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Designing to aid situation awareness during active ship bridge alarms

Identifying and fulfilling information requirements of bridge alarms in target rich environments

Master's thesis in Interaction Design and Technologies

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Gothenburg, Sweden 2022

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Abstract

A large part of seaborne accidents can be directly attributed to a lack of situation awareness (SA). Upholding sufficient (SA) by sufficiently perceiving information, comprehending its meaning and projecting its future status is crucial for decision making in these situations. Designing for SA in complex environments requires a sufficient understanding of the requirements posed by the context. Using a situation awareness oriented design process, the thesis first identified SA requirements in target rich environments which were used, in combination with SA design principles, to propose a prototype of an integrated alert system directly on an on-bridge radar where alerts could be better contextualized and handled by officers. Subject matter experts were involved, both when defining requirements as well as during evaluation of the prototype. Results showed that although SA was generally supported by the concept, there was an overarching preference of separating non-navigational alerts from the radar. Recommendations were also presented, as resulting the evaluation and the process as a whole. Limitations, future work, and ethical considerations of such a concept are further discussed.

Keywords: Situation awareness, integrated bridge systems, alarms.

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Glossary

ACC Adaptive Cruise Control, an automated function that keep the speed even though circumstances might change.

AIS Automatic identification system, automatic position tracking using data communicated by vessels.

Alerts Umbrella term for auditory or visual notifications of immediate or potential danger to the vessel.

ARPA Automatic Radar Plotting Aid, system-based calculations of collision avoidance data based on the own vessels course and speed and those of another.

BCR Bow Crossing Range, the distance at which one vessel crosses the bow of another.

CPA Closest Point of Approach, indicates the closest point between two vessels.

ECDIS Electronic Chart Display and Information System, a geographic information system visualizing the surrounding situation in combination with electronic navigational charts.

GDTA Goal-Directed Task Analysis, a normative task analysis focusing on specifying situation awareness requirements.

HTA Hierarchical Task Analysis, a descriptive task analysis focusing on sequences of tasks.

OOW Officer On Watch, referring to the officer currently responsible for navigation.

Operator Referring to the operator of bridge systems, which involves officers, pilots and captains depending on the situation.

PPI Plan Position Indicator, a type of radar display visualizing the radar antenna in a circle.

SA Situation Awareness, the perception, comprehension and projection of one's surroundings.

SME Subject Matter Expert, referring to people with extensive experience in the maritime domain.

Target vessel Referring to a vessel that has been targeted through the on-board systems, either manually or automatically.

TCPA Time to Closes Point of Approach, the time to the CPA usually in minutes.

1

Introduction

The means of operating maritime vessels have changed over the years. Navigators devote themselves more to monitoring and planning, while surveillance and execution are offloaded to automated systems [6, p. 200]. The information presented on the bridge has become more integrated to, among other things, increase information transfer, and improve safety, as well as, efficiency [7]. These integrated bridge systems consist of several components to control and monitor ship communications, propulsion, fires and alarms, stability, collision, and navigation [7].

In their overview of 250 accident reports from The National Transportation Safety Board (NTSB), the Japan Transportation Safety Board (JTSB), and the Marine Accident Investigation Branch (MAIB) between 1983-2020, Panagiotidis et al. reported collisions (22.1%) being the most common type [8]. For collisions specifically, the most common contributing factor was decision errors (18%) followed by inappropriate planning (11%) [8]. Furthermore, the majority of collisions occurred in locations either prone to high traffic or restricted freedom of movement such as ports, gulfs, canals or river with only 13% of collisions occurring in the open sea[1]. Busy waterways such as these have been affiliated with an overarching risk of ship-to-ship collisions by others [9], some locations, such as the Shenzhen Port near HongKong, approximated to account for 50% of the total risk [10].

To reduce the risk of severe incidents such as collisions, bridge systems integrate various forms of alerts. According to the Maritime Safety Committee (MSC), the purpose of on-bridge alerts is to *"enable the bridge team to devote full attention to the safe operation of the ship and to immediately identify any alert situation requiring action to maintain the safe operation of the ship."* [11]. Alerts are divided into different categories. Alerts for collisions and grounding fall under category A, which originate from the work station they are directly tied to, such as alerts from the radar [12]. In contrast, category B alerts do not need the contextual information that the work station provides and are thus displayed on the central alert management human machine interface [12]. A third category has later been added, category C, which refers to alerts carrying important information although unable to be attended to by the bridge team, such as engine status [11].

1.1 Situation awareness in the maritime domain

The most commonly used definition of situation awareness (SA) is proposed by Endsley [13] as: *“the perception of the elements in the environment within a volume*

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[1] https://zenodo.org/record/5592999, accessed on April 9 2022

of time and space, the comprehension of their meaning, and the projection of their status in the near future" [14, page. 792]. Endsley further divides SA into three interconnected levels; Level-1: perception, Level-2: comprehension, and Level-3: projection [15]. In an analysis of 177 accident reports, as many as 71% were associated with situation awareness (SA) issues onboard vessels [16]. Baker likewise concludes in their analysis that situation awareness and assessment is the dominant factors in human failures [17]. An analysis examining 27 collisions between 1998 and 2012 including 39 vessels of medium size (500 to 24999 gross tonnage) found decision errors (82%) to be the greatest cause [18]. Inappropriate situation awareness was found to be present in 33% of cases [18]. However, only cases involving a faulty comprehension of the situation were put into this category, essentially limiting their definition to just the Level-2. Given that situation awareness relies on perception, and acts as a foundation for decisions [15], it is likely that SA deficits could be related to a larger number of collisions. For example, Chauvin et al. found a lack of visibility, attention deficits and perceptual errors to be present during collisions (56%, 31%, and, 15% respectively) [18]. Grech et al. [16] analyzed maritime accidents in relation to Endsley's Three Level Model [15]. Out of 177 accident reports, 58.5% of SA errors were attributed to Level-1, 32.7% to Level-2 and 8.8% to Level-3 [16] which, similarly to the aviation domain [19], indicates that issues with perception is the largest factor. Similarly, Sharma et al. found attention and communication to affect navigator situation awareness the most [20].

1.1.1 Situation awareness and alerts

Even though the sole purpose of some on-bridge alerts is to notify the bridge crew as to avoid collisions, accidents still happen as a result of shortcomings of these systems. Out of the marine occurrences including vessels of 150 gross tonnage or greater investigated by Transport Safety Board of Canada between 1998 and 2018, 31 (16%) were identified to be caused by one or more design issues of human-machine interfaces, some of which were directly attributed to shortcomings of alert systems [21]. An analysis of sea borne collisions done by the Nautical Institute (NI) found 13% of cases involving total unawareness of the other vessel up until the collision [22]. A MAIB report of 33 collisions between 1994-2003 found poor lookout (65%) and insufficient use of radar (73%) to be the most common contributory factors. Similarly to the NI report, 24% of vessels were totally unaware of the other ship until it was too late to avoid collision [23]. Another 19% of vessels were unaware of each other until the actual collision occurred [23]. One example is the collision between the bulk carrier Kinsale and the cargo vessel Eastfern southwest of Dover. The report by the Marine Accident Investigation Branch (MAIB) found that the bridge teams of both vessels broke several COLREG-rules, most notably by failing to have a proper lookout and using all available means to determine a risk of collision [24]. The International Regulations for Preventing Collisions at Sea (COLREGs) [25] are a common set of rules adopted in 1972, meant serve as common grounds of operation in trafficked situations [26]. Another example, although not a collision, puts a larger emphasis on the on-bridge equipment, and more specifically the radar, as a contributing cause. On the morning of 17 October 2006, the ferry Maersk Dover, the tanker Appollonia and container ship Maersk Vancouver were found in a close-quarter situation in the Straits of Dover. The Marine Accident Investigation Branch (MAIB) found the radar on board of the Maersk Dover to be a major factor in this close-quarters situation [27]. Two important aspects played a role in this. Firstly, the auto tuning of the radar picture was insufficient to produce a clear display of surrounding vessels, thus making the officer of the watch unaware of Appollonia. Secondly, the situation could have been avoided if the alarm system of the radar would have been properly set up in advance, although as mentioned in the report, alarms are commonly avoided in heavy trafficked areas such as this one.

Not only is SA affected by system factors such as the interface design, complexity and automation, but also by internal aspects such as stress, attention and workload [15]. Bridge operators often have to juggle simultaneous information from various sources such as verbal communication, displays, alerts, and their surrounding environment [28, p. 123]. A common problem in the maritime domain is that the level of workload is heavily dependent on the situation, leading to an uneven distribution where some situations will require high levels with a lot of information presented to the bridge crew [28, p. 123]. Baldauf et al. found during their visits to six different vessels that alerts were unevenly distributed throughout a voyage [29]. Most alerts were produced in confined (16.6/hour) and coastal (11.8/hour) waters while the open seas were calmer [29]. A previous study by the same researchers found denser areas such as during departure to produce as much as 40 alerts per hour [30]. The systems responsible for producing the largest amount of alerts was the radar with the most common alerts related to collision avoidance (31%) and lost targets (20%) [29].

1.2 Issues with modern day system alerts

Semi-structured interviews with SMEs with at least 8 years of vessel navigation experience revealed several problematic aspects of alerts in terms of operator experience (see section 5.1.3). All three participants expressed that uneven distribution of alerts was indeed a common occurrence in target rich environments, in line with the results found by Baldauf et al. [29]. In these situations, alerts tend to be perceived as disturbances, sometimes communicating superfluous information that did not increase situation awareness of operators. The increasing occurrences or alerts in target rich environments can be seen as a form of informational overload that can't be matched by the cognitive abilities of the operator [1, p. 36]. This in turn leads to gaps in operator SA because some information is left unprocessed [1, p. 36]. Furthermore, given their sudden appearance, alerts might require the operator to attend a secondary task before the main task has been completed which puts a large demand on memory to remember where the main task was left off [31]. Interviewees expressed that a common remedy was to configure the thresholds of collision avoidance alerts coming from the radar, reducing them to a level which would decrease the number of alerts. This was also found to be common practise by Baldauf et al. [29]. Although this reduces occurrences of alerts, in turn making them less distracting, the implications to vessel safety might be drastic.

1.3 Interface elements to support SA

Various attempts have been made to tailor interfaces and their elements to aid SA in different contexts. In their Oz-project, Still and Temme created an interface for pilots that coherently integrated relevant information to improve comprehension [2]. Interface design is also important for establishing a sufficient understanding of a system involving some sort of automation [32]. By clearly notifying the state of automation in addition to crucial flight parameters through the interface, the SA of pilots was found to be improved [33]. Some success of improving understanding of complex automated systems has also been found through ecological interface design. Burns et al. found that restructuring an interface to better show existing relationships in the system might improve SA during unanticipated events [34]. By directly displaying time headway, time to collision and range rate of the automated system, drivers' reliance on the adaptive cruise control increased in traffic, indicating that providing information of the state of an automated system might be more beneficial than alarming operators when such system fails [3]. These are examples of how interface elements in the forms of displayed information can be used to aid situation awareness, but work has also been done to explore elements that are more interactive. Aylward et al. proposed a ship route exchange function between the own vessel and a vessel that was manually targeted [5]. This way, the operator is able to interact with an interface element (in this case another vessel) to produce information according to their current SA needs. Providing feedback of the state of an automated system has also been argued by Norman to be an effective strategy of reducing automation-related problems [35]. As presented, SA can be supported through various implementations. Interface elements will thus be defined as implementations involving both more passive forms of visualizations as well as interactive features to adjust what information is transmitted by systems.

1.4 Alerts and interaction design

Interaction design has been defined as a *"specification of digital behaviors in response to human or machine stimuli"* [36, p. 1061], capturing the essence of a process that tailor the use of a digital system centered around the user [36]. Visibility, the ability perceive functions and their contents, has been argued to be one of the important principles in interaction design [37, p. 36]. Visibility is also crucial for the three core components of *perceiving elements*, *comprehending their meaning* and *projecting their future status* of situation awareness. Furthermore, a the core functionality of alarms is to raise awareness of a certain piece of information [1, p. 147], thus meant to increase visibility of a developing situation. Although, as previously presented, this provided visibility might come with a cost for the user experience: disturbances (see 1.2). While the given definition of interaction design are mostly focused on direct interaction, a broader scope of user experience has also been suggested as central to the practise [37, p. 12]. Thus, it's not just the direct interaction and responses of alerts that is relevant for the field of interaction design, but also the more qualitative experiences resulting from their appearances.

1.5 Stakeholders

The thesis is written in collaboration with an active project conducted by the User Experience team of the Automation Technology department at ABB Group. The thesis will be written in accordance to the requirements posed by Chalmers University of Technology.

1.6 Research question

A lack of situation awareness can be attributed to a large portion of maritime accidents, and in target rich areas collisions are the most common. Although alerts play an important role in avoiding collisions, they do not always fulfill their goal of providing sufficient SA. Alerts have a tendency to drastically increase their frequency in target rich environments, in turn causing them to pose challenges for the situation awareness of operators. A common practise is to reduce the thresholds of alerts, which severely decreases their ability to provide crucial information for collision avoidance. Lastly, it has been argued that the interfaces of systems are able to improve operator SA, which can be done by various interface elements such as visualizations or interactable features. Thus, the following research question is proposed:

> *What interface elements can aid operator situation awareness during active alerts in a target rich environment?*

Defining SA requirements is a core aspect of the situation awareness-oriented design process presented by Endsley by being crucial input into the following stage of design conceptualization [1, p. 47]. As such, defined SA requirements can be seen as an important input for the design process, but also a contribution for future work. Sharma et al. did analyze SA requirements for the maritime domain, but their analysis covers the overarching task of piloting large ships [20]. To the writer's knowledge, a similar identification of SA requirements do not currently exist of target rich environments. Thus, the following sub-question is presented as support:

> *What situation awareness requirements do bridge operators have in a target rich environment?*

1.6.1 Thesis contributions

This thesis will take on a *research through design* approach tackling a problem which is ill-defined with no objectively correct solution [38]. The contributions of this thesis will then act as an example of what process, what methods and what proposed solution can be used to tackle this problem [39]. Specifically, by answering the sub-research question, the thesis provides an insight into what SA requirements exist for bridge operators in target rich environments, and by answering the main research question, showcases how the requirements can be utilized in a situation awareness oriented design process. Similar work of capturing SA requirements has been done, but for the broader context of carrying out a full voyage between two points [20]. As the main contributors of insights were expert users, the contributions can be seen as concrete representations of their needs and pain points. This lays a foundation of designing solutions that create direct value for experienced operators in target rich environments. By using a situation awareness oriented design process, the thesis explores how such a process can be used in the maritime domain. By answering the sub-research question, a foundation of SA requirements is defined, which can in turn be used by other designers turning to a similar process. Lastly, the resulting recommendations produced by the thesis will capture not only reflections of the result, but also of the process, in turn providing insights for future endeavors in similar contexts.

1.6.2 Thesis delimitations

The scope of the thesis will be delimited to navigation in target rich environments. It will not cover the specific bridge systems used for docking, mooring or during special operations. This is the case for both answering the main and the sub-research question. Regarding the main research question, the type of alert management covered in this thesis will also be revolving around the errors that emerge during voyage and traffic monitoring, not those that might appear during other operations.

2

Theory & Background

The following sections will more explicitly present the context of a bridge system, theoretical background of situation awareness, as well as related work in the field.

2.1 Situation awareness

The origin of situation awareness (SA) can be traced back to Oswald Boelcke, a fighter pilot in the first world war [40]. Boelcke realized *"the importance of gaining an awareness of the enemy before the enemy gained a similar awareness, and devised methods for accomplishing this"* [40, p. 97]. Since then, three main approaches have formed; the Perceptual Cycle Model, Theory of Activity, and, the Three Level Model [41].

Starting with the Perceptual Cycle Model, Smith and Hancock proposed that SA resides, not in a person or in the world, but in the interaction between them [42]. The mental models of individuals create expectations, which are adjusted through interactions, forming a "perceptual cycle" [42]. Theory of Activity is a less holistic approach by mapping human cognition into eight blocks, each one having an important role in developing SA [43]. The final, and most commonly used [13], is the Three Level Model proposed by Endsley. Endsley [14] defines situation awareness as; “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” [p. 792]. This definition puts the emphasis on the individual who forms their SA based on their representation of their surroundings as a foundation for decisions and performance [15]. Endsley divides situation awareness into three hierarchical, but interconnected, phases [15]:

> *Level 1 - Perception of elements in the environment.* The first level refers to perception of elements and their informational value, which can be expressed by status, attributes, and dynamics. Examples from the maritime domain might be gauges, instruments or information on a display.
> *Level 2 - Comprehension of the current situation.* The second level refers to a comprehension of the situation, based on the perceived elements, in relation to the current goal. Examples here might be understanding the discrepancy between the current and the target route.
> *Level 3 - Projection of future status.* The third and highest level refers to an ability to predict future states based on elements and the current

comprehension. This might be planning for weather conditions or use of rudder to avoid collisions.

2.1.1 Situation awareness information requirements for maritime navigation

Sharma et al. interviewed seven maritime navigators with an average of 4.2 years of experience to form the basis for a Goal-directed Task Analysis (GDTA) exploring dynamic situation awareness requirements while piloting large ships [20]. SA requirements were categorized according to the Three Level Model presented by Endsley [15]. Relevant Level-1 information requirements were ship and equipment status, route, traffic and weather involving information such as speed, position and location of targets. To achieve Level-2 SA, navigators used the first-level information to compare disparities between the current and an ideal system state. Examples are deviations in speed, location, current route versus the planned route etc. In addition to comparing disparities, operators also used the second level to form a comprehension of a combination of information types from the first level. Examples are the impacts of weather conditions and traffic, or the current status of emergency parameters, such as available manpower and sea room (i.e. distance to shore or other hazards, limiting the freedom of maneuvering). Relevant Level-3 information requirements were projections of traffic, route, and weather conditions, such as future position and movement of targets, wind speed, and visibility etc. Importantly, it was noticed that navigators did not wish for many parameters to be projected during operation. Furthermore, it was found that SA requirements differed in temporality, some being more relevant at certain stages, while others were needed throughout the whole operation. There was also a need for clear and effective communication to uphold sufficient SA, such as between the navigator and the co-located pilot. Navigators emphasized the importance of preparation by using checklists and port-specific manuals. Lastly, attentional tunneling while attending a task, and switching between conflicting tasks were found to be existing risks for situation awareness.

2.2 The situation awareness-oriented design process

The situation awareness-oriented design process was introduced by Endsley in 2003 to improve the development of complex systems in supporting SA [1]. The process entails gathering and analyzing SA requirements, applying design principles for improving SA, and evaluating SA of the proposed design. Requirements are gathered through a GDTA based on interviews with SMEs. The benefits of this is, firstly, by focusing on goals instead of tasks, a proposed solution is better suited for a dynamic environment, and secondly, by focusing on required information for each goal, the proposed solution can provide the right information to increase SA in all levels of workload [15].

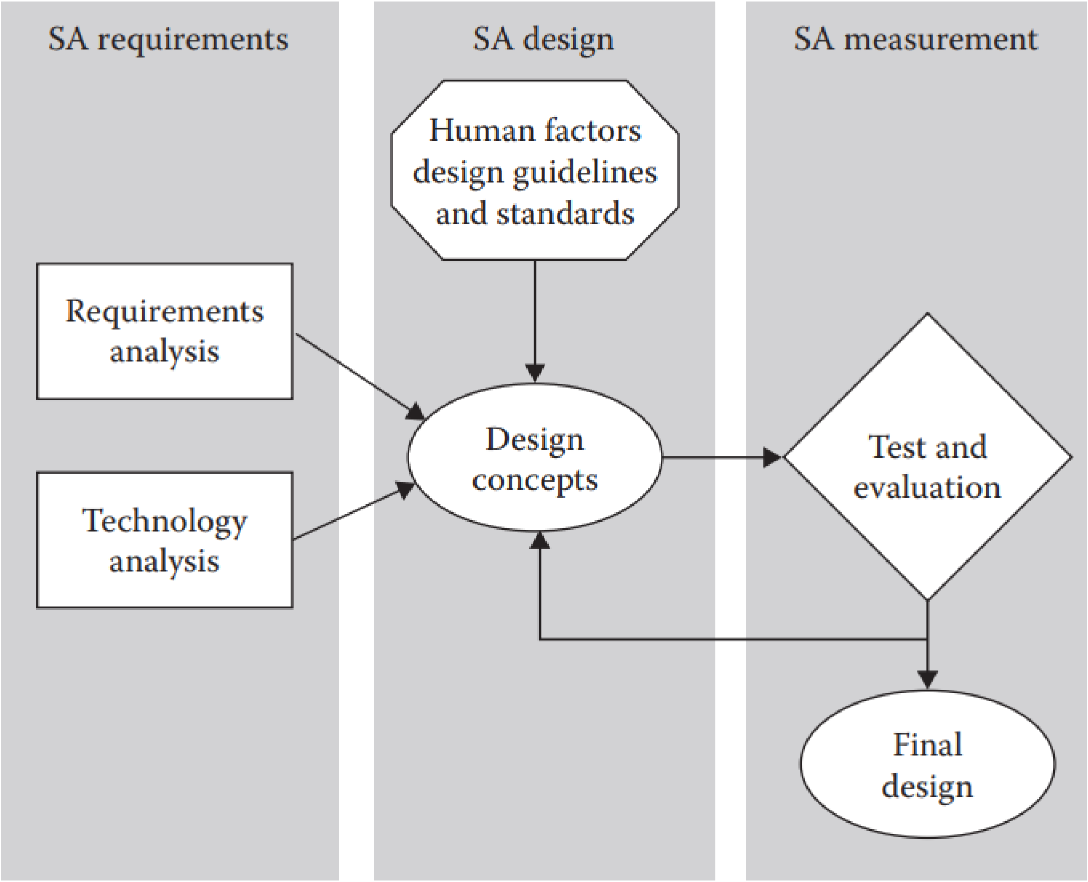

Figure 2.1: Illustration of the situation awareness-oriented design process presented by [1].

