing a critical and constructive representation of accident investigation.

The final set of interviews were focused on selected individuals to provide additional information and some validation of trends that were becoming evident in the total data set, including accident data, literature, and previous interviews. The findings are mainly included in chapter 5, in emerging and contributory factors and some input to Annex 4 on accident investigation.

5 Findings

This chapter presents *emerging and contributory factors to accidents*. The information used here comes from the entire set of interviews as well as literature, and addresses objective 3: synthesis of findings with experience-based knowledge. The findings in 5.1 and 5.2 are based on interview excerpts, at times supported by literature. The findings in 5.3 were assembled from the findings in section 5.2 and mapped against situation awareness levels. The consequence, in terms of the OCEAN project, are to be found in section 8 'Annex 1: Input to OCEAN Technology Development'.

5.1 Usability

One participant commented that the maritime industry likes new solutions that are ready. Most are risk averse to take on unproven equipment. This is a problematic mindset – if we want good tools, there needs to be trial and error. And we only know the quality of it when it has been tried in the wild. We need space to experiment and figure out how it works over time. But we cannot sell a prototype. A response was that in IT there is a community of beta testers. We do not have beta testers in maritime. There are few upgrades, and installations tend to be fit and forget, so that the product is frozen in time.

> *[Maritime electronics company] claims that: performance standards hamper us for making good systems. We can make better things for the leisure industry.*
>
> *From a design point of view it's a training problem. For me the question is what do we need to bring on board and how to make it work. We shouldn't train people to used poorly designed systems. I don't think the seafarers are the problem. The shipping office, the people buying the systems. Match the needs of the people put onboard to do a task – that should be our focus, to help the perform better. What IS supporting them? The seafarers' statements not to be taken at face value but start with them. It's not about what we can do or create but what we want to achieve.*
>
> *It's easy to focus on UX but the interaction lives in a broader environment which is not understood by UX. Then you just need to be trained. The manufacturers should be in our investigations and we should demand more of them. If a thing can be sold, that's fine, but does it match the needs?*
>
> *OCEAN Interviewees*

5.2 Emerging and contributory factors

The MTO (human, technical, and organisational factors) model has been used here to group the conditions we have found to be underlying the more overt causes; some of them are well known whereas others can be regarded as emerging or becoming visible. Not many of them have been addressed in any coherent way. Most, if not all, are qualitative. The first is human living and working conditions – and the effect this has on human actions, the second is organisation level issues and the third is technology. The fourth is a special case of technology, the growing implementation of, and reliance on, ICT.

5.2.1 Human living and working conditions

An investigator commented that most of the navigational accidents they are seeing have an element of issues with alertness which is often related to fatigue. This was shown by the MAIB in 2004[13], where the presence of two-watch systems (6 hours on and 6 hours off) leads to fatigue and is a symptom of low crewing levels. The problem does not seem to have decreased.

---

[13] https://www.gov.uk/government/publications/bridge-watchkeeping-safety-study

In addition, one interviewee commented that the navigational systems are not really set up for people with very poor cognitive states. A poor cognitive state can include fatigue, low alertness, and mental health issues, to name a few. Sampson, Ellis, Acejo and Turgo (2017) observed a deterioration in seafarers' mental health between 2011 and 2016, from 28% of respondents to 37% in 2016[14]. Fewer crew, taxing watch systems where you work nights and sleep days, technology taking over more of the interesting bits of the job, may lead to something an interviewee called 'low-intensity monitoring':

> *Yeah, we can expect people to be bored and fall asleep, so we have to have some countermeasures for that, absolutely.*
>
> *OCEAN Interviewee*

The lack of effective navigational performance links to this strongly – and the trend towards increasing amount and complexity of technology intensifies the problem. More alarms are conceived of and implemented, but many alarms are disabled, and an accident investigator comments that it would appear from the evidence that people are happy to almost exclusively follow the prompts in response to electronic triggers. This 'working to alarms' increases the passive way of working. More policies are implemented but many seafarers are lacking operational skills and may have language issues – which compounds the problem of understanding rules and policies. A Master said:

> *[it's surprising] how many different nationalities, backgrounds, experience levels and … the different paths people have followed and how different the people arrive on board.*
>
> *OCEAN Interviewee*

The interviewees also point out that technology deteriorates the skill of reading the physical environment – the ability to detect things and understand what is going on around you. The integration work is still ongoing (Lützhöft, 2004) – matching what is seen out of the window with the data and information on the screens. But it takes time:

> *This is something we gain as a seafarer on the bridge by experience and by time, but unfortunately because they are relying or over relying on the equipment and electronic equipment that will result in that this barrier is, we can say, reduced or it's not there anymore.*
>
> *Let's just pretend we woke him up a couple of minutes before the collision or whatever. That's probably not enough either.*
>
> *OCEAN Interviewees*

Experience also provides a backdrop for interpreting situations, which was frequently mentioned during the interviews. Even though the comments are made in hindsight, it is clear that many situations are misinterpreted:

> *[the other ship] saw but did nothing until too late.*
>
> *They were busy monitoring other situations that they probably believed were more urgent.*

14 https://www.sirc.cf.ac.uk/Uploads/Publications/Changes%20to%20seafarers'%20health%202011-2016.pdf

The crew didn't completely understand the situation they were in and were not able to take any decisions.

So there was a lot of involvement actually, but it was only very late that he observed the not under control lights on the [other ship's] mast.

OCEAN Interviewees

There is a case to be made for looking at education, training, and experience. However, training cannot be used as an excuse to accept poor design:

…training is not the key to performance. [but is asserted and assumed to be]

Most navigational accidents we are seeing have an element of … inadequate HMI, and very frequently ECDIS familiarity / knowledge.

OCEAN Interviewees

We need to make sure that this is a workplace where people are motivated, experienced and understand the risks involved, and are supported to do their job. IMO are considering repealing trials on one man bridge because they are still being applied as a justification for operating with reduced crewing despite the trials being cancelled 25 years ago.[15]

5.2.2 Organisation level issues

The industry increasingly proclaims the benefits of a good safety culture but according to an investigator some companies do not follow through. For example, an interviewee provided a blame interpretation of safety in the pre-emptive sense of not trusting your crew:

Client wanted full time monitoring of an oily water separator to prevent illegal oil discharge [so that] the crew knows they are being smartly monitored.

OCEAN Interviewee

It is commented that there is probably a place for better qualifications and operational requirements. This responsibility is all put on the companies at present – who in turn then rely on the individual performance of navigators. There is a very high expectation that people will comply, but very little assessment of whether people can actually do so in the systems they work in. This often seems to be either due to a lack of awareness of human performance dependencies and what affects performance, or because the commercial option to get new crew is easier for a company.

Rules are good if humans follow them.

