Human factors root causes of accidents in inland navigation: HMI and wheelhouse design

Phase 2a - Report

INTERGO
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Preface

Incidents in Inland Waterway Transport (IWT) change and are experienced to increase in severity & cost of claims. Human factors account for about 70-80% of all incidents, according to databases and literature. Also changes in IWT itself develop like increasing automation, other business models, etc. The European IWT sector wants to learn from accidents aiming for prevention in the future by defining risks and future measures. Policy makers and insurers are challenged to counter this trend and to anticipate on technology push. They realise interaction between human and technology is becoming more crucial when automation is increasing. They are asking for a framework for the design of the future wheelhouse.

Human factors root causes in European IWT have not been researched on sector level before but are necessary for developing effective mitigating measures. To feed the framework aimed for the sector agreed to learn from human factors root causes of accidents.

As information about causes from accident databases is limited, additional information from the field, sciences, other sectors, and human factors experts have been added. Researchers, specialised in human factors and safety, have analysed multiple sources to reveal human factors root causes. Based on triangulation approach, real world information from questionnaires, interviews and on-board-observations helped to reveal context of human factors root causes. They have integrated knowledge and state of the art expertise from other transport sectors. Stakeholders' decision making about execution of recommendations still must take place.

This study could not have been conducted without the enthusiasm, critical interest, openness, hospitality, and expertise of all the experts we met.

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Abbreviations

AIS	Automatic identification system
CCNR	Central Commission for Navigation on the Rhine
CCTV	Closed-circuit television
CEMT	Classification of European Inland Waterways
CESNI	European committee for drawing up standards in the field of inland navigation
CESNI-PT	European committee for drawing up standards in the field of inland navigation - Technical requirements
DIN	German Institute for Standardization
EBU	European Barge Union
ECDIS	Electronic Chart Display and Information System
EEMUA	Engineering Equipment and Materials Users' Association
EN	European Standard
ENC	Electronic navigational chart
ESO	European Skipper's Organisation
ES-RIS	European Standard River Information Services
ES-TRIN	European Standard laying down Technical Requirements for Inland Navigation vessels
ETA	Estimated time of arrival
HF	Human factors
HMI	Human-machine interface (= MMI)
HSI	Human systems integration
GUI	Graphical User Interface
IACS	International Association of Classification Societies
ISO	International Organization for Standardization
IT	Information technology
IVR	International Association for the representation of the mutual interests of the inland shipping and the insurance and for keeping the register of inland vessels in Europe
IWT	Inland Waterway Transport
IWT Platform	European Inland Waterway Transport Platform
MMI	Man-machine interface (= HMI)
PTZ-camera	Pan Tilt Zoom camera
RIS	River Information Services
SEA Europe	Shipyards' & Maritime Equipment Association
SHEQ	Safety, health, environment, quality
SOLAS	Safety of Life at Sea
TASCS	Towards a sustainable crewing system
UIC	International Union of Railways
VHF	Very high frequency (marine 2-way radio communication)

Management Summary

The European inland shipping industry (united in the European IWT Platform), insurers represented in the IVR and the Dutch Ministry of Infrastructure and Water Management, commissioned a study of the human factors root causes of accidents in Inland Navigation. They experienced an increase in the number of accidents and claims related to inland navigation every year since 2014, just like the amount of the claims.

An additional motivation for the study was expressed by Paul Goris, president of the IWT Platform: "The Inland Waterway Transport sector is on the eve of a major transition in terms of sustainability and digitalisation. This requires further development of standards and certain safety requirements."

This study has been commissioned in two phases. In phase 1 of this study in 2020 – based on data and expert analysis - it was concluded that in 70-80% of these incidents human factors are involved. Several factors were identified that contribute to these incidents. As a follow-up two separate studies were defined: phase 2a and phase 2b. This report covers phase 2a: an in-depth study into three factors that relate to the root cause of inadequate Human-System-Integration: *wheelhouse design*, *Human-Machine Interface (HMI)*, and current and future levels of *automation*. In a separate report (phase 2b) the organisational factors *communication*, *fatigue and stress*, *specific waterway situations* and *qualifications of the crew members* are addressed.

Both studies in phase 2 consisted of an international questionnaire for skippers and barging companies (85 respondents), followed by 10 selected vessel visits with interviews and observations to obtain an overview of the current wheelhouse and HMI designs. Both older and the newer vessels of different sizes have been visited. Also, a comparison with other (transport) sectors like rail and aviation is made to see how standards, regulations, and guidelines are used to create effective and safe work environments.

It was learnt that wheelhouses are very different and that new (assistive) devices enter the wheelhouse often causing a 'Christmas tree' of systems. Technical possibilities and economic conditions will increasingly necessitate shift operations and a change of personnel on the individual vessels and personnel from vessel to vessel. Whereas a helmsman previously used to stand at the same control position for years, perhaps even all his life, and would thus become very familiar with it and adapted himself to it, he can now reckon increasingly with having to operate a different ship at some point in time (source: EN 1864:2008). This shift may introduce a risk of human error when operating another vessel, especially in unforeseen circumstances. Also, the introduction of new assistive devices may provoke a false sense of safety when these are not designed, located, or introduced properly.

The results of the questionnaire showed that about 60% of the respondents think uniformity in wheelhouse design is important. In tankers - where crew often changes from vessel - this is even 76%, and only 6% disagree (rest has no opinion). However, this uniformity is now only present to some extent *within* some shipping companies. The same accounts for controls and displays at the helmsman's position. This research shows that even 'classic' instruments like rudder control and propulsion control, navigation lights controls, etc. have varying positions across the inland navigation fleet. Although most respondents are satisfied with those locations, it must be noted that these results may be influenced by the fact that skippers got used to a certain configuration or even were responsible for the design. If respondents were dissatisfied, they were mostly not 'vessel owners'. From the vessel visits, the authors (registered ergonomists) conclude that even in some of the newer vessels, location of primary controls (rudder, engine, VHF) and primary displays (radar, ECDIS) is not according to ergonomic standards that are common in other transport modalities. Reachability, visibility, and legibility are often compromised, leading to (potential) errors and musculoskeletal disorders. The use of touchscreens is in practice often difficult as they need to be within reach to operate and within a certain field of view to read. Some displays have a very high luminance (which is annoying at night) or cause a strong glare which impairs reading. Usability of some systems is sometimes inadequate as illustrated by the need of additional 'work around' paper instructions for the meaning of controls or alarms. The mandatory technical requirements for inland navigation vessels (ES-TRIN: CESNI, 2021) contain only general goal-based requirements regarding HMI's and wheelhouse layout. This is a good basis, but it is insufficient to guide designers or engineers in developing ergonomic wheelhouses and helmsman's positions. The non-mandatory European standard EN 1864 (2008) about ergonomic and safety requirements for wheelhouses of inland navigation vessels offers more guidance. However, this standard is not according to the latest ergonomic insights and lacks a systematic design process approach as common for other industries. The influence of automation is not considered in this standard yet.

Automated/assistive devices increasingly play a role in inland navigation. Skippers mostly appreciate these systems. However, from the vessel visits it became clear that the availability and reliability of information sometimes is unclear to the skipper and may create a false sense of safety. AIS/ECDIS information may be lagging, ENC information occasionally is incorrect, safety margins unknown to the skipper etcetera. On the other hand, some information still needs action and interpretation by the skipper, for instance, awareness and selection of the right VHF channel, and looking up current water levels and integrate this information with other navigation information. It is concluded that quality of information technology and automation can be improved in terms of availability and reliability, but also in usability and integration of information for optimal information processing, decision making and operation. Note that information integration is more than just adding information to a system: integration truly supports quick and safe decision making.

The first recommendation is to update and improve the available wheelhouse and HMI design guidelines. A user- and task-based approach should be followed, and guidelines should anticipate on developments in automation. These design guidelines do not necessarily have to be mandatory. Industry commitment is an important first step in general use of these guidelines. It should be appealing for industry to adhere to the design guidelines. New guidelines are obviously most interesting for new vessels or major refurbishments but may also guide (re)placement of additional systems.

The other recommendation is to develop a vision on minimum required availability, reliability, usability, and integration of information and automation at the helmsman's position. This should lead to systems that are safe and truly support navigation, without introducing new risks like distraction, creating a false sense of safety, and too many or unclear alarms.

Both recommendations may be combined. Also, synchronisation with recommendations from Phase 2b (about the organisational factors *communication*, *fatigue and stress*, *specific waterway situations* and *qualifications of crew members*) is important because technical and organisational issues are interrelated. A roadmap should first be developed, involving all stakeholders in the ecosystem of inland navigation, because new guidelines should first of all be appealing to use for all parties involved.

1. Introduction

The number of accidents and claims related to inland navigation has risen every year since 2014, just like the amount of the claims. Depending on the source analysed 44-92% of these accidents are related to human factors as a primary cause. The International Association for the representation of the mutual interests of the inland shipping and the insurance and for keeping the register of inland vessels in Europe (IVR), the European Barge Union (EBU) / European Skipper's Organisation (ESO), European Inland Waterway Transport Platform (IWT Platform), and Dutch Ministry of Infrastructure and Water Management are looking for ways to prevent such accidents and initiated research in two phases, starting from January 2020. Phase 1 consisted of a data and expert analysis of human factors root causes and was finalised in November 2020[1]. In phase 2 the highest risk activities as defined by phase 1 will be subjected to in-depth analysis. This phase 2 focuses on verification and enriching of results from phase 1 on two main areas: 'nautical technical factors' and 'organisational factors' contributions. We unravel these factors that influence human behaviour.

The steering group decided splitting phase 2 into two lots: 2a. Focus on the human-machine interface in the wheelhouse, also seen in the light of current and future levels of information provision and automation, and 2b: Focus on organisational aspects as plausible root causes, being communication, fatigue and stress, specific waterway situations, qualification of the crew members. Both phases were executed separately with their own steering group. Parts of the implementation however were carried out simultaneously in order not to unnecessarily burden skippers.

In the phase 1 report[1] it is suggested that "The quality of man-machine interfaces in the wheelhouse must be investigated further because poor quality or poor coherence can have a direct effect on distraction, situational awareness and a sense of safety."

The main research question formulated by the steering group from this suggestion for phase 2a is:

"In what way is the present general wheelhouse layout in conflict with a good human-machine integration?"

or alternatively:

"How does the ideal wheelhouse look like to minimise human errors?"

Sub-questions include:

1) What are examples of good human-machine integration/interface (HMI) and what do science and literature say about it?
2) What points of interest are there concerning the connection / interface between human-machine and the technology in the wheelhouse on board of inland vessels, also in view of increasing automation?
3) What recommendations are there - regarding optimal human-machine integration - for the design of the wheelhouse on board of inland vessels?

The purpose of the final report from this research phase is that it is a supported steppingstone to the future development of a European evidence-based framework and design guideline on HMI and wheelhouse design on how to apply design principles to provide a safe and effective design.

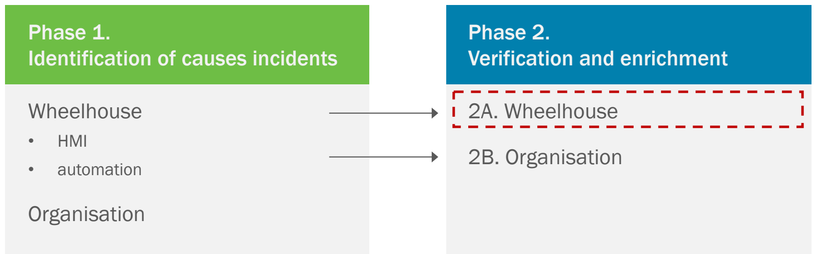


Figure 1: Schedule of part 1 and part 2 topics for this study and report

[1] Human factors root causes of accidents in inland navigation - Phase 1: data and expert analysis. Intergo, version 1.1, November 2020.

To solve problems structurally, it is necessary to look at the underlying root causes. Symptoms, experienced as causes of accidents, are caused by problems in a certain context, which in turn have been provoked by root causes. Focussing on symptoms will not lead to lasting improvements. Focus on root causes will.

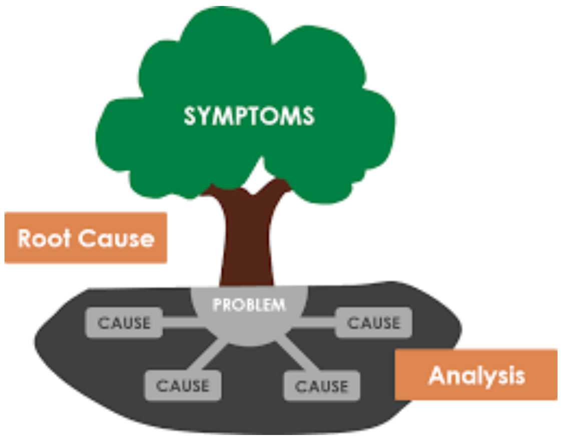


Figure 2: Visualisation of symptoms, context with problems and root causes in accidents

It should be noted that wheelhouse and HMI design, on the one hand, and organisational factors, on the other, both determine human behaviour. A perfectly designed wheelhouse alone is therefore no guarantee of safe sailing, as organisational influences can still trigger unsafe behaviour. This report covers the wheelhouse and HMI design. Organisational factors as root causes are reported separately on request of client (*Human factors root causes of accidents in Inland Navigation: Organisational Factors. Intergo, 2021*).

Guide to the reader

This report is structured as follows. The approach is presented in *Chapter 2*. In *Chapter 3* some general results regarding the questionnaire and vessel visits can be found. Then, the three main topics of this part of the study are covered: Wheelhouse design (*Chapter 4*), HMI (*Chapter 5*), Automation (*Chapter 6*). We end this report by providing a summary of root causes and recommendations in *Chapter 7*.

In the annexes (separate document) an overview of vessel characteristics is given in *Annex 1*, a summary of positions of controls and displays from respondents in *Annex 2*, and selected references in *Annex 3*.

This report is directed at several stakeholders in IWT: for instance, Policy makers, Insurers, Shipbuilders, System integrators, Ship owners, Crew IWT, Operational management IWT, SHEQ/ HF professionals, Authorities, Education organisations, Classification organisations, IWT industry organisations.

2. Approach

We first analysed the nautical-technical aspects in-depth during field research (questionnaire and observations/interviews) focusing on the most plausible root causes. Second, we combined these results with knowledge from science and our extensive experience in HMI and 'cabin' design from other transport modalities (rail, road, maritime & aviation), added with our knowledge from experts in developing HMIs and wheelhouses. This triangulation approach is a powerful and scientific method for valid results *(Figure 3)*. Based on these results we defined recommendations for safe HMI and wheelhouse design.

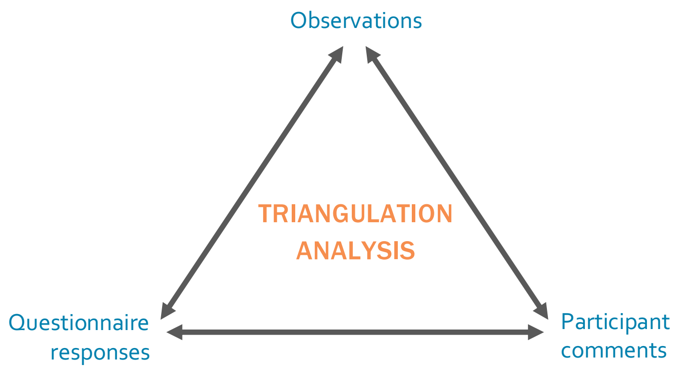


Figure 3: Triangulation approach, combines data from questionnaires, facts from observations in real world and verification by participants, leading to valid results.

More in detail, we used 3 major steps, apart from preparation, feedback loops and reporting:

1) Preparation of collection of best practices.
2) Collection and evaluation of cases in HMI and wheelhouse design.
3) Evidence based recommendations for safe HMI and wheelhouse design.