50 design principles are presented in five categories, (1) general guidelines for supporting SA, (2) coping with complexity and automation, (3) designing alarm systems, (4) information uncertainty, and, (5) supporting SA in teams [1, Chapter 6-11]. The general principles include (1) organizing information around goals, (2) supporting comprehension by presenting Level 2 information, (3) assisting Level 3 projections, (4) supporting global SA, (5) supporting both top-down and bottom-up processing, (6) using critical cues for schema activation, (7) supporting parallel processing, and, (8) careful information filtering [1, Chapter 6]. These principles can then either be used to evaluate if the specified SA requirements are currently being fulfilled [44, 1, p. 85], or serve as direct guidelines during prototyping [1, p. 79].

However, most of the 50 principles for designing SA-oriented solutions are all aimed at different problems. Thus, seven general principles (G1-G7) and six specifically focused on alert systems (A1 - A6) were used to, in combination with user insights, guide the design of the concept.

G1 *Organize information around goals* [1, pp. 79]. Information relevant to the operator goals should be presented in close proximity of each other as opposed to, for example, near the sensors that raised them.

G2 *Present Level 2 information directly to support comprehension* [1, pp. 79-81]. Show direct relationships between relevant information types, such as deviations from a route.

G3 *Provide support for projections by integrating Level-3 information* [1, p. 81]. Present information that might aid the projection of a future status of other vessels or the own vessel.

G4 *Support global SA* [1, p. 81]. Provide a broad overview of the situation. In relation to alerts, aid the ability to, at a glance, understand what systems are currently in an error state [1, p. 167].

G5 *Support trade-offs between bottom up and top down processing* [1, p. 82]. Organizing information around goals supports top down while improving global SA aid bottom up processing, which needs to be balanced.

G6 *Make critical cues for schema activation salient* [1, p. 82]. Display critical cues for schema activation to increase understanding of when certain actions might be needed. In relation to alerts, this is highly relevant for the thresholds set by the operator.

G7 *Use information filtering carefully* [1, pp. 83-84]. Although in complex systems, there is a lot of information that might be relevant in general, but less important for specific types of situations. Thus, the operator should be in charge of what information to look at and when.

A1 *Support alarm confirmation activities* [1, p. 164]. Operators will often seek out extra information to assess the validity of the alert, which is a process that needs to be accessible.

A2 *Make alerts unambiguous* [1, p. 164]. Reduce the risk of misinterpreting alerts according to preconceived notions.

A3 *Reduce false alarms* [1, p. 164]. While the aspect of engineering systems and alerts as to produce less false alarms is outside of this scope, some suggestions are given are given from an interface-perspective, one being the ability to adjust thresholds.

A4 *Set missed alarm and false alarm trade-offs appropriately* [1, p. 165]. Support the ability of rapidly assessing the legitimacy of an alert, providing an ability to project future outcomes.

A5 *Minimize alert disruptions to ongoing activities* [1, p. 166]. Although the purpose of alerts is to raise awareness of a certain situation, this can result in unnecessary disruptions of current tasks leading to operators in some cases disabling them. Thus, let the user be in charge of what tasks should be prioritized and use alerts to support their decisions.

A6 *Support the assessment and diagnosis of multiple alarms* [1, p. 167]. For complex systems, assist operators in understanding what systems are in an "alert state", which alerts are novel, and the sequence of which alerts were activated [1, p. 167].

2.3 On-board bridges

The information presented on the bridge has become more integrated to, among other things, increase information transfer, and improve safety, as well as, efficiency

[7]. Multiple personnel are often operating the bridge of a vessel [7, 20]. Although the bridge crew might consist out of different roles depending on the situation and vessel, the typical composition involves a captain, a pilot and an officer [20]. The captain has the main responsibility of safe operations, and acts on the information provided by the pilot and officer [20]. The pilot has local experience, for example about the specific port that is visited, in turn informing the captain about relevant regulations to aid navigation [20, 45]. The officer aids navigation by monitoring relevant information and communicating it to the captain [20]. However during an observation on two ferry voyages (see section 4.1.2.2), it was found that for shorter trips, pilots are never on the bridge. In addition, the captain is only present during departure and docking, leaving the responsibility of monitoring and maneuvering fully to the two officers on the bridge.

The main systems used on a bridge are dual electronic sea charts (ECDIS), dual Automatic Radar Plotting Aid (ARPA) radars, a conning display for visualizing ship status, GPS/GDPS, speed measuring systems, autopilot and gyro compass, communication system with external and internal radio, as well as, a black box [7]. As was seen during observations in simulators and on-board a ferry (see section 5.1.1), but also raised during semi-structured interviews with experts (see section 5.1.3), the most commonly used systems for monitoring traffic were the radar and ECDIS. For an overview of bridge systems, see figure 2.3. The systems directly surrounding the two chairs of the pilot and officer will be referred to as the "main bridge", which can be seen in figure 2.2. If a pilot is absent, the chairs can be used by two officers or an officer and the captain.

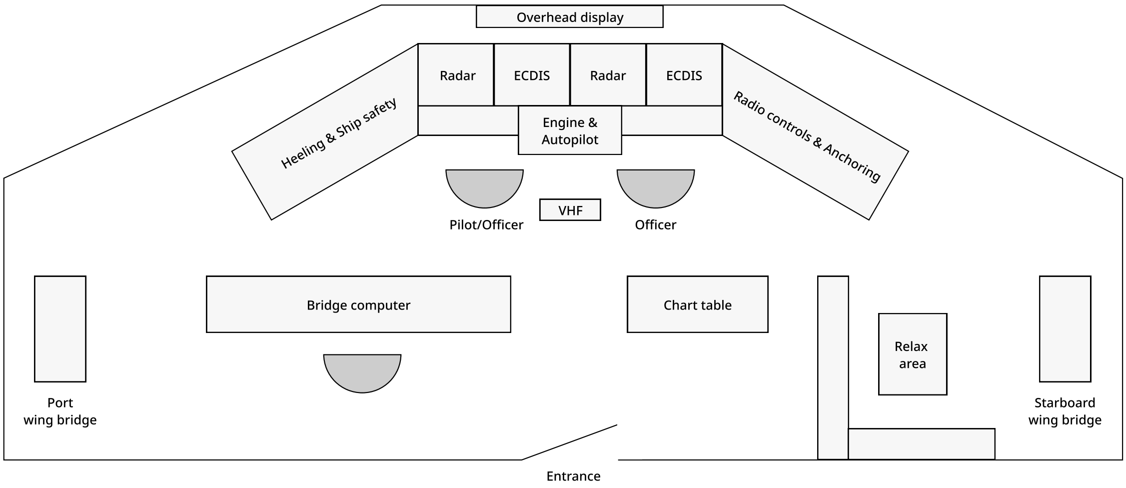

Figure 2.2: Bridge layout based on an observation on a ferry (see section 4.1.2.2).

Figure 2.3: Example of a bridge layout, taken on a research vessel.

2.4 Alerts

The purpose of on-bridge alerts is to act as decision support, as stated by the International Maritime Organization: *"The alert messages should be completed with aids for decision-making, as far as practicable. An explanation or justification of an alert should be available on request."* [11, p. 9]. Bridge alert systems should differentiate between four types of priorities for their alerts; emergency alarms, alarms, warnings, and, cautions [11]. Emergency alarms are used when there is a risk of immediate danger to people or the vessel, requiring urgent action. Alarms also require urgent action, but because of a dangerous situation that might not necessarily be a danger to people or the vessel. Warnings refers to alerts which require immediate attention but usually as precautions. Cautions are at the lowest priority, which are alerts that require extra attention beyond a normal situation. Emergency alarms, alarms, and warnings are all able to produce sound if they remain unacknowledged by operators [11]. Worth noting is that acknowledging alerts are common interactions required by regulations [11]. Cautions are the only types that do not require active acknowledgement by an operator.

The four priorities presented have also been divided into different categories of alerts. Category A alerts have to originate from their associated work station to provide enough contextual information through the system itself [12, p. 25]. Thus, not only is awareness raised of a situation, the interface and its elements (such as surrounding vessels on a radar) is meant to support the decisions of the navigator. Category A alerts include collision avoidance and grounding, and can originate from the radar or ECDIS. Conversely, Category B alerts do provide enough information by just raising awareness and can thus originate from a system other than the origin [12, p. 25]. To acknowledge an alert, the operator have to interact with the system that produced it, this will cause the alert to be silenced, but reappear if the cause if not remedied. Many of the bridge systems are able to produce alerts of different categories. Some examples are for closest point of approach, shallow depth off-course, approaching waypoints, steering and failures of various systems [46, p. 1659]. However, the largest producer of alerts in target rich environments has been found to be to be the radar producing Category A alerts in the form of collision avoidance and lost targets [29].

As was found during observations of bridges, as well as interviews with SMEs, the bridge crew do have some possibilities to adjust alerts, namely through thresholds. These alerts are to a large extent navigational and are produced in relation to the surroundings of the vessel, such as traffic. An important form of information is Closest Point of Approach (CPA), which refers to an estimated point where the distance between two objects is the lowest. This can be imagined as "safety zones" around vessels and most modern radar systems will produce alerts when a vessel is inside, or heading inside the set threshold for CPA of the own vessel. Another common threshold to set is for Time to Closest Point of Approach (TCPA), which simply is the time until two objects reaches their closest point.

2.5 Interface elements to aid SA

Regarding Endsley's three level model, principles do exist for supporting each level in an appropriate way. Level-1 can be supported by co-locating information that is relevant for a particular goal [1, p. 79], by for example grouping all relevant information regarding the status of vessel engines. Level-2 might be supported by directly displaying relationships between current and required values [1, pp. 79-80]. One example might be showing deviations between the current and the planned bearing of a vessel. Level-3 can be supported by assisting projections, for example by displaying trends among points of data [1, p. 81].

Attempts have been made in various domains, using similar principles to support SA through visual information. Still and Temme, in their Oz-project, created an interface to aid pilots in understanding available thrust of the plane, which was at that time mentally calculated using information from dials and gauges [2]. By creating an interface where each element integrates into a coherent display (see figure 2.4), pilots could directly see the relationships between important information, allowing them to get a better understanding of the situation, as well as offloading their cognition [2]. Burns et al. developed an ecological interface to support SA on a nuclear power plant, by plotting trends and grouping related information [34]. When compared with the regular interface, it was found that it provided support in situations where procedures were lacking [34]. In other words, restructuring visual information was found to support SA in novel contexts such as unexpected events.

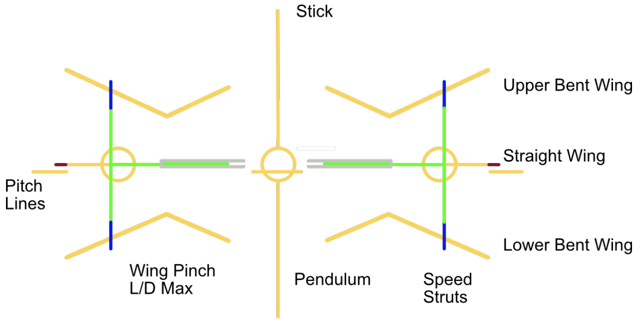

Figure 2.4: The interface of the updated pilot interface from the Oz-project [2].

Seppelt and Lee created a visual interface communicating the behavior of the adaptive cruise control (ACC) to increase operator trust [3]. The information to be displayed was chosen to be as close as possible to the type that drivers use when driving manually. Time headway, time to collision and range rate was thus integrated in a dynamic interface, constantly updating to the information handled by the ACC, in turn displaying a geometrical shape that was responding to what is in front of the vehicle (see figure 2.5). Displaying this otherwise complex combination of information through a geometrical shape allowed drivers to quickly assess the state of the system before they had to take over control of the vehicle [3].

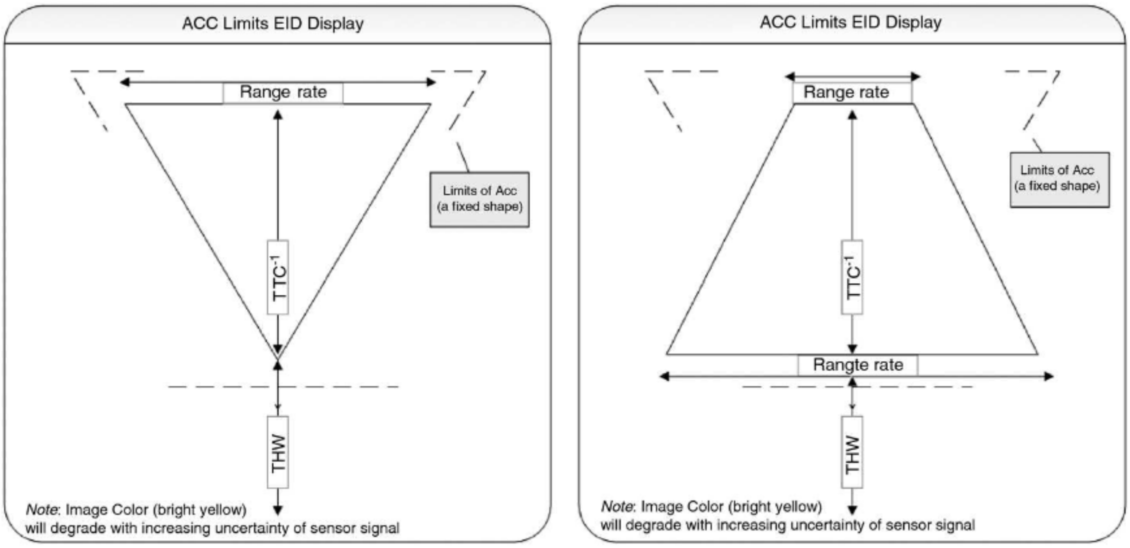

Figure 2.5: The geometrical shapes displaying the state of adaptive cruise control in a vehicle, created by [3].

Various attempts have been made regarding improving decision support on specifically for ship bridges. Having integrated COLREG-rules, Du et al. created a decision support function for encounters with other vessels [4]. By calculating three different zones, representing required actions as defined by COLREG-rules in response to surrounding vessels, the solution was found to support situation awareness by communicating intention estimations [4]. The same authors evolved the function by connecting different types of alerts representing the three different zones [47].

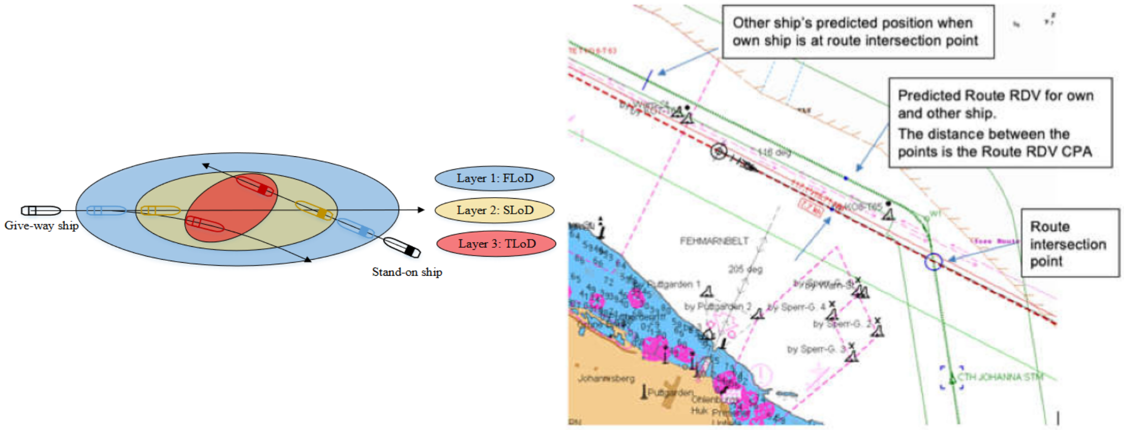

Figure 2.6: Left: Integrating COLREG-rules into an on-bridge decision support function [4]. Right: Visualizing routes of target vessels for decision support [5].

Other works have focused on visualizing information as decision support. Aylward et al. used a ship route exchange function to communicate routes between vessels, which was visualized through the ECDIS-system [5]. The function is able to visualize the next seven waypoints of a targeted vessel and calculate the predicted future position in relation to the own vessel [5]. Evaluation of the function showed a high level of trust and an ability to support SA, although the risk of over-reliance might lead to more breaches of COLREGs [5]. Other related workings have revolved around inviting the user directly into the decision support systems. One example was presented by Riveiro et al. where users could interact with parts of the vessel detection capabilities of bridge systems, allowing them to integrate their expert knowledge to increase efficiency in detecting anomalies [48].

3

Methodology

Following, an introduction will be made to research through design and human centered design, as well as each method used throughout the process activities.

3.1 Research through design

In his essay, Gaver discusses the role of *research through design* in relation to traditional theories of science, and argues how such a domain is different in its theoretical contributions [39]. Gaver argues that traditional principles of science are rigorous, and specifically fit for theory that is describing the world, making them incompatible with the generative nature of design [39].

The field of design often works with *wicked problems*, which are complex issues without a clear or correct solution [38]. This means that a designer works with domain-specific decisions to create artifacts which changes the context they inhabit, to in some cases produce a desired outcome which confirms the theories used [39]. This makes design theory unfalsifiable by failing to specify criterion for refutation [49]. Research through design is better seen as a generative practice, using past artifacts as input for new ones, thus producing knowledge in a narrow scope of possible solutions [39]. The theory thus becomes support for the practice of design to be applied in various contexts. The contexts themselves, as Gaver argues, are subject to change, which on one hand, is the overarching goal of design, but on the other hand hinders the possibility of a unified collection of theory [39]. Although this lack of unity invalidates research through design as a scientific practice, a unified collection of theory would essentially restrict design from being applicable in the large variety of contexts it currently enjoys [39]. Applicability in a large variety of contexts not only makes design versatile, but it allows knowledge to be created by motivating discussions of alternations, methods and processes to inspire future work, which is the core of research through design [39].

Regarding this thesis, a research through design approach will be used in the context of target rich environments. Theory will be used, but as Gaver argues [39], as support for decisions and choice of methods.

3.2 Human-Centered Design

The main principles of the Human-Centered Design approach (HCD) are: using the understanding of users and the context as a foundation, user involvement throughout the process, driven by user evaluation, an iterative process, addressing the whole user experience, and, multidisciplinary teams [50]. HCD entails the following activities, done in an iterative manner [50]: understanding and specifying the context of use, specifying the user requirements, producing design solutions, and, evaluating the design. This thesis will carry out its process according to the HCD activities, in combination to the specific design recommendations for SA suggested by Endsley and Debra [1, Chapter 4].

3.3 Observations

Observations are sessions of examining and recording a specific type of context, often related to human behavior, either with a more or less open mind (semi-structured) or according to a predefined set of factors [51, p. 285]. For either type of observation, it is important to narrow down the scope before conducting the methods so that data collection is focused and guided [52]. The level of participation of an observer might differ depending on the context and what results are expected. it can range from secret outsider to full participant, the former reducing risks of the observer affecting behavior but also reduces the granularity of insights [53, p. 116]. Full participation on the other hand gives a direct insight into the behavior but might not be possible for all contexts, such as when observing skilled operators [53, p. 119]. As for recording data, several alternatives exist, and continue growing as technology advances. Some common ways of gathering data are note taking, pictures, audio recording and video [53, p. 120-123]. As to what to observe, while depending on the results sought after, common focuses involve an actor, an action, a receiver, a context, and a setting [53, p. 127-134].

3.4 Interviews

Interviews are a common form of method to gather personal attitudes or experiences from people of interest [51, p. 225]. Interviews can range from being unstructured, or informal, where prepared questions are either lacking or open, to structured, or formal, where questions are heavily relied upon and often tailored to look for specific answers [54, p. 134]. Since the 1990s, semi-structured interviews have been growing in popularity as a method of using well prepared questions but allowing greater flexibility in answers as well as follow-up questions [55]. Although just relying on interviews for gathering data might not sufficiently capture the picture, as behavior might differ from what participants say [56]. Thus, to achieve a fuller picture, interviews are recommended to be paired with methods such as observations [56]. Interviews as a method also runs the risk of interviewer bias where questions or answers are adjusted to suit a certain narrative [57, p. 150].