OCEAN Interviewee

Many of the issues mentioned revolve around regulations and policies. One respondent said that people tend towards non-conformance for a number of reasons which we have to explore before we know 'why' an accident occurred. It is pointed out that, after an event, there is always a rule found to point to which has been broken, and it is made worse by conflicting rules and

[15] MSC 107/5/5 27 March 2023; DEVELOPMENT OF A GOAL-BASED INSTRUMENT FOR MARITIME AUTONOMOUS SURFACE SHIPS (MASS); Trials under regulation I/13 of the STCW Convention in which the officer of the navigational watch acts as the sole lookout in periods of darkness in relation to MASS trials.

regulations. SMS systems can be too large or inappropriate, as exemplified by a Master, followed by an investigator:

> *I mean I've got a ship here with about 30 different nationalities all working in a second language with a management system which I've struggled to understand myself so how on Earth they find it is beyond me.*
>
> *And the difference between being compliant is that is that the safe enough? Is it OK to be compliant and not do anything more than that?*
>
> *OCEAN Interviewees*

There is the ever-increasing administrative burden, shown in both research and mentioned by interviewees. Management imposes themselves on the bridge by requiring more and more information, paradoxically making demands, and conveying a desire to not receive bad news from the ships, as shown by multiple studies performed at The Seafarers International Research Centre (SIRC). Turning to OCEAN, an interviewee from the shore side states that one new management reporting software product is put on a ship every month which imposes reporting requirements. The general message is that it is insensitive because it is built for shore, not tested for ship use, there is no support and no technology training. It is also unreliable because it is untested (before sending it onboard) (personal comm. Shenoi & Earthy). Over and above the workload and frustration this adds to onboard work, it also has a negative effect on the ship shore relationship.

On the organisation level, bordering to technology, we have placed technology manufacturers. Marine manufacturers are all developing their systems in their own way. Responsibility is not taken unless there are legal requirements. A comprehensive discussion with an interviewee concerned inherently safe design and applying systems safety engineering principles "If you don't get the cornerstone right it won't work", and he went on to point out that no single point failure should ever give a hazard. Furthermore, he discusses how to demonstrate safety:

> *Maritime regulation is based on demonstrating equivalence. But for new technology equivalence to what? In other sectors of industry demonstration of safety is usually that risks are reduced to ALARP.*
>
> *OCEAN Interviewee*

5.2.3 Technology

The technical category contains both well-known, yet still unsolved, issues as well as some emerging factors. Increasing complexity and 'intelligence' of technology is pushing the human out of the team. If humans are not considered in design of the system, they will perform work to integrate themselves, to make sense, to make work work.

> *A ship runs itself most of the time.*
>
> *OCEAN Interviewee*

A participant describes how on a ship the fallback is always the human, this is the way rules are written and technology is designed. He continues to state that normal operations are generally ok, for example foreseeable things like blackout. Humans used to be able to manage such operations, but now new technology makes you stand back and let the technology solve itself.

> *No suppliers want to do integration, so the level is going down in the engine room. The bridge is getting slightly better.*

OCEAN Interviewee

There are several concepts and factors that describe human reactions to technology, often in a negative way – although the reactions are human and to be expected. One example is the so-called over reliance, trusting that a system will do what it was designed and installed to do, trusting a system that projects trustworthiness – which could hide weaknesses in the system. The example provided here is about AIS, but the insight can be applied to any technology.

> *When we use the AIS on for collision avoidance, we are missing a huge major feature, which is AIS are not able to show or display all the targets around you.*
>
> *The AIS is working according to others information, not something you are getting it from your ship.*
>
> *So if the others AIS is not accurate or not working or switched off. You are not going to see the target. On the on the screen or the display if you are relying on the 100%.*

OCEAN Interviewee

A familiar category which is becoming more serious is alarms. Multiple interviews confirm that it is increasingly commonplace to have to allocate one crew member to acknowledging, silencing, or otherwise managing alarms in critical situations such as fire onboard, or sensitive situations such as pilot onboard or mooring – when you may need all the people you have. The other possibility is to disable the alarm (permanently or temporarily) to be able to do your job with full attention – risking that dangerous situations go undetected and escalate into the unmanageable, or at the very least cause costly damage.

> *But people switch it off because there's just too many alarms.*

OCEAN Interviewee

The interviews brought other examples of alerts as a risk to the working environment. In the case of a particular ship, the fire panel alarms that could not be muted was a serious stressor on the bridge, and the Master ended up cutting power to this by removing the fuse. In another case, here with the Engine Control System, which is supposed to help decision making, needed the allocation of a crew member dedicated to acknowledging/silencing alarms. Simply, the readouts were completely incomprehensible to the engine crew, who were unable to integrate the raw data represented on the screens. This type of system, while somewhat helpful when operations stay within the normal operating envelope, becomes the direct opposite in the case of a stressed system (technically as well as human), to the extent where it demands allocation of crew member, not to use it for its intended purpose, but to stop it being a nuisance. This effect - only using decision support in normal, calm situations – has long been identified but is still not being taken seriously.

And, finally, maintenance. This is an emerging factor which could be underlying many of the other more overt factors – for example System/equipment failure – the second largest event type in the EMSA statistics. This trend has been identified by AMSA, who highlight the benefits of a planned maintenance plan[16]. The maintenance issues span both physical machinery and software and a deceptively small example is circuit breakers. A breaker can sustain a maximum number of operations, and they can be reset remotely. Maintainability needs to be designed for, including a) front line maintenance of replaceable items to keep things working as expected; b) enabling or rigging workarounds to keep things going; c) replacing things that

[16] Planned maintenance (amsa.gov.au)

have unexpectedly stopped working. As systems get more complicated and the amount of IT increases and software is involved, the ability of crew to do this also decreases. What are the issues associated with advanced ICTI in addition to the general concerns and issues contained in Annex 2: Qualitative KPIs, in Annex 3: Concerns regarding advanced ICT and some of the specific technical hazards related to trends in the use of ICT in the marine industry which are moreover detailed in Earthy and Lützhöft (2018)?

An important point to emphasise is that since then the reliance on IT has been continuously increasing the issue of cybersecurity. Maintenance of IT introduces a whole new set of issues, an interviewee gives an example of when you think you have spares, but they are not updated:

> *A passenger ship carried spares (cards) in a box. An event took place, they talked to OEM, helped them identify which card to use and found a card in the box. However, these spares were not updated, and there was perhaps 10 years' worth of errors and omissions. Nobody is trained to update the spare parts and the software. And if someone tried to determine the versions of software etc., it is not recorded.*
>
> *OCEAN Interviewee*

The interviewee continues:

> *All data on a ship treated with same level of integrity. We have to treat all software on a ship as the lowest integrity level. It's not mandated. Safety critical systems – are we doing the analysis, no.*
>
> *OCEAN Interviewee*

The interviewee explains the provision of safety evidence for systems with different levels of complexity is very different. For example, a television reboot is ok, restarting an airplane engine is another question. Demonstrating successive safety integrity levels is also significantly more demanding (both in process and implementation).