Scope

The scope for this study is incidents in professional inland waterway transport while navigating in Europe (i.e., the ship is moving). This scope excludes recreational traffic unless involved in an incident with a professional vessel. Also, incidents while loading/unloading, being moored, etcetera are excluded. We do acknowledge however that processes besides the actual sailing of a vessel may influence the quality of navigating by having an effect on planning, workload, rest/fatigue, and environmental circumstances.

To illustrate the scope of this study, the tasks that apply during incidents studied in this project are highlighted in a list of all tasks (*Table 1*, as derived from the TASCS[2] study based on the directive with harmonised competences of boat masters and boat men). As mentioned, the other tasks may contribute to the causation of incidents during sailing & manoeuvring (by simultaneous task performance or by influencing those tasks), which is considered in this study.

[2] TASCS - TOWARDS A SUSTAINABLE CREWING SYSTEM. European Social Partners Organisations EBU, ESO, ETF, 2019.

Navigation

Voyage planning, org. crew change
Sailing & manoeuvring
Mooring & unmooring
Organise and control work

Operation of the vessel

Bunkering, Ballast water & waste management

Cargo handling, stowage, passengers

e.g., Handling hoses, cleaning tank, freight document, control checking strength & stability;
Passengers

Inspection

Periodic inspections (vessel / hardware / software etc.)

Maintenance & repair

Maintenance (preparation & coordination),
Planning maintenance by external parties

Communication

Crew management & shift handover,
Organisation & execution of training

HSE, Emergencies & calamities

Control work & rest time (shifts),
Developing safety plans, Instruct the crew in safety drill

Entrepreneuring

Acquisition (follow-up cargo),
Commercial accounting,
Personnel administration,
Vessel account, (Port duties etc.)

Other tasks

Studying, waiting, Housekeeping (cooking, cleaning accommodation)
Teaching apprentices

Recovery & free time

Pause, leisure, sleep, standby

Travel

Commuting to/from vessel

Table 1. Overview of tasks in IWT (source: TASCS, 2019). In **bold** are the Navigation tasks that apply during incidents studied in this project.

Categorisation of vessels

To be able to compare databases, the reported vessel types had to be categorised in four major groups. Additionally, the steering group requested to specify container vessels as special subtype in this research phase:

- Containers;
- Dry cargo (including barges);
- Tankers;
- Passengers.

2.1 Step 1 – Preparation of collecting best practices

The main goal of this step was to prepare the collection of best practices in wheelhouse design and HMI in the field in cooperation with stakeholders. The following activities have been performed:

- Kick off session in the Netherlands with the steering group for planning & organisation of data collection.
- Inventory of relevant, existing IWT regulation standards on wheelhouse layout, and HMI for on board vessel technology (propulsion/ electrical equipment), level 1-3 automated navigation/ information systems and cargo specific monitoring systems.
- Test session by researchers in the state-of-the-art IWT simulator of Maritime Academy Harlingen for a thorough understanding of the systems on board the various vessel types in preparation for the vessel visits.
- Online workshop with representatives from MMI suppliers and wheelhouse builders, united in Shipyards' & Maritime Equipment Association (SEA Europe) on March 22, 2021, to learn best practices they already apply now and what is expected in the future. Five European system integrators and one shipyard were delegated.
- Development of a questionnaire. This questionnaire was reviewed by the steering group, and translated into Dutch, English, and German. The questionnaire was open for response via the online survey tool - *Typeform* for two weeks. Themes of the questionnaire included:
  - General information on the participant e.g., employment function of participant, nationality, years of sailing experience, stretch they sailed;
  - General information on the vessel e.g., type of vessel, dimensions, weight;
  - Layout of the wheelhouse and instruments used in the wheelhouse e.g., placement of instruments, satisfaction or dissatisfaction of instruments, usage of newer technologies in wheelhouse;
  - Image of the wheelhouse: participants were asked to upload a picture of their wheelhouse;
  - Contact information of the participant, used to arrange vessel visits or answer follow-up questions;
- Members of the steering group invited captains via their supporters to fill out the questionnaire. After one week during the collection phase, one reminder was sent to participate in the questionnaire.

2.2 Step 2 - Evaluation of best practices safe HMI and wheelhouse design

In this step we first analysed the questionnaire results. The questionnaire was filled in by 85 participants. See *Annex 1* for an overview of the vessels involved.

From the 85 participants we selected 10 exemplary cases on specific aspects in HMI or wheelhouse design with learning potential for a more in-depth understanding reflecting IWT as inclusive as possible. We performed the in-depth-study by observations and interviews with boat masters during a vessel visit while sailing or alternatively by an online interview due to COVID-19 measures. This selection of cases was made on (diversity in) the following criteria:

- Type of vessel (container, tanker, dry bulk, or passengers);
- Form of employment (self-employed or organisation);
- Nationality of participant;
- Experience;
- Conventional stretch sailed (within the boundary that the vessel's current position was within 3 hours travel time from Utrecht);
- Use of guidance systems;
- (Dis)satisfaction about instruments
- Being involved in an incident: ship-ship, ship-infra, grounding or no accident);
- Sailors vision on the importance of social media in regard to accidents;
- Photos of the wheelhouse were used to include both 'new' and older wheelhouse designs.

We prepared the in-depth understanding observations and interviews by detailed semi-structured questionnaires, observation lists and a data-processing model.

We evaluated the cases in relation to science, actual human factors standards and best practices from other transport modalities with help of a gap analysis (maritime, rail, aviation, and road transport). The gap analysis with other sectors comprised of an inventory of existing standards about ergonomic design of control rooms, ship bridges, driver cabins, flight decks etc.

2.3 Step 3 - Evidence-based recommendations for safe HMI and wheelhouse design

This last step included formulating evidence-based recommendations for good HMI and optimal wheelhouse design, based on the field research and human factors science and best practices in other transport modalities, aimed at the target population of regulators, barge operators/ vessel owners, and suppliers/builders. Recommendations are suitable for new construction or renovation, indicating the level of evidence and prioritised for safety impact. The level of evidence of a recommendation is indicated as follows:

- ***[Evidence: H – High]*** Recommendation proven by scientific research and published in international literature or standards.
- ***[Evidence: M – Moderate]*** Expert judgement of HF Professionals (registered human factors experts) with extensive experience in mission critical design).
- ***[Evidence: L – Low]*** Literature, standards, and common practice, however without traceable or sufficient evidence.

The following activities were performed:

- On 22 July 2021, we shared the draft results to the steering group for feedback.
- On 9 September 2021, the steering group discussed the draft report 2A.
- On 13 September 2021, report 2B was discussed within that steering group.
- Comments were processed, and the two reports were aligned.
- On 27 September 2021, before finalising the report, we verified the conclusions and recommendations on HMI and wheelhouse design during a workshop with representatives of HMI suppliers and wheelhouse builders, united in SEA Europe.
- Presentation of study in CESNI-PT November meeting.

3. General results

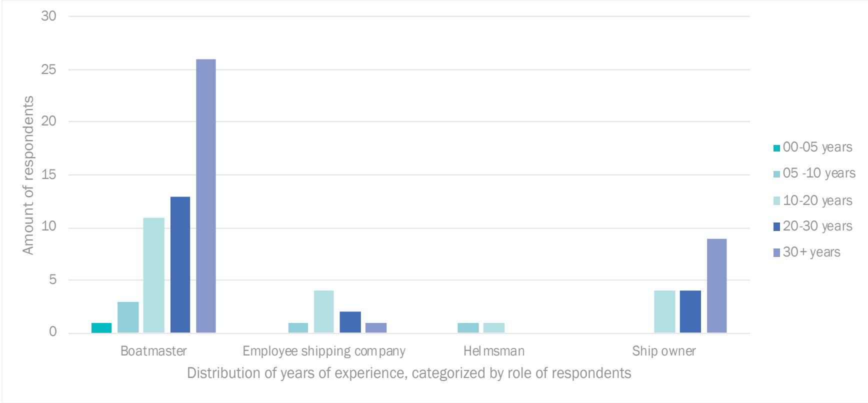
Characteristics of respondents to the questionnaire

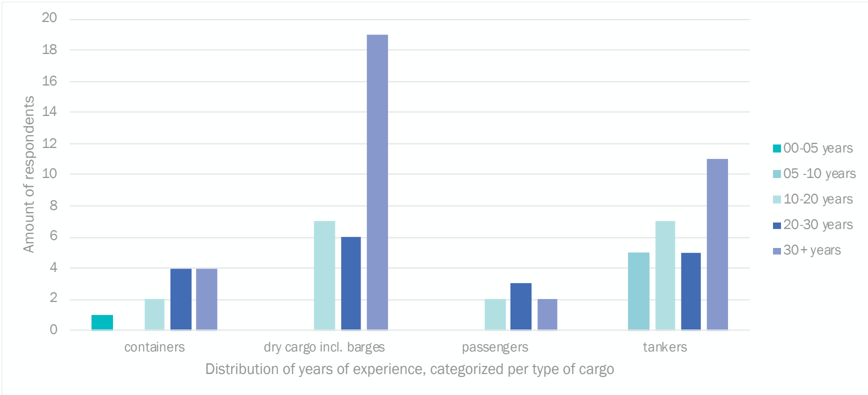
In two weeks, 85 respondents filled in the questionnaire. Majority of the respondents have Dutch or German nationality.

Category cargo	#	%	NL	DE	BE	FR	CZ	PL	SK	Other
Containers	*11*	13	8	1	1	1				
Dry cargo incl. barges	*32*	38	19	11		1				1
Passengers	*7*	8	2	4						1
Tankers	*29*	34	19	6	1		1	1	1	
(Blank)	*6*	7	3	2	1					
TOTAL	*85*	100%	60%	28%	4%	2%	1%	1%	1%	2%

The purpose of the survey was to question experienced skippers of different types and sizes of vessels. That goal has been achieved (see *Figure 4*).

- 64% of respondents was a boat master.
- 70% of the respondents has over 20 years of experience in inland navigation. Also, less experienced respondents are also represented in the research.
- 60% of the respondents was willing to provide additional information.
- 37% of the vessels is 2051-4000 tons (CEMT-class Va[3]); 17% of the vessels was <1251 tons (CEMT-class I to III) and 14% was over 4000 tons (CEMT-class VIa).





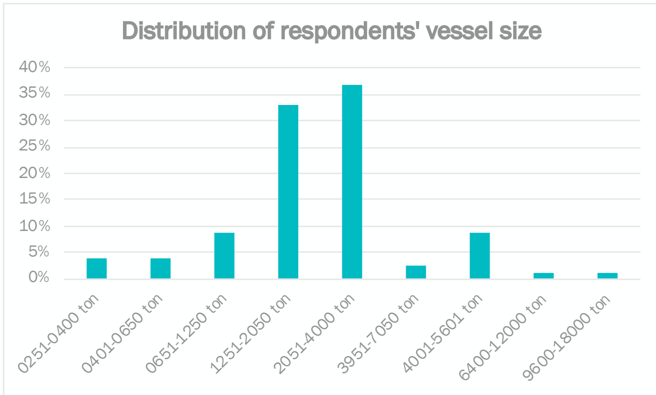


Figure 4.
Experience in role (top), per vessel type (middle), and vessel size (bottom)

[3] For an explanation of CEMT classes see: https://en.wikipedia.org/wiki/Classification_of_European_Inland_Waterways

Most respondents have at least once experienced an incident. Most reported incidents belong to the operating mode A1 (*Figure 5*):

- 52% of the respondents reported a ship-ship incident
- 18% of the respondents reported a ship-infra allision
- 21% of the respondents reported a grounding.

In research phase 1 it was concluded that no specific focus on certain types of incidents is necessary in this phase 2.

Vessel visits

Based on the criteria mentioned in paragraph 2.2 a selection of 10 small to large vessels including different types of cargo was made for further investigation. Detailed characteristics of these vessels are summarised in *Annex 1*.

Gap analysis

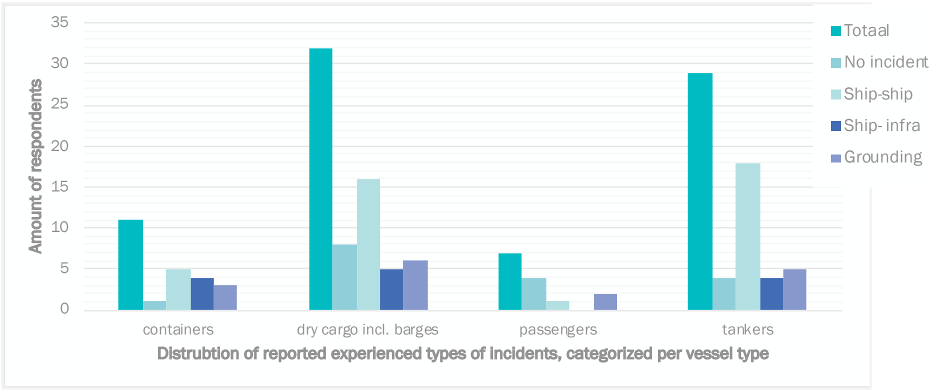
Results from the gap analysis are incorporated in the next chapters.

Results for the main topics

In the next chapters the results from the questionnaire, the vessel visits, and the gap analysis are presented for each of the three main topics:

- Wheelhouse design (*Chapter 4*)
- HMI (*Chapter 5*)
- Automation (*Chapter 6*).

Recommendations are formulated per topic and in *Chapter 7* a summary is provided.



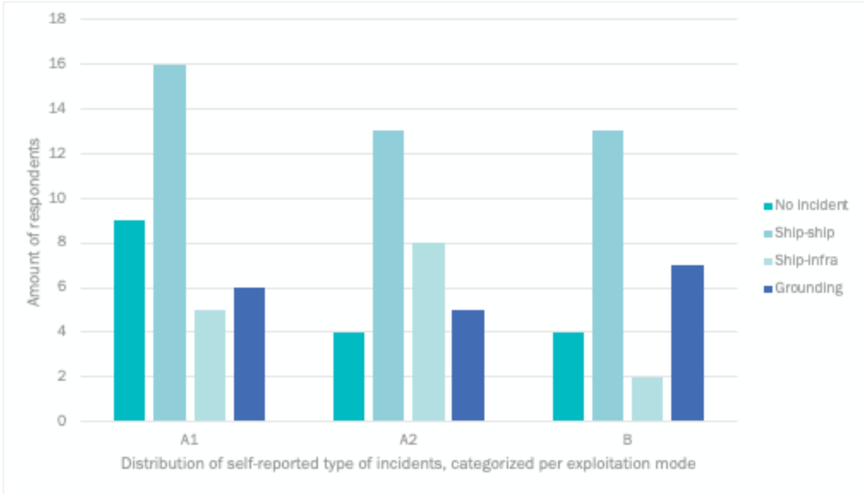


Figure 5. Experienced incidents per vessel type (top) and per exploitation mode (bottom). A1: navigation for a maximum of 14 hours, A2: navigation for a maximum of 18 hours, B: navigation for a maximum of 24 hours, in a 24-hour period. See further: https://www.ccr-zkr.org/files/documents/reglementSTF/stf1_072016_en.pdf