3.5 Technology analysis

A technology analysis entails gathering and building an understanding of existing technologies such as displays, sensors, networking devices or software, and is usually done in parallel with requirement analysis [1, p. 48]. The purpose of this is to explore what existing solutions might be candidates for improving SA by, for example, providing a better alternative for presenting information. The results of this method are then used as input for the conceptualization of design solutions [1, p. 48].

3.6 Thematic analysis

Thematic analysis is a method for analyzing qualitative data, which can be applied on a wide range of theoretical frameworks [58]. The method is used to find patterns, or themes, throughout the data, producing a coherent set of insights through a systematic process [58]. A separation can be made between two types of thematic analysis; *inductive* and *deductive*. An inductive approach is *"driven by the data"* in the sense that common patterns are extracted with minimal presumptions by the researchers [58], making it suitable exploration early on in a design process [59]. Although it is worth noting that a total absence of predefined notions is unrealistic [59]. On the other hand, a deductive approach entails concepts or theoretical constructs to be brought into the process of finding themes, making the emerging patterns more confined to the barriers set by researchers [58]. This approach is then more suited for answering specific research questions [59].

To conduct thematical analysis in a systematic manner, Braun and Clarke present six phases [58].

> Phase 1: familiarizing yourself with your data. This entails repeated reading of the content to produce initial ideas and understanding of the content.
>
> Phase 2: generating initial codes. After getting to know the data, the researcher starts to produce *codes*, which can be seen as labels of the most basic building blocks of the content.
>
> Phase 3: searching for themes. After codes have been produces and implemented in the whole data set, different relationships can be explored between them. This will result in groupings of codes; a collection of themes and sub-themes.
>
> Phase 4: reviewing themes. In this phase, themes are revised to create homogeneity within and heterogeneity between. Themes should also be cross-checked with the data set to assure that they are coherent and have sufficiently defined boundaries.
>
> Phase 5: Defining and naming themes. Good themes will not be too diverse, have sufficient delimitations and address the research question. After these criteria have been fulfilled, they can be named.
>
> Phase 6: producing the report. When writing about the themes, each one needs to be sufficiently supported by data. Thus, set out to choose

extracts that best captures the essence of each theme when producing the report.

3.7 Goal-Directed Task Analysis

The main method for analyzing SA requirements, and thus operational requirements, is a Goal-directed task analysis (GDTA) [1, p. 63]. Being a type of cognitive task analysis, GDTA examines goals for a particular domain, the decisions to reach them, and the supporting SA requirements [1, p. 63]. The method relies on semi-structured interviews with subject matter experts (SMEs) using questions revolving around information needs for various decisions rather than methods of gathering information or ways of executing tasks. The outcome is a hierarchical tree, visualizing goals and sub-goals, their decisions and information required for each decision, which in turn is categorized by the three levels of SA, as visualized in figure 3.1. The method has been used in various domains, such as military [60], aviation [61, 62, 63], maritime [20], and assistive technologies [64].

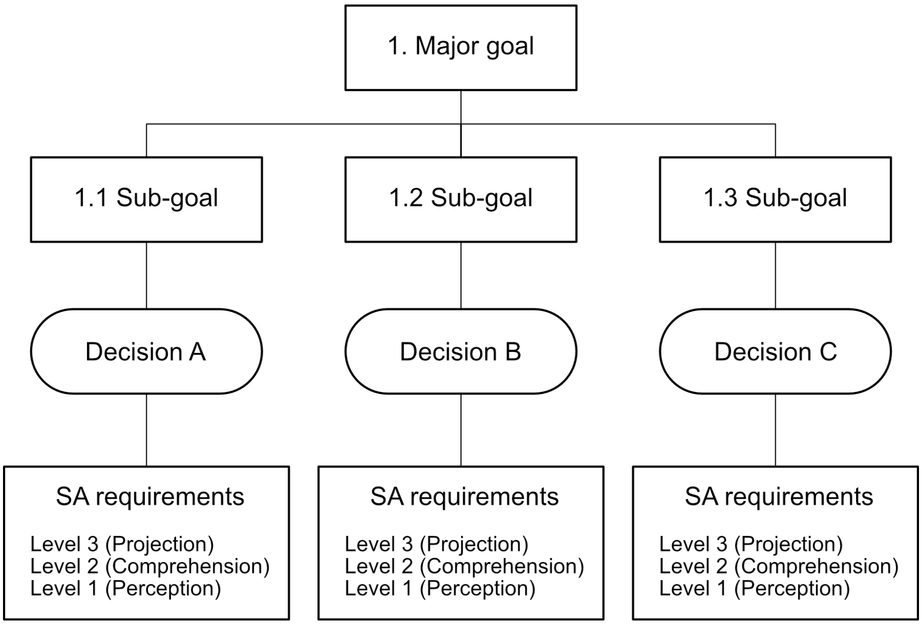

Figure 3.1: Graphical representation of the tree structure of a goal directed task analysis

While a GDTA provides insights into what information is needed by each operator, it lacks the ability to examine how that information is transferred in a real scenario. The GDTA provides insights into what information is needed in an optimal situation - making it a normative representation of data. Certain interview questions which will be analyzed beyond the GDTA, but observations will also be used to better understand how the information is actually used, i.e the descriptive representation. This will attack the problem from several directions, essentially using triangulation of methods to get a representation of the context that is more true to life [65].

3.8 Hierarchical Task Analysis

While the GDTA is a normative method, looking at information requirements to fulfill goals, the hierarchical task analysis (HTA) can be seen as descriptive method of tasks as they are performed, together with their relationships to each other [66, p. 86]. Different types of data collection methods such as observations, existing documentation, interface inspection, or interviews, can provide input into an HTA [66, p. 83-85]. Like the GDTA, a main goal is specified, which is broken down into sub-goals but where they differ is that sub-goals in an HTA are broken down into tasks [66, p. 86]. To specify relationships, plans are created, describing what conditions must be fulfilled before a task is executed [66, p. 88]. An HTA is often, like the GDTA, visualized through a tree structure (see figure 3.2).

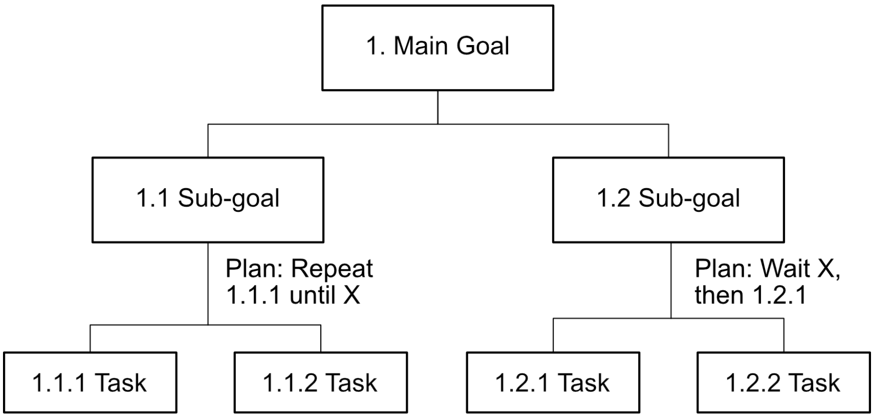

Figure 3.2: Graphical representation of the tree structure of a hierarchical task analysis

3.9 Sketching and prototyping

Because of its versatility and inexpensive nature, sketching is often done at early stages of design, allowing for exploration [67, p. 139]. The specified user requirements, together with relevant SA-specific principles were explored during this sketching phase.

Furthermore, Buxton differentiates between sketching and prototyping, stating that prototyping only happens as ideas converge [67, p. 139]. As ideas started to focalize, the efforts moved into low-fi prototyping on the digital platform of Figma[1]. Using the four purposes of prototypes presented by Lim and Stolterman [68], the process started to move towards creating prototypes of evaluative purposes rather than idea generation, as was the early focus. However, these early versions of the prototype were low fidelity wireframes, i.e. interface skeletons consisting out of buttons, menus and panes [69, p. 340]. Because of their low fidelity, they were still

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[1] https://www.figma.com/

candidates for change, which is a valid property given that they are also capable of eliciting general understanding of the overarching concept, and can thus be used as material for user feedback [69, p. 344]. This notion of evaluating rough prototypes and implement changes according to feedback has gone by the name of *"rapid prototyping"* [70]. As the prototype was refined, the fidelity increased, preparing it to be self-sufficient enough, both visually and interactively, to mimic a real on-bridge radar for evaluation purposes.

3.10 Design workshop

A design workshop is a versatile session where various generative activities are carried out, often early on in a design process [51, p. 139]. The versatility of a workshop thus allows it to be tailored with specific methods for a desired outcome. In this case, the methods chosen for the workshop were intended to produce ideas aimed to touch upon a specific user insight.

3.10.1 Brainstorming

Brainstorming is a common method for team to produce ideas by sharing what comes to their mind in relation to a defined scope [37, p. 385]. Each contribution should be valued the same and critique should be left out at this point [69, p. 282]. Ideas are commonly shared verbally but it is recommended to keep records of some sort [37, p. 385], for example by writing ideas down or using post-it notes. One strength is its dependency on group thinking, allowing ideas from one person to inspire the rest of the group [71, p. 173]

3.10.2 Creative matrix

The General Morphological Analysis was developed by Fritz Zwicky as a way of mapping out multidimensional relationships through a matrix [72] in [73]. These matrices can consist out of several dimension, entailing a broad exploration of alternatives by filling out the cells [73]. A simple example, based on the one given by Ritchey [73], is a matrix consisting out of two dimensions, color and size. Color can be attributed with two conditions, red and blue, while size can be attributed with three; small, medium, and large. This will create a 2x3 matrix with a total of six cells, each one, when filled out, housing a an item with unique properties. The morphological matrix has been tweaked by LUMA System of Innovation [2] to a method by the name of creative matrix [74]. The creative matrix divides its matrix into two categories, one related to people and one about solutions, and thus is able to break conventional thinking, and generate a large number of ideas [74].

3.10.3 Solution sketch

The solution sketch is a method allowing participants to spend more time expanding on one idea (or a combination of several) by sketching it out more thoroughly [75].

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[2] https://www.luma-institute.com

The sketch can be rough, and supported by text to explain parts of it, although it has to be self-explanatory because if "no one can understand it in sketch form, it's not likely to do any better when it's polished" [76, p. 114] Solution sketches are usually done after an initial set of ideas has been produced [75], such as through a creative matrix.

3.11 Think aloud protocol

The think aloud protocol, also known as "verbal protocol", is a technique of collecting qualitative data by allowing a participant express their thoughts about the experience of interacting with an artefact [69, p. 440] often according to a set of predefined tasks [77]. This requires both that participant and the researcher to have access to a prototype of some sort. The participant needs access to be able to interact, and the researcher needs to be able to observe what the participant is doing.

The think aloud protocol as also been suggested by Endsley as an indirect form of evaluating SA [1, pp. 260-261]. The results of this protocol thus provided mainly two categories of insights (a) understanding of the extent of SA support given by the prototype for understanding alerts, and, (b) critical incidents in relation to task performance [69, p. 437]. In addition to providing these insights, the interactions themselves were intended to act as support for the interview questions that followed the think-aloud protocol, as the questions were directly related to the use of the prototype. The think aloud protocol might run into problems of representing a full picture of SA, as it relies on individuals to effectively communicate their understanding [1, p. 261]. Thus, it's beneficial to complement it with other methods.

4

Execution and Process

The process will follow a Human-Centered Design approach, using the suggested SA design recommendations by Endsley and Debra [1, Chapter 4]. The following chapters will be categorized according to the HCD activities of understanding and specifying the context of use, specifying the user requirements, producing design solutions, and evaluating the design [50]. The full process can be seen in figure 4.1. Planning the scope of the thesis was done around Christmas 2021, and a planning report defining many of the methods to be used and the structure of the process was finalized at the end of February 2022. From this point, the process of executing methods and report writing lasted until early June the same year. For a full plan, as defined in the planning report, see D.

For all methods involving external users, forms of consents were handed out and signed. Participants were informed of the purpose of the thesis, how long their data will be stored and that they will remain anonymous throughout the analysis, which in turn complies with the requirements posed by article 5 of the EU General Data Protection Regulation regarding processing of personal information [78]. Furthermore, participants were informed that they could at any time opt out, either during the session or seven days after the data collection had commenced. All participants kept a signed copy of the consent form.

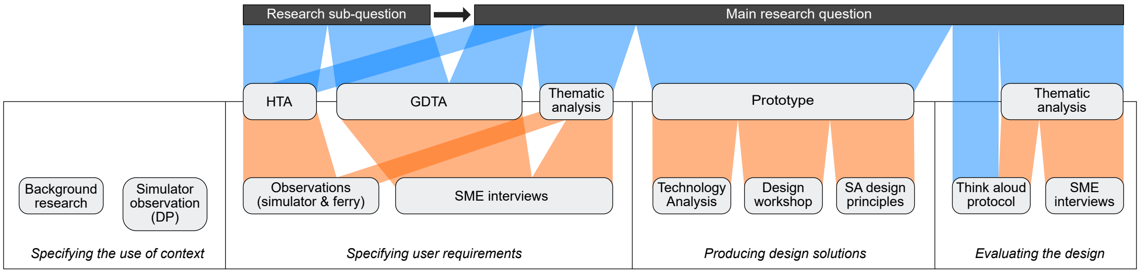

Figure 4.1: Visualization of the methods and outcomes in relation to the two research questions and the HCD activities.

4.1 Specifying the context of use

In the following phase the context was explored by relying on background research and simulator observations in target rich environments.

4.1.1 Background research

Reading previous work was the initial step towards forming an understanding of the domain. Background research entailed using various digital libraries to find books and articles of previous work in the maritime domain, involving discovering existing problems and suggested methods of designing for a complex context.

4.1.1.1 Observing a simulation with a DP system

An observational study was carried out on the Maritime Studies department of Chalmers University of Technology which acted as a way of familiarizing with the common systems used on a bridge. Participants were three students, one man and two women ($M = 30.6$ years old) enrolled in their fourth year on the Master Mariner programme at Chalmers University of Technology.

The simulated scenario was to carry out a realistic operation close to an offshore facility specifically using a class 2 DP system of the Kongsberg K-Pos DP-21/22 model (see figure 4.2). Students had prepared for the session in advance by clearly defining roles and responsibilities in case of emergencies in the simulation. The appointed senior dynamic positioning operator (DPO) was handling the DP system throughout the simulation, with input from the junior DPO. The researcher was located in the control room with full view of the systems used by the students during the three hours that the session lasted.

Figure 4.2: The observed simulator room. A Kongsberg K-Pos D DP2 system can be seen in the bottom left corner.

This bridge housed a DP system, which is an automated system that keeps the vessel in a fixed position, often used on working vessels when close to off-shore facilities [79] which was outside of the scope of this thesis. Although this was the case, the session allowed the researcher to familiarize with common systems used, and look closer at the alert management solution used in the DP system.

4.1.2 Observations

While the first observation was to understand the domain, the purpose of the following observation sessions were first and foremost to focus on what tasks were performed on a bridge, but also what kind of information, and its origin, is used in target rich environments. More specifically, this includes interfaces of bridge systems, visual gaze out of the bridge windows, communication, and sequences of actions. This would both provide an insight into the context and types of information mentioned during interviews, as well as an understanding regarding potential sequences of decisions and tasks. The observations were also an opportunity to further increase understanding of the on-board systems and how they are used.

4.1.2.1 Observing simulations in target rich environments

Three observational studies were carried out on the Maritime Studies department of Chalmers University of Technology. Participants were six students, five men and one woman ($M = 27.8$ years old) enrolled in their fourth year on the Master Mariner programme at Chalmers University of Technology.

Each observation spanned over a whole simulation session in which students were tasked to safely navigate a target rich environment. One session involved two students each. All three sessions repeated the same simulation scenario and lasted approximately two hours each. These sessions were part of the student curriculum as mandatory final displays of their accumulated knowledge from their years in the program. The scenario used for each simulation session revolved around effective use of on-bridge equipment to navigate and avoid close-quarters situations in the English Channel. Weather conditions were clear. Each pair of students were assigned one of two roles, a first or second operator, upon which students were instructed to switch halfway through the session.

The simulators used were full scale versions of the WÄRTSILÄ Navi-Trainer Professional 5000 model, including four Transas 4000 MFD systems configured to replicate two radar and two ECDIS systems. The observations were done through the control room, with an ability to see all the interfaces available on the bridge in real-time. Roof-mounted cameras provided a direct overview of the bridge and audio from the simulation room was fed directly into the control room, making it possible to hear verbal communication between the operators. All UHF and VHF contact was made directly with the instructor who was located in the control room.

The researcher had an unobtrusive role during the sessions, partly as to not disturb the students in their final simulation, but also because the control room where the researcher was sitting had access to cameras, audio and real-time representations of the interfaces used on the bridge. The instructor also acted as support for questions that the researcher might have of the observed simulation session, such as certain terms used by the participants or the meaning of information displayed on systems. During each session, notes were taken by the researcher but, in agreement with the instructor, no audio or video was recorded. The role of the researcher can be defined as known but non-disruptive, which Zeisel defined as being a *recognized outsider* [53, p. 117].

The notes, supplemented by the researchers recollection of the sessions, were compared between the three sessions, and common patterns were the basis for the hierarchical task analysis (see figure 5.2 and 5.1). A part of the technology analysis was also done at this point, mainly exploring what equipment was would be available on a bridge, how they are set up and what information they provide.

4.1.2.2 Observation on-board a ferry

An observation session was carried out on-board a ferry vessel, focusing on the tasks carried out by a trained bridge crew when seaborne. The observed crew consisted out of three officers, all men. All officers shared several years of on-bridge experience mostly on ferries, both of shorter voyages such as the current one, but also longer. One officer also had past experience of navigating cargo ships which involved voyages spanning over days or weeks.

The session stretched over two shorter trips (roughly two hours each) during the same day. The purpose of the session was to complement the findings from observing simulations by providing insights from a real-world context what tasks are commonly carried out and by whom. As preparation, an observation protocol was created with input fields for time, task, purpose, and actor. However, this also introduced limitations regarding what insights could be gathered as unobtrusiveness was prioritized for safety reasons. While the simulators allowed direct access to the system interfaces used by the participants through the control room, the on-board bridge did not allow such an opportunity. Similarly to the simulation observations, the role of the researcher was, as Zeisel defines it, a *recognized outsider* [53, p. 117]. The researcher stood behind the main bridge with a clear view of what systems the officers interacted with, taking notes regarding their tasks, purpose and who did what.

The result provided, in combination with the result from the simulations sessions, input into the HTA regarding sequences of tasks. Some insights were also gathered from the notes regarding potential pain points in relation to alerts.

4.1.2.3 Insights gathered from observations

The following key insights were gained from the observations, for full results, see section 5.1.1.

- The radar is an important system for monitoring the surroundings throughout target rich environments meaning that the alerts it produces will be close at hand for the operators.
- In general, alerts can be categorized into two types; navigation and other. Navigation alerts refers to those directly or indirectly affecting the route of the vessel. These often emerge from the radar, ECDIS, or other systems on the main bridge. Other alerts refers to a broader category and are often handled away from the main bridge, for example through panels mounted on

walls or the on-bridge computer. Examples of these alerts would be fire alarms or sprinkler malfunctions.
- For some alerts, it's hard to pinpoint the source on an alert just by sound and requires full attention of the whole crew.
- Alert thresholds were more carefully set and adjusted during the ferry trip, while left untouched during the simulation session.
- Both the ferry trip and the simulation sessions had active alerts going on in the main interfaces (ECDIS/radar) throughout the voyage. In the case of the ferry, these alerts were deemed unimportant, but for some reason, not acknowledged anyway. A possibility might have been to not lose their information, as happens if the alert is acknowledged and disappears, in case it would be necessary in an upcoming situation.

4.1.2.4 Hierarchical Task Analysis

A hierarchical task analysis (HTA) is a method to describe sequences of tasks as they are performed, and showcases potential relationships in-between [66, p. 86]. The HTA was based on the tasks observed form all observations, together with relevant insights from interviews with SMEs, and visualized using a digital diagramming platform by the name of Lucidchart[1].

4.1.2.5 Insights gathered from the HTA

The following key insights were gained from the observations, for full results, see section 5.1.2.
- In bad weather conditions, there is a higher reliance on systems to understand the surrounding situation.
- The type of target information that is available through the systems does vary because of its cusomizability, making it versatile enough to fill in a range of SA gaps.
- Monitoring the situation is a constant back and forth between main bridge systems and looking out of the main windows.
- There is a constant feedback loop of monitoring the situation, executing maneuvers and monitoring the result. This entails that the operator will be spending a great deal of time close to the main bridge when monitoring and maneuvering the vessel which is arguably the reason why the radar, ECDIS and maneuvering controls are within reach from the same position. Thus, alerts that require the operator to move away will disturb this loop.