As with all categorisations, there will always be factors that fit more than one category or lies between them - in this case the most obvious one is the intersection between humans and technology. On some ships there are seafarers who may not be able to be a perfect fallback because they are fatigued, depressed or unable to understand the complex systems.

> *Need improvements to the design of navigational systems such that they cater for sub-optimally performing navigators.*
>
> *The integration of these devices together … they do tend to be quite disparate … ships that are coming into service can be slightly better, but obviously there's a lot of ships that just don't fit into that bracket at the moment.*
>
> *Make consoles that work in safety critical situations. When you panic and you forget everything …*

For integrated bridges or navigation system, SOLAS V/15 and SN.1/Circ.265[17] provide principles and guidance for design and safe management; a comprehensive overview of rules in force for the design of bridge navigation equipment is included in the OCEAN D3.1 deliverable[18].

---

[17] GUIDELINES ON THE APPLICATION OF SOLAS REGULATION V/15 TO INS, IBS AND BRIDGE DESIGN
[18] OCEAN D3.1 is freely available from www.ocean-navigation-awareness.eu

Take-home message

- Usability should be considered
- Issues with alertness are often related to fatigue or poor crewing levels
- There is a lack of wellbeing support for many crew
- Experience is eroded by new technology
- Experience also provides a backdrop for interpreting situations
- Blame culture is still common
- An expectation that people will comply with rules, but no assessment if it is possible
- Compliance issues are exacerbated by conflicting rules and regulations
- Increasing administrative burden causes workload, frustration on board and tension to the ship-shore relationship
- Humans will perform work to integrate themselves, to make sense, to make work work
- Rules are written, and technology is designed with the human as the fallback
- Often need to allocate a crew member to managing alarms in critical situations
- Trusting that a system will do what it was designed and installed to do is "overreliance"
- Trusting a system that projects trustworthiness can hide weaknesses in the system
- Decision support systems can become disruptive in stressed situations
- Maintenance is an emerging factor which could be underlying many others

Take-home message IT/maintenance

- There is no code inventory for a ship
- There is no IT architecture for the specific ship
- There is no known level of integrity for systems or components
- There is no common practice amongst suppliers
- There is no software/systems process or contract requirements for software for a ship
- It only gets worse through the system/ship's life.

5.3 Contextual effects on awareness

These factors and comments (shown in Table 6) are generic and contextual, pointing to high-level issues that are relevant to the work situation. Mainly their usefulness lies in providing an awareness of what the work situation is like onboard even if it cannot be directly affected by design. However, the majority of the factors are such that they potentially have an effect on the work environment, and thus constitute a basis for situation awareness. If the factors are not taken into account that basis may be weak, and we may well end up in the situation which was described in section 3.5.1 – many of those who experience an accident, or an incident, never even see it coming. Using the situation awareness levels as a framework and summarizing some of the issues in 5.2, we see some possible barriers (for example experience, technology, regulation) and we see how the barriers are eroded. It is straightforward to see that these processes can be disturbed by broken barriers, but what is not straightforward is what we can do about it.

Table 6: Mapping of barriers/eroded barriers to SA levels

Barriers/eroded barriers	**Impacts SA levels**[19]
Experience is shorter that before, so technology is trusted and …	All
Technology lulls them into safety and they work to alarms (which are disabled)	Comprehension, Projection
Crew are bored and lose alertness	Perception
They are fatigued and depressed – probably alone and lonely	All
They are in a double bind between conflicting regulations, conflicting messages from shore…	Projection
Lack of experience, patterns to recognise	Comprehension, Projection
Technological systems that are not integrated and do not allow for judgment of probabilities	Comprehension, Projection
Lack of support for planning and decision making, both by experience and design	Comprehension, Projection

Even if many of the issues in Table 6 are difficult to address directly by design, some ways forward can be teased out. Technology might be designed so that it presents a true level of trustworthiness and does not invite 'overtrust'. Alarm systems are long overdue for being designed in a way that allows people to assess a situation without information overload and a highly stressful noise environment (this is a finding in D2.3). Workplaces should be designed holistically, including layout, screens and workload to support safe and efficient work, taking into account human capability and variability.

Regarding the lack of experience or patterns to recognize, it should be possible to consider the human propensity for pattern recognition, and support the recognition, or perception that a certain type of situation is developing while there is time to do something about it (this type of decision making is also studied in D2.3). As mentioned earlier (3.5.1), in a set of 255 accidents, almost 60% of the people involved never saw it coming. If there was information available that could have supported the analysis of the developing situation, it was not picked up. This implies that whatever we are doing presently to collect and present information is not sufficient, and part of the solution may lie in trying to move the goalpost back in time, and free up more time for interpretation. This is supported by the finding that the interpretation of the situation was in many cases delayed, incomplete, or incorrect.

[19] **Perception (Level 1 SA)**: The first step involves the processes of monitoring, cue detection, and simple recognition, which lead to an awareness of multiple situational elements and their current states.
Comprehension (Level 2 SA): Requires integrating this information through pattern recognition, interpretation, and evaluation to develop a picture of that portion of the world of concern to the individual.
Projection (Level 3 SA): Involves the ability to project the future actions of the elements in the environment.

6 Summary and conclusions

This section addresses the overall aim of the work in task 1.1, to shortlist the dominant causes identified, including latent or less recognized causes including HCD and systems risks, and thereby validating pre-proposal hypothesis regarding navigational accidents:

> Navigational accidents are predominantly the result of a chain of events, often triggered by human error. However, there are underlying, influencing factors comprising technical or organizational matters, as well as human behaviour.

Quoting from the Project proposal, it was stated that "*the mission of [accident] reports is to clarify a particular incident, rather than to draw a wider picture of hazardous practices*". This has been shown to be mostly true, although some meta-studies have been performed, as well as studies with specific aims – such as the navigational accidents report (EMSA, 2022b).

It was also presumed that "*… investigative reports from previous accidents remain the most important source of information*" and that while this statement may still be true, this task could not confirm it. Although the approach was as described: "*… a more holistic approach for the identification and categorization of reported navigational accidents will be attempted…*" the problem may partly be due to the technique "*… based on an in-depth reassessment of past accidents*" and the participants "*… [with] a panel of senior navigators*". There was nothing wrong with the participants in and of themselves but most of the time was spent discussing human failings and the apportioning of blame (although often finding more than one culprit). In addition, the proposal describes how the experts should be complemented with "*… available data from statistics and literature*".

The three task objectives summarised the above description of work:

1. In-depth reassessment of publicly available navigational accident investigation reports.
2. Assessment of navigation accident probabilities, consequences and risk.
3. Synthesis of findings with experience-based knowledge

As mentioned, the original plan for the in-depth reassessment did not provide enough useful data, which prompted the interviews with accident investigators and other experts. Regarding objective 2, even after reviewing a limited number of sources it was soon clear that the abundance of methods, taxonomies and causes made it impossible to compare or group probabilities, consequences and risks. Therefore, we could not provide a large set of completely statistical or quantitative results for this report – nor as a major contribution to other tasks and work packages, as the project proposal stipulated. However, throughout the report we have identified take home messages from each section. These messages have been thematically grouped here. Some quantitative data are available. The first set of points provides some basic accident statistics and comments on the complexity and inconsistency of existing accident data.