4. Wheelhouse design

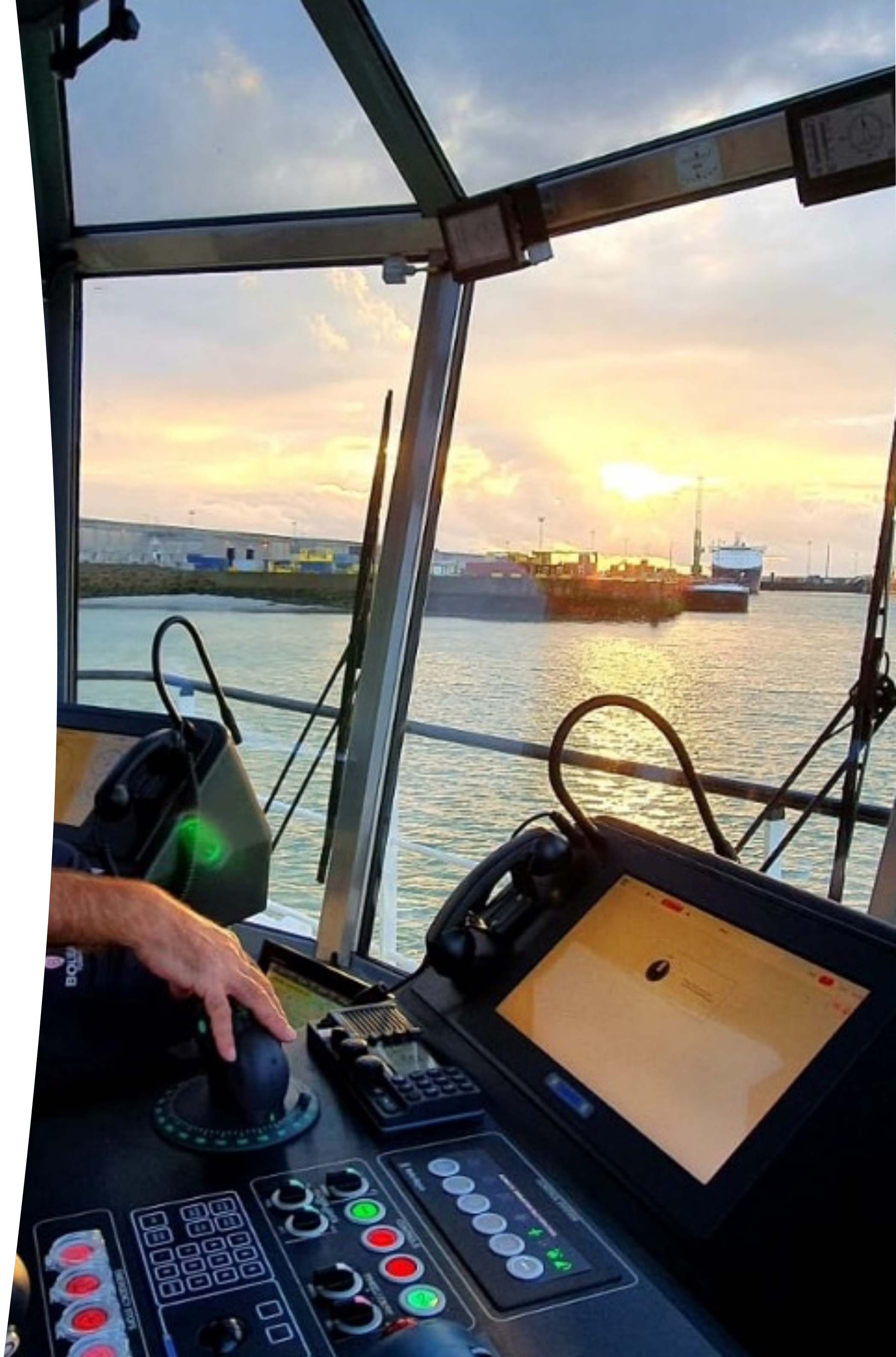
4.1 Context from the data and expert analysis

A good design of the working interfaces can prevent the occurrence of human error because design is such that information and actuation is on 'logical' locations, visible, legible, reachable, understandable, etc. Furthermore, it will prevent musculoskeletal injuries by taking human dimensions and capabilities into account[4]. In this context, requirements are set for a design in occupational health and safety regulations and in other sectors in, for example, the Machinery Directive.

Phase I of this research identified complaints about the wheelhouse becoming a 'Christmas tree' of added systems with no systematic human-system integration being applied. Also, in the preparation of phase 2 no formal standards were mentioned by shipping companies and suppliers/builders as being applied in wheelhouse design. This has led to a situation where at the best shipping companies use their own design philosophies allowing for flexible operation by rotating personnel within a company. Between companies, even within a subsector like liquid bulk, familiar with relieve skippers, this is not easy. Furthermore, this Introduction of new systems or interior elements may be guided by available space rather than the best location for such a system.

In this section we will focus on the general wheelhouse design. The next chapters will cover the HMI's and the influence of automation.

[4] Many papers and books cover this subject. For instance: Delleman, N.J. et al. Working Postures and Movements. CRC Press, 2004.



4.2 In-depth understanding

Uniformity in lay-out

A wheelhouse can be considered as a 'small control room': safety critical processes are being executed and monitored requiring both concentration and simultaneous, communication, meeting and often also coaching. Nowadays navigation is mostly based on direct sight from the helmsman stand, supported by information from displays and executed by controls in the wheelhouse.

ES-TRIN 2021 contains mandatory regulations for wheelhouse design in inland navigation. Although *Chapter 7* contains requirements for the wheelhouse it provides only general indications about equipment that is mandatory and issues like unobstructed view. It does not provide guidance on the design of the wheelhouse as a whole. EN 1864:2008 (*Inland Navigation Vessels – Wheelhouse – Ergonomic and safety requirements*) has some non-mandatory examples of wheelhouse layout. EN 1864 was not mentioned during Sailing for Excellence and other preparatory meetings by stakeholders, which may indicate that it is not very well known. SEA Europe delegates also cover maritime industry; they indicated to be familiar with EN 1864 but mention voluntary guidelines from classification societies as more relevant to adhere to in practice and mostly deliver customised design. Quality and usability of ES-TRIN and EN 1864 are discussed below and in *Chapter 5* for HMI issues.

About 60% of the questionnaire respondents think it is (very) important if the wheelhouses of the vessels they sail have (approximately) the same layout (*Figure 6*). This is less the case for respondents in dry cargo (44%) and containers (54%), where the majority lives on the vessel and crew is dedicated to their vessel (*Figure 7*). In accordance, from the self-employed skippers only 5/17 (29%) agree with the importance of a uniform design of the wheelhouse which seems understandable because they sail the same ship all the time and they may have had personal input in the design. On the other hand, in tankers 76% agree and only 6% disagree with the importance of standard wheelhouse design (18% no opinion).

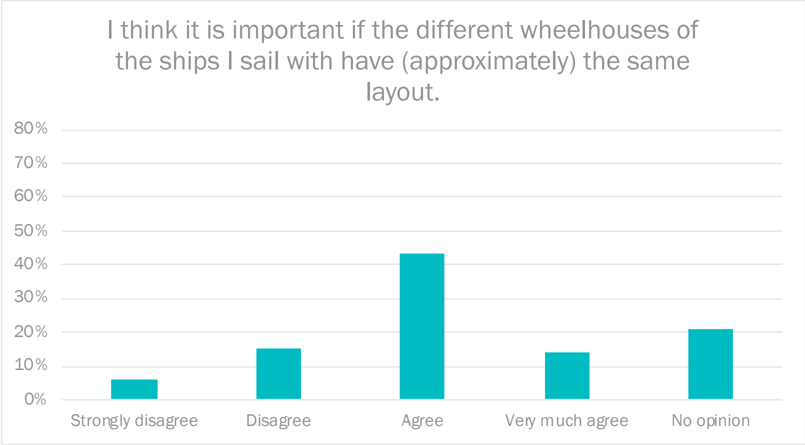


Figure 6. The importance of uniform layout of wheelhouses.

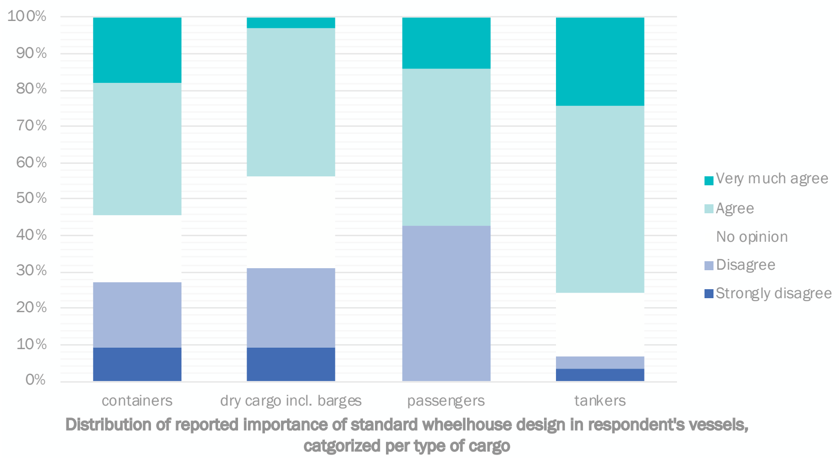


Figure 7. The importance of uniform layout of wheelhouses per vessel type.

From the vessel visits it also appears that uniformity is generally considered very important. This ensures that skippers who are not familiar with the vessel can also sail it. In addition, uniformity is important in emergency situations. Emergency situations may require a skipper to react quickly and precisely and knowing how to find the important tools is important for this. It is important to note that the concept of uniformity is particularly appealing for new vessels. For older vessels it is considered too expensive to refurbish. In many shipping companies a uniform layout is being applied, however this is not based on formal standards but merely on copying and improving the latest company wheelhouse. Standards differ between companies as does the design approach within the organisation and the degree of user participation.

- In designing a wheelhouse layout not only tasks directly related to sailing & manoeuvring and (un)mooring are relevant. Also, tasks like voyage planning, crew management and crew change, operation of the vessel, (monitoring of) cargo handling, entrepreneurship, and even relaxing, take place in the wheelhouse. Therefore, multiple task areas need to be considered.
- It is noteworthy that the sector pays a lot of attention to crew training. The layout of the wheelhouse rarely facilitates remote viewing by a 'trainee' in the wheelhouse chair. During the ship visits, there was a ship with an extra radar + ECDIS screen near the administrative workplace where the 'master' could easily supervise navigation tasks by the trainee, or the trainee could observe the radar and ECDIS without disturbing the helmsman. This seems a good example of space allocation for the task of training/coaching.

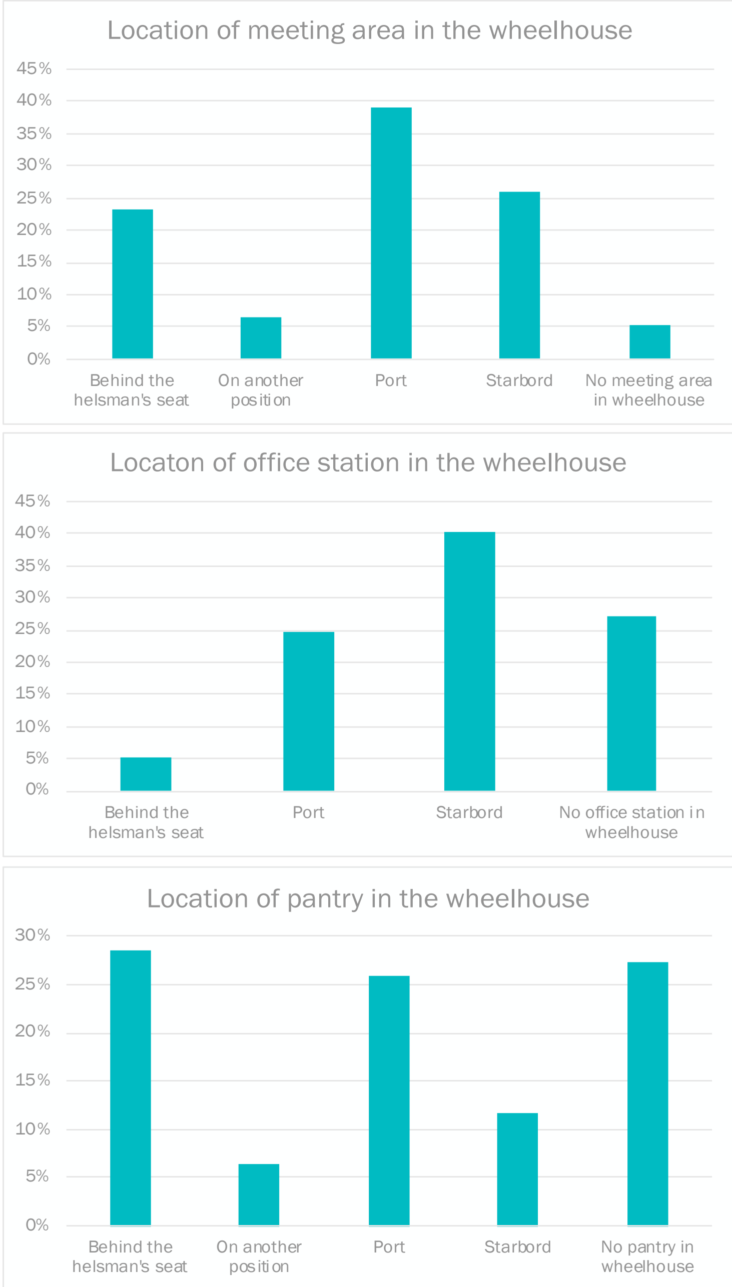


Figure 8. Location of meeting area (upper), office (middle), and pantry (lower) in the wheelhouse

- One wheelhouse was fitted with an (extra) toilet. During a longer sailing period, when colleagues are resting and the helmsman is navigating, it is relatively easy to use the toilet. Measures to avoid having to leave the helmsman's position, such as stopping to drink while sailing, as one respondent indicated, are counterproductive because dehydration is known to contribute to human error and fatigue[5].

In the questionnaire the location of 'supportive' areas besides primary task navigation was determined (*Figure 8*):

- Location of the meeting area is mostly on port side (40%) followed by starboard and behind the helmsman (both about 25%; 10% have no meeting area or it is located elsewhere;
  - In passenger vessels mostly (70%) behind the helmsman.

- Location of the office station is mostly on starboard (40%);
  - 27% have no office station in the wheelhouse (50% of dry cargo vessels).

- Location of the pantry:
  - 30% behind the helmsman;
  - 25% port;
  - 30% has no pantry in the wheelhouse (passenger vessels 45% no pantry).

Task areas for monitoring operation of the vessel, monitoring safety state of the vessel, and voyage/ cargo planning are mostly interrelated and combined with navigation. This is because information and displays are being used for all these tasks in different stages of use of the wheelhouse. From the in-depth analysis we learned that in smaller wheelhouses almost all task areas are stacked at the helmsman stand, leading to e.g., laptop use on the knees while sailing. See *Chapter 5* for details.

Working environment

Furthermore, during the visits and from the questionnaire several examples of bad environmental factors (mainly lighting) were observed: lighting during night with too eminent spots, surfaces on ceilings or consoles that merely function as a mirror, or use of very light, bright colours in the desk and ceiling. High contrasts in the visual environment, glare and reflections contribute to reduced perception and readability of displays.

[5] https://www.nhs.uk/conditions/dehydration/

Watson, Phillip, Andy Whale, Stephen A. Mears, Louise A. Reyner, and Ronald J. Maughan. 2019. "Mild Hypohydration Increases the Frequency of Driver Errors During a Prolonged, Monotonous Driving Task". *Physiology & Behavior* 147 (2015) 313–318.

Lessons learned from other sectors in working environment and layout design

In the wheelhouse at the helmsman's position concentrated work using direct vision and instrumentation and automation is interspersed with interruptions by own crew or remote communication. In other sectors like rail, automotive, road freight, maritime, industry standardisation for layout and work environment is common and mandatory, see *Figure 9*. For the maritime sector ISO 8468:2007 (*Ships and marine technology — Ship's bridge layout and associated equipment — Requirements and guidelines*) exists. SEA Europe delegates mention some cruise industry adhering to it. But, also in Inland navigation vessels a European standard EN 1864:2008 (*Inland navigation vessels – Wheelhouse - Ergonomic and safety requirements*) was identified. This standard serves as a non-mandatory means of demonstrating compliance with the high-level ergonomic requirements of the mandatory ES-TRIN 2021 (Art. 31 *Special provisions applicable to vessels sailing with minimum crew*).