4.2 Specifying the user requirements

The following phase focused on understanding the user requirements when navigating a vessel in a target rich environment to provide an answer to (a) provide insights into SA requirements for understanding alerts, and, (b) provide a full range of SA requirements to answer the research sub-question of "*What SA requirements do bridge*

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[1] https://www.lucidchart.com/

operators have in a target rich environment?". To accomplish this, the results of a semi-structured interview was used as a foundation for a GDTA [1, p. 63].

4.2.1 Semi-structured interviews

To complement the results of the observations, as well as, provide more in-depth insights into informational needs, interviews were carried out with three SMEs. Three experts with navigational background participated, all men currently working in Sweden. Each expert had at least 8 years of experience (with an average of 19.3 years) of actively working with navigation bridges. All three were currently working on-board vessels and the vessel types they hade experience from varied from pilot boats, research vessels, merchant vessels and cargo vessels.

In addition to exploring the normative SA requirements, the semi-structured interview also explored the descriptive nature of navigating in a target rich environment, including common pain points related to alerts that officers might experience. Two of the interviews were carried out through a remote video conferencing software, while one was done in person. Each interview lasted around one hour and audio was recorded for each one.

Questions were prepared for all interviews, but some of them being open ended as to explore the domain, which has been recommended at earlier stages of a design process [54]. It is also suggested by Endsley that interviews meant to provide a foundation for a GDTA are less structured to allow a wider exploration of informational needs [1, p. 66]. Initial questions should also touch upon the overall goal to open directions of further exploration for the remainder of the interview [1, p. 66]. All questions can be seen in appendix B.

To prevent the conversation from steering off track, some additional follow-up questions were prepared, such as *"Tell me more about why you would want to know that [piece of information]"* and *"Tell me how you used that information in the past"*. When a first draft of a GDTA is created, it is then suggested to act as a foundation for further interviews to confirm or deny existing informational needs, as well as with each successive interview, expand on the contents of the GDTA [1, p. 74-75]. A similar concept has also been proposed elsewhere, using previously mapped out knowledge as *"communication props"* during subsequent expert interviews [80]. Thus for each successive interview, the same prepared questions were asked, but in relation to the current iteration of a GDTA.

4.2.1.1 Thematic analysis

Data in the form of audio recordings from all three interviews were transcribed and coded in MAXQDA 2020[2]. One interview was separately coded by two researchers, this led to a common ground of codes and how they should be used for the remaining interviews. The remaining interviews were then coded by one researcher. New codes appearing after all interviews were coded were discussed between the same two researchers to reach a common ground of how they should have been used upon which changes were made in the codes and their content according to the

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[2] https://www.maxqda.com/new-maxqda-2020

reached conclusion. The coding was done in MAXQDA 2020 and the codes together with the interview material were imported into Figma to allow a visual platform for discovering themes. MAXQDA 2020 allows several codes to be specified for the same extract, allowing relationships between codes to be found. For example, an extract mentioning alerts as disturbing would have both the code "alert" and "disturbing" attached to it. Thus, the extracts and their associated codes could be grouped up in Figma, eventually forming themes, sub-themes and relationships between them (see figure 5.3). To capture the most out of the data, as suggested at early stages of a design process [54], the approach was made to be rather inductive, following the six phases presented by Braun Clarke [58]. Throughout the process, relevant data regarding information, decisions and goals were input into a GDTA and the remaining themes gave insights into common tendencies or pain points when navigating in target rich environments.

4.2.1.2 Insights from the thematic analysis

The following key insights were gained from the thematic analysis of SME interviews, for full results, see section 5.1.3.

- Alerts can be highly distracting as they require physical attendance, often in other parts of the bridge, without providing enough new information to the operator to be worth the effort of attending them.
- Main systems, such as radar and ECDIS, do produce alerts with information that in cases where the operator has sufficient awareness of the surroundings. In these cases, acknowledging these alerts can be seen as distracting.
- Navigation alerts can be an important tool for avoiding close-quarters situations by raising attention and acting as reminders
- Proactive maneuvers are crucial to avoid close-quarters situations. To do this, the operator builds a strategic, overarching, understanding of the situations as well as a tactical, more detailed, view.

4.2.2 Goal-directed Task Analysis (GDTA)

As suggested by Endsley, each SME interview revised the current GDTA until the final version was formed [1, p. 74-75]. What resulted was a wide collection of goals, sub-goals, decisions and their necessary information, in turn defining the SA requirements. Although required for the sub-question, the full result was boo broad for the main research question. Thus, not all findings were directly relevant for defining SA requirements for alerts.

4.2.2.1 Insights from the GDTA in relation to alerts

The following key insights were gained from the GDTA, for full results, see section 5.1.4.

- The voyage plan is the standards to which decisions throughout the voyage are weighted again. Thus, alerts regarding deviation from the route will be important

- Actively configuring equipment is done to fulfill the current informational needs. Time intervals for vectors and radar range are two examples of reconfigurations provided decision support to operators by providing information about the current and predicted future situation of surrounding vessels.
- Vessels of primary importance are those in direct or indirect relationship with the planned route.
- Three goals are related to alerts; understanding the cause of an alert, understanding the type of alert and, finally resolving alerts (1.1.6 and 1.1.7 in figure 5.5 2.4 in 5.6).
- Level-1 SA requirements are perceiving what type of alert is active and what caused it.
- Level-2 SA requirements are understanding relationships between the alert and the own vessel, the traffic situation and the voyage plan.
- Although alerts are, by nature, reactive, there are Level-3 SA requirements to project bearing and distance of other vessels, as well as future position of both other but also the own vessel.

4.3 Producing design solutions

This section will cover how the insights were translated into a concept, as well as the evolution towards a final prototype. The SA design principles presented by Endsley [1, Chapter 6-11] were used throughout the development of the concept.

4.3.1 Technology analysis

A part of the technology analysis had been done during the observations and at this point, manuals that were accessible were read through to understand what features do exist in existing radars. However, many of the manuals that are accessible are from older systems, thus posing a problem to this approach. The following key insights were gained from the technology analysis, for full results, see section 5.1.5.

- Some systems, such as the radar and ECDIS, are integrated and able to directly communicate with each other by sending different types of information to be displayed on either screen. However, most systems are not, and require attendance away from the main bridge.
- The observed radar and ECDIS systems usually categorized alerts with colors or symbols based on their severity.
- Although the DP system often exists on vessels outside the scope of this thesis, their alert management systems were found to differ compared to the observed radar and ECDIS systems.
  - They have an ability to see alert history, allowing an operator to build SA over already acknowledged and inactive alerts.
  - They have an ability to expand alerts to provide a fuller description such as cause and suggested courses of action.

4.3.2 Early concepts

Already in the early stages, the concepts focused mainly on the radar. Firstly, the radar and ECDIS were found to be the most commonly used systems when navigating. These systems are also able to produce alerts on their own, and as Baldauf et al. found, often do to a large extent in target rich environments [29]. Contrary to the ECDIS, SMEs expressed during interviews that the radars are the most trustworthy regarding the information produced. Thus, the radar was deemed a good candidate to implement an integrated alert system into given that information relevant for navigation are more trustworthy from this source. Secondly, implementing the concept into a radar would afford evaluation methods that were feasible given the time frame and budget of the project. The prototype could be produced in software such as Figma, and it would be able to stand on its own to a greater extent, while a more abstract implementation would require access to simulators or similar replications of ship bridges. Although this second reason is not exclusive to the radar per se as it could be said for all existing bridge systems.

At this stage, the found user requirements were, in tandem with SA principles, being experimented with and realized into sketches. How the research findings were translated and what SA principles were used will be presented next.

Alerts in the PPI

The following research insights are covered by this interface element:

- The observed radar and ECDIS systems usually categorized alerts with colors or symbols based on their severity.
- Level-1 SA requirement of perceiving type and cause of an alert.
- Level-2 SA requirement of understanding relationships between the alert and the own vessel, the traffic situation and the voyage plan
- Two of the important goals revolving alerts are understanding the cause and the type.
- Vessels of top priority are those affecting the intended route, either directly or indirectly.

The following SA design principle(s) are covered by this interface element:

- G1 - Organize information around goals
- G4 - Support global SA
- A1 - Support alert confirmation activities
- A6 - Support the assessment and diagnosis of multiple alerts

To better support Level-1 SA requirements of being able to perceive type and cause, alerts were implemented into the objects on the plan position indicator (PPI), the central part of the radar interface, which in turn was meant to provide an overview of how alerts related to the traffic situation (supporting part of the Level-2 SA requirement). To differentiate alert priority, two symbols together with different colors were used, similarly to what has been observed in current systems. Alerts of the highest priority were given the color red, while lower priority were yellow. Objects in the PPI differed visually in the following way. Fully red triangles indicates vessels responsible for an active and unacknowledged alert. Triangles with a red border represents an active but acknowledged alert, meaning the vessel is still within some set alert threshold, but the operator has acknowledged the alert through the interface. Triangles with grey borders indicates a vessel that has not caused any alerts and yellow squares including a plus-sign represents lost targets, which are previously tracked vessels but were at some point lost. Connecting alerts to vessels this way would also support the finding that vessels of primary importance are those in close relationship to the planned route. This way, an operator would directly see if any vessels close to the intended route are currently seen as a risk.

Regarding SA design principles, as specified in the GDTA, one important subgoal in relation to alerts is understanding cause (see 1.1.6 in figure 5.5). The overview provided by implementing alerts into the PPI organizes information around goals, thus supporting G1. This same overview should in essence support global SA (G4), as well as, support the assessment and diagnosis of multiple alerts (A6). Lastly, in addition to clicking alerts in the list to acknowledge them, the PPI can directly be used instead (supporting A1). By clicking a red vessel, the alert for caused by it will be acknowledged and potential audio raised by the alert muted.

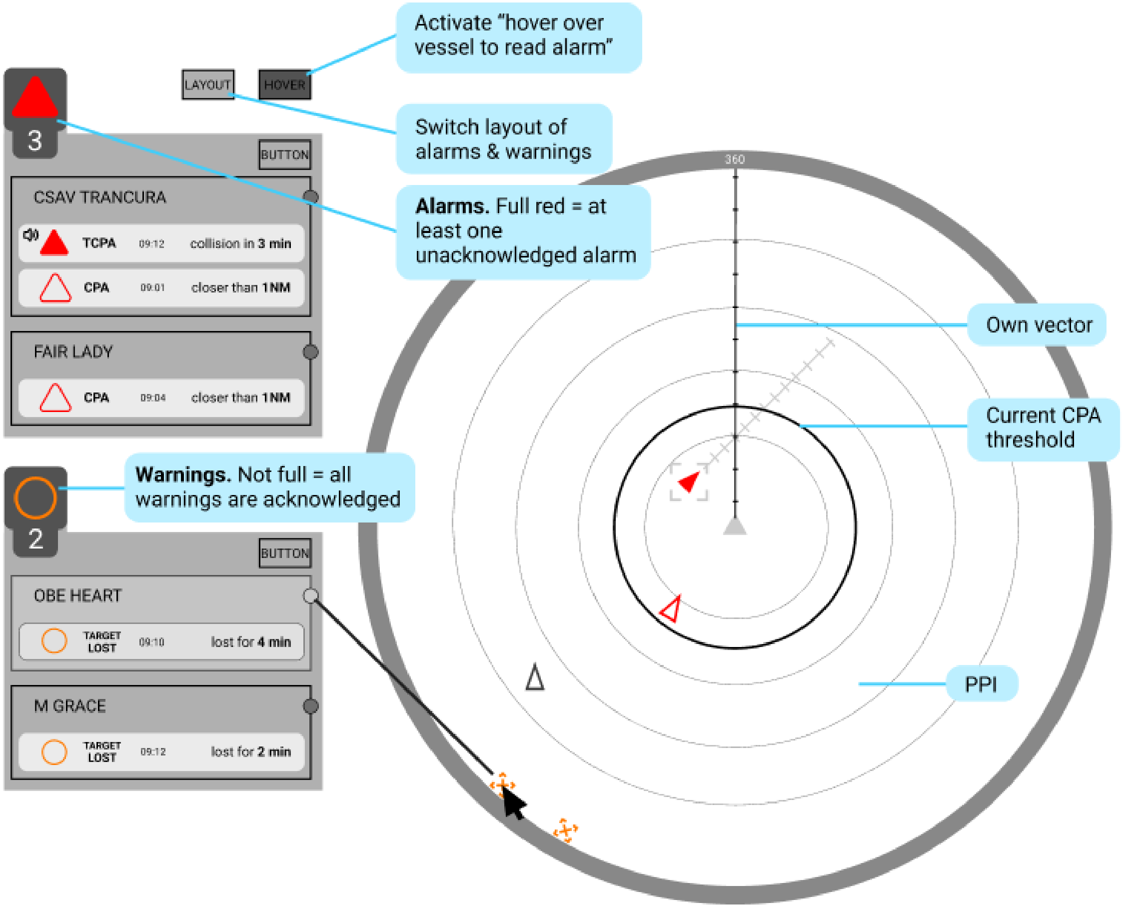

Figure 4.3: First wireframe of the concept including contextualizing lines and alerts directly in the PPI.

Contextual lines

The following research insights are covered by this interface element:

- Two of the important goals revolving alerts are understanding the cause and the type.
- Level 2 SA requirement of understanding relationships between the alert and the own vessel, the traffic situation and the voyage plan
- Main systems, such as radar and ECDIS, do produce alerts with information that in cases where the operator has sufficient awareness of the surroundings. In these cases, acknowledging these alerts can be seen as distracting.

The following SA design principle(s) are covered by this interface element:

- G1 - Organize information around goals
- G2 - Present Level 2 information directly to support comprehension
- A2 - Make alerts unambiguous

- A5 - Minimize alert disruptions to ongoing activities A6 - Support the assessment and diagnosis of multiple alerts

To further increase comprehension, an ability was added to see relationships directly between objects causing alerts and the alert list by hover over targets in the PPI or items in the list (see figure 4.4). While showing alerts directly on vessels in the PPI aids understanding of the cause, the contextual lines were meant to provide further support by directly connecting vessels to their respective alerts when hovering. Thus, G1 would be further supported by tying a closer connection between type and cause. At it's core, contextual lines also support G2 given that a direct relationship is shown between two important factors of interest.

As been mentioned, the operator is able to acknowledge alerts directly through clicking on objects in the PPI. However, it is with the feature of contextual lines that this accessible way of acknowledgement might shine the brightest. When hovering over a vessel, a line is displayed between the vessel and the alert in the list related to it. The operator is thus aware exactly of what alert will be acknowledged if they click on that vessel, which likely saves some time compared to current radar systems that require the operator to go through the list manually. Although likely not solving the problem, the time and effort saved this way might reduce the extent to which alerts are perceived as distracting (somewhat supporting A5).

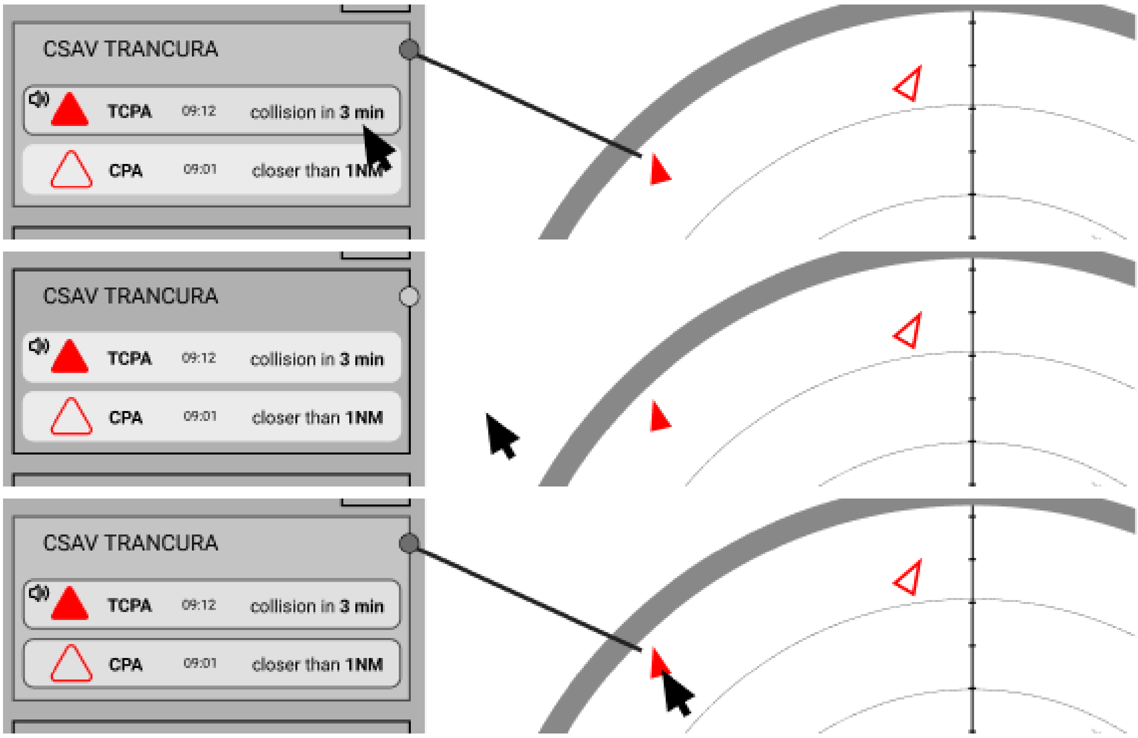

Figure 4.4: Hovering over items in the alert list, or objects on the PPI, shows contextual lines between them.

CPA threshold and vector visualizations

The following research insights are covered by this interface element:

- Proactive maneuvers are crucial to avoid close-quarters situations. To do this, the operator builds a strategic, overarching, understanding of the situations as well as a tactical, more detailed, view.

The following SA design principle(s) are covered by this interface element:

- G3 - Provide support for projections by integrating Level-3 information
- G6 - Make critical cues for schema activation salient
- A3 - Reduce false alerts

While vectors are actively used for surrounding vessels, the same function on the own vessel might also aid projection (supporting G3) and thus provide a tool for predicting collision avoidance alarms. By having a visual vector on the own vessel, it might also be easier to understand break points for schema activation (supporting G6). For example, by being able to predict where the own vessel will be in a selected number of minutes, the operator can get a clearer understanding of what potential maneuvers are needed and when.

Another element is the visualization of the set CPA threshold. Currently this is not visualized beyond the how many minutes are chosen in the radar interface. By implementing a visualization of the threshold directly into the PPI, it is thought to both create clear borders for schema activation and provide support for projecting how close vessels are to the threshold (supporting both G3 and G6).

The CPA threshold is meant to be kept customizable, which is one way of giving control of false alerts to the operator (supporting A3). Although current systems already have the ability to adjust both CPA threshold by distance in nautical miles, and vectors by how many minutes to predict.

4.3.2.1 Design workshop

SA principles had thus far been efficient for inspiring elements in line with the research findings, however, the insight that alerts were disturbing needed extra work. Thus, the purpose of the workshop was to brainstorm around current alerts and how to make them less disturbing. The workshop was carried out on-line using a remote video conferencing software together with a digital workspace named Miro[3]. Participants were four women (M = 28.8 years old) attending their second year of the Master's programme in Interaction Design and Technologies on Chalmers University of Technology. The workshop lasted for one hour and the facilitator took notes during the whole workshop and also had access to the digital workspace after the session ended to analyze results.

Before brainstorming, it has been suggested to perform simple warm-up exercises, which could be totally unrelated to the general scope of the session [37, p. 385]. Thus, because the workshop was occurring close to the Eastern holiday, an egg-hunt

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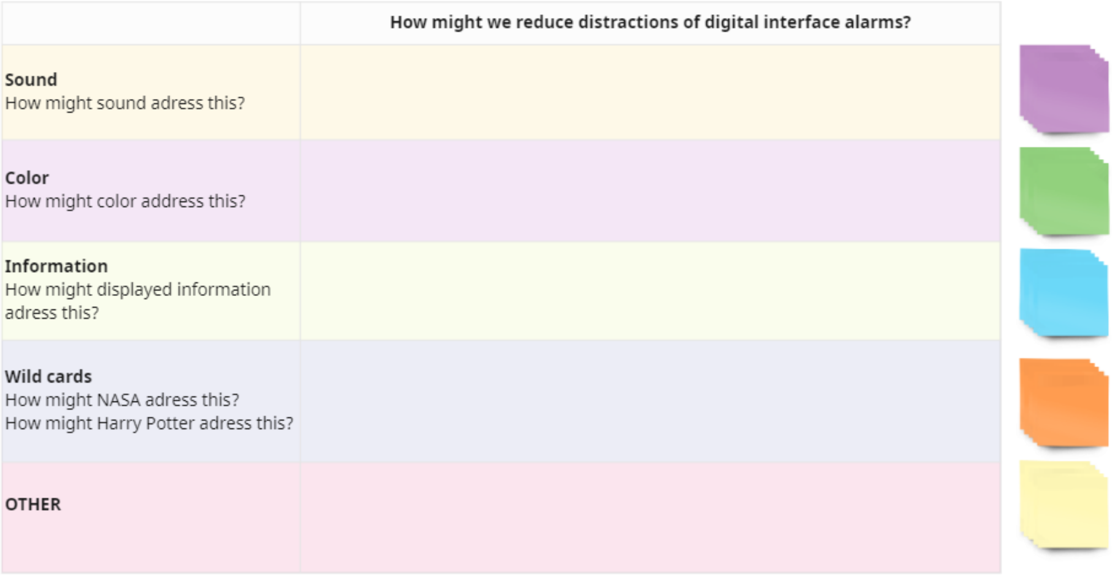
[3] https://miro.com/

was created on Miro. Pictures of eggs were hidden behind various objects spread out on the digital workplace and tied to each egg were short beginnings of sentences. Some examples of those used are "The last movie I saw was..." and "The cow sounds like...". Participants were tasked with finding eggs and finishing the sentences until all eggs were found. The purpose of this warm-up exercise was to create a light-hearted atmosphere where participants felt that they could share ideas.