Statistics and accident reports

- The EMCIP special investigation reports that 28% are navigation accidents.
- The British Isles and surrounding waters have the most incidents (including total loss).
- South China, Indochina, Indonesia and the Philippines have the most total losses.
- 70% of navigational accidents around Europe occur in internal waters.
- Using existing accident reports or databases for re-analysis is complicated due to:
    - Multiple accident investigation taxonomies.
    - Multiple underlying reasons for investigations.
    - Data sets are different, and in many cases very hard to query.
- New taxonomies have been tried but had to be simplified.
- The SHIELD taxonomy and tool may be implemented by EMSA.
- The relationship between accident event and safety recommendations is unbalanced.

    - Human action/factors 60% vs. recommendations 22%.
    - System or equipment failure/ship related 24% vs. recommendations 60%.
    - Safety Management System 2% vs. recommendations 51.5%.
- Careful analysis will reveal the underlying factors to so-called human error.

The second set of points summarize the results regarding accident investigation in two sections; the first is based on interviews and the second is a discussion. Although not directly within scope, it contains information that provides part of the understanding as to why datasets are so different and how accident investigation can be improved to cater for human factors and for managing future risks. The complete results are in Annex 4.

Interview summary investigation

- An investigation team needs to be multidisciplinary
- HF competence involvement is crucial and needs to be early and embedded
- Collecting HF data needs to be early in the process
- Investigations should be more systemic
- Better supporting frameworks are needed
- Using existing regulatory material would help

Discussion investigation

- If investigators lack a toolset (e.g., human factors, IT) an investigation will lack precision
- If it is a totally new technology to a sector of industry, no one knows the consequences
- The accidents that are chosen to be investigated are not chosen for learning
- The industry needs evidence to support introducing new regulatory requirements
- If we only investigate failures of control, we assume that it is the most important activity
- Accident investigation as currently practiced will not find the problems of the future
- We have to move into prediction

The third set of points includes causes of accidents, both well-known as well as latent and less recognized, and a limited but interesting set of quantitative data points.

Human, technology, organisation

- The lack of ergonomics, work-oriented design and consistency causes concerns.
- Usability should be considered.
- Humans will perform work to integrate themselves, to make sense, to make work work.
- Out of 225 navigational accidents, in almost 60% of the cases, the humans involved did not see the situation developing. In the rest of the cases something was observed but misinterpreted.
- Out of 255 cases, 25% had delays in interpretation, 30% made a wrong or incomplete diagnosis, 30% made the wrong decision, for the rest something changed unexpectedly.
- In 229 accidents, plans were wrong or incomplete.
- Almost half the human action issues concern BRM, coordination and resources.
- Issues with alertness are often related to fatigue or poor crewing levels.
- There is a lack of wellbeing support for many crew.
- Experience is eroded by new technology.
- Experience also provides a backdrop for interpreting situations.
- Technology both helps and hampers work.
- Trusting that a system will do what it was designed and installed to do is "overreliance".
- Trusting a system that projects trustworthiness can hide weaknesses in the system.
- Often need to allocate a crew member to managing alarms in critical situations.
- Decision support systems can become disruptive in stressed situations.
- An emerging contributing factor identified is systems/software issues.
- Blame culture is still common.

- Increasing administrative burden causes workload, frustration on board and tension to the ship-shore relationship.
- An expectation that people will comply with rules, but no assessment if it is possible.
- Rules are written and technology is designed with the human as the fallback.
- Procedures and policies do not always match the way work is done.
- Compliance issues are exacerbated by conflicting rules and regulations.
- Maintenance is an emerging factor which could be underlying many others.

This fourth set of points contains a group of issues for an emerging cause: IT maintenance.

IT/maintenance specific issues

- There is no code inventory for a ship.
- There is no IT architecture for the specific ship.
- There is no known level of integrity for systems or components.
- There is no common practice amongst suppliers.
- There is no software/systems process or contract requirements for software for a ship.
- It only gets worse through the system/ship's life.

From the review we can conclude that most of the underlying factors from the hypothesis are indeed present and contributory to marine accidents. Adding the findings from the interviews, we see a validation and a strengthening, as well as a finer-grained set of conditions underlying events. This includes factors like work and living conditions; fatigue, depression, and low motivation – impacting on the professional culture and situation awareness. Seafarers are struggling to balance conflicting pressures and procedures – with more and more time used for administrative work. Technology helps and hinders simultaneously, complex systems projecting trustworthiness and hiding weaknesses, alarms being a special case of being both a barrier and a nuisance. ICT is suspected to be strongly emerging as an underestimated and under-researched factor.

This deliverable also contributes to task 1.2 *Metrics (KPIs) to measure and improve navigational safety*. The take-home points have been interpreted from a Key Performance Indicator (KPI) perspective as well as ensuring their relevance to navigational accidents. This resulted in a list of indicators that support an assessment of the state of an organisation regarding navigational safety, listed in Annex 2. They are grouped under headings indicating the phase(s) in which they apply.

While metrics in engineering is a quantitative term, and a noun describing a specific type of measurement, in fields such as the social and behavioural sciences, measurements can have multiple levels, which include nominal, ordinal, interval and ratio scales. Nominal refers to classification and membership of a group, ordinal measures can be compared and be on different levels, interval shows mathematical difference and ratio shows magnitude[1]. The following KPIs cannot be measured in the engineering sense of the word, but they can be assessed. Detailed operationalization, scaling and weighting of the KPIs are not applied here but will be a subject for task 1.4.

Finally, this deliverable spans a larger scope that described in the objectives. It is because we conclude that it is impossible and inappropriate to break out navigation and navigational accidents. Ships are no longer independent. Their safe operation is the result of an interaction with a range of offship systems, including energy, trade, and information. Any systems failure (system meaning any combination of people, technology, and organisations) may have navigational consequences.

[1] wikipedia

7 References

Allianz (2022) Safety and Shipping Review 2023, Retrieved from https://www.allianz.com/en/press/news/studies

DMAIB (2021) https://dmaib.com/reports/2021/application-and-usability-of-ecdis

Earthy, J., & Lützhöft, M. (2018). Autonomous ships, ICT and safety management. In H. A. Oltedal & M. Lützhöft (Eds.), Managing Maritime Safety. New York: Routledge.