In general, design standards for control rooms, driver cabins etc. (*Figure 9*) are based on a task-based design approach, anthropometric data (dimensions of the target population), vision/ grasp and task characteristics. Most of these design standards also address environmental factors like lighting and applications of colours and materialisation of interior elements. Note that most of these standards are not mandatory by law but are accepted industry standards that for instance are used in procurement of new vessels/vehicles/rooms.

Related to generic wheelhouse layout, the Annex A of EN 1864 provides some informative examples for layout. The vessel visits showed that 2 out of 3 wheelhouses that were built after 2008 (the year of publication of this standard) comply with these layout examples (see *Annex 1*). Important aspects for wheelhouse layout missing from ES-TRIN 2021 or EN 1864 are provisions for workstations on the bridge wing and for an auxiliary workstation next to the helmsman's stand: extra 'eyes' in bad weather conditions, or for training/coaching/ supervising (e.g., in Rail standard UIC 651 seating and sight requirements for a second person are set - *Figure 10*; in ES-TRIN 2021 only basis requirements for a second person in high-speed vessels are set). Also, no design process is prescribed or suggested in EN 1864 in which all task areas are defined, and wheelhouse dimensions are considered.

Examples of ergonomic design requirements and guidelines in other industries

In several transport modalities and industries mandatory guidelines and standards exist for the design of the workstation and direct work environment to match the environment to the human tasks and human capacities. Standardisation of design mitigates the risk of slips, lapses, and mistakes during transportation. Examples outside inland navigation are:

- ISO 8468 (2007): Ships and marine technology – Ship's bridge layout and associated equipment – Requirements and guidelines.
- UIC 651 (2002): Layout of driver's cabs in locomotives, railcars, multiple-unit trains and driving trailers.
- UIC 612 - part 0-2 (2009): Driver Machines Interfaces for EMU/DMU, locomotives and driving coaches.
- DIN 5566 - part 1-3 (2006-2020) Railway vehicles –Driver cabs.
- ISO 16121 – part 1-4 (2011-2012): Road vehicles - Ergonomic requirements for the driver's workplace in line-service buses.
- ISO 11064 - part 1-7 (1999-2013): Ergonomic design of control centres.

Figure 9. Layout requirements and guidelines in several industries (other than IWT)

o **2.7.2 - Arrangement and dimensions of windows**

The front windows must be suitably dimensioned to enable the driver and the second man, if any, to observe the track and (visual) signals correctly, while complying with the conditions specified in point 3 - page 13. Consequently, the distance from the top edge of the front window or of the heated second window (if any) to the floor on which the driver stands upright, must not be less than 1 800 mm.

Figure 10: Excerpt from Rail standard UIC 651 on task area for coaching including relevant requirements

4.3 Evidence-based recommendations

1) There are ample indications that standardisation in wheelhouse layout has advantages from safety, health, and operational perspective. In other industries the use of standards in control room/ driver cab / bridge design is already mandatory. In inland navigation EN 1864 is not mandatory but one way of showing compliance with ES-TRIN 2021. As stated in EN 1864: "*Technical possibilities and economic conditions will increasingly necessitate shift operations and a change of personnel on the individual vessels and from vessel to vessel. Whereas a helmsman previously used to stand at the same control position for years, perhaps even all his life, and would thus become very familiar with it and adapted himself to it, he can now reckon increasingly with having to operate a different ship at some point in time.*" EN 1864 (2008), however, needs to be updated or replaced (see below), both from technological as from ergonomic point of view, and its use to become more appealing. ***[Level of evidence: H]***

2) Common for the standards mentioned in *Figure 9* is the use of task areas, including traffic zones and entry area, but also primary, secondary, tertiary zones for displays & controls. In inland navigation this approach may translate into requirements that are:

- Strict for navigating: the navigating controls & displays (speed, course, sight, visibility, alerting other vessels, safety state);
- Strict for navigating, but not for the navigating tasks: controls & displays for operation of vessel, regulating own environment: lights, climate;
- Less strict: e.g., during mooring (journey preparation, administration, crew change, managing, ...).

Now, this separation in tasks and priorities is only implicitly present in EN 1864. As an option, workstations on the bridge wing and an auxiliary workstation next to the helmsman's stand (*Figure 11*) can be included, as well as tertiary tasks like personal hygiene and coaching.

Based on existing layout designs of wheelhouses it seems possible to describe a generic wheelhouse design (process) based on primary, secondary, and tertiary tasks within the wheelhouse; primary tasks being more urgent than e.g., tertiary tasks which are also relevant. In *Figure 12* an example of such a generic layout is presented for a large wheelhouse for vessels with larger crew. Vessel with less crew require other task areas or same task areas but of smaller size and subsequent other design requirements. This example is partly in accordance with the example of a large wheelhouse in Annex A of EN 1864. This may be the basis for future development with stakeholders. Current examples for smaller wheelhouses in EN 1864 may need adaptation for e.g., administrative tasks and voyage/ cargo planning tasks and entrance of the wheelhouse within in sight of the helmsman. Details directed at design of the control position will be discussed in next chapters. ***[Level of evidence: H]***

Figure 11. Example of an auxiliary workstation with ECDIS and Radar next to the helmsman's position to implement the coaching task, in this case combined with the administration and cargo planning task area.

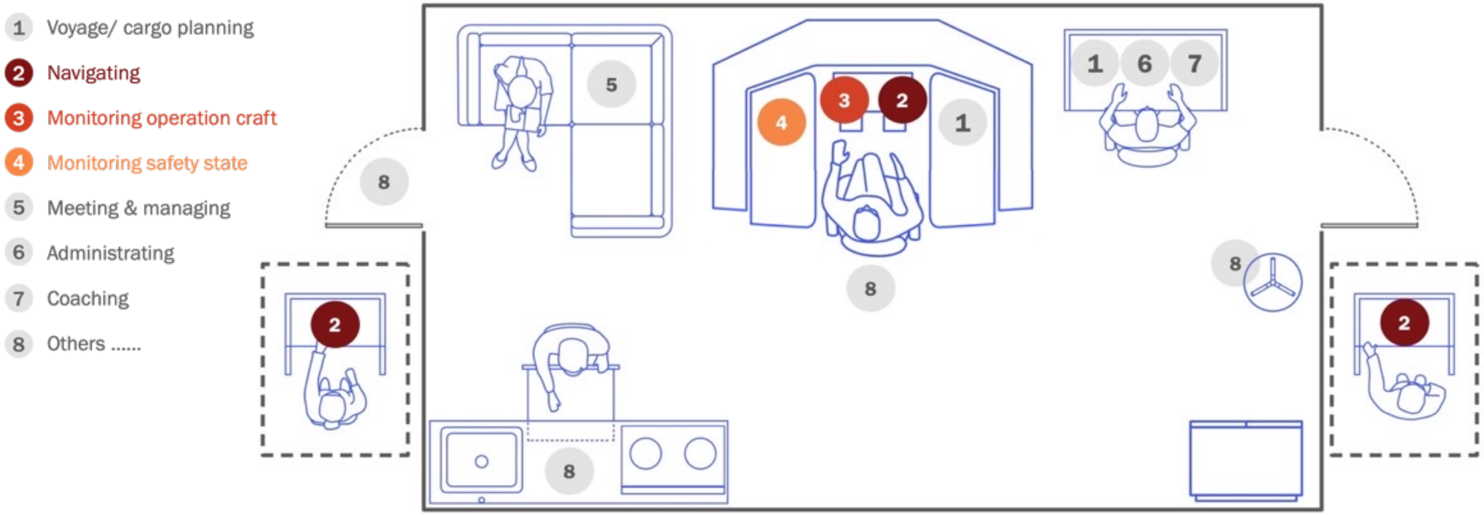


Figure 12. Example of a task based generic wheelhouse layout for a large wheelhouse, based on common ergonomic layout design approach and detailed results from the questionnaire and vessel visits. Separate design requirements are to be detailed in the next chapters

3) Further digitalisation and automation of IWT is currently developing[6]. In the coming years even deployment of autonomous sailing in commercial services may be expected. This will have an impact on the (design of the) wheelhouse and on remote workstations that will monitor and control the ship, as well as on the design of jobs and required competences. Autonomous operation is beyond the scope of most existing standards in all industries, although for instance autonomous metros are operated in several cities around the world. The influence of digitalisation and automation in IWT on the control position is discussed in the next two chapters. Autonomous sailing is beyond the scope of this report, but it already should be incorporated in standards including a roadmap towards future proof IWT. ***[Level of evidence: H]***

4) Next to the layout of the wheelhouse also environmental conditions should be standardised. These conditions comprise amongst others:

- Lighting: glare of displays, reflective coefficient (e.g., UIC 651 is clearer than ISO 8648), lighting levels
- Climate
- Acoustics
- Vibrations
- Materialisation of interior elements.

EN 1864 contains these issues to some extent or refers to some extent to other standards (although these are often not up to date anymore). ***[Level of evidence: H]***

In the next chapter focus is on the Human Machine Interface (HMI) of the control position.

[6] See *Flagship 6: A roadmap for digitalisation and automation of IWT* in COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. NAIADES III: Boosting future-proof European inland waterway transport. 24.6.2021.

5. HMI

5.1 Context from the data and expert analysis

The Human Machine Interface (HMI) focuses on that part of the wheelhouse where skippers interact with controls and information systems for navigating and vessel/load control. These systems are located around the helmsman's position (control position).

In phase 1 of our study, there is no hard data indicating HMI as a root cause because it is not registered as a cause in the incident registration. However, it was noted from literature (Feyer, 2019[7]) and acknowledged by the Sailing for Excellence focus group that assisting devices - e.g., bridge collision warning systems, CCTV, AIS, radar - are often implemented in the wheelhouse as an add-on. So, more and more systems enter the wheelhouse without an integral focus: how do these systems effectively (together) support in navigation? The wheelhouse has been called a 'Christmas tree' of added systems.

Human-system integration[8] is hardly being applied in the IWT sector. This may lead to bad human-machine interfaces and too many or irrelevant alarms or stimuli.

In the next section we focus on the 'logic' and usability of the layout of all devices at the control position.

5.2 In-depth understanding

Location of devices

In the questionnaire respondents marked the position of their instruments in a schematic illustration representing the helmsman stand, with 18 zones around the helmsman (*Figure 15*). Also, they indicated to what extent they were (very) (dis)satisfied with the position. In *Annex 2* the location of all devices (including respondents' satisfaction) is summarised.

- Location of devices
  In conclusion: even 'classic' instruments like rudder control and propulsion control, navigation lights controls, etc. have varying positions in the helmsman stand: starboard or port side and varying from very close to the helmsman without reaching to some reaching needed by the helmsman. 'Newer' instruments on board like AIS installation information, automatic sailing systems, CCTV displays, and controls are more widespread over the helmsman's stand.
- From the questionnaire it is shown that most of the respondents are (very) satisfied with location of devices (*Figure 13*):
  - Ship course information
  - Ship control
  - Navigation
  - Communication means
  - Status information ship

It must be noted that these results may be influenced by the fact that skippers got used to a certain configuration or even were responsible for the design ('buy in bias'). If respondents were dissatisfied, they were mostly not 'vessel owners'.

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7 Feyrer, J. Evaluierung von Assistenzsystemen zur Brückenkollisionsverhütung in der Binnenschifffahrt. Masterarbeit TU Berlin, 30.12.2019.

8 Human Systems Integration (HSI) is the systems engineering discipline directed at addressing human performance in technology development and system acquisition. This includes designing for human capability, proficiency, human utilization, accommodation, survivability, health, and personnel safety, in the acquisition strategy. Alert! Issue No. 24, page 3, 2010.

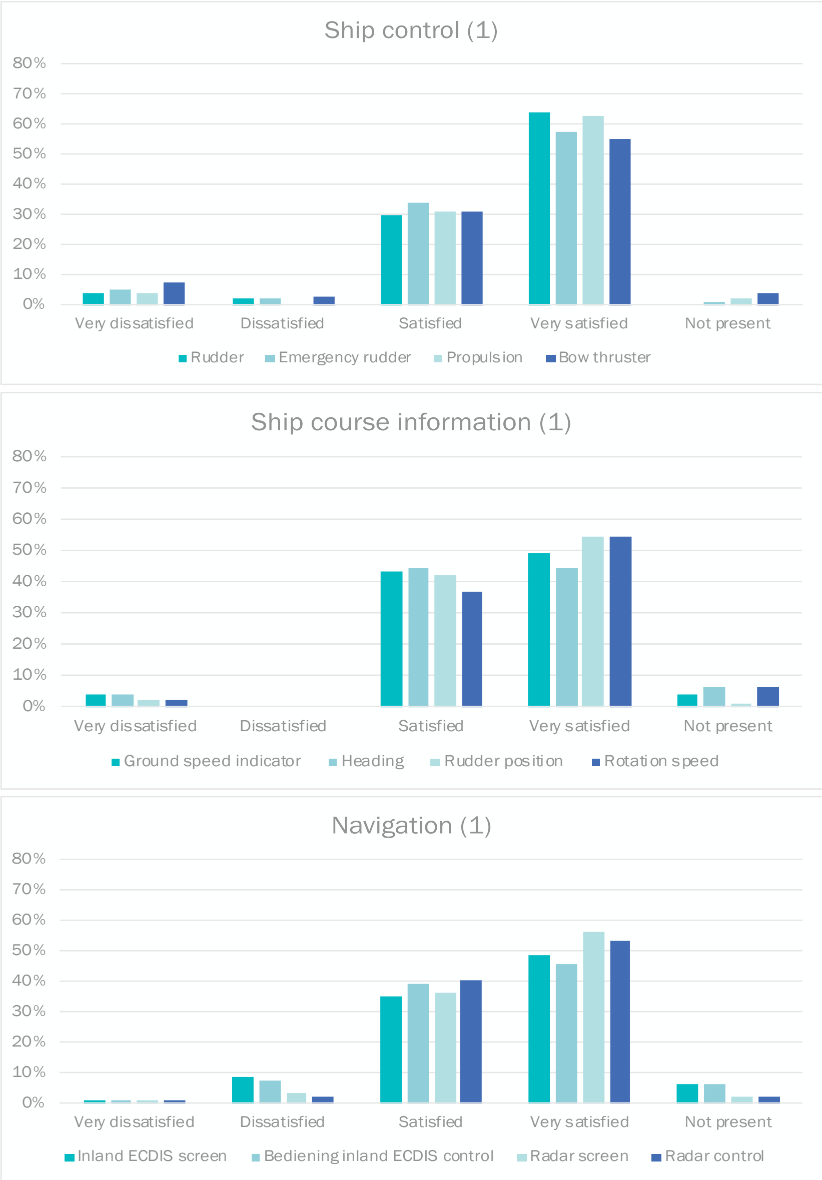


Figure 13. To what extent are you satisfied with the location of the systems related to .... Ship control (upper graph), Ship course information (middle), Navigation (lower).