After the initial warm-up exercise, participants were tasked to brainstorm what associations they had to alerts, i.e. how they have experienced alerts, what objects they associated with them and how they reacted. Using the benefits of group thinking of widening one's perspective [71, p.173], this 10 minute session would provide a springboard of associations for the next method where they would be tasked to focus on ideas to reduce distractions.

Following the brainstorming session was 20 minutes of Creative Matrix. The participants were tasked with producing ideas to fill out each row of the matrix, using all dimensions to come up with ideas of how to reduce distractions of alerts in digital interfaces. The five dimensions were sound, color, information, wild cards and other. Wild cards were meant to spark creativity by making participants ideate what Harry Potter or NASA would have done to reduce distractions [51, p. 95]. Matrices such as these are meant to allow broad explorations of alternatives by coming up with ideas for each dimension [73].



	How might we reduce distractions of digital interface alarms?
Sound How might sound adress this?	
Color How might color address this?	
Information How might displayed information adress this?	
Wild cards How might NASA adress this? How might Harry Potter adress this?	
OTHER	

Figure 4.5: Creative Matrix set-up used during the design workshop

At this point, the team had diverged ideas in several directions. To narrow down the scope to just a few suggestions, solution sketches were used where participants chose one idea or a combination of several of those proposed during the creative matrix and sketch them out more thoroughly for 20 minutes. Each participant did this individually on their own section of the digital workplace. After 20 minutes had passed, each participant presented their idea for the rest of the group.

After the workshop had commenced, the facilitator used affinity diagramming of the post-its generated during the creative matrix to find common themes [51, 81, p. 17] and summarized written notes for each idea presented from the solution sketch.

4.3.2.2 Insights from the design workshop

The following key insights were gained from the design workshop, for full results, see section 5.1.6.

Some of the proposed ideas, such as categorizing alerts by color and symbols and tying alert information directly to objects which raised them, were already covered by the SA design principles presented by Endsley [1, Chapter 6-12]. However, two solution sketches revolved around expandable lists of alerts positioned away from the main areas of the interface. While this might seem like a minor thing, it does introduce two interesting aspects into alert management. Firstly, alerts can be expanded to find out more information if needed. Secondly, in times where focus is required on something specific on the interface, the operator is less disturbed by the alerts because alerts are positioned far from the main parts of the interface. When the crucial situation is resolved, then the operator can attend to the list and acknowledge active alerts.

4.3.3 Further translating requirements into interface elements

Bridge alert integration

The following research insights are covered by this interface element:

- Alerts can be highly distracting as they require physical attendance, often in other parts of the bridge, without providing enough new information to the operator to be worth the effort of attending them.
- For some alerts, it's hard to pinpoint the source of an alert just by sound and requires full attention of the whole crew.
- There is a constant feedback loop of monitoring the situation, executing maneuvers and monitoring the result. This entails that the operator will be spending a great deal of time close to the main bridge when monitoring and maneuvering the vessel which is arguably the reason why the radar, ECDIS and maneuvering controls are within reach from the same position. Thus, alerts that require the operator to move away will disturb this loop.
- In general, alerts can be categorized into two types; navigation and other. Navigation alerts refers to those directly or indirectly affecting the route of the vessel. These often emerge from the radar, ECDIS, or other systems on the main bridge. Other alerts refers to a broader category and are often handled away from the main bridge, for example through panels mounted on walls or the on-bridge computer. Examples of these alerts would be fire alerts or

sprinkler malfunctions.

The following SA design principle(s) are covered by this interface element:

- G4 - Support global SA
- A1 - Support alert confirmation activities
- A5 - Minimize alert disruptions to ongoing activities
- A6 - Support the assessment and diagnosis of multiple alerts

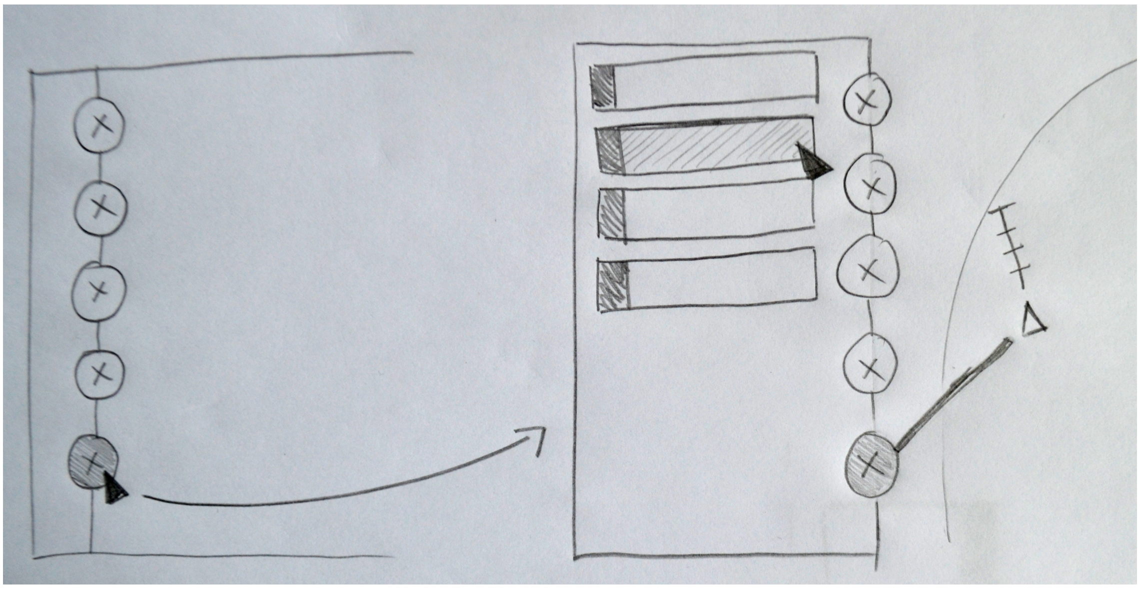


Figure 4.6: Initial sketches regarding integrating non-navigational alerts into the radar

As was defined by the HTA, a large part of an operator's time on a bridge is to monitor, make maneuvering corrections and then monitor the result of those actions, entailing that a large portion of the time will be spent next to the main bridge. It was also observed on the ferry that there are cases where the whole crew has to spend time to identify the source of an alert. Interviews with SMEs also raised the issue of alerts away from the main bridge require physical attendance to be acknowledged, in turn distracting them from their main tasks. To alleviate these issues, a full integration of all on-bridge alerts was implemented into the current concept. This would entail one interface with several alert categories, with the ability to see the cause and type of each alert, as well as acknowledge them without physically walking to them. However, the operator or someone else, might still be required to physically walk there to fix the problem even if the alert has been deactivated through the radar interface. In some cases, this is not something that can be avoided as, for example, an alert caused by a faulty cable will need that cable to be replaced.

An integrated alert solution such as the one presented would allow operators to acknowledge alerts from other bridge systems through one interface (supporting A1) and thus reduce the time and effort required to mute an active alert (supporting

A5). Such an interface would also provide an overview of the full situation of alerts (supporting G4) and allow the operator to diagnose several alerts at once (supporting A6).

Early sketches experimented with multiple categories, which were later reduced to three according to the observation that alerts can be divided into two categories: navigational and non-navigational (see figure 4.6). However, three categories were implemented to separate alerts directly relevant for navigation and route alerts that traditionally originate in an ECDIS. The three final categories were navigational, route, and equipment alerts (see figure 4.8), the last-mentioned bundling together alerts that typically originate from systems away from the main bridge, such as panels mounted on the back of the bridge. At this point, different layout options were tested out to see how the alert list would fit into a traditional radar layout.

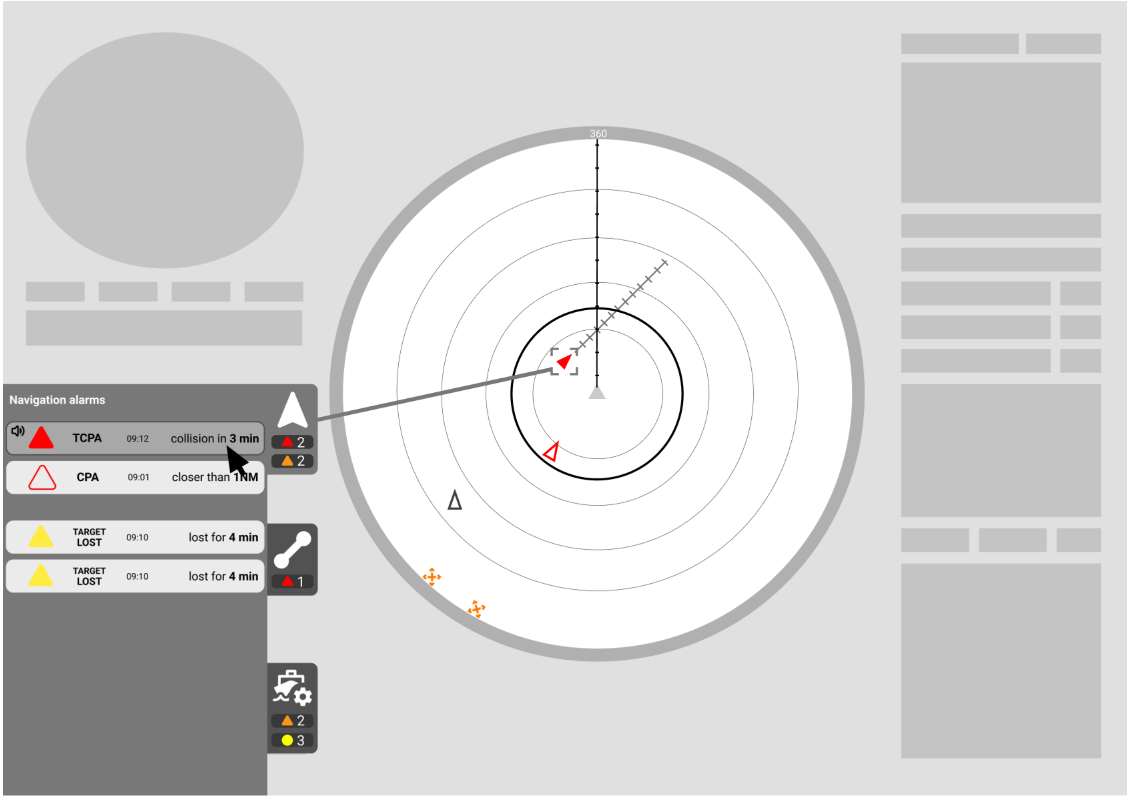


Figure 4.7: Wireframe of evolved integration with three types of alert categories

Expanded alert descriptions

The following research insights are covered by this interface element:

- Level-1 SA requirements are perceiving what type of alert is active and what caused it.
- Level-2 SA requirements are understanding relationships between the alert and the own vessel, the traffic situation and the voyage plan.

The following SA design principle(s) are covered by this interface element:

- G2 - Present Level 2 information directly to support comprehension
- G4 - Support global SA
- A2 - Make alerts unambiguous

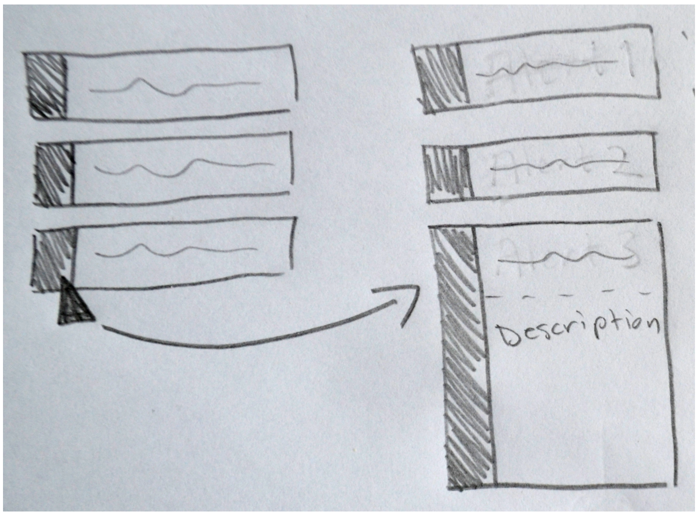


Figure 4.8: Wireframe of evolved integration with three types of alert categories

Based on inspiration from the design workshop as well as what was observed in the DP systems at the very start of the design process, expandable alert descriptions were implemented for the third category, equipment alerts. It was only implemented on this category because the other two, navigation and route alerts, were meant to provide SA support directly through the PPI while equipment alerts had their origin in other systems around the bridge with information not directly related to the radar. Thus, the PPI couldn't be used to communicate that information visually and an expandable description was more fitting.

The descriptions were planned to be short and covering the cause and type of alerts, thus decreasing alert ambiguity (supporting A2) and giving a better overview of the real situation on-board (supporting G4). A better understanding of the alert would arguably also benefit the comprehension of how an alert relates to ship safety (supports G2). Although these benefits would arguably be most noticeable in operators with less experience, or for alerts of rare occurrence.

Muting audible alerts for five minutes

The following research insights are covered by this interface element:

- Alerts can be highly distracting as they require physical attendance, often in other parts of the bridge, without providing enough new information to the operator to be worth the effort of attending them.

- There is a constant feedback loop of monitoring the situation, executing maneuvers and monitoring the result. This entails that the operator will be spending a great deal of time close to the main bridge when monitoring and maneuvering the vessel which is arguably the reason why the radar, ECDIS and maneuvering controls are within reach from the same position. Thus, alerts that require the operator to move away will disturb this loop.

The following SA design principle(s) are covered by this interface element:

- G5 - Support trade-offs between bottom up and top down processing
- A5 - Minimize alert disruptions to ongoing activities
- A6 - Support the assessment and diagnosis of multiple alerts

Using the insights of postponing alerts from the design workshop, a button was implemented which is able to mute all active alerts from the whole bridge for five minutes. Worth noting is that this does not acknowledge the alerts, only mutes the sound of them. Acknowledging does have the same effect of turning off the sound but only for that one alert, requiring a longer sequence of actions in case there are several alerts active. Such a button would allow operators to disable their sound temporarily to solve another more prominent situation such as a close-quarters situation. Thus, when the prominent situation is over, there is a natural break-point between tasks which is a time more suited for handling interruptions [82, 83]. The button might also be beneficial outside of crucial situations, for example by providing an ability to read about active alerts without being exposed to blaring alert sounds.

Alert history

The following research insights are covered by this interface element:

- Both the ferry trip and the simulation sessions had active alerts going on in the main interfaces (ECDIS/radar) throughout the voyage. In the case of the ferry, these alerts were deemed unimportant, but for some reason, not acknowledged anyway. A possibility might have been to not lose their information, as happens if the alert is acknowledged and disappears, in case it would be necessary in an upcoming situation.

The following SA design principle(s) are covered by this interface element:

- G4 - Support global SA
- G7 - Use information filtering carefully

A large inspiration for the alert history how the observed DP system saved acknowledged alerts in a history that was accessible if needed. As SA is build up over time [1, p. 84], having access to already acknowledged alerts will likely improve global SA by providing an overview of past issues (supports G4). It will also provide an indirect filtering capability because acknowledged alerts are never lost but can be revisited.

4.4 Evaluating the design

Five experts with navigational background, all men currently working in Sweden, were involved in the evaluation. Each expert had at least 8 years of experience (with an average of 15.5 years) of actively working with navigation bridges. While they all shared experience of bridge systems, the types of vessels involved varied between tankers, offshore, pilot boats, ferries, cargo vessels, and bulk carriers, both in Swedish and international waters. Only two were still currently working on vessels. The majority of the experts also have experience in using and facilitating bridge simulators for educational purposes.

During the process of implementing each interface element, the prototype evolved into a semi-functional digital interface. To see the prototype used during the final evaluations, see section 5.2. All participants carried out the think-aloud first, followed by the interview. Each session lasting approximately one hour.

4.4.1 Think aloud protocol

An interactive prototype was used by all participants while the screen activity, as well as audio, was recorded. Both video and audio allowed the researcher to revisit the material to complement the findings from the session. The prototype was implemented in Figma[4] and displayed on a laptop. To interact, the participants used a wireless mouse. During the sessions, the researcher sat next to the participant, taking notes and reading tasks. The tasks given to participants were meant to force some kind of interaction with all the implemented features to provide a foundation of how they would affect SA. To see the complete list of tasks, see appendix A. The researcher was positioned next to the participant to be able to see the screen during interaction (see figure 4.9).

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[4] https://www.figma.com

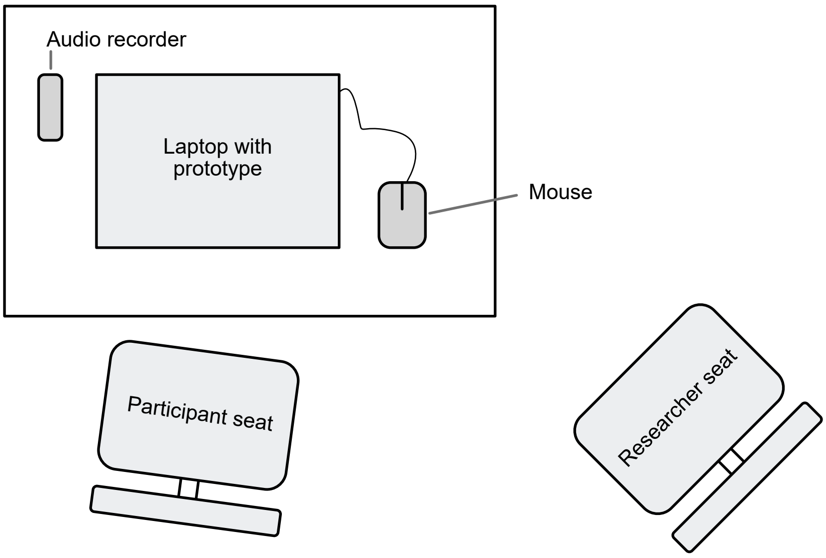


Figure 4.9: Illustration of the setup used during the think aloud protocol.

Before the session, the participants were instructed to verbally communicate their thoughts rather than what they do. To guide the interaction, participants were presented with different tasks that encapsulated the features of the prototype in various target rich scenarios. The first two tasks, revolving around configuring alert thresholds, were meant to also act as practise tasks for getting used to the think aloud protocol. During the session, written notes were taken and during observed critical incidents, as suggested by Hartson and Pyla, the participant was asked to clarify [69, p. 437].

4.4.2 Semi-structured evaluation interviews

Eight questions were asked revolving how the participants had experienced the implemented features of the prototype to affects their SA of the presented scenarios. Although some follow up questions were asked to clarify parts of answers, the focus was to cover the full set of prepared questions for all of the participants, as to (a) cover all the implemented features [84, p. 197], and, (b) get a foundation for comparing answers. During the interviews, the prototype was available to act as a boundary object [85, p. 149], allowing participants to go back to certain states, functioning similarly to an extension of the think aloud protocol [69, p. 469]. Having the prototype accessible during the interview aided participants in understanding the context of the questions as some features might have been foreign to what they usually have on a bridge. It also aided by clearing up potential misunderstandings that the participants had regarding the exact functions of features, which might have went unnoticed during the think aloud protocol.

The first six questions referred directly back to the context presented in the prototype, but the last two questions regarding integrated alert systems and the ability to mute alerts for five minutes were asked in a more hypothetical way, such as: *"how would this affect your situation on a bridge?"*. The reason for this is that these two concepts are broader than what could be implemented in the prototype. Thus, these two questions relied on the participant understanding the function, but extrapolated it into the understanding of bridges that they had built up after years of experience. To see the full set of questions, see appendix C.

4.4.3 Deductive thematic analysis

While the thematic analysis performed after the initial interviews were done in an inductive manner, the focus here was a deductive approach to tailor the expected results to align with the research question, as an inductive approach runs the risk of disconnecting answers from questions [59]. Following the six phases of thematic analysis presented by Clarke and Braun [59, 58], where this deductive approach differed most from the inductive approach was during the creation of codes. The codes in this iteration of thematic analysis were focused on SA which, together with the questions covering each feature, provided insights into how each interface element related to each of the three levels of SA. Similarly to the previous thematic analysis, one interview was coded by two separate researchers to reach an agreement on the codes to be used for the remaining data. The remaining data was coded by one researcher, but new codes were discussed and potential corrections were carried out.