EMSA (2022a) ANNUAL OVERVIEW OF MARINE CASUALTIES AND INCIDENTS 2022, retrieved from https://www.emsa.europa.eu/accident-investigation-publications/annual-overview.html

EMSA (2022b) Safety analysis of EMCIP data – Analysis of navigation accidents, retrieved from https://www.emsa.europa.eu/publications/item/4830-safety-analysis-of-emcip-data-analysis-of-navigation-accidents.html

Endsley, M.R. (1995). "Toward a theory of situation awareness in dynamic systems". *Human Factors*. ***37*** *(1): 32–64.*

Equasis (2021) World Merchant Fleet report, retrieved from https://www.equasis.org/EquasisWeb/public/HomePage

Hollnagel, E. (1998) Cognitive Reliability and Error Analysis Method (CREAM). Oxford: Elsevier Science Ltd.

Hollnagel E., Wears R.L. and Braithwaite J. (2015) From Safety-I to Safety-II: A White Paper. The Resilient Health Care Net: Published simultaneously by the University of Southern Denmark, University of Florida, USA, and Macquarie University, Australia.

Kerstholt, J., Passenier, P., Houttuin, K., & Schuffel, H. (1996). The effect of a priori probability and complexity on decision making in a supervisory control task. Human Factors, 38(1), 65–78.

Lundberg, J., Rollenhagen, C., & Hollnagel, E. (2009). What-You-Look-For-Is-What-You-Find—The consequences of underlying accident models in eight accident investigation manuals. *Safety Science, 47*(10), 1297–1311. https://doi.org/10.1016/j.ssci.2009.01.004

Lützhöft, M.H. (2004). "The technology is great when it works": Maritime Technology and Human Integration on the Ship's Bridge. Unpublished Ph.D. thesis, Linköping University, Linköping.

Lützhöft, M, Sherwood Jones, B and Earthy, J.V. (2006) Making Safety by Tying the Knot: Examining Resilience in Shipping. *Proceedings of the 2nd Symposium on Resilience Engineering*. Juan-les-Pins, France, November 8-10, 2006.

McBride, T. (2008) A Model for Investigating Software Accidents. *Journal of Research and Practice in Information Technology*, 40 (1), 19-31.

Pomeroy, R.V., Earthy, J.V. (2017) Merchant shipping's reliance on learning from incidents – A habit that needs to change for a challenging future. *Safety Science* 99 (2017) 45–57.

Taylor, J.R, Kozine, I. (2022) Operations Error Analysis of the Use of Electronic Chart Display and Information System (ECDIS*). Proceedings of the 32nd European Safety and Reliability Conference (*ESREL 2022).

UNCTAD (2022) REVIEW OF MARITIME TRANSPORT 2022. https://unctad.org/system/files/official-document/rmt2022_en.pdf

III 9/4/7 26 May 2023
LESSONS LEARNED AND SAFETY ISSUES IDENTIFIED FROM THE ANALYSIS OF MARINE SAFETY INVESTIGATION REPORTS IDENTIFIED ISSUES RELATING TO THE IMPLEMENTATION OF IMO INSTRUMENTS FROM THE ANALYSIS OF DATA Analysis of marine casualties and incidents based on data reported in the European Marine Casualty Information Platform (EMCIP)

8 Annex 1: Input to OCEAN Technology Development

These points are directly relevant to the OCEAN project in that it connects and interprets comments from interviewees to the development.

a. 4D-SAD could be seen as more feeds to BNWAS – how integrated with 4D-SAD will it be? And how will it keep people alert and functioning? Is it a DSS or Alertness system?
b. Does everyone on the bridge need a separate instance of 4D-SAD (personal DSS) or should there be one, shared access instance for shared SA?
c. X reports that bridge alarms are often sent to silent mode. Should BAM also feed BNWAS?
d. 4D-SAD is for all ships and the Job To Be Done is "making safety" (Lützhöft, Sherwood Jones & Earthy, 2006).
e. BNWAS, what if ship is close to shore, even if there is escalation of alarms.
f. I'm not sure we've got voice communication integrated with the 4D-SAD. Maybe we should have?
g. We have to make sure we are not losing bits of information.
h. ... should be easy to use, provide stimulation and triggers.
i. Easy to read both day and night.
j. AI and DSS systems may risk facilitating cognitive lock-up – people fixate on one explanation or course of action (Kerstholt, Passenier, Houttuin & Schuffel, 1996).
k. Out of the 225 accidents, almost 60% of the people involved never saw it coming. This has consequences both for training and equipment design.[20]

[20] For example, how to get people to be aware and pay attention

- Give them something to do
- Consider scanning patterns
- Use a Red-yellow-green system, cross checking each other
- Help people pick up weak signals and dangerous signals
- Help people recognise patterns (situations)
- Make it easy to identify the next step

9 Annex 2: Qualitative KPIs

Design phase – applies when technology and tools relevant to navigational safety are selected and installed. Applies when workspaces linked to navigational work and/or safety are planned and built.

- To what extent is work-oriented design taken into account?
- To what extent is usability taken into account?
- To what extent are new risks following new technology being monitored?
- Is there a code inventory for the ship(s)?
- Is there an IT architecture for the ship(s)?
- Is there a software/systems process or contract requirements for software for the ship(s)?
- To what extent is the organisation aware of the level of integrity for systems or components?

Through-life phase – covers all operational phases

Humans

- To what extent does crew perform unnecessary work?
- To what extent does work scheduling take into account the risk of fatigue?
- To what extent does crewing level planning consider the risk of fatigue?
- To what extent is crew wellbeing being considered?
- To what extent does BRM support coordination?
- To what extent is the availability of resources for effective BRM being considered?

Technology

- To what extent are the (negative) effects of (new) technology being tracked:
- Experience/skill fade?
- Having to perform integration work
- Overreliance caused by traits of the technology
- Seemingly trustworthy technology can mask weaknesses
- Decision support systems can become disruptive in time-critical situations
- Alarm management can cause stress or crew resource issues
- To what extent does the organisation manage/monitoring maintenance as a possible risk?
- How often is the software code inventory reviewed for the ship(s)?

Organizational

- To what extent does the organisation work actively to avoid a blame culture?
- To what extent is the organisation learning from incidents and accidents?
- To what extent do procedures and policies match the way work is done?
- To what extent does the organisation track and manage conflicting rules and regulations?
- To what extent does the organisation manage the administrative workload onboard?
- To what extent does the organisation assess the possibility of compliance?
- To what extent does the organisation avoid designing rules with the human as a fallback?
- To what extent does the organisation avoid technology with the human as a fallback?

10 Annex 3: Concerns regarding advanced ICT

In 2016 as part of an initiative to establish a common understanding amongst a wide range of stakeholders in shipping regarding the opportunities and challenges associated with the use of ICT the Southampton Marine and Maritime Institute and Lloyd's Register (under the leadership of Prof. Shenoi and Earthy) held workshops to review the benefits and issues associated with the marine use of ICT. The concerns identified at these events are outlined below and were previously published (Earthy & Lützhöft, 2018). Some of them overlap with other technology concerns, and the list has been updated with findings from the present study.