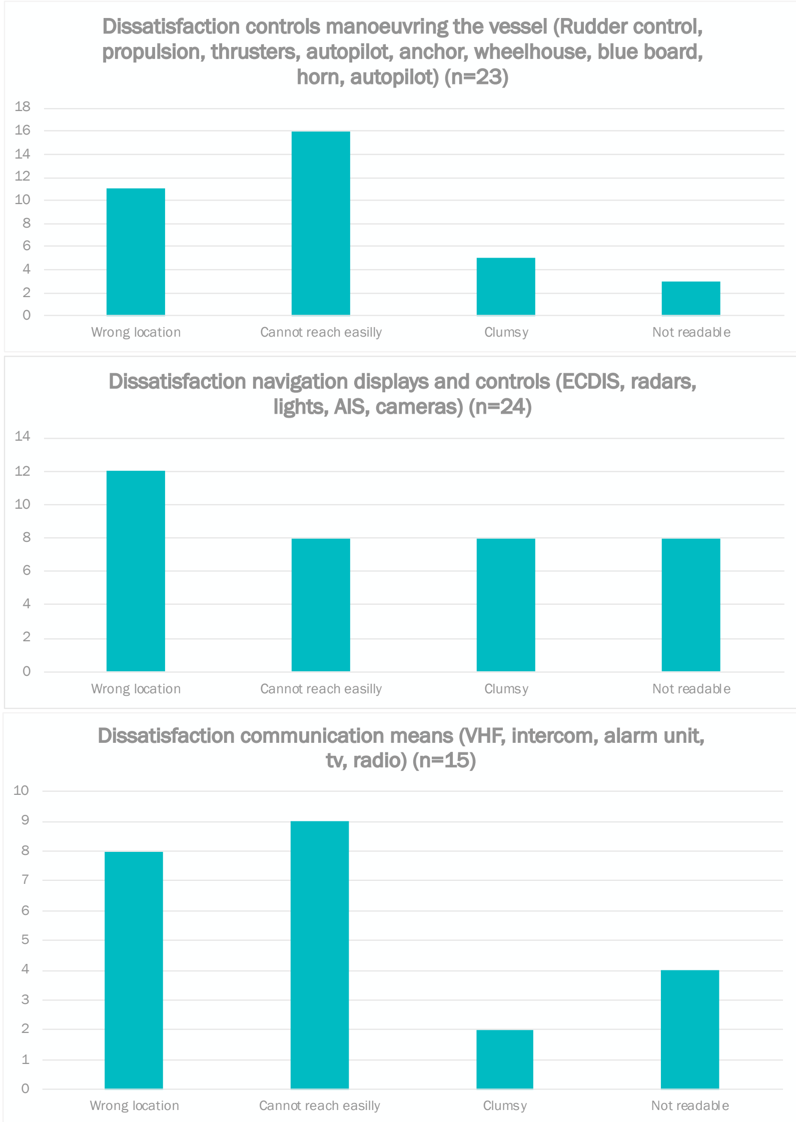


Figure14. Questionnaire responses on what is the reason for not being satisfied with the location of systems related to maneuvering controls (top), navigation displays and controls (middle), and communication means (bottom). Multiple answers were possible.

Nevertheless, each control or display (except control of the extra radar) got at least one dissatisfied response; on average 25-35% of the respondents noted at least one reason to be dissatisfied with the location of some controls or displays. The main reasons for dissatisfaction are (*Figure 14*):

- for controls and communication means: not easily reachable or are at the wrong location.
- for displays: not easily visible/legible or are at the wrong location.

The use of touchscreens may be interesting in this respect because they are a display and control at the same time. This is challenging from a legibility and reachability perspective. Fifty-four (54) out of 85 respondents (64%) have touchscreens in the wheelhouse for various purposes. Most often mentioned touchscreen applications are engine, alarm, and vessel control systems, but also ECDIS, radar, CCTV, and intercom are sometimes touchscreens.

Despite satisfied respondents, from the vessel visits it appeared that even in the most modern vessels HMI locations are not according to common ergonomic guidelines and do not comply with detailed requirements from EN 1864. This may contribute to human error or musculoskeletal effects. Most often we observed issues with:

- Predictability: Steering gear is most often (60% of respondents) located on port (EN 1864 requires starboard), engine operation is most often (68%) located on starboard (EN 1864 requires port);
- Reachability: controls/devices on the left and right (vertical) side are often beyond normal reach distances (areas 6 and 9 in *Figure 15*, over 350 mm reaching distance measured from shoulder point as defined by EN 1864). E.g., control of VHF and hydraulics we have witnessed to be over 1000 mm from the shoulder. Also, touchscreens are often not within reach, thus requiring the skipper to lean sideward or forward, or leaving his seat although EN 1864 requires touchscreens to be within a grasping range of 350 mm from the shoulder (*Figure 16*).

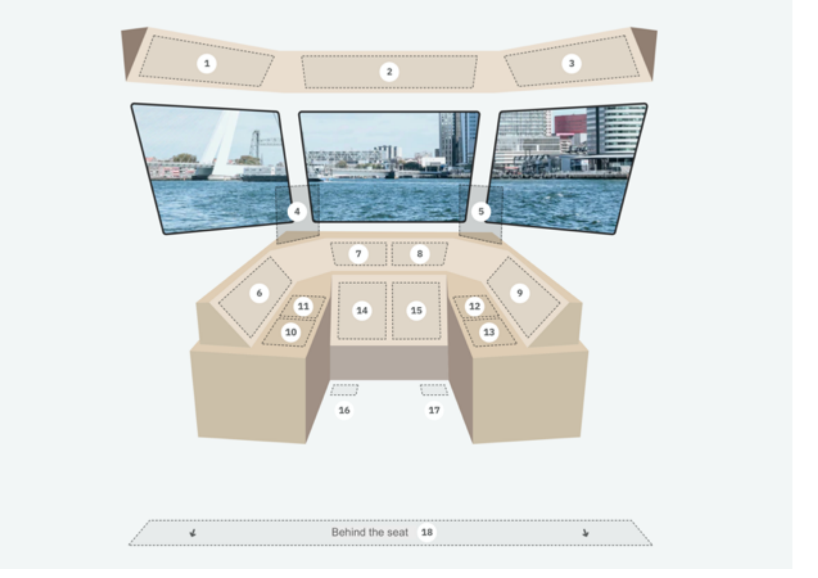


Figure 15. Schematic illustration of the helmsman's position (console). The numbers refer to the questionnaire: respondents were asked to indicate where certain devices are located and whether they are (dis)satisfied with the location. In Annex 2 the location of all devices including respondents' satisfaction is summarised.

Figure 16. Observations from vessel visits: unfavourable working postures when operating VHF (top) and a motor management touchscreen (bottom).

- Visibility: some displays that show important information, like the VHF-selection controls are outside the primary and secondary field of vision (e.g., in the rear of areas 6 and 9 in *Figure 15*). This means that they can only be seen if one turns his head actively. Relevant information can thus easily be missed.
- Legibility: e.g., ECDIS displays are often located in the lower forward section of the console (areas 14 and 15 in *Figure 15*). Reading distances in relation with character heights may then be such that they are not legible with normal visual acuity. This may lead to extreme forward bending and/or changing glasses (*Figure 17*).

Controls for steering and propulsion are nearly always reported within reach (in areas 10, 11, 12 and 13 in *Figure 15*). They are however not always within grasping area 1 (350 mm from the shoulder) according to EN 1864 (*Figure 18, left*). Sometimes the main controls are also present on a pod at the armrest of the seat (*Figure 19*), which is an ergonomically sound idea. Generally, helmsmen adopt a twisted-leaning (*Figure 18, right*) working position sitting in the highchair, with the course controls within easy reach and the propulsion on the other side within easy reach, with or without feet on the desk during longer distances *(Figure 18, right*).

Control of the chair appeared quite difficult in many vessel visits. It is therefore not easy to enter or leave the position which is important in emergency situations. Also, changing work posture from sitting to standing is hampered if the chair is hard to operate. Often, the chair is positioned between the two side panels of the console. Therefore, some extra space between chair and side panel is needed to allow the helmsman to operate his seat. However, this takes up valuable horizontal space to reach to controls. To get on/ off the seat, the seat is usually moved forwards and backwards.

During the ship visits, it was noticeable that operating equipment for radar or CCTV is often effectively concealed in the console housing via pull-out drawers, but often - contrary to what is required and prudent - at a great distance of reach.

Figure 17. The distance from seat (eyes) to ECDIS (straight ahead/down) can be quite large in some vessels up to approx. 1,9m. Legibility of characters can be difficult.

Figure 18. (Left) Engine control within reach but outside primary grasping area. (Right) Twisted leaning working position to compensate far reaching.

Information presentation & interaction

- Large differences have been observed in images of wheelhouses considering the density of instruments as well as during the vessel visits: see for instance a packed console in *Figure 20* vs. a less packed consoles in *Figure 18 (left)* and *Figure 19*. On one hand, this is logical due to the age of a ship, where additional systems have been installed in an existing wheelhouse. On the other hand, it also seems to be the result of choices in design philosophy for the realisation of redundancy and manufacturer-specific characteristics of the implementation of instrumentation.
- Almost all primary displays have dimming functions or some night mode. This is particularly useful at night, so that the displays do not blind the skipper during watching in the dark. However, we also observed situations where this was not the case, like touchscreens, or where every display had to be adapted separately and in practice people do not use the function.
  - Additional displays like for cargo monitoring/ planning (often during sailing also in dark times) and CCTV monitors produce relatively high luminance, sometimes applied also during dark situations for monitoring engine rooms. Eyes must adapt during ca. 45 minutes to dark again after being exposed to a light situation. Existing requirements do only include these instruments on a basic level only (ES-TRIN 2021 art. 7.02; *ESI-II-6 Appropriate auxiliary means for observing the area of obstructed vision*).
  - Ideally relevant information displays have 3 modes for day, night, and times between.
- System integrators, represented in Sea Europe indicate that most systems are used in both the inland waterway and maritime sectors. Manufacturers follow SOLAS and IACS regulations. No specific guidance exists for the use of e.g., touchscreens or CCTV technology. They indicate regulation would be welcome.
- Some displays, even high priority like for navigation are not free of glare (*Figure 20 - left*). Legibility is thus impaired.

Figure 19. Example of a control on a pod mounted on the arm rest.

Figure 20: Left - Example of non-matted screen for radar or ECDIS, leading to impaired legibility

Figure 20. Right - Example of controls having different orientations.

- Orientation of some instruments vary over vessels: sometimes in forward direction, sometimes in sideward direction (*Figure 20-Right*). Also, multiple languages are often applied within the design of one vessel. This is not in convention with basic human factors guidelines. Possibly 'underneath' the desk instruments require so many space that optimal arrangement for regular use is impaired.

Findings considering alarms are integrated in the next chapter.

Redundancy

It is good design when elementary controls and information are redundant: when the primary device fails, operation or information retrieval is still possible through a second or even a third device. We have observed many good examples in wheelhouses. However, in some cases a second display is installed for redundancy purposes only: it has no other function. Then, it may use valuable space (e.g., in the primary field of view) that also could have been used for other devices. Thus, in general, it is wise to be sparse with redundancy: like in other sectors – for instance in Rail – redundancy is required for some safety critical instruments only. Also, solutions where redundancy is achieved by – temporarily – using a display for secondary information with primary information seem better economically and ergonomically than using dedicated redundant displays with no other function.

Outside view – Direct or mediated (CCTV)

- It is important that the view around the wheelhouse (front/side/rear) is unobstructed (as required by ES-TRIN 2021 art. 7.02 plus ESI-II-6). During locks and in narrow waterways it is important for the skipper to have a clear view of the sides of the vessel (often cameras or mirrors). Raising the wheelhouse is also a possibility for improving (over)view. It can be concluded from vessel visits that the ease of direct view from the helmsman's seat to, for example, the aft section differs from ship to ship.
- All visited vessels and 87% of the questionnaire respondents apply CCTV systems for a proper situation awareness. Most of the respondents have the monitors hanging above the console or on a stand on the console (Appendix 2). Some ships have monitors integrated in the console. The monitors that are not integrated can often be used for multiple purposes, such as TV, navigation, and PC (see Redundancy). From the vessel visits we conclude there is a huge difference in type, positions, and amount of camera's applied, and position of images. Some show a nice realisation (*Figure 21*). EN 1864 does not cover camera philosophy, use of pre-sets and incidentally PTZ-cameras nor spatial orientation.

  Control of cameras (if present) are required to be within easy reach, however most of the visited vessels did not show this. Mostly, these systems have been added to the design later in an existing design when little space is left for optimal use.

Figure 21: Example of effective CCTV image philosophy with fixed cameras

Lessons learned from other sectors in work environment and layout design

As mentioned in paragraph 4.2, in other sectors - e.g. rail, aviation, automotive, road freight, maritime, industry – standardisation of work environment and work station design is common and mandatory (see *Figure 9*). Some of these standards and guidelines – particularly ISO 11064 – include a design process.

EN 1864 (2008) for inland navigation wheelhouses addresses most of the relevant issues. Most obvious shortcomings in the existing requirements for HMI at the control position from ES-TRIN and EN 1864 are however:

- Lack of a design process description (as mentioned in *Chapter 4*).
- Lack of description of (anthropometric/ body dimensions) target population or use of population characteristics in the design process.
- No clear design philosophy: in most other industries the (range of) eye positions is used as a basis to define body support areas and from there areas for (primary, secondary, and tertiary) controls and displays are taken.
- No clear motivation of choices for location and position of instruments.
- No requirements for a wiper area that shall guarantee unobstructed view during rain (as train, bus and truck standards have).
- Not up-to-date related to 'new' technologies (e.g., AIS installation controls, touchscreens, rudder propellors, CCTV).

Furthermore, for instance in rail industry, every system change needs to be assessed on its impact on safety. A safety case must provide the evidence of how the system under consideration complies with the specified safety requirements, within the defined scope of its proposed use (EN 50126-1: 2017).

5.3 Evidence-based recommendations

ES-TRIN 2021[9] *Chapter 7* describes requirements for the wheelhouse. However, requirements are specified in very general terms only, e.g., "*Control equipment needed to operate the vessel shall be brought into its operating position easily. That position shall be unambiguously clear*." And: "*Monitoring instruments shall be easily legible.*" No elaboration of 'easily', 'clear', 'legible' etc. is provided. For some equipment more detailed requirements are specified in Annex 5 of *Navigation and information equipment* but these requirements do not consider the relationship between the several controls and monitoring instruments, the relationship with the several tasks the skipper must perform, the position of the skipper, and the characteristics of the skipper. In Chapter 31 *Special provisions applicable to vessels sailing with minimum crew* the only explicit reference to ergonomics is made (art. 31-02): *The principal control units and monitoring instruments shall be ergonomically arranged*. In the application instruction for this article reference is made to the European standard for ergonomic and safety requirements for wheelhouses in inland navigation EN 1864 (2008). This standard is not mandatory but just one way of showing compliance with ES-TRIN 2021; the other ways are only very general descriptions (see *Figure 22*).

[9] European Standard laying down Technical Requirements for Inland Navigation vessels (ES-TRIN). CESNI, Edition 2021/1.