5

Results & Analysis

Following, the results from the whole thesis will be divided into three parts, the first part covering the methods up until the final evaluation, the second will present the final concept and the third will present results from the final evaluation.

5.1 Process results

In this section, results will be presented from all methods including external users up until the final evaluation.

5.1.1 Simulator and ferry bridge observations

The following results are from observations of target rich environments in a simulator and a ferry (see section 4.1.2.1 and 4.1.2.2). When monitoring the situation around the vessel, the most commonly used systems were the radar, the ECDIS and looking out of the windows. The redundant nature of on-bridge equipment allows duplicate systems to be configured to differ in what information they display, for example by enabling AIS information on one but not the other radar, which is often done when configuring systems prior to departure.

AIS stands for Automatic Identification System, which are communication exchanges between vessels usually found in their ECDIS systems. The information that is communicated is, among other things, the name of a vessel and a customizable alias. This information was found to serve two functions, (a) the ability to call the name directly on the radio channel that is shared by all surrounding vessels, and (b) allow the bridge crew to have a shared understanding of what vessel they were talking about. Modern bridges are often capable of integrating this information into the radar. During two simulation sessions, AIS was active on both radars. During the third simulation session, one radar had AIS turned off, while the other had it activated. The AIS provides the radar with names of the different vessels.

Regarding customizing settings of on-bridge systems, time intervals for vectors differed between the two radars in all sessions. It was found in interviews with SMEs that vectors are commonly used as decision support because of their ability to predict future locations of surrounding vessels (see section 5.1.3.1). Vectors are visualizations produced by the radar and often activated for vessels which might be of interest to the operators. Their predictions are based on the current speed and heading of a surrounding vessel, which are visualized by a straight line. The length of the line depends on how many minutes the operator wants the vectors to predict, and, as was observed, is often changed by the operator. One example is from one of the simulation sessions where the operator discovered through the radar that another ship is heading straight towards their own route. The operator adjusted time intervals from 6 minutes to 12, and saw that given the own ships greater speed, the other vessel would be passed before it was able to cross the route and thus not risking a close-quarter situation. The displayed range generally differed between the two radars as well. One radar was commonly used to operate on a lower distance and thus higher fidelity, while the other was set on a greater distance. However, there was a tendency on the ferry to run both radars on a higher range to a greater extent compared to the the scenarios in the simulations. It is worth noting that the simulation sessions were specifically done in target rich environments while operators on the ferry did express that the current trips were rather poor in surrounding vessels. Although relying on a greater radar range most of the time, operators did change it in some situations, for example closer to port. Time intervals for vectors of surrounding vessels, however, were changed more regularly. During the voyage, important events, irregularities, and scheduled checkups were, usually by the helmsman, written down in a logbook.

The majority of the time spent, both by the ferry crew and by the students in simulations, was dictated towards monitoring the surrounding vessels using the radar, ECDIS and lookout. Maneuvers were always done in relation to the surrounding traffic in a manner that was as proactive as the situation allowed. Identifying targets was found to mainly be done in one of two ways, although in all cases the operators varied their gaze mainly between the radar, the ECDIS-system, the windows and the compass. In some cases, if the radars range was set at a closer range, vessels were first identified by visual sight through the windows. Most commonly though, a vessel was identified on the radar before looking for it through the bridge window to confirm.

Regarding alerts, thresholds for alerts were not adjusted prior to departure in the simulation sessions. Thus, the standard thresholds were used, which produced several alerts during all three simulation sessions. These alerts were however never attended to by any of the operators. One contributing factor might have been that the sounds for all alerts were disabled by default and thus not disturbing the operators as much. Another reason might have been the fact that this was a simulation session part of a curriculum, which in itself presents to possible factors for the lacking management of alerts. Firstly, although the sessions were opportunities for students to display their knowledge, active management of alarms was not required for students to get their grade. Secondly, the fact that the scenarios played out in a simulator might have made students more relaxed, especially regarding tasks which were not important for getting their grade. On board the ferry, however, the crew spent more time preparing and adjusting the thresholds for navigation alarms, but this did not lead to voyages free of alerts even though no close situations were encountered. During the ferry observations, two categories of alerts could be differentiated. One category include alerts from systems outside of the commonly used navigation systems of radar and ECDIS. During one instance, an alert caused the whole bridge crew to look for the cause. The alert was hard for the crew to locate, even though it originated from a panel located at the back of the bridge.

Eventually, the source was found and the alert was silenced using the panel. The same alert re-appeared numerous times during the voyages, but now that the source was known, one of the crew members walked to the panel to silence it each time. The other category of alerts include those that specifically originate in the radar and ECDIS. While many of these alerts were acknowledged when appearing, it did occur that some were harder to interpret. For example during one occasion, one ECDIS produced an alert which required the operator to look at the radar before understanding fully what it meant. Both these examples imply that better support needs to be provided regarding the cause and type of error.

Similarly to the simulation sessions, the ferry did have a number of active alerts throughout the voyage that were unacknowledged. The main difference was that the students in the simulation sessions did not attend alerts at all, while on the ferry, alerts that were seen as crucial were acknowledged and those that were deemed unimportant were left unattended.

5.1.2 Hierarchical task analysis

The tasks observed during the observations were summarized in an HTA (see section 4.1.2.4), which is explained below.

Prior to the departure, a voyage plan is set up. This task was limited in the simulation sessions but the students did set up at plan months in advance, although their plans were not representative of how a real voyage plan would be set up. Thus, the tasks 1.1.1, 1.1.2, and 1.1.3, were filled out with results from interviews carried out with subject matter experts. Additionally, before the departure, relevant checklists were used in all three sessions to assure system operability. This involves checkups of equipment as well as configuring systems for the planned voyage although none of the operators configured thresholds of alerts at this point.

As seen during the observations, detection of a vessel often followed by manual targeting through the radar, and the vector of the vessel was activated. In some cases, the vectors provided enough information to decide if there is a risk of a close-quarters situation. In other cases, relevant information such as CPA and TCPA, as well as AIS information such as name and alias was looked at. Verbal communication might happen between the two officers at this point, either to notify or discuss some of the vessel-specific information. A decision is then taken regarding the appropriate course of action. If more information is needed, or the intention of the own vessel needs to be clear to the target, radio communication is established. After an action is carried out, the crew analyzes the result by continuing to monitor the traffic situation. This process is a constant loop of monitoring traffic, identifying risks, take actions and analyzing the result. A similar process of a typical collision avoidance task has been broken down and related to Endsley's three level model by Grech et al [28, p. 49]. They propose the following relationships between the tasks and levels of SA:

- 1. Perceive vessel(s) in the vicinity (Level-1)
- 2. Comprehend how the vessels relate to your own. Are the routes intersecting? Who is responsible of giving way? (Level-2 and Level-3)

- 3. Act to avoid a potential collision.
- 4. Monitor the effect of the action.

5.1.3 Thematic analysis of SME interviews

The following results are from the semi-structured interviews with three SMEs (see section 4.2.1). Following the six phases of thematic analysis presented by Braun and Clarke [58], five interconnected themes emerged from the data, with various sub-themes (see figure 5.3).

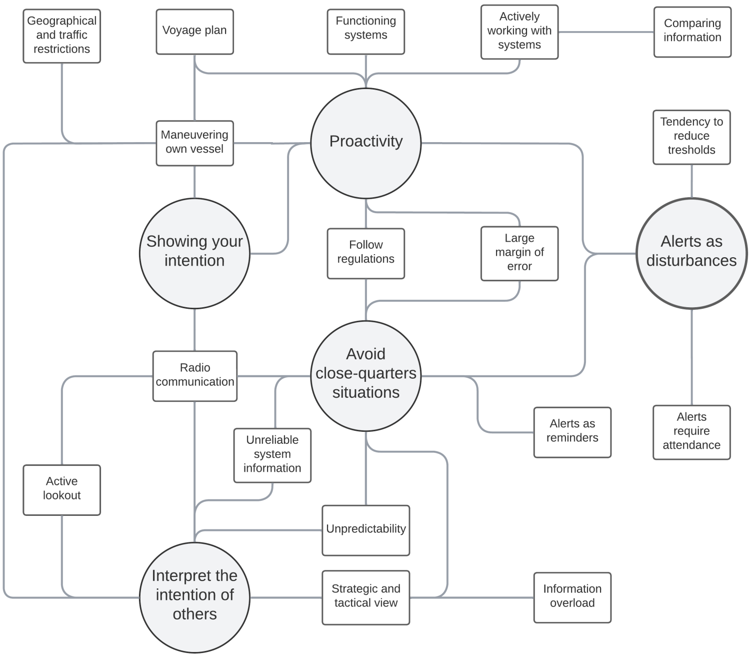


Figure 5.3: The themes and sub-themes found during the thematic analysis of initial SME interviews

5.1.3.1 Proactivity

Proactivity was a core theme which was interconnected to many others. Much of the work on a bridge is done in a proactive manner, from planning the voyage to maneuvering long in advance.

P1 ad P3 both argued that many situations can be solved by using the information from on-bridge systems, such as CPA and vectors, proactively. This will allow one to implement early maneuvers, which in turn feeds proactive data into the on-board systems on surrounding vessels. P3 further added that these early maneuvers, because of their proactive execution, can be more subtle. For example, the direct impact on the traffic situation by yawing 5 degrees will be negligible but will increase as a result of simply letting time pass. Nonetheless, P2 argued that these proactive decisions are crucial from a safety-perspective. For example, waiting with establishing radio contact with a target in hopes that the situation resolves itself might seem reasonable in some cases, but if the situation gets worse, there might

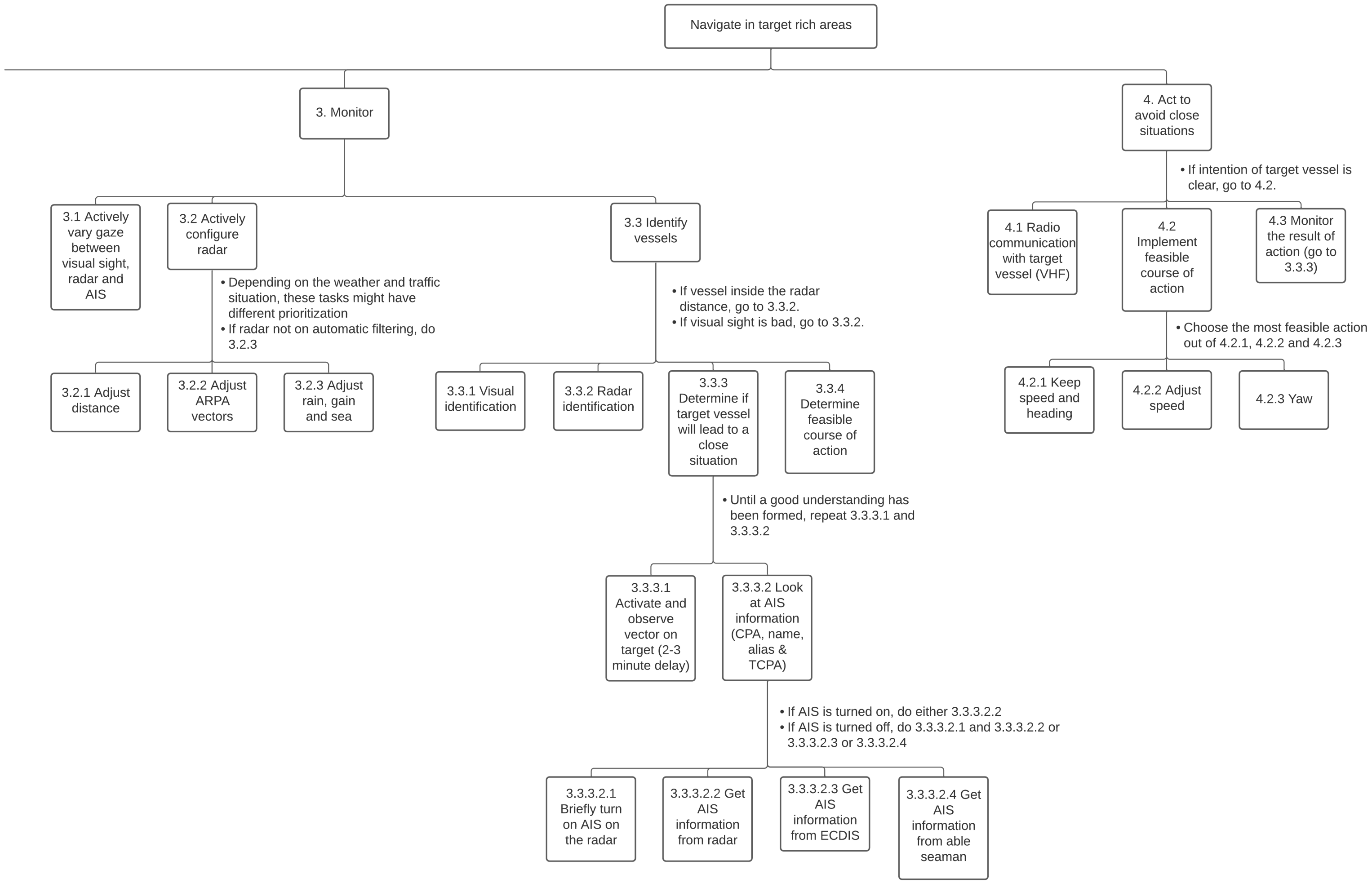


Figure 5.1: Hierarchical Task analysis over the tasks involved when navigating a target rich environment, part 2.

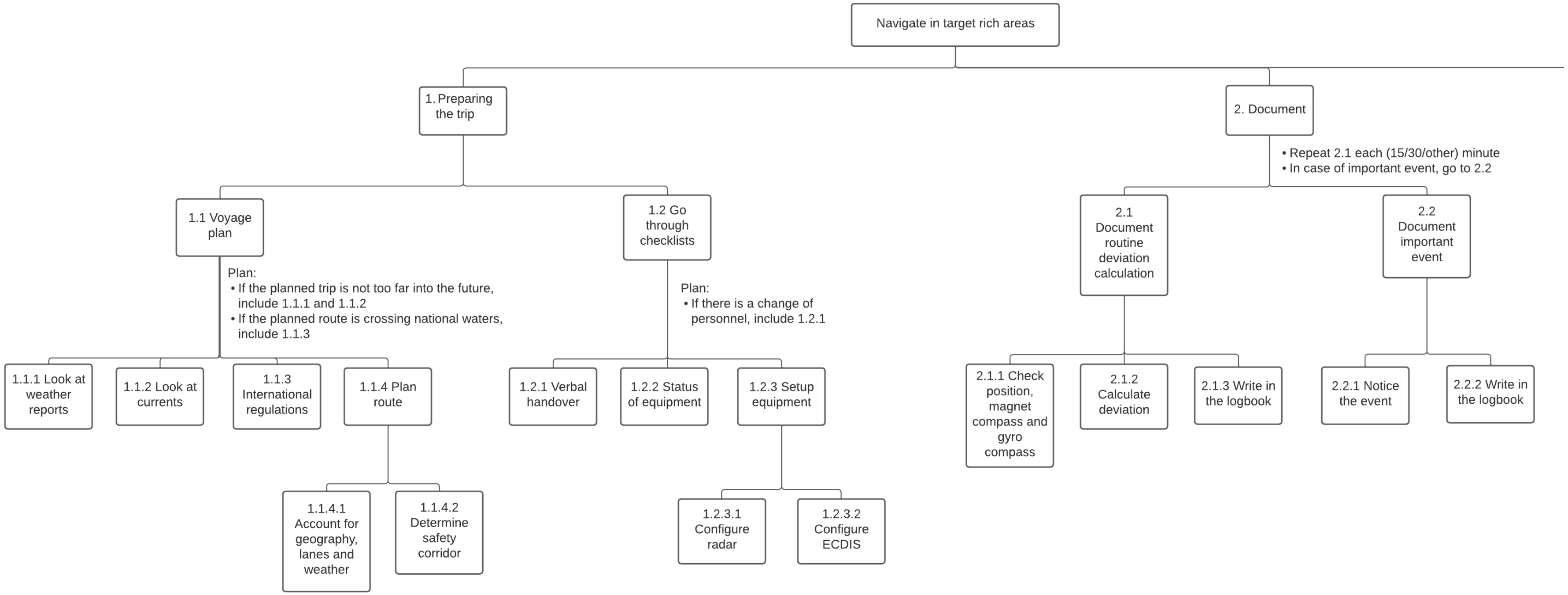


Figure 5.2: Hierarchical Task analysis over the tasks involved when navigating a target rich environment, part 1.

not be any guarantees that radio contact can even be established. Thus, it is better to proactively seek contact, and if that fails, there will be a larger set of options to resolve the situation compared to the options at a later stage.

The voyage plan consists out of several different elements, such as weather reports, applying for permissions for certain zones, and points of interest. It also involves a planned route, which was defined by P2 as *"the most effective way of reaching point B [the destination]"* together with a predetermined corridor for navigation, which was expanded upon by P2: *"You input a certain collateral distance for your route, which is how far sideways from your predetermined route you are allowed to travel"*. The systems are then capable of notifying the operator if that distance is breached, making it an important type of alert. Regarding the importance of the voyage plan, P2 expressed it in the following way: *"The plan is also, from a safety perspective, very important for navigation because it allows us, already ahead [of departure], to know that if we follow it, we will avoid geographic obstacles. We also know what will happen and approximately when to take contact [with coastal stations or docks]"*. Thus, the voyage plan is an important part of the proactive work carried out by a bridge crew by providing predictability. As expressed by P3, this is not necessarily because the plan is set in stone because the plan is, as P1 expressed, subject to change during the voyage. The reason for the importance of the voyage plan is first and foremost safety and predictability because following it "assures that there will be no geographical hindrances, and we will also know what will happen as well as when we need to take contact [with coastal stations]", as expressed by P2. P3 also added that *"You don't need to slavishly be on the red line [planned route], but you should at least go in the same direction so that you don't deviate"*. As already implied, the voyage plan cant account for everything, such as traffic situations, but it allows the operators to have a foundation for many of their decisions during the voyage.

5.1.3.2 Avoid close-quarters situations

Safety in target rich areas was defined by P3 as *"...to feel that I have a margin, enough margin, in the mutual encounter between different vessels to allow enough freedom of movement without exposing the other vessel to an unnecessary risk"*. While collision course refers to the situation of the routes of two vessels overlapping such that there will be a high risk of collision, *"close situations"* can be seen as a buffer for this, a buffer that is often represented by the CPA-alert. P1 preferred it in general to be more than 1NM, while P3 preferred it to be more than 3NM although this is prone to differ depending on geographical restrictions, such as open sea versus a canal, as well as how heavy the traffic is. The heavier the traffic and the narrower the pathway is, the smaller the buffer zone must be.

P2 expressed using all the systems provided on a navigation bridge to the best of your capabilities to be important for the safety of the operation. One voyage can span over large areas, meaning that situations with larger restrictions can come and go, in turn changing what distance would be appropriate to other vessels. This does require the crew to be dynamic, and configure their systems after the situation ahead. While this is often done with the radar by increasing or decreasing the range of what is shown (tactical & strategic view), the configurations of alerts is risked to be left untouched (see section 5.1.3.4).

Similarly to what was found during the observation sessions, during the interviews, all three participants raised the importance of changing system parameters. P3 used the terms of "strategic view" and "tactical view", the former provided by a *"radar set to a range of 12 nautical miles to see what happens further down the route"* and the latter provided by the other radar which is set on *"3-6 nautical miles around you where you need more tactical actions to, for example, hold a good distance for passage"*. P3 expressed: *"In a target rich areas... It doesn't have to be just one vessel, it can be several that interact in different ways. You first have to build a strategic picture of how this situation might evolve, and then you build the tactical. The strategic view is built you can build from further away before reaching any sort of close quarter situation. You try to get information about the vessel, what's the speed, how close will we be if I keep my current course and speed and how much room do I have to make corrections?"*. This divide between a tactical and strategic view shows the relationships between proactivity and avoiding close quarters situations where information ahead will benefit potential future encounters. P1 expressed the importance of adjusting the range of the radar dynamically dependent on the situation, especially in weather conditions where the visual sight is diminished. Furthermore, the importance of adjusting range also covers the ECDIS-system. P1 expressed that *"if you have set a long range on the electronic navigational chart then you can miss small areas of shallow water"*.

These situations where there is greater distance to other vessels are also relevant for alerts. P3 explained that in areas that are less prone to traffic, the bridge crew might diverge their focus to administrative tasks and in these situations, alerts catches the attention of the crew to check their navigational equipment. P3 also mentioned bridge navigational watch alarm systems which works as a safety net by alerting crew off the bridge if the operators have been inactive for too long.