1. Skill set - Is there a need to change this on board ships? Skills will be required to maintain future platforms and seafarers are not trained in this.
2. Reliability & verification – ICT systems in combination may act unpredictably. Marine software engineering is not at the same level of quality as other fields of engineering. The fast pace of change in ICT systems combined with a lack of validation and verification may lead to quality issues.
3. Over-dependence – Systems offer improved situational awareness (e.g., AIS) but the risk of over-reliance and reduced vigilance is present. ICT systems can introduce complacency – engine control rooms and bridges are filled with 'alarms' and 'beeps' and crew accept this rather than demand good alert design and management as the norm.
4. Reduction/introduction of risk – Is the risk associated with ICT systems accepted/understood by those using it? The possibility of ransomware is possible, and there is a lack of competence to deal with this and other such incidents.
5. Security – Constant connection to the internet means security updates become a requirement. Rolling this out means additional costs and a need for constant support from the operator's IT department and the supplier.
6. Pace of change –The fast pace of change may lead to quality and reliability issues. New features/updates are constant, so designers remain competitive but being forced to update software is not in the ship owners interests, particularly if the current version works.
7. Maintainability – Maintaining ICT based systems requires a different skill set, therefore ship operators may become reliant on suppliers rather than themselves/ crew to maintain the systems and diagnose issues.
8. Roles of Ship and Shore – Seafarers may feel that shore teams do not fully understand how a ship operates, i.e., separate shore units asking for the same information. Crew may feel devalued if too much responsibility is given remotely to shore. Constant monitoring by shore operations increases transparency but may give crew the feeling that they are disconnected/lack control/being watched by 'big brother'.
9. Usability of systems – Many of the ICT systems used on board ships are not designed with ships in mind. They are developed by non-maritime suppliers, without the involvement of mariners, and hence the software is not designed for the job. There is a lack of common UI, and often a lack of understanding about how to interpret the data received. Too much variation in software design causes issues, such as when crew transfer to a new ship (training is required to learn new systems).
10. Ownership of data – Large amounts of data are produced by ships but who owns these? Who is responsible for the security of these? A solution is to understand where sharing and access differ, and to whom these apply.
11. Autonomy – This introduces massive challenges and a risk of knowledge evaporating. Traditionally hands-on roles, such as master, superintendent, etc. may be replaced be people with no sea experience.
12. Legal issues – Who is at fault in the event of a cyber-attack? Who is liable: equipment manufacturer, designer, supplier, ship owner? There is also very little delineation of product liability and maritime regulations which makes it difficult to prove who is the negligent party in a cyber-attack.

13. There are additional legal issues relating to data protection, authentication, and access to ICT systems, particularly when personal data is exchanged.

Item 13: data protection and access control and Item 9 usability, customisation. In regard to IT, commonly a user logs in which provides access but also a record of use. For OT this is very uncommon – it has no idea who is using it. One reason is that almost always it is the service engineer's password being used, to allow maximum access and reduce the number of queries. Maximum access of course implies the possibility of causing damage. Access control can also be used to personalise the interaction depending on what different users need to see – which makes it item 9: usability.

Items 4: reduction/introduction of risk and 10: ownership of data. The lack of control also has an impact on data integrity.

11 Annex 4: Accident investigation

This chapter presents the findings relating to accident investigation, the current state of it and comments relating to how it might be improved. It provides part of the explanation for why the re-analysis of accident reports turned out to be so challenging and presents a constructive discussion of how investigations can be improved. Several issues were uncovered, mainly about the investigation team and support for human factors competence, but also regarding the process, including the collection and the models or frameworks for analysis.

> *So I really think that the [Accident investigation board] should try to involve human factors experts in the accident investigations and I really think they should try to find out what were the perceptions, actual perceptions and beliefs of the people there were involved in the accidents.*
>
> *OCEAN Interviewee*

Accident investigation team

There are many reasons for performing an investigation. They can be performed by individuals with varying competence, or teams. Because many ship systems are likely to be involved, one expert will likely not be enough, and there is a need for many experts in the team. One example of this was mentioned by an interviewee; several cases where [an organisation] made poor reports, and the quality depended on competence of investigators.

> *Class does their own [investigation], to see if it's a class issue. The investigators could not find a root cause. External bodies were called in, a manufacturer (not the manufacturer). The ship had complete power loss, and loss of propulsion. It resulted in a collision and hull damage. The report had 40 pages on the dent in the hull, nothing on the power loss. It was done by a surveyor, not an accident investigator.*
>
> *OCEAN Interviewee*

For such reasons, the investigation team needs to be multidisciplinary, but not many AIBs have HF competence and only in the Western world. Competences should include seafaring, documenting and collecting evidence, interview techniques, human factors. There are not enough people with HF competence, and even if teaching time is granted, it is never enough. There is also a need for general competence to get face validity and rapport with seafarers, so generalists are still needed.

> *You know that sort of face validity that a seafarer has with another seafarer, that's gold dust. You get them opening up to you.*
>
> *OCEAN Interviewee*

This is not only about the accident investigation but also the lack of proactive safety work in the maritime sector.

> *... even quite large companies, and you look at the size of the safety team that are doing the work and this sort of OPS team that are supporting them in terms of the technical Superintendent and the sort of fleet managers and so forth. So small ... if you go to EasyJet and you talk to them about fatigue risk management for example. They have over 15 people just managing fatigue risk management.*
>
> *OCEAN Interviewee*

The timeliness of involvement is crucial, it needs to be early and embedded. Otherwise, a newcomer can disturb the process. HF should be in from the beginning, or it is too late. You can only really do it with embedded HF people because the contracting process is too long to get them in otherwise.

> *You need to build up knowledge both within the human factors specialist and within the maritime specialist in order to work well together. Because if you're dragging your human factor specialist out right into a maritime investigation and start to make interviews ... the human factors specialist either doesn't understand anything, or interrupts the interview, constantly asking questions and that messes up the interview and makes the maritime investigator, who understands everything, very annoyed, and not wanting the human factors specialist in the team later because they mess up ... the irony is that interviewing is one of the HF tools that we're actually really good at. So ... the HF has to be embedded, this idea that you can, phone a friend, from consultancy and get them in is ridiculous.*
>
> *OCEAN Interviewee*

Rail and aviation investigations are described as good, as they send experts in their field to the investigation. The level of complexity in maritime is said to be becoming similar to those domains – as an example, one of the interviewees had calculated that there are more lines of software code on a ship than a plane or train. But it's not that easy...

> *Accident investigation – it's not a homogenous thing. Means different things to different stakeholders. Many agendas to fill. They may be missing the point when talk about HF and organisation factors. And what is a HF person? The way NTSB was interviewing was almost like a hearing in a courtroom. Then they brought in the HF expert. Asking about fatigue. Factors of humans rather than human factors.*
>
> *OCEAN Interviewee*

Process – collecting

A clear theme that emerged was the importance of time, both the time available for investigation and the representation of time for the event itself. This time pressure leads to prioritising the traditional, seafaring focus. The investigators gather the tangible evidence first, and even before that is done, the "human has moved on".