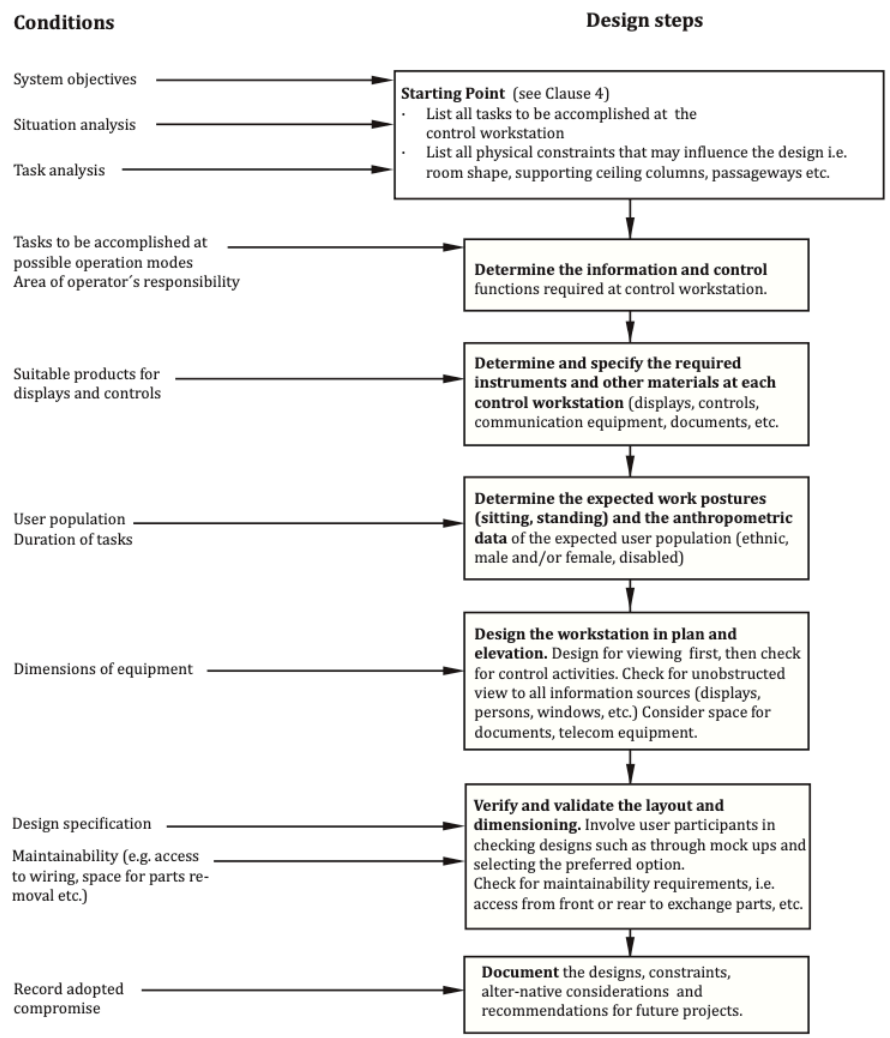
- *The provisions [in ES-TRIN Article 31.02, point 10] are deemed to be fulfilled if:*
  - *a) the wheelhouse is arranged in accordance with European Standard EN 1864:2008; or*
  - *b) the wheelhouse is designed for radar navigation by one person; or*
  - *c) the wheelhouse meets the following requirements:*
    - *aa) the control units and monitoring instruments are in the forward field of vision and within an arc of not more than 180° (90° to starboard and 90° to port), including the floor and ceiling. They shall be clearly legible and visible from the normal position of the helmsman;*
    - *bb) the main control units such as the steering wheel or steering lever, the engine controls, the radio controls, and the controls for the acoustic signals and the warning and manoeuvring signals required under national or international navigational authority regulations, as appropriate, shall be arranged in such a way that the distance between the controls on the starboard side and those on the port side is not more than 3 m. The helmsman shall be able to operate the engines without letting go of the controls for the steering system and while still being able to operate the other controls such as the radio system, the controls for the acoustic signals and the warning and manoeuvring signals required under national or international navigational authority regulations, as appropriate.*
    - *cc) the warning and manoeuvring signals required under national or international navigational authority regulations, as appropriate, are operated electrically, pneumatically, hydraulically, or mechanically. By way of derogation, it may be operated by means of a tension wire only if safe operation from the steering position is possible in this way.*
- *The rate-of-turn indicator shall be located ahead of the helmsman and within his field of vision. [Article 7.06 Navigation and information equipment, point 4]*
- *The arrangement of display units, rate-of-turn indicators and control units shall be ergonomic and user-friendly [Radar & rate-of-turn, article 7, point g)*

Figure 22. Ergonomic requirements as stated by ES-TRIN 2021, Chapter 31 Special provisions applicable to vessels sailing with minimum crew. ESI-III-10 Equipment for vessels to be operated according to standards S1 or S2.

In our opinion the more generic requirements do not offer adequate guidance to design an ergonomic control position or wheelhouse. EN 1864 is more elaborated than ES-TRIN in this respect but is not at the same level of maturity as standards from other industries. We propose the following improvements:

1) Based on the findings in this study, and trends towards more digitally disclosed information about infrastructure, environment, etc., it is recommended to revise EN 1864:2008 or develop new guidelines to incorporate the following:

- A design process with explicit choices for target population (anthropometric data/ body dimensions, work postures), defining vessel process characteristics and accordingly tasks etc. ISO 11064-4 provides a design process for workstations in control rooms (*Figure 23*).
- A distinction between primary, secondary, and tertiary tasks per area in the wheelhouse: primary tasks being safety critical tasks directly relating to navigating containing most frequently used and high-priority information and controls, secondary tasks containing less frequently used/ lower priority supporting the primary task, and tertiary tasks directed at non-essential devices like climate control. Guiding principle is that primary controls shall be within easy reach, and primary displays within primary field of vision. Secondary controls shall be reached within arm length and displays seen without head movement. Tertiary controls and displays may be outside the secondary envelopes. The exact dimensions/angles depend on the population chosen; these can be easily deducted from anthropometric sources and/or may be elaborated for e.g., a general EU working population. ISO 11064-4:2013 describes this full approach for workstations. In more dedicated standards for train and truck cabins the approach is translated in concrete design requirements. An IWT vessel – because of differences in sizes, application, and exploitation – seems somewhat in between regarding complexity. This means that it seems feasible to develop a standard or guidelines that describe both design process and workstation requirements depending on target population characteristics and size, application, and exploitation of vessel. In *Figure 24* and *Figure 25* some examples of future task-based helmsman stand layout specifications are drawn up.



NOTE Each design stage in the process may result in a feedback loop to one of the earlier steps.

Figure 23. Control workstation design steps (ISO 11064-4:2013)

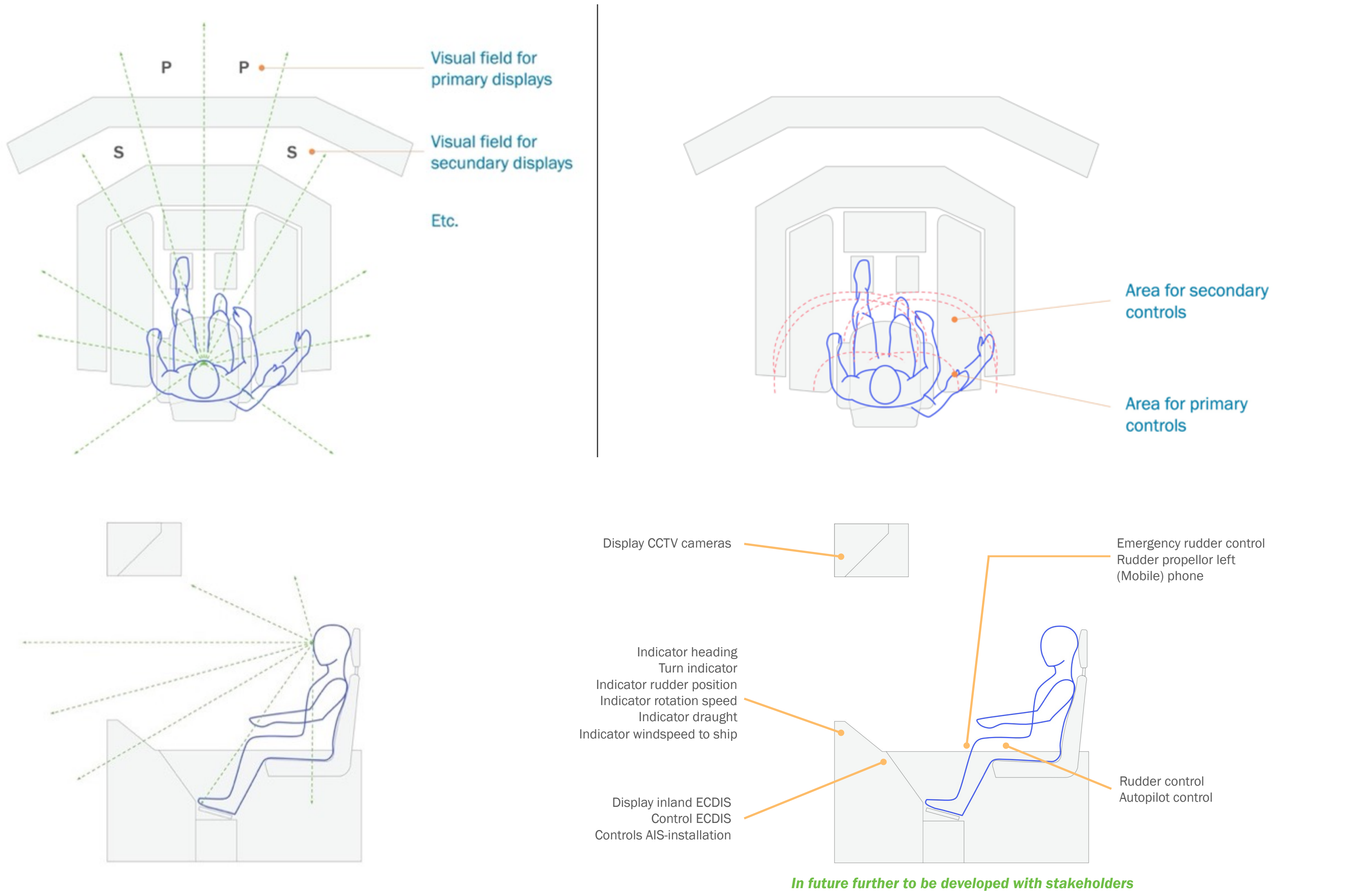


Figure 24. Principles for ergonomic requirements based on visual field (top), and location for devices based on reach envelopes and visual field (bottom).

- Space effective realisation of redundancy e.g., through a display that normally is being used for secondary information seems a better solution to overcome the period to repair. A risk analysis should guide the decision whether redundancy is necessary and how redundancy can best be obtained.
- Guidelines should accommodate for increasing use of touchscreens, pods, etc.
- For information system ES-RIS 2021/1 states e.g., in art. 1.04 that E.g., Art. 1.04: information must be able to read according to MMI guidelines, and art. 1.05: ECDIS-systems shall be designed according to ergonomic principles in order to guarantee user-friendly operation. This is formulated quite open while for GUI (graphical user interface) design, including legibility of information, many standards already exist. ISO 9241 series deal with human system integration. We recommend using ISO 9241 as part of procurement of information systems.
- Human factors guidance for design and use of CCTV;
- Redundancy of systems needs to be based on a risk analysis. In general, redundancy through a display that normally is being used for secondary information seems a better solution to overcome the period to repair than to reserve valuable space for a separate redundant display;
- Guidance on implementation of automation (see next chapter);
- (Inter)national conventions in IWT, and specifically wheelhouse design, need to be considered to make new guidelines as feasible and acceptable as possible.

2) These improved ergonomic guidelines need also be introduced with ship builders and suppliers of ship systems. Engineers need to be trained in using the guidelines properly. SEA Europe delegates support the importance of understanding and disseminating relevant knowledge in wheelhouse design.

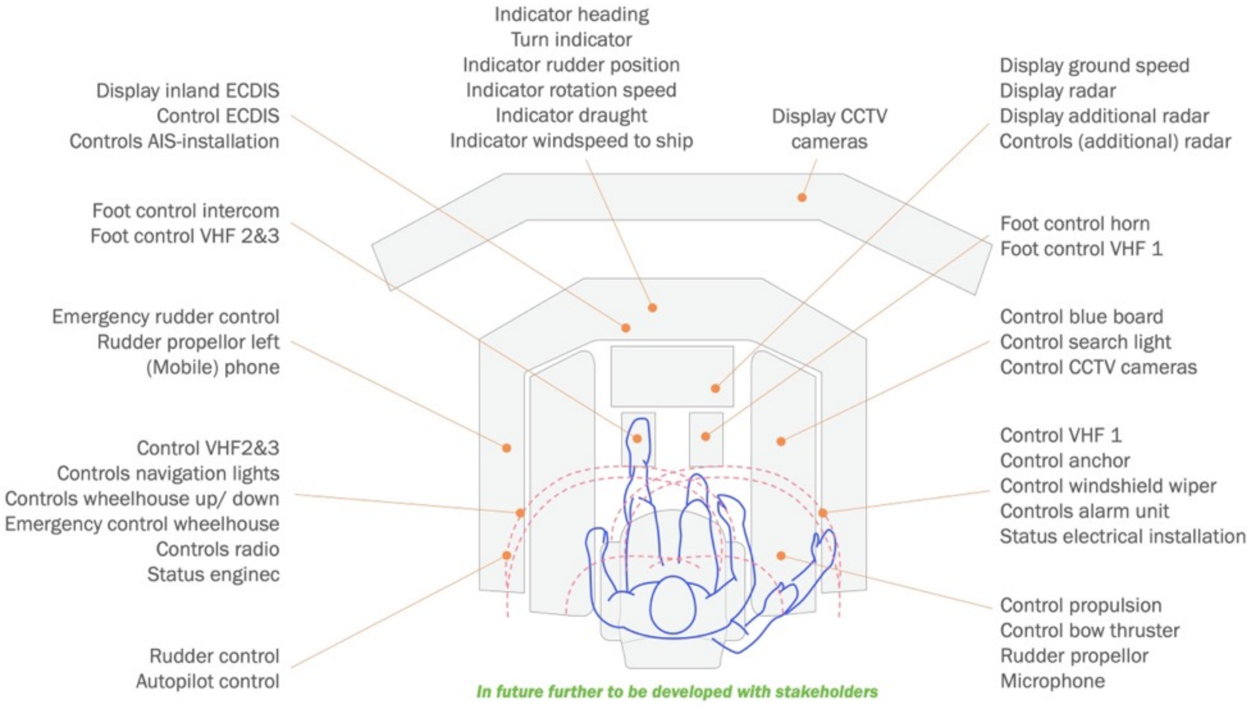


Figure 25. Examples for location of controls and displays. This is based on the inventory in the questionnaire and basic ergonomic principles. This needs to be elaborated in future guidelines.

6. Automation

6.1 Context from the data and expert analysis

In this chapter we will focus on the influence of increasing automation in the wheelhouse. The Sailing for Excellence focus group in Phase 1 hypothesised that age and the use of electronic equipment may be related: older skippers prefer to navigate by hand and may not fully benefit from automation.

From literature it is well known that intermediate levels of automation are very challenging to humans. Feyer (2019)[10] applied this knowledge to bridge collisions warning systems and showed that existing systems have many limitations or pitfalls. Also, working with radar, AIS and electronic charts may be challenging because of the quality of some systems and the fact that the wheelhouse sometimes has become a 'Christmas tree' of added systems. It was also noted that there may be too many or irrelevant alarms generated by these systems. In the former, a skipper may not fully comprehend the information provided by the system and make a wrong decision, in the latter alarms will be ignored. Also, if one does not fully understand the capabilities and limitations of assisting devices this may lead to a false sense of safety. Anecdotally, suppliers of those systems suggest that the skipper may focus on other tasks or even leave the wheelhouse where in fact the system has limitations.

[10] Feyrer, J. Evaluierung von Assistenzsystemen zur Brückenkollisionsverhütung in der Binnenschifffahrt. Masterarbeit TU Berlin, 30.12.2019.

6.2 In-depth understanding

Use of automation

In the wheelhouse since the introduction of new technologies there is an increasing use of automation, e.g., track control, anticollision warning, and bridge height detection. In the questionnaire the respondents indicated (*Figure 26*):

- 19% use track control;
- 15% use anticollision warning;
- 10% use bridge height detection.

Reliability of information / trust

There is a risk of over-trust due to a false sense of safety using new technology.