5.1.3.3 Show your intention and interpreting the intention of others

The themes of showing intention and interpreting the intention of other vessels can be seen as two sides of the same coin. P3 stated that *"showing your intention by acting early aids the flow of traffic"*, meaning that communicating an intention can, and often is, done through maneuvers alone. Maneuvers are then expressed in the on-board systems of other vessels, which gives gives them plenty of time to react on the basis of your action. The intentions of others can be interpreted in the same way, by monitoring the on-board systems and, although this is not always enough, or as P1 expressed it; *"...sometimes you can easily interpret how a vessel has planned its route, for example passing a certain buoy and then turning. Those situations you can interpret yourself, but its not fully certain that it will be correct"*. In moments where intentions are unclear, P2 expressed that "communication is a password for most things". P2 further provided an example: *"Say that you have got hold of a vessel [through radio communication] that you've come into a close-quarters situation with. In this case, you should keep it short and informative, both what your intention is, if you plan to hold your bearing, or yaw, or what you plan to do in your situation, but also ask what they are planning to do"*. P1 mentioned a similar situation that might occur in restricted areas; overtaking another vessel. Some of these situations require vessels to be rather close to each other in which radio communication becomes crucial. To ease radio communication, AIS information is used to read the name of a target before calling their name out on the area-shared VHF-channel. The AIS information provides the ability to directly call a name instead of a position, in turn aiding communication in target rich areas.

Interpreting the intention was expressed to be harder of some vessels, for example fishing boats as mentioned by P3, given their ability to maneuver faster than larger vessels, making them unpredictable. P1 expressed that in situations where these smaller vessels are present, an over-reliance on the ECDIS becomes problematic, partly because the inherent delay of the system but also because smaller vessels seldom broadcast their own AIS information, in turn making radio communication with them troublesome.

5.1.3.4 Alerts as disturbances

Alerts come in several forms and can originate from various on-bridge systems. Alerts themselves are meant to be proactive means of raising awareness towards a developing situation, but the actual handling of alerts also has a proactive aspect to it, namely by adjusting thresholds for activation. While adjustments of thresholds are likely meant to provide an ability to tailor alerts to various contexts throughout a voyage, the values are sometimes set so low that realistically, the alert would rarely activate. One example of this was expressed by P3 in relation to the radar-bound CPA-alert; *"Some [operators] reduce the threshold to 0.1 nautical miles, which is more or less 180 meters, which is very near, but some have 0.3, others maybe around 0.5. There you have a... it is flashing red. It's a trigger point letting you know that you have something very close. Many [operators] thinks it [the flashing] is disturbing and therefore reduces [the threshold]"*. The tendency to turn off some alerts was also expressed by P1 and P2. P1 shared: *"I have worked on merchant vessels and we used to almost turn off all alerts because otherwise there are so many elements of irritation on the bridge and you have to run and resolve alerts all the time"*, indicating that alerts not only cause irritation by their presence but also causes disturbances because they require active action by operators. P3 expressed a similar concern over alerts: *"The radar beeps, ECDIS beeps, there are beeps almost all over and you have to resolve these alerts, making them a bit disturbing and removing some of the focus you have on the things out there because you have to accept or resolve these alerts"*. P1 also mentions decision making in relation to alerts: *"It is very irritating to make decisions and people don't really hear because alerts are playing. Then you go over there to reset [the alert], but then it [the alert] comes back because the problem still exists"*.

Although some alerts are required to be turned on by regulations, such as those originating from the ECDIS-system regarding moving outside of the safety corridor, P2 (63) expressed a tendency to turn off radar alerts, such as for CPA, in traffic heavy areas; *"The problem for us that tend to navigate close to coasts and in traffic heavy areas, we can't go with alerts on because they activate all the time, causing them to lose their effect"*. What is interesting is the notion that alerts in abundance "lose their effect". The exact meaning of "effect" is not obvious, however if it refers to the ability of raising awareness about something unknown to the operator, which is arguably the purpose of alerts in the first place, then the notion of "losing effect" not only refers to each single alert just being part of a sea of disturbances, but it also hints towards alerts carrying superfluous information. A connection between superfluous information and disturbances of alerts was expressed two participants. In an example of a chaotic situation, P1 mentioned: *"You already know that everything is falling apart, they don't need to notify me. I know where I am and that is very stressful"*. P3 brought up an example of a close-quarters situation where both vessels have been aware of each other for some time but the situation requires for them to go closer than the threshold for the CPA-alert is set to, upon which P3 adds: *"And then the alert goes off, and becomes red until I do something. In that case, I am already there and I'm already aware of the situation"*. P3 also explained another situation where passing by a port activates collision avoidance alerts for docked vessels, *"It [an alert] can be perceived as disturbing in heavy trafficked areas, for example if you pass by a port, the alerts will activate for a vessel that is docked. You are not going to hit a docked vessel, but the system still alerts you"*.

5.1.4 Goal-Directed Task Analysis (GDTA)

The following results are from the GDTA based on the interviews with three SMEs (see section 4.2.2). While the numbering of tasks in an HTA represents a sequence of actions, the numbering of goals in a GDTA is for reference only [1].

The goal of monitoring involved gathering sufficient information to understand if an action is required (see 5.5). Sub-goals here involve predicting intentions and assessing the current situation by identifying vessels, alerts and various factors affecting the own route. The goal of acting is adjust according to the current situation, which can be in response to a developing situation or proactive maneuvers (see figure 5.6). The goal of communication is mostly using radio to clear up intentions that were not picked up through monitoring (see figure 5.7). Breaking down the goals for alerts specifically, two sub-goals can be found under the goal of assessing the situation; understand the cause (goal 1.1.6) and understand the type (goal 1.1.7). A third sub-goal can be found under the goal of acting; resolve alerts (goal 2.4) which builds on a thorough understanding of the type and cause together with comprehension of how the alert relates to the assessment of the whole traffic situation, the voyage plan, and predicted target intentions.

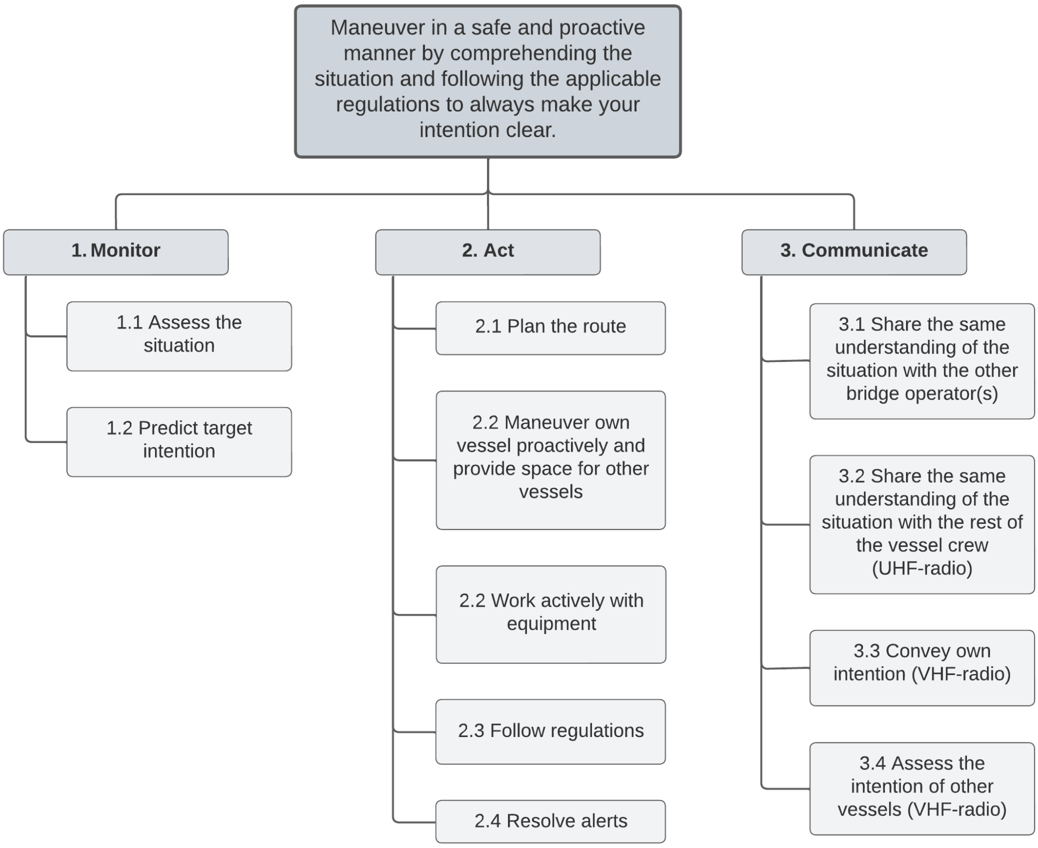


Figure 5.4: Main goal and sub-goals of the finalized Goal-Directed Task Analysis (GDTA)

5.1.4.1 Level-1 SA requirements

Level-1 SA requirements, i.e. perception, in target rich environments entail perceiving the status of the own vessel and its equipment, relevant objects in the surrounding traffic, the voyage plan, current weather conditions, as well as, separate between alert cause and their type (see table 5.1). It is worth noting that the alert specific requirements are identifying cause and type, which might seem to be the same as the sub-goals of understanding cause and type. However, Level-1 SA requirements refers to perceiving information, which in some cases is enough to understand the cause and type, but to fully understand what an alert means in more complex situations, comprehending relationships (Level-2 SA) is often also required. Thus, the goals of understanding type and cause will in some situations require more SA support than just noticeable elements.

5.1.4.2 Level-2 SA requirements

Level-2 SA requirements, i.e comprehension, in a target rich environment involve the need to understand various types of relationships (see table 5.2). Navigators need to comprehend how objects relate to each other as well as to relevant regulations

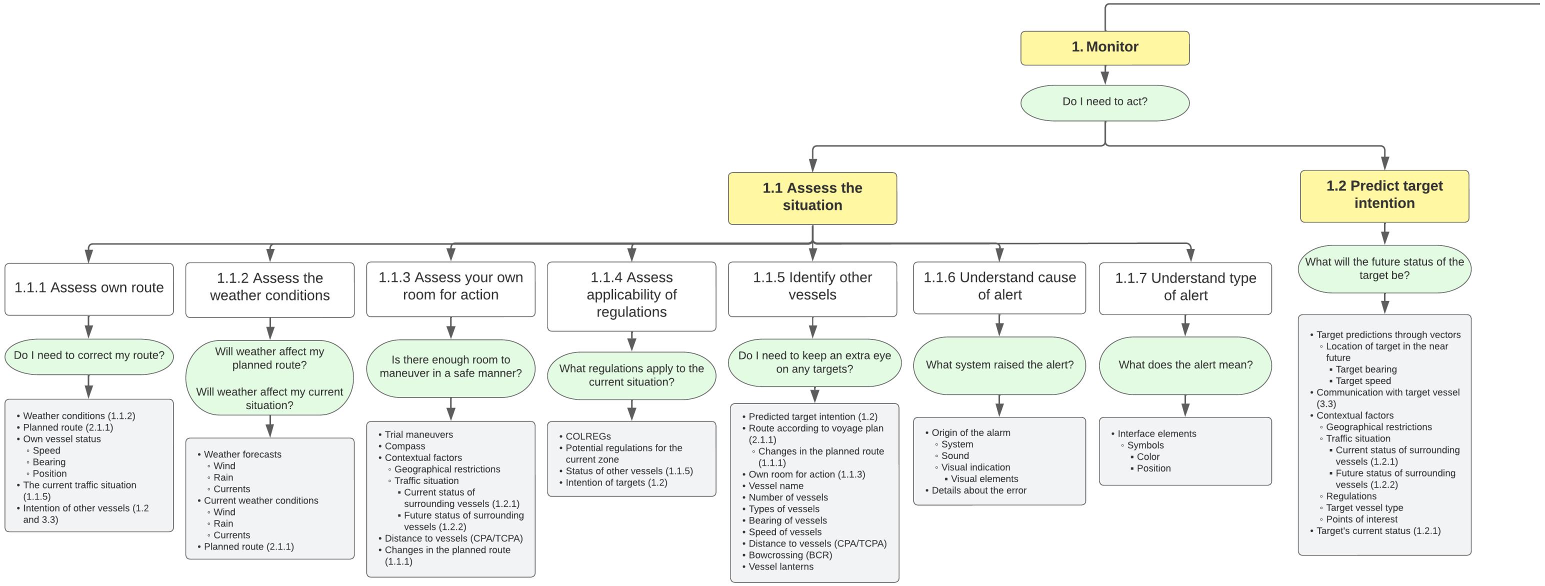


Figure 5.5: Subgoals of monitoring broken down into decisions and supporting information.

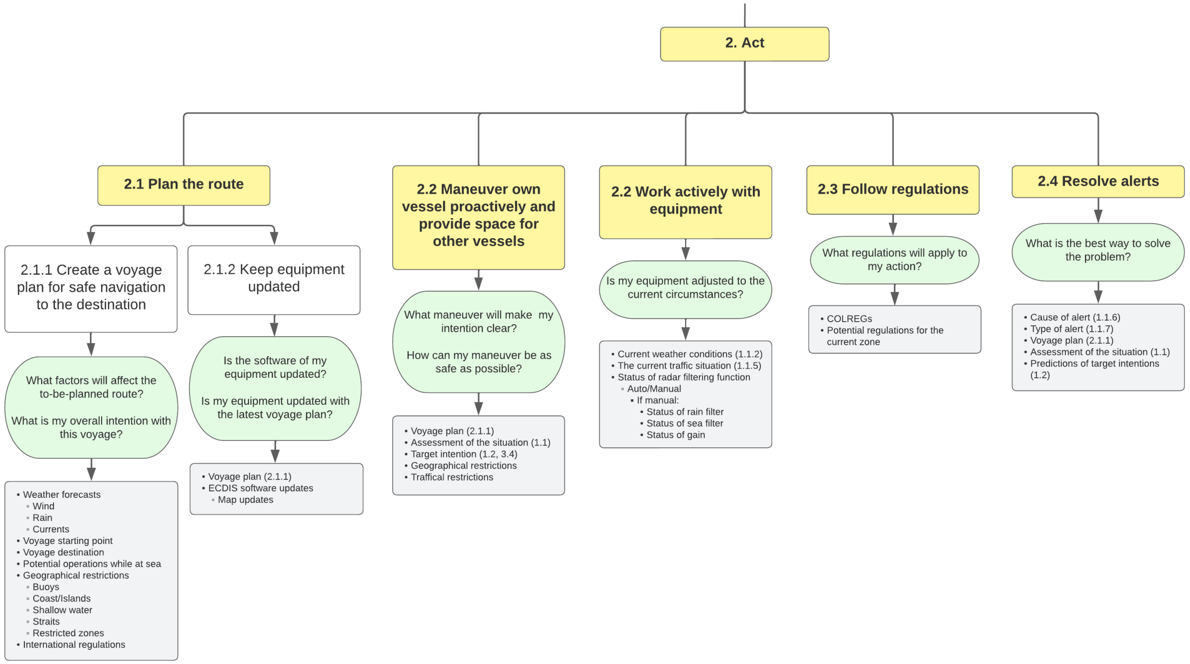


Figure 5.6: Subgoals of acting broken down into decisions and supporting information.

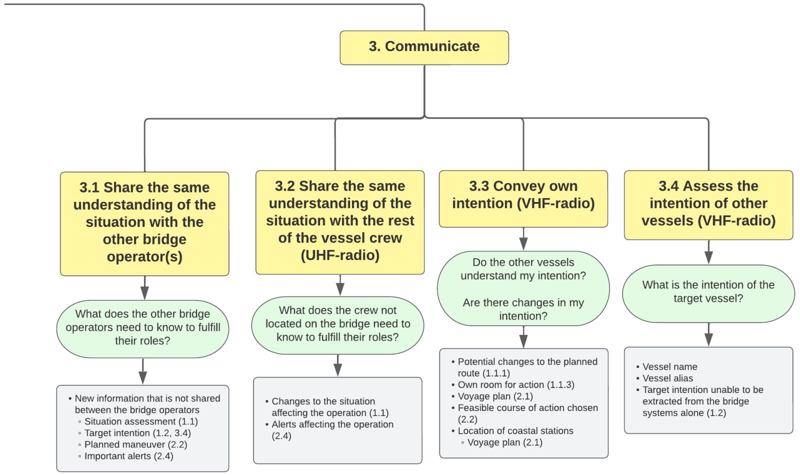


Figure 5.7: Subgoals of communicating broken down into decisions and supporting information.

Table 5.1: Level-1 SA requirements for navigators in a target rich environment

Own vessel status

- Speed
- Bearing
- Position
- Distance to vessel

On-bridge equipment

- Available software updates
- Operational status of systems
- Configuration of systems
- Configuration of alerts

The current traffic situation

- Number of vessels
- Types of vessels
- Bearing of vessels
- Speed of vessels
- Name of vessels
- Alias of vessels
- Type of operation carried out by vessels

Voyage plan

- Voyage starting point
- Voyage destination
- Planned route
- Potentially planned operation at sea
- Points of interest
- Points of radio contact
- International regulations

Alerts

- Cause of alert
- Type of alert

Current weather conditions

- Wind
- Precipitation
- Currents

in the current traffic situation, which also extends to the own vessel. Furthermore, operators need to understand how alerts affects the safety of the own vessel, what implications they have on the traffic situation as well as the voyage plan.

5.1.4.3 Level-3 SA requirements

Level-3 SA requirements, i.e. projections, in a target rich environment involves a need for predicting several types of information types, such as intentions of other vessels, position of own vessel and weather conditions (see table 5.3).

5.1.5 Technology analysis

The following results are from the technology analysis carried out during the activity of producing design solutions (see section 4.3.1).

Polaris radars from 2005 have their radar alerts in the top left corner [86, p. 16]. Click and hold the "SYSTEM ALARM" button to acknowledge AND read a short description of the cause. Losing tracked targets also has an alert, which can be acknowledged by pressing the "LOST TARGET" or "CEASE TRACK" buttons. On the radar screen, a diamond symbol will flash where the target was lost. When the system is set to automatically acquire new targets, each new target will produce

Table 5.2: Level-2 SA requirements for navigators in a target rich environment

Traffic situation

- Speed of vessels in relation to each other
- Bearing of vessels in relation to each other
- Distance of vessels in relation to each other
- Vessels in relation to contextual restrictions

Regulations and safety

- Target vessel location in relation to regulations

Alerts

- Alert in relation to own vessel status
- Alert in relation to the traffic situation
- Alert in relation to voyage plan

Own vessel

- Own vessel in relation to the traffic situation
- Own vessel in relation to the voyage plan
- Own vessel in relation to contextual restrictions

Table 5.3: Level-3 SA requirements for navigators in a target rich environment

Intention of other vessels

- Projected position of other vessels
- Projected bearing of other vessels
- Projected distance of other vessels
- Projected operations of other vessels

Own vessel

- Projected position of own vessel

Projected weather conditions

- Projected wind
- Projected precipitation
- Currents

an alert by making the "NEW TARGET" button flash. Acknowledge this alert by pressing the button. CPA-TCPA collision warnings makes the button "COLLISION WARNING" start flashing, which can be acknowledged by pressing the button

Instead of displaying on one short description of each alert, radars of the FURUNO brand implements an alert window that displays all currently active alerts accompanied by short descriptions [87, p. 61]. The Kelvin Hughes brand additionally allows all audible alerts to be muted with the click of a button [88, p. 1.23], although it doesn't provide an alert window for all active alerts. All three brands allow the operator to customize thresholds for CPA alerts.

Dynamic positioning (DP) is an automated system that uses GPS-signals to keep the vessel in a fixed position, making it crucial for offshore vessels to counter the conditions at sea when close to fixed facilities [79]. Controlling the DP system is often done through an interface on the bridge where the operator is able to adjust settings, monitor the status, maneuver and respond to alerts [79]. The range of tasks possible using the system puts a large demand on the interface to intuitively present its various functions and information types but also to aid navigation between them.

During the observations of a DP-simulation, the Kongsberg K-Pos DP-21/22 system was used (see section 4.1.1.1). Alerts in this system used a similar form of notification as was presented for the Polaris radar, a flashing icon which needs to be acknowledged by the operator. Similarly to the Furuno brand, an alert window is also implemented, displaying all active alerts. However, the implementation of the alert window in the DP-system provided two advantages. First, it stores historical data of all messages including time stamps, allowing an operator to go back to an alert if needed. Secondly, and more importantly, it gives the ability to expand each alert to read details about why the alert was issued, what possible consequences might be, as well as a corrective action. During the observed simulation session it was found that alerts leading to non-functional, or sub-optimal DP performance required participants to suddenly shift from a more relaxed state of monitoring to a focused mindset of identifying and solving the problem. The ability to expand alert messages to read their description was a feature that was used frequently in these situations.

There has been proposals to improve the current alert functions of radar systems. Du et al. proposed an alert system for collision avoidance in give way situations by internalizing estimations of target intention, relevant COLREG regulations and the development of the situation [47]. This allows the alert system to act as decision support for when actions are required and when they are permitted according to COLREG regulations [47]. Another proposal is to include target bearing in addition to CPA and TCPA when calculating risk for collisions, allowing the alert system to be more precise in its predictions [89]. There have also been proposals for improving on-bridge alert interfaces outside of the radar, such as implementing voice recognition to reduce interrupting ongoing actions [90].