> *It's 'Hoover up the evidence'. Harvest as much of it as you can. Anything that's sensitive or might well expire or whatever. Let's get all that hoovered up and photograph. Absolutely everything that doesn't or does move or whatever and get all that in place. But by that point then the human beings moved on from there really.*
>
> *OCEAN Interviewee*

Event focus and timeline are important in accident investigation. The view is, that unless you pick it up in the field, it is almost too late.

> *There's a pressure to get things out the door and so dealing with something like human factors, which requires more effort mentally and it takes special skills and you know, there's a reticence to take on the new skills if you've been at sea for 20 years.*
>
> *OCEAN Interviewee*

Process – analysis and recommendations

One early suggestion was to make more meta level studies, because it can lead to insights and trends that we otherwise would not pick up, a type of sense making.

> *It's because the investigator needs to make sense. That sense making again of what's going on in the accident. So they can look at the contributory factors and work out what's going on.*
>
> *OCEAN Interviewee*

There is a desire to perform a systemic investigation, but still grounded in the accident. This is affected by the method and the categorisation available to the investigators.

> *The framework for collection and storage impacts the content of the individual report, database and the possibility to do meta level analyses. The present EMSA framework CREAM is inappropriate - has been agreed even by the person who designed it as well as many nation states in IMO.*
>
> *OCEAN Interviewee*

However, the development of frameworks is slow, and the development of technology is fast. The investigators cannot develop a complete picture of the events and causal factors if the supporting structure is not there.

> *Is it possible to investigate IT/software as a cause of an accident? Yes. It's done in other sectors. Difficult in maritime because it's a series of independent subsystems, loosely coupled. Determine if system A caused a failure in system B is very hard. No framework for analysis.*
>
> *OCEAN Interviewee*

What a report contains is also governed by the mandate of the investigators. There has been a long tradition of assigning blame and changing this mindset is difficult, not least because of the way the maritime stakeholders relate to each other. It could be called an investigative 'trap' and it follows a compliance – blame route.

> *...they always, they kind of love to blame.*
>
> *I think from a company perspective it's probably about the insurance or the side of it ... obviously a misadventure by a crew member is an insurable risk but misadventure by a company isn't.*
>
> *I think the problem is nobody challenges the [investigators] on it. Nobody points, says to us you are doing blame now.*
>
> *[recommendations] at company level. ... There has to be a drive. And doing that takes quite a lot of resources. You kind of want to pick your fights to do it. And because the litigious nature of shipping, I think we're always gonna have that pushback ... we're looking at sort of cultural recommendations, you know, adopting learning culture, adopting just culture ... The irony is they already think they're there, but they're [not].*
>
> *OCEAN Interviewees*

The investigators do see a positive change in the process, even though it still revolves around compliance.

> *Human error models, a start point for investigation, but to get traction with recommendations one needs firm evidence that rules are not effective or where there are gaps in regulation.*
>
> *Our recommendations have changed over the last four years. They're starting to become higher and more systemic.*
>
> *OCEAN Interviewees*

Furthermore, a new taxonomy may be implemented – the SHIELD (see section 3.4.3)

> *And I think that'll help us. Derive these trends, but it'll get not just the sort of maritime taxonomy stuff, you know, collisions and all the sort of other data you normally need. It'll also hopefully give you more reliable data around what the people were doing, because at the moment it's so difficult.*
>
> *OCEAN Interviewee*

Part of the solution may be to use the existing regulatory material, both for improving the process and developing the investigators' skills. The IMO documents for accident investigation are 'very good' according to the interviewees. Below is a summary, a commented list of these.

1. MSC.255(84) Casualty Investigation Code – two parts mandatory and desirable, desirable is where the requirements for HF are:
    a. "2.12 A marine safety investigation report means a report that contains:
    b. .5 analysis and comment on the causal factors including any mechanical, human and organizational factors;"
2. A.1075(28) outlines the need for investigators to receive formal in 'all but the most specialised' aspects of human factors investigation.
3. A.884(21) which was replaced by A.1075 is still used by MAIIF and contains parts of the 'ergonomic' method for investigation (determine relationships between work system elements' and 'factors in the work system that influence human performance'.
4. A.957(23) outlines the need for remedial action to have a sound understanding of human aspects in accident causation.

The most serious issue which came up was the lack of data on human actions and human behaviour. Without this, the reanalysis of investigations and reports will keep going nowhere and end up with the same conclusion, as happened in this task when attempting to do reanalysis – existing reports do not contain enough detail, especially not on the human in the system.

> *I mean, I'm trying to use my data in [organisation] looking at human actions. And there's nothing there.*
>
> *And it's very easy to say it was just that one human being that did it. And of course, nobody else would ever do it if they were faced with the same set of events or consequences...*
>
> *OCEAN Interviewees*

An emerging contributing factor identified in some of the interviews is systems/software issues. Our concern now is that accident investigation is even more blind to systems/software issues than to human factors/human-systems issues. Interviewees did not discuss the actual model for investigation of software, but literature supports the concern (McBride, 2008). Finally, if we want accident investigations to improve safety, we need to not only improve the quality, the content, the focus on human behaviour and the recommendations – but think about what the wider consequences might be. The following passage is from the accident re-investigation interview where one of the participants quoted a senior officer in the Norwegian Navy, who was talking about the officer of the watch on Helge Ingstad:

> *The guy on the bridge? He didn't want him to be blamed. He said that this accident is due to our responsibility. Poor training. Poor systems. I am to blame; I did the error. The responsibility is mine, so do not punish him because that will severely undermine our ability to improve safety in the Navy because if they punish this guy, nobody will tell me the truth anymore.*

Discussion

This section is about the role of accident investigation. It is about the scope of accident study, the process, goal, outcomes and the type and range of root causes. We need to look in more places than traditional investigations do.

Human Factors in accident analysis

There is nothing wrong with accident investigation – if you have the competence and a framework or tool to analyse the incident – a tool which will be most accurate when analysing known situations, in other words derived from previous incidents. Traditional accident investigation is not geared towards finding new things, and in the maritime sector the goal is to find out what happened. If the scope is outside the investigator's toolset, which is often the situation with human factors and IT - it will be difficult to get precision on describing or explaining what happened. If it is a totally new technology to a sector of industry, no one knows.

The number of accidents that say human error is the root cause is still high, but why? One reason could be the large and confusing number of taxonomies. In addition, there is no formal need for an investigation to go beyond human error – as soon as that cause has been established the insurance kicks in or someone goes to prison – or both. If you go beyond that it is for learning and in fact, having accidents is an inhuman and expensive way of learning.

How much can we learn from incidents?

This is an ethical argument for not waiting for accidents to happen. The accidents that are chosen to be investigated are not chosen for learning. And to learn new things one needs to understand what one should be looking for. The interviews told us a lot about what those things might be.