- It is important that automation is reliable to a certain extent. A system that is unreliable will not contribute to performance, and eventually its information will be ignored even when correct. On the other hand, a system that is highly reliable is prone to human complacency (overreliance): the information will be believed blindly even when incorrect. A system that is too unreliable will be sabotaged or anticipated on (increase mental workload). The risk of overreliance may already be present in inland navigation because respondents indicate a lot of trust in the information (*Figure 27*). Also, during the simulator and vessel visits some hazardous issues related to information trust were identified:
    - In the interviews during vessel visits 4/10 skippers mentioned AIS seriously lagging and not displaying correct information (e.g., ETA not updated). Skippers seem to be aware of this and therefore *say* that they can't/shouldn't rely solely on AIS while sailing. However, we also *observed* skippers behaving trusting the systems e.g., by not calling via VHF before leaving the port/terminal because ECDIS did not show vessels to be present (radar was turned off,

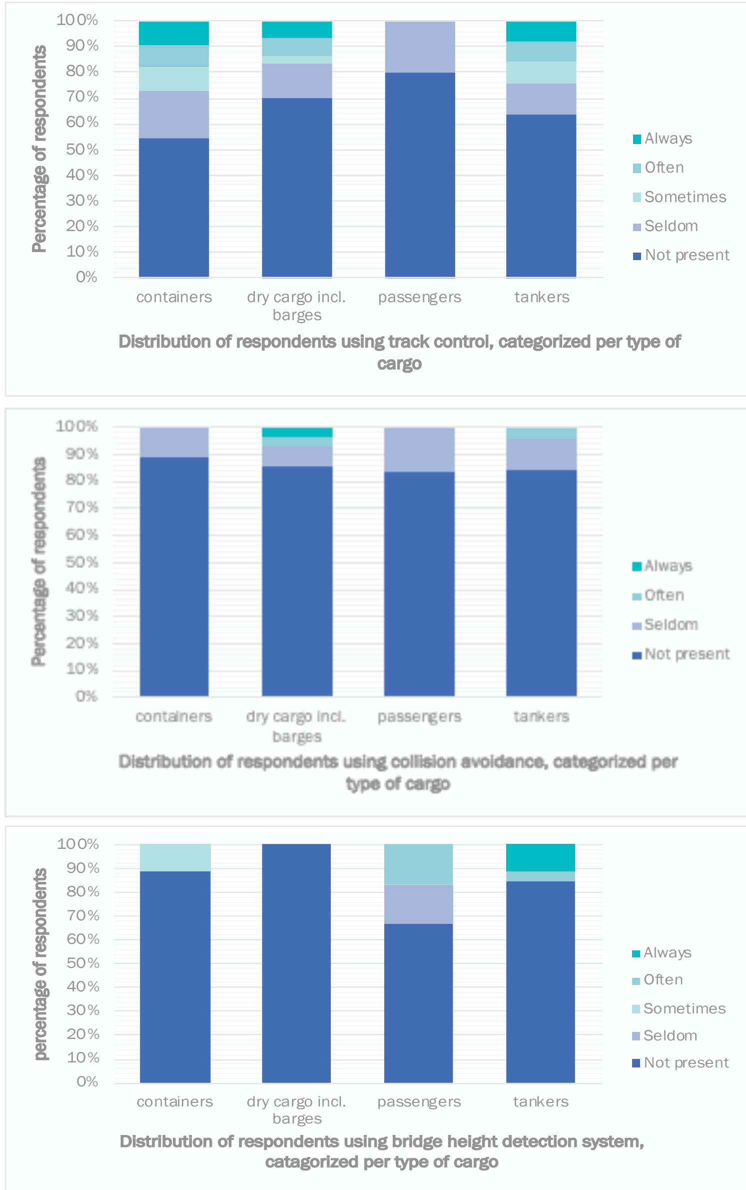


Figure26. The presence and use of automated system: track control (top), anticollision warning (middle) and bridge height detection (bottom).

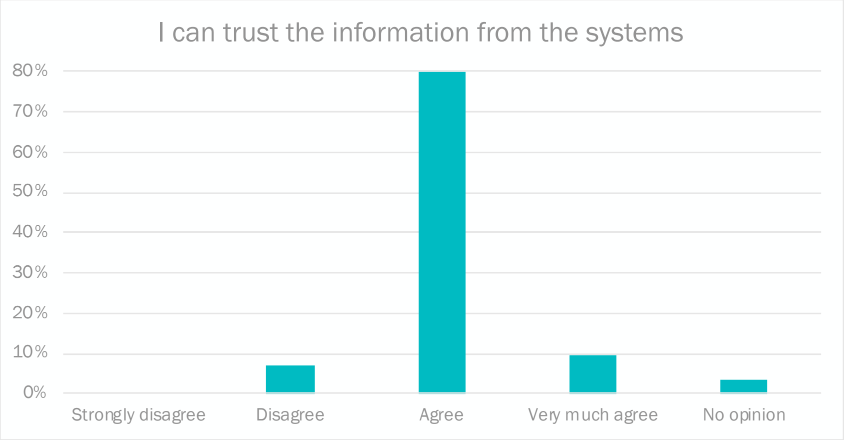


Figure 27. Trust in quality of information system.

"because of daytime situation to prevent wear"). Obviously, not all ships have AIS yet, like yachts. Traffic managers on waterways daily see multiple inland vessels in their sector without proper AIS signal, due to "instantaneous technical hiccup", according to the skipper. It is thus unwise to uniquely sail on ECDIS information.

- Also, ENC information is not always unmistakable. In the collision of a benzene tanker with the weir near Grave (NL) in 2016 the ECDIS gave a wrong impression of the situation because the RWS database on which ENC is based was faulty[11].

- Ways to calibrate automation information on real world is sometimes inhibited. Users then need to trust on insecure information.
  - Radar: sport boats are sometimes difficult to identify according to skippers. High-voltage pylons, bridges with an n-shape, a group of animals on the water and heavy rain may create 'noise' on the radar, or the signals echoing from adjacent buildings. Local knowledge is necessary to discern signals from noise.
  - Range of the VHF radios is poor. Information missing from ECDIS thus cannot be completed with this source of information.
  - Bridge height detection systems to avoid collisions with bridges[12] – although generally appreciated – were at instances considered too obtrusive because they generate many alarms (including false positives). The skipper then needs to acknowledge the alarm. One system will sometimes lower the wheelhouse automatically when there is no risk for collision (can be overruled by skipper). From an ergonomic expert's point of view, the simple interface of such a system is appealing; it may however not be clear whether the system is actually monitoring the situation, as it is hard to discern if it is on or off. Besides, water level gauges or other River Information Systems are not always present or standardised to calibrate the system's signal.
- It is important that skippers understand the capabilities and the limitations of systems. 92% of the respondents think it is clear what the systems in the wheelhouse can and cannot do. However, during the visits, quite often skippers were unable to exactly mention the capabilities, actual settings, and limitations of assistive devices. User manuals are sometimes missing or are hard to understand or not in the right language. In normal operation this may not be a problem. From literature[13] and practice in other transport sectors[14] it is known that an incomplete understanding of these systems in terms of reliability, capabilities, and limitations, may eventually lead to incidents.

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[11] Dutch Safety Board. Collision with the weir near Grave by a benzene tanker. 03.05.2018.

[12] Feyer (2019) identified multiple HMI issues with these systems.

[13] Foroughi CK, Devlin S, Pak R, Brown NL, Sibley C, Coyne JT. Near-Perfect Automation: Investigating Performance, Trust, and Visual Attention Allocation. Hum Factors. 2021 Aug 4
Wickens CD, Clegg BA, Vieane AZ, Sebok AL. Complacency and Automation Bias in the Use of Imperfect Automation. Hum Factors. 2015 Aug;57(5):728-39.

[14] Van der Weide R, Schreibers K, and Weeda C. To Beep or Not to Beep: Developing a Non-Fail-Safe Warning System in a Fail-Safe Train Protection Environment. In: Human factors In Transportation. Edited by Giuseppe di Bucchianico, Andrea Vallicelli, Neville A. Stanton, Steven J. Landry. CRC Press, 2017

Automation as a cause of incidents

From the questionnaire it showed that 60% (particularly in tankers) think limited knowledge about working with automation is a major cause of accidents and incidents during navigation (*Figure 28*). Furthermore, in the most experienced group this is also true (*Figure 29*). It could however not be determined in the questionnaire if the respondents refer to themselves or to their colleagues. From the vessel visits it became clear that certainly not every older/experienced skipper is reluctant in using automation: some were enthusiastically using systems like bridge collision warning.

The fact that tanker skippers in majority think automation is an important cause may be related to tankers generally having more automation than other vessels.

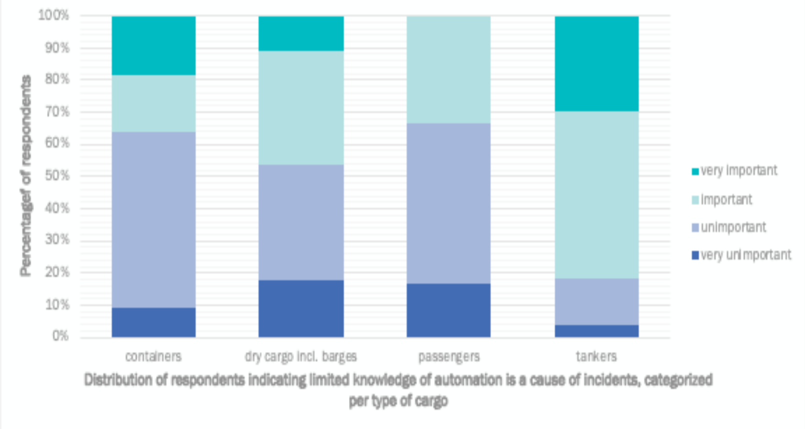


Figure 28. To what extent do you experience limited knowledge about working with automation as a major cause of accidents and incidents during navigation (per type of vessel)?

Integration of information

Ninety percent (90%) of the respondents think that the information in the wheelhouse is well integrated. Nevertheless, from the interviews and observations it became clear that integration of information can still be improved, compared to other transport modalities. Delegates from SEA Europe recognise the need for an *integral* perspective on human-machine-interaction in automation including information technology. Some identified opportunities are:

- Switching to the right VHF-channel. The actual VHF-channel is also known in navigation software but switching in time is dependent on the awareness of the skipper. The VHF-operation is mostly positioned outside the horizontal primary and even secondary fields of view, so calibrating the actual channel with needed channel as indicated on ECDIS is inhibited.
- Water levels: skippers indicate that finding the current water levels is sometimes difficult and unnecessarily time consuming, e.g., by getting the information from websites during navigation (also true for obstructions, shipping notifications, etc.). River Information Services play an important role in this. The information may be integrated in navigation software (some products do have this integration already).

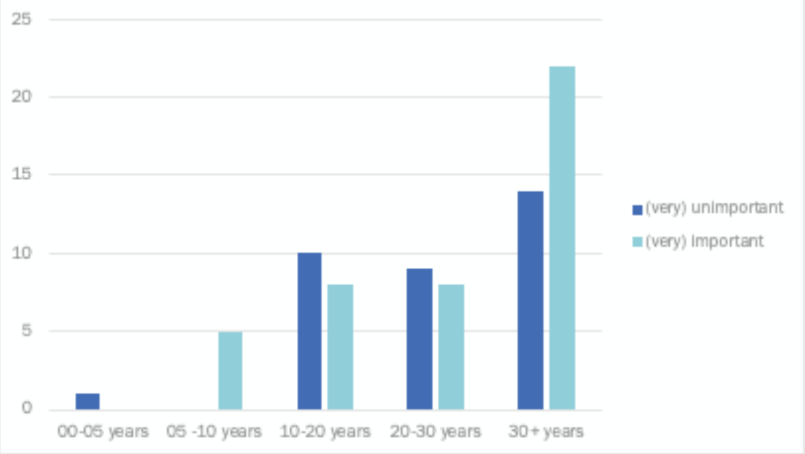


Figure 29. To what extent do you experience limited knowledge about working with automation as a major cause of accidents and incidents during navigation (dependent on years of experience)?

However, reliability of information is currently hard to verify. Finding/arranging the right exemptions per municipality/ port control takes a lot of time and is not always easy to find. Berths, water points, wall power connections could all be built into navigation software. Now, additional sources like Pegel online and external apps are being used. Some form of standardisation or integration may be helpful.

- Overlay radar/navigation software: we have not observed daily use of this ECDIS navigation mode during the visits. Skippers experience the screen getting too cluttered with information and that it is possible that one can no longer read/identify important information on the screen.
- Overview area of messages in touchscreens over the different 'pages' summarising relevant messages or incidental settings like current use of spud-pole is lacking. Now we have observed one vessel applying paper reminders centrally on the console when using certain gear like crane, spud-pole or having muted an alarm etc. (*Figure 30*).

Figure 30. Paper reminders centrally on the console when using certain gear like crane, spudpole or having muted an alarm.

Alerts/ alarms

From the questionnaire it seems that opinions about the number of systems (*Figure 31*) and the number of alerts/ alarms (*Figure 32*) are divided. In dry cargo the number of systems is considered too high by most skippers. About the alarms 35% of all respondents indicate too many alarms; 40% disagree. Almost all respondents answered questions about the absolute number of alarms in the lowest possible category that could be chosen:

- During a malfunction, the wheelhouse averages **in the first 10 minutes**: up to 10 alerts/ alarms.
- During a normal situation, in the wheelhouse there are **on average per hour** less than 6 alerts/ alarms.

The vessel visits gave rise to some concern. In general, the number of alarms is indeed low, and visual + auditory alarms often are reserved for urgent matters only. Almost all alarms during observations were ignored. People told about adapted settings that colleagues were not aware of. We

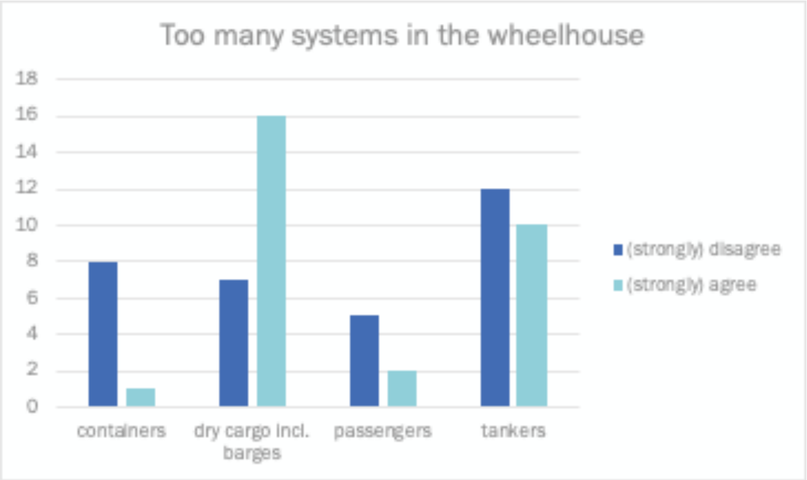


Figure 31. There are too many systems in the wheelhouse (n=61).

came across an example of a system being turned off due to an overload of alarms (i.e., collision avoidance). These alarms could not be disabled, so eventually the complete system has been turned off or removed. Furthermore, multiple examples were mentioned where an alarm is activated but it is unclear - or it takes time to identify - which system generated the alarm. Irrelevant logic follow-up alarms also occur. We witnessed some examples of 'paper tricks' to clarify alarms, reminders of use of automation and alarms without consequences. These examples indicate a failing design.