5.1.6 Workshop

The results of the design workshop with four Interaction Design master students will be presented below (see section 4.3.2.1). Affinity diagramming was used to find common themes [51, 81, p. 17] from the creative matrix and notes were summarized for each idea presented during the solution sketch.

5.1.6.1 Creative matrix

Affinity diagramming showed several emerging themes from the topic of reducing the distracting properties of alerts. Various types of properties were mentioned. One theme revolved around properties differentiating between categories of alerts. Different types of sound can be used to separate alerts either based on severity or category where subtle sounds can be used for less crucial alerts. Alerts that require immediate attention, require sounds that are (a) more distinct, and (b), loud enough to be noticeable. Colors can also assist by reserving red or orange for more crucial alerts. One point that was raised here is the use of color on active interface elements to notify which object raised what type of alert. A second theme was regarding reducing cognitive load by presenting less information in contexts that are already high in workload. A third theme was temporality. Sounds and strobing light can be adjusted in frequency and intensity to control the perceptual load presented to the operator. For example, alerts that are less crucial could use a slower strobing or a lower volume which could increase in intensity the longer the alert is unattended. Several suggestions were also made regarding compilations of alerts of lower severity which could be accessed on demand. Locations of alerts in a graphical interface, which was a fourth theme, revolved around placing notifications and alert-specific elements at the edges of the interface or around the physical screen. Other topics were also raised, such as remote control, accessibility and haptic feedback.

5.1.6.2 Solution sketch

Based on the ideas presented during the creative matrix, each participant used their individual section of the digital work space to draw a more fleshed out concept.

Solution 1: Alerts popping up but minimizes after a few seconds until it can be acknowledged. A list of alerts stored in a side panel that can be expanded to display the type of alerts, as well as allowing operators to acknowledge the alert. Color as well as sound of the popped up alert are matched after the severity of the alert.

Solution 2: Alerts are stored in the corner of the display. Symbols are used to communicate the type of alert as well as its severity. Combination of color, sound, and symbol are used to provide a higher level of accessibility when differentiating alerts. Interacting with the symbol allows the operator to read details of the alert. Hiding alert descriptions should be easy or their description should be located on a part of the interface that never hides important information on the screen. For example never be overlayed on top of the radar view but on the side.

Solution 3: Differentiates alerts according to their severity. Less crucial alerts use a notification system where short descriptions are provided. Red and orange is reserved for crucial alerts. Each alert requires acknowledgement from the operator before it can be hidden to make sure that the alert has been perceived. The interface can also use motion, by for example, replicating vibrations.

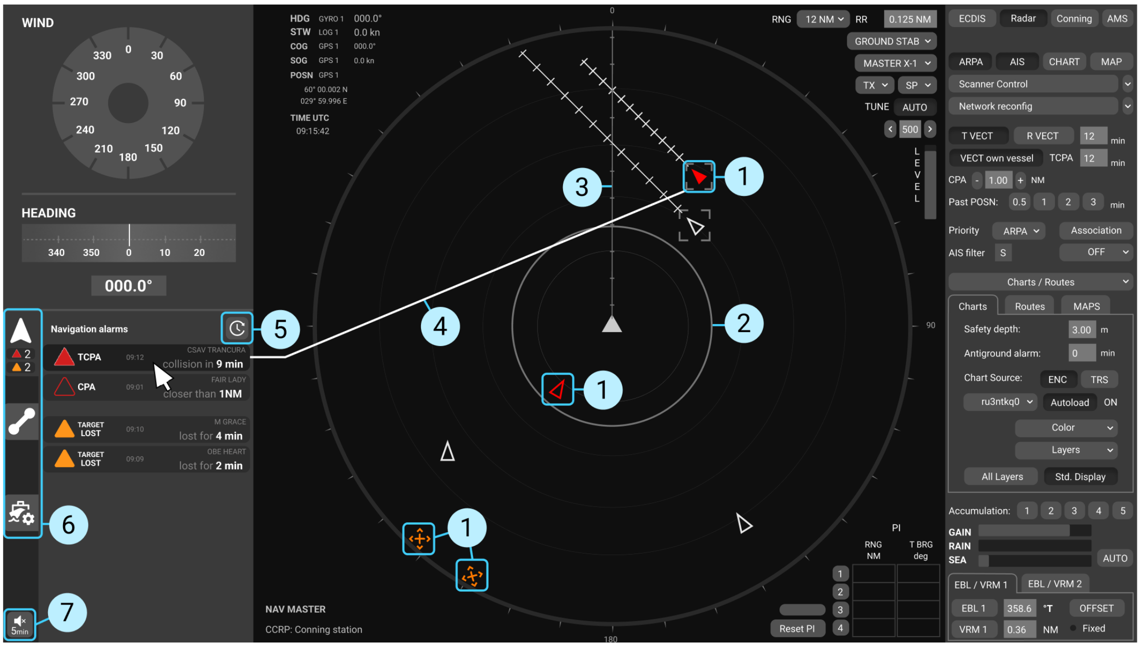
Solution 4: Colors and lights are used outside of the display, for example around the frame of the screen. The system uses sounds that are easily distinguishable to decrease the time it takes to learn their associations. Alerts are also stored inside an expandable list. Alerts are stored in a list that can be expanded when there is time for it.

5.1.6.3 Analysis

Differentiating alerts is important and several ways have been proposed such as symbols, sound, color and location. Information should be given regarding the descriptions of alerts but not hide information from the interface itself. This will allow the operator to (a) understand the reason of the alert and (b) assess its severity by seeing all contributing elements. This is highly relevant for collision alerts as they directly relate to elements displayed on the radar interface. It is also in line with already established regulations, such as Lloyd's register: *"The presentation and display of alarms and warnings is not to mask, obscure or degrade essential information* *displayed to aid navigational functions and maintain awareness of the navigational information"* [46, pp. 1662-1663]. Allowing the operator to see surrounding vessels while a collision alert activates provides the ability to understand what vessel cause the alert to activate and what maneuvers might be feasible. Although this is how some radar interfaces already works by separating the main view from alerts, which are often located in a side panel. This still requires operators to click on the alert to read its details and what caused it, forcing an extra step in the interaction. One solution might be to integrate relevant information into the active radar view. Some suggestions during the creative matrix did touch upon this, one example being the use of colors to highlight objects that raised an alert. In the context of a radar, in addition to always showing the radar-view even if an alert activates, surrounding vessels triggering collision avoidance alerts could be highlighted in a certain color. Two of the solution sketches dove deeper into the storage of already activated alerts. They both involved lists that were positioned at the side of the interface and could be expanded if there was need for it. This introduces two interesting aspects into the topic of handling alerts. Firstly, it is possible to expand the lists or their items to read more thorough information if there is need for it, which could decrease ambiguity of alerts. Secondly, it allows the operator to attend the alerts when there is time for it, allowing a sort of "postponing" in situations that require focus. Such a solution would be in accordance with the suggestion by Bailey et al. that interruptions are better suited during task breakpoints [82, 83] or when the workload is low [91], allowing the operator to finish up their main task before expanding the list of alerts.

5.2 Final concept

Following, the final prototype with the implemented interface elements will be presented. All interface implementations are shown in figure 5.8 except for the expanded alerts which can be seen in figure 5.12.



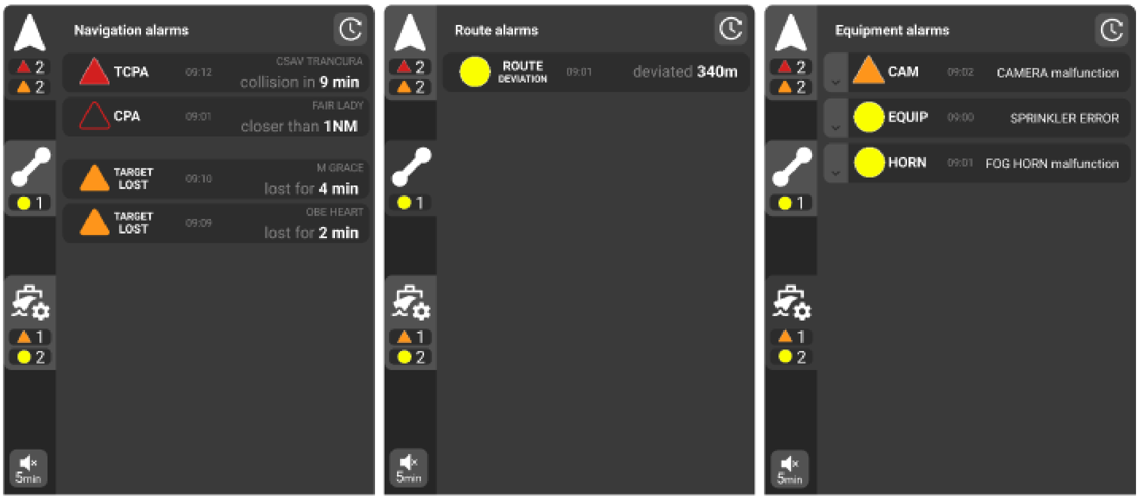
TCPA 09:12 CSAV TRANCURA collision in **9 min**

CPA 09:01 FAIR LADY closer than **1NM**

TARGET LOST 09:10 M GRACE lost for **4 min**

TARGET LOST 09:09 OBE HEART lost for **2 min**

Figure 5.8: A display of seven out of the eight interface elements implemented in the prototype. **1**: Alerts in the PPI. **2**: CPA theshold visualization. **3**: Vector for the own vessel. **4**: Contextual line. **5**: Alert history. **6**: Alert category tabs as a result of integrated bridge alerts. **7**: Muting alerts for 5 minutes.



TCPA 09:12 CSAV TRANCURA collision in **9 min**

CPA 09:01 FAIR LADY closer than **1NM**

TARGET LOST 09:10 M GRACE lost for **4 min**

TARGET LOST 09:09 OBE HEART lost for **2 min**

ROUTE DEVIATION 09:01 deviated **340m**

CAM 09:02 CAMERA malfunction

EQUIP 09:00 SPRINKLER ERROR

HORN 09:01 FOG HORN malfunction

Figure 5.9: Each section of the three categories of alerts; navigation alerts, route alerts and equipment alerts, which can be navigated to through the tabs.

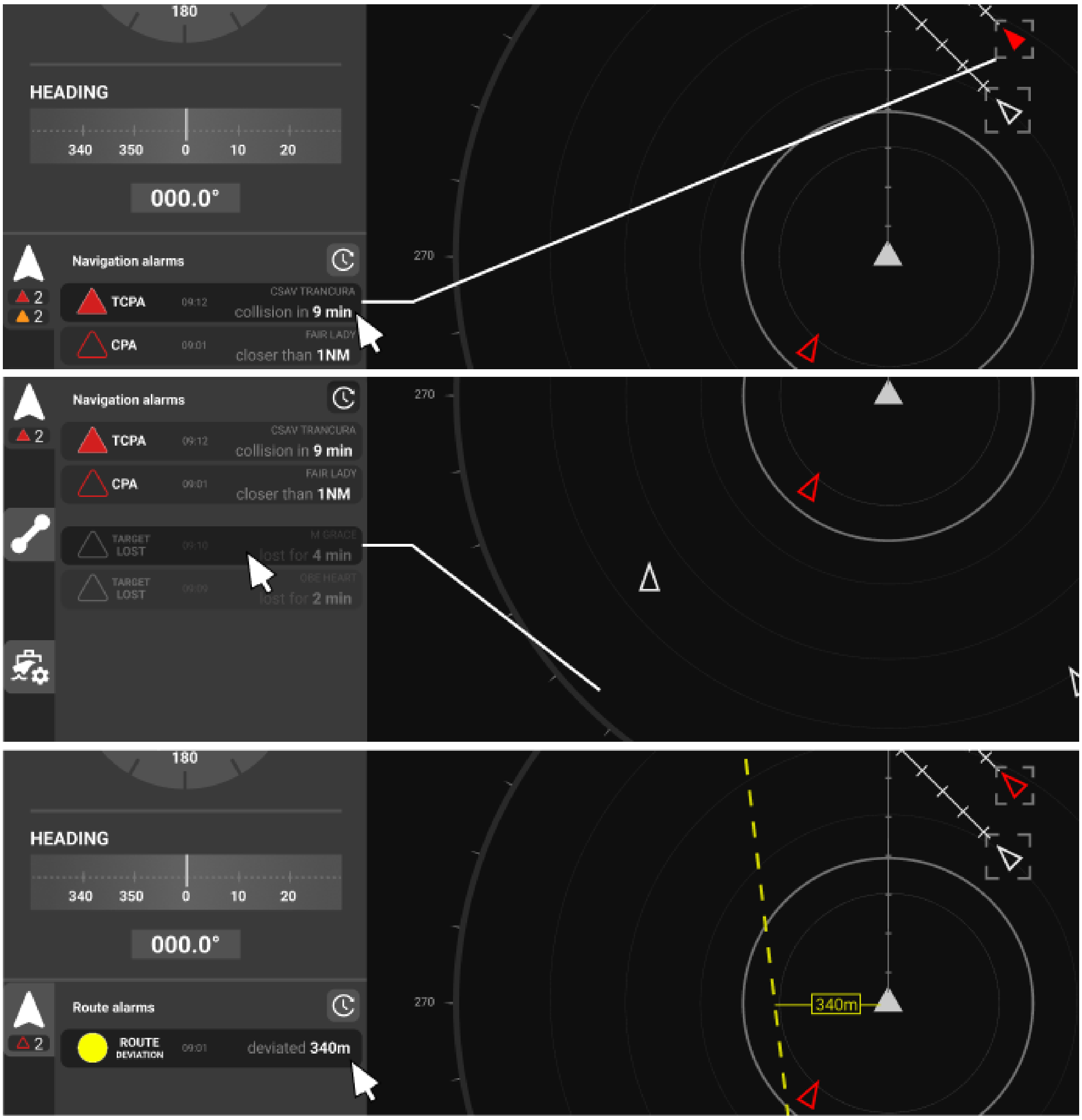


Figure 5.10: Three variations of contextualizing the alerts. Top shows alerts related to current surrounding vessels, middle shows contextualization of acknowledged lost targets, bottom shows an alert for deviating from an intended route.

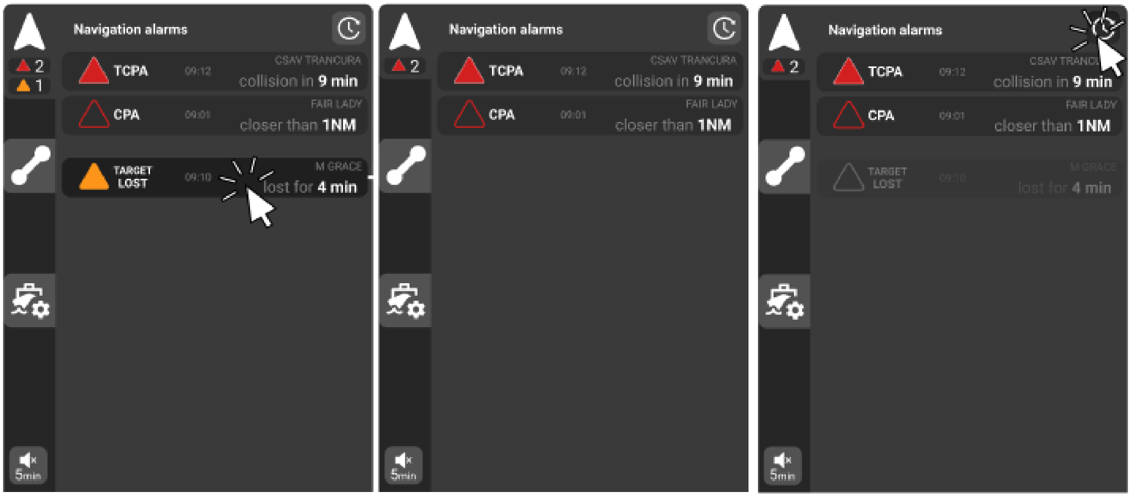


Figure 5.11: The interface element of an alert history. Left shows two active lost-target alerts, right shows after they have been acknowledged and moved to the history section.

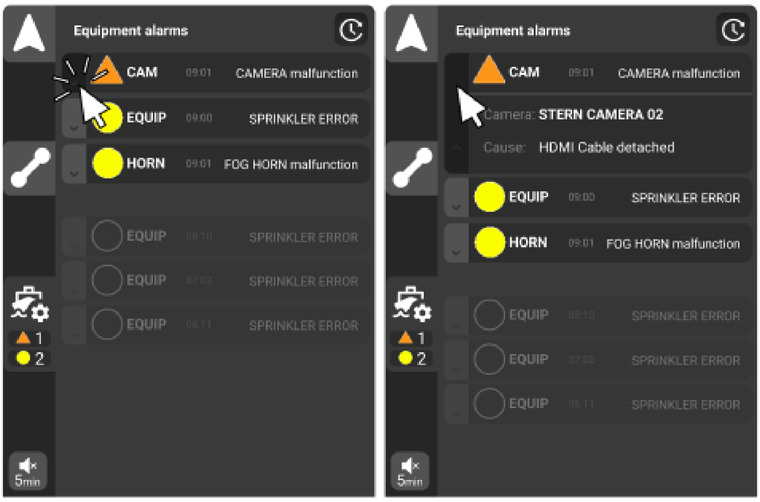


Figure 5.12: The interface element of an expanded description for equipment alerts.

5.3 Evaluation results

Following, the results from the final evaluations with five SMEs will be presented (see section 4.4), starting with the think-aloud protocol.

5.3.1 Think-aloud protocol results

The results from the think-aloud protocol with five SMEs will be presented below (see section 4.4.1)

5.3.1.1 Connecting the PPI to the alert list

Hovering over alerts in the list produced a connection between the alert and the vessel that caused it in the PPI. This caused participants to verbally confirm which types of alerts were caused by what vessels after seeing the contextual lines, indicating that there is support for Level-2 SA regarding displaying connections for navigation alerts.

Although, in one case, the participant already understood what types of alerts were caused by what vessels before hovering over the list. This indicates that the traffic situation presented in the prototype might have been too simple (i.e. too few alerts) to really showcase the potentials of the contextual lines when hovering over list items.

5.3.1.2 Alert history

When trying to find the button producing the alert history section for the first time, two of the participants spent 5-10 seconds before they found it while the other three found it within 5 seconds. However the second time they were tasked with browsing the history, all five participants would press the correct button within 2 seconds.

5.3.1.3 Acknowledging alerts and the PPI

A solid red color of the vessel on the PPI, together with a flashing icon consisting out of the same solid red on its related alert in the list, were both meant to indicate an active and unacknowledged alert. On the other hand, an object that consisted out of a red border on the PPI was meant to represent an acknowledged but still active alert. The same was true for its corresponding alert in the list where the icon was visualized with a red border and without flashing.

For one participant, it was unclear that the vessels in the PPI were interactable, but after hovering over one, the same contextual line was produced. Because this same line was produced as when hovering over alerts in the list, the participant expressed that in that case, it was probably possible to acknowledge alerts through clicking the vessels. The participant then sucessfully acknowledged all active alerts just through the PPI.

Furthermore, two participants tried to, through the alert list, acknowledge the CPA-alert which was already acknowledged, as indicated by the icon with a red border rather than solid and flashing.

5.3.1.4 Categories of alert types

The three alert tabs, representing each type of alert, were successfully used for navigating between the categories by all participants. However, there was scepticism against the core concept of integrating several categories of alerts into the radar interface (see section 5.3.2.4). The icons representing the type and number of alerts for that specific category was understood by the majority of participants. One participant did not draw that connection straight away, but after navigating to the system alerts section and seeing that the colors and symbols for the active alerts matches those visualized in the tab, this participant expressed that the tab icons were indeed representing active alerts for that category.

5.3.1.5 Muting alert sounds for five minutes

The mute button was meant to silence active alerts for five minutes without acknowledging them. Four out of five did find the button within five seconds, the fifth participant found it within ten. All participants understood that audio was silenced for 5 minutes although there were some misunderstandings if this button also acknowledged the alerts.

5.3.1.6 Alert descriptions

For the category of system alerts, two types of descriptions were provided for each alert. First, the same type of description regarding type as for route and navigation alerts directly into each list item. Secondly, and section that could be expanded through a button that would provide more extensive information about type but also cause.

Descriptions of system alerts did, as for navigation alerts, aid operator understanding about cause, leading to them presenting specific strategies of amending the problem which was not possible without the extended description. This, in combination with bridge experience, allowed operators to reason about how crucial these systems alerts were in relation to vessel safety. Thus, these short descriptions could be said to support both Level-2 and Level-3 SA by supporting comprehension of the alerts in relation to safety, as well as, aid prediction of future status. However, it is likely that experience plays an important role even with this kind of support present.

Each system alert has an attached button on their left side that, when clicked, provides a drop-down section with a more extensive description of the type and cause. When tasked with reading this expanded description, four out of five participants struggled with finding the button that would produce the drop-down section. Three participants found it eventually through trial and error where they pressed