Something happens and there is an investigation

Investigations are good on hull and equipment (physical things) and good on establishing a timeline. They are starting to get better on organisation but do not satisfactorily address Human Factors, technology, nor rapid changes in industry. Investigations tend to be ship focused rather than situation focused.

There has been considerable technical change within the maritime industry but so far, the underlying ship technology remains unaltered. There still remains a strong culture of taking lessons from incidents and responding with new requirements within the maritime safety regulatory regime to address the issues. The industry is aware that this is not sufficient to ensure that the level of safety is improved but is also reluctant for any increase in regulatory requirements without evidence to support the introduction (Pomeroy & Earthy, 2017).

Choices for investigation
What we are not doing is choosing accidents with a high potential for learning. The accidents chosen to investigate are the big and legal issues relating to loss and fatalities. We rarely investigate near misses that could have been catastrophic, for example the Casino Express[21] evacuation and even the Costa Concordia nighttime evacuation and the ship-to-shore passenger transfer. The speed of adoption of new technologies is so fast, that we cannot investigate all new risks (Pomeroy & Earthy, 2017).

The case of software
As an example, we look at software. At the moment, all industries are still learning how to address software. The field of software engineering lacks a general model with which to investigate failures during development. Causal models have been suggested but are less useful when investigating accidents where causes are due to interactions between components or the failure of the system itself, rather than physical weaknesses. Investigations into safety critical domains tend to be about how the system was operated more than how the system was developed. If we only investigate failures of control, we will be making the assumption that control is the most important activity. If existing models of accident investigation are to be extended to deal with failures of software development, then the scope of investigation must be extended beyond that of system control (McBride, 2008).

We need some kind of prediction
We cannot learn that much from the past given that the future will be different. We cannot carry on trying to learn from incidents in the way we have been doing. In responding to incidents, the assumption is that we have a steady state, whereas in fact it is a revolution. There is also a time lag – the trends growing now are not picked up or reported because they are not included in investigation frameworks or incident categories. If we want to pick up new risks or growing concerns, we need something else.

In summary, looking forward as the maritime industry adopts radical change, in both technology and operations, it cannot afford to wait to learn from incidents which would cause societal objection. Greatest use must be made of the experience of other industries and the various methodologies that are available for considering the impact of hypothetical 'incidents', encouraging the acceptance of evidence that does not result from real incidents (Pomeroy & Earthy, 2017). Accident investigation as it is currently practiced – a team going on a ship – is not going to find the problems of the future. Basically, we have to move into prediction – it is still investigation but not as we know it.

---

[21] https://www.havkom.se/utredningar/civil-sjoefart/rs-200601-937-kb-grundstoetning-med-roro-passagerarfaerjan-casino-express-utanfoer-holmsund-ac-laen-den-24-november-2004 (in Swedish)

12 Annex 5: The Consortium

Høgskulen på Vestlandet	Inndalsveien 28 P.O Box 7030 5020 Bergen, Norway	https://www.hvl.no/en/
KYSTVERKET NORWEGIAN COASTAL ADMINISTRATION	Flathauggata 12 5523 Haugesund, Norway	www.kystverket.no
	Heroon Polytechniou 9 Zographou campus 15780 Athina, Greece	www.ntua.gr
CIMNE EXCELENCIA SEVERO OCHOA	C Gran Capitan, Edifici C1, Campus Nord UPC SN 08034 Barcelona, Spain	www.cimne.com
TELEDYNE RESON Everywhereyoulook™	Fabriksvangen 13 3550 Slangerup, Denmark	www.teledynemarine.com/reson
OKEANOS	Rua Da Mae De Deus Reitoria Apatado 1422 9501 801, Ponta Delagada S Miguel Acores Portugal	www.uac.pt
KONGSBERG	Kongsberg Maritim: Strandpromenaden 50 Po box: 1009 3183 Horten, Norway	www.kongsberg.com
KONGSBERG	Kongsberg Seatex: Pirsenteret 7462 Trondheim, Norway	www.kongsberg.com
UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH	Calle Jordi Girona 31 08034 Barcelona, Spain	www.upc.edu
IRISH FERRIES	Alexandra Road Ferryport D01 W2F5 Dublin, Ireland	www.irishferries.com
IWDG	Merchants Quay V15 E762 Kilrush, Clare Ireland	www.iwdg.ie
The Nautical Institute	Lambeth road 202, SE 7LQ London, United Kingdom	www.nautinst.org
LR	Fenchurch street 71, EC3M 4BS, United Kingdom	www.lr.org

13 Annex 6: Project Summary

The OCEAN project is focused on enhancing operator awareness in navigation, to reduce the frequency of severe accidents like collision and grounding, to mitigate ship-strike risks to marine mammals, and to mitigate the risk presented by floating obstacles to ships.

The OCEAN project will contribute to an improved understanding of accident root causes, and will strive to reduce the resulting human, environmental and economic losses through socio-technical innovations supporting ship navigators.

The OCEAN consortium, coordinated by Western Norway University of Applied Sciences, includes 13 partner organizations across 7 different European countries from the industry, academia, NGOs and end users.

Around 3.000 maritime incidents occur every year in the European maritime fleet. 28% of these accidents are categorised as severe or very severe accidents, resulting in the loss of life onboard, pollution, fire, collisions or grounding. Navigational accidents are dominant in these statistics according to the European Maritime Safety Agency, be it for cargo, passenger or service ships.

The OCEAN project ambition is to contribute to the mitigation of navigational accidents by supporting the navigators to do an even better job than they do presently. The OCEAN consortium will address the most pertinent factors that may contribute to events becoming accidents: training, technical, human or organisational factors, operational constraints, processes and procedures, commercial pressures, and will recommend improvements and amendments to regulations, standards and bridge equipment design approaches.

OCEAN seeks to enhance navigational awareness "on the spot" and to improve the performance of evasive manoeuvring to avoid collision with near-field threats. The project will deliver and demonstrate several human centred innovations. For example, the 4D Situation Awareness Display which will be developed in the OCEAN project will improve the visualisation of navigational hazards, integrating current bridge information systems with marine mammal and lost floating containers detection and tracking capacity specifically developed by the project.

Going further, the project will design and implement a European navigational hazard data infrastructure to feed multi-source observations and hazard predictions relating to floating containers and large aggregations of marine mammals into the existing distributed maritime warning infrastructure. OCEAN seeks to transfer this data ecosystem to relevant European organisations for deployment and maintenance.

Co-funded by Horizon Europe, the European Union's research and innovation programme, the consortium of 13 members represents 7 European countries, Norway, Greece, Spain, Denmark, Portugal, Ireland and UK, all located on major European coastal regions. Members include a coastal administration, a ship operator, maritime safety and transport researchers, marine mammal ecology and conservation experts, companies specialised in maritime information systems and sensors, a professional organisation, a risk and safety management organisation, as well as data infrastructure, data fusion and satellite imaging specialists.

UK participants are supported by UK Research and Innovation Grant Number 10038659 (Lloyd's Register) and Grant Number 10052942 (The Nautical Institute).