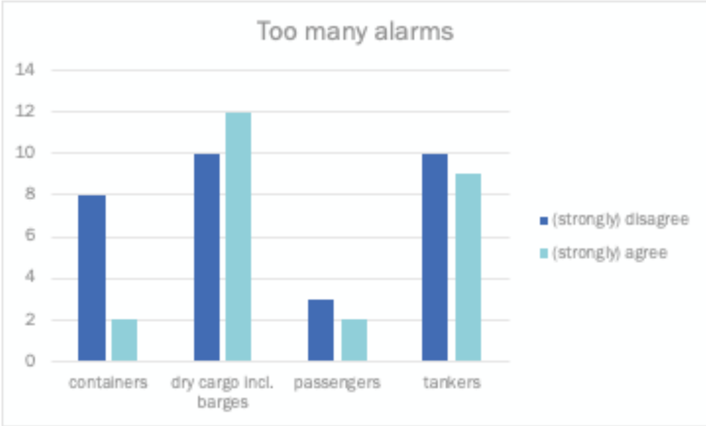
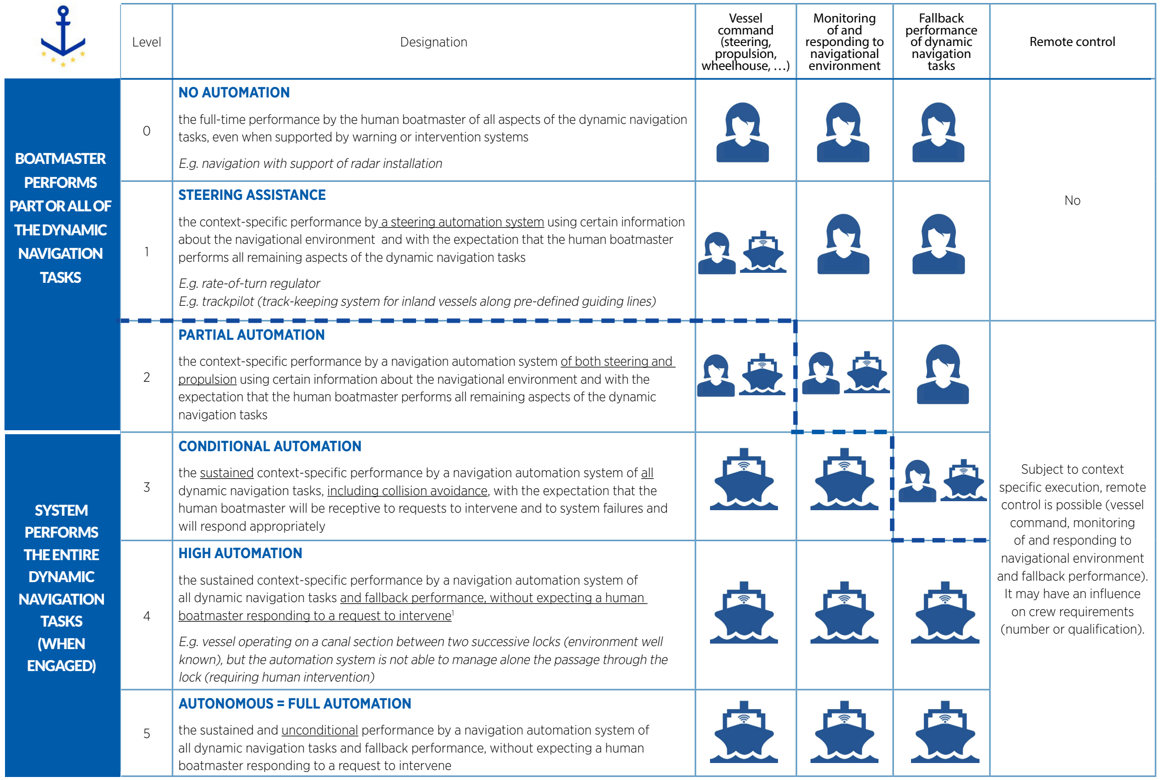


Figure 32. There are too many alarms in the wheelhouse (n=56)



	Level	Designation	Vessel command (steering, propulsion, wheelhouse, ...)	Monitoring of and responding to navigational environment	Fallback performance of dynamic navigation tasks	Remote control
BOATMASTER PERFORMS PART OR ALL OF THE DYNAMIC NAVIGATION TASKS	0	**NO AUTOMATION** the full-time performance by the human boatmaster of all aspects of the dynamic navigation tasks, even when supported by warning or intervention systems *E.g. navigation with support of radar installation*				No
	1	**STEERING ASSISTANCE** the context-specific performance by a steering automation system using certain information about the navigational environment and with the expectation that the human boatmaster performs all remaining aspects of the dynamic navigation tasks *E.g. rate-of-turn regulator* *E.g. trackpilot (track-keeping system for inland vessels along pre-defined guiding lines)*				
	2	**PARTIAL AUTOMATION** the context-specific performance by a navigation automation system of both steering and propulsion using certain information about the navigational environment and with the expectation that the human boatmaster performs all remaining aspects of the dynamic navigation tasks				Subject to context specific execution, remote control is possible (vessel command, monitoring of and responding to navigational environment and fallback performance). It may have an influence on crew requirements (number or qualification).
SYSTEM PERFORMS THE ENTIRE DYNAMIC NAVIGATION TASKS (WHEN ENGAGED)	3	**CONDITIONAL AUTOMATION** the sustained context-specific performance by a navigation automation system of all dynamic navigation tasks, including collision avoidance, with the expectation that the human boatmaster will be receptive to requests to intervene and to system failures and will respond appropriately				
	4	**HIGH AUTOMATION** the sustained context-specific performance by a navigation automation system of all dynamic navigation tasks and fallback performance, without expecting a human boatmaster responding to a request to intervene[1] *E.g. vessel operating on a canal section between two successive locks (environment well known), but the automation system is not able to manage alone the passage through the lock (requiring human intervention)*				
	5	**AUTONOMOUS = FULL AUTOMATION** the sustained and unconditional performance by a navigation automation system of all dynamic navigation tasks and fallback performance, without expecting a human boatmaster responding to a request to intervene				

[1] This level introduces two different functionalities: the ability of "normal" operation without expecting human intervention and the exhaustive fallback performance. Two sub-levels could be envisaged.

Figure 33: Definition of levels of automation in inland navigation, by CCNR (2018)

Impact of increasing automation of navigation

Most vessels still operate at automation level 0, no automation for dynamic navigation, considering the degree of automation as defined by the CCNR[15] (2018; *Figure 33*). The actual introduction of automation varying from steering support (level 1), decision support systems (level 2) to automated execution sometimes under human supervision (level 3-5) leads to a shift in the helmsman's focus from continuously looking outside to an almost full focus inside on displays during full automation (level 3) during local direct control of navigation. Only from level 4 stage the impact on direct outlook needs should be reflected in the design. Until then, the challenge is to provide the increased amount of (supporting) information in such a compact and user-friendly way that the effectiveness of the technology is optimised, and safety can be increased. This can be done by integrating current separate buttons and indicators in a new electronic standard interface in which the right information is available at the right time through different access levels for contractors, maintenance parties, etc. The parallel with the transition in the European rail sector is large (*Figure 34*).

Figure 34: Example of how the railway industry had moved away from train-specific driver desks with lots of levers and gauges (top) to a harmonised EU Driver Desk (UIC 612-0) based on task areas and HMIs for each task (bottom).

[15] CCNR (2018). Automated navigation. Definition of levels of automation in inland navigation. Source: https://www.ccr-zkr.org/12050000-en.html

6.3 Evidence-based recommendations

1) In addition to the recommendations in paragraph 4.3 about wheelhouse design and paragraph 5.3 about HMI guidelines we recommend developing additional guidance about automation. It is a general trend that more information becomes available and will be introduced in the wheelhouse as a separate device or integrated in existing devices like navigating tools. This guidance should include the following subjects ***[Level of evidence H]***:
    - Reliability and trust
        - The capabilities and limitations of a system shall be clear to all users both by design and education.
        - The reliability of a system shall at any time be clear to all users; this may be done by transmitting and disclosing the level of (un)certainty of the information through the system.
        - Always risk analysis shall be performed to identify the number and effect of misses, false positives, and false negatives on human behaviour.
        - A monitoring system should periodically disclose possible effects of the automation on human behaviour. Unwanted effects are for example improper multitasking, delayed reaction times, improper order of task execution, excessive prolonged shifts etc.
    - Usability and system integration
        - Usability guidelines (e.g., ISO 9241) can assist in user interface design to assure that systems will indeed support the user's process without unnecessary time spent, distraction etc.
        - It must be avoided that users have to gather information from different sources to make split-second decisions. Decisions must be supported by integrated information. Note that information integration is more than just adding information to a system: integration truly supports quick and safe decision making.
        - It must be avoided that new information hides existing information.
    - Alarm management
        - If systems generate alerts/alarms these shall always be categorised in primary alarms (action is immediately needed), secondary alarms (action needed within a certain time frame), and tertiary alarms (no direct action needed but the issue shall be investigated at next maintenance). Each alarm should alert, inform and guide[16]. An alarm shall be clear in its origin (which system triggered the alarm), its background (why did the alarm trigger), and the required action. Every alarm should be help rather than a hindrance. Noninformative, logic follow-up alarms should be suppressed. When the action has been taken, the alarm should also provide feedback on the success of the actions taken (and stop automatically with success). In general, the user must be able to stop the alarm or override it, but this depends on the criticality of the function (this must be part of the risk analysis).
        - Develop guidance for a maximum number of alarms in the wheelhouse. As a rule of thumb, based on international guidelines for the process industry (EEMUA[16]), the maximum number of alarms could be formulated in terms of: during a malfunction on average up to 10 alarms in the first 10 minutes would generally be doable; and during a normal situation on average per hour less than 6 alarms.

2) An industry-wide rationale should be developed for secure standard clearances for both classic manual operations up till level 3 systems with conditional automation. These clearances shall both consider technical aspects and human behaviour. In other sectors this interdisciplinary approach results in leading indicators such as time to control speed/ course change to a danger point[17]. ***[Level of evidence M]***
3) Technology (ship build) and river information technology (RIS) are becoming increasingly intertwined. This development should be reflected in the future organisation of regulation by technical committees. ***[Level of evidence: L]***

[16] EEMUA Publication 191 Alarm systems - a guide to design, management, and procurement. Third edition, 2013.

[17] Burggraaf, J.; Groeneweg, J.; Sillem, S.; van Gelder, P. What Employees Do Today Because of Their Experience Yesterday: How Incidental Learning Influences Train Driver Behavior and Safety Margins (A Big Data Analysis). Safety 2021, 7, 2.

7. Summary root causes and recommendations

Based on data and expert analysis of accidents in European IWT, combined with in-depth study by questionnaires, interviews, and live observations during sailing we have summarised the human factors root causes for accidents in European IWT and added recommendations for optimal HMI and wheelhouse design in this chapter to mitigate the associated risks in the future. Furthermore, an integral approach described in a roadmap is suggested.

7.1 Summary of recommendations

The detailed findings and recommendations from the previous chapters 4, 5 and 6 can be summarised into two root causes with associated recommendations for HMI & wheelhouse design, including automation / information technology (IT). Some recommendations are related to organisational root causes, which are also included in the Phase 2b report of this study focusing on organisational root causes *communication*, *fatigue & stress*, *qualification*, and *environmental aspects*.

Root cause	Recommendations
1) Design of wheelhouses and HMI's is not following a common design approach and is not according to state-of-the-art ergonomics and human factors standards in other transport modalities leading to (potential) errors and musculoskeletal disorders.	***Update and improve the available wheelhouse and HMI design guidelines:*** • Design guidelines should be user and task-based: the wheelhouse can be arranged according to the (priority in) tasks that need to be performed in the wheelhouse. For the helmsman's position the same principle can be used. ISO 11064-4:2017 about the ergonomic design of control room workstations provides an inspirational example for generic workstation design steps. • Guidelines should accommodate for increasing use of touchscreens, pods, etc. • Anticipate on the inevitable shift towards higher levels of automation impacting the design of local helmsman stands, HMI and remote-control centre workstations. • ES-TRIN 2021 and EN 1864:2008 about ergonomics and safety of inland vessel wheelhouses provide a basis, but currently do not provide adequate guidance on designing ergonomic wheelhouses and HMI's. • These design guidelines do not necessarily have to be mandatory. Industry commitment is an important first step in general use of these guidelines. It should be appealing for industry to adhere to the design guidelines, e.g., through a higher residual value when selling the ship or for ease of classification. • New guidelines are interesting for new to build vessels or for major refurbishments but may also guide partly (re)placement of additional systems in the wheelhouse.

Root cause	Recommendations
2) The availability, reliability, usability, and integration of information at the helmsman's position is not optimal leading to (potential) errors in interpreting information, over-trust in information/automation, ignoring alerts, distraction, and a false sense of safety.	***Develop an integral vision on minimum required availability, reliability, usability, and integration of information and automation at the helmsman's position*** *The following issues may be incorporated in this vision on information and automation:* • The minimum quality of ENC/ECDIS information and VHF range, integration of water levels in other systems, overlay of radar/ ECDIS, support in (auto) selecting the right VHF channel and developments in RIS. • Reliability of information sources should be transferred to the crew, e.g., by incorporating uncertainty in the signal used, and by actively training of crew in the capabilities and limitations of those systems, to avoid a false sense of safety. • Usability guidelines (covering ergonomics of human-computer interface e.g., ISO 9241) and ergonomics guidelines (viewing and grasping areas e.g., ISO 11064) in user interface design to assure that systems will indeed support the user's process without unnecessary time spent, distraction etc. • It must be avoided that users have to gather information from different sources to make split-second decisions. Decisions must be supported by integrated information. Note that information integration is more than just adding information to a system: integration truly supports quick and safe decision making. • An alarm philosophy (guidance on design, managing and procuring effective alarm systems e.g., based on EEMUA 191) to avoid too many and unclear alarms from systems. • A process for system developers to prove that their systems are safe and usable, and how they will monitor system performance effects on human behaviour. • An industry-wide supported standard for secure clearances (e.g., above the wheelhouse and under the keel) for both classic manual operations (no automation) up till level 3 systems with conditional automation. This contributes to effectiveness, understanding, acceptance and trust in assistive systems and thus to safety. This vision may be incorporated in the wheelhouse/HMI design guidelines (recommendation 1).

7.2 Recommendations – An integral approach

The next challenge is to translate the recommendations of phase 2a and 2b into concrete measures and implementation. This doesn't happen overnight.

Recommendations from Phase 2a and 2b reports should be considered together: although some recommendations may be technical for instance, successful implementation requires people to be trained and organisations to be supportive. An integral system perspective is needed.

A major hurdle in the successful implementation of major changes such as we propose is the human element. Knoster's model of change (1991) offers guidance, containing 5 important success factors in a change process (*Figure 35*). The model also contains the behavioural effects of those involved when such a factor is missing or insufficiently developed. This model illustrates the psychology behind people's reactions to change and provides insight into directions for improvement.

LEADERSHIP AND STRATEGY			PEOPLE AND RESOURCES		EMPLOYEE BEHAVIOUR
Vision	Incentives	Action plan	Competences	Resources	CHANGE
	Incentives	Action plan	Competences	Resources	Confusion rather than clarity
Vision		Action plan	Competences	Resources	Resistance instead of commitment
Vision	Incentives		Competences	Resources	Turning instead of heading
Vision	Incentives	Action plan		Resources	Anxiety instead of confidence
Vision	Incentives	Action plan	Competences		Frustration instead of enthusiasm

Figure 35: Five necessary ingredients for successful organisational change, including typical employee behaviour if one ingredient has not been developed fully (Source: Knoster, 1991).

An integral step-by-step approach must be applied in following-up the recommendations, with attention for technology, organisation (including leadership and strategy) and people. Careful interaction with stakeholders and experts is required and solution packages should be defined. This increases the chance of achieving the objectives in a steady and supported manner. The approach should be described in a roadmap.

We recommend developing this roadmap together with the relevant stakeholders within the European nautical field. At least the following steps should be described in the roadmap (*Figure 36*):

1) Making aware of and inform on relevant root causes among all stakeholders, for instance via campaigns with examples of good design and HMI.
2) Learn teams working on solution packages how to take relevant subjects into account. Decide on interrelationships with recommendations from Report 2b and stay in sync with interrelated work packages.
3) Disseminate or prescribe guidelines and regulations for relevant stakeholders.

For self-employed skippers who also live on their vessels and hardly ever change crew, the need for certain recommendations may be smaller but not necessarily irrelevant when, for example, an existing vessel is acquired or sold.

Making aware	*Inform*	*Learn*	*Prescribe*
• Campaigns	• Seminars • Master classes	• Training • Education	• Guideliness • Regulation

Time →

Figure 36: Step-by-step approach for developing recommendations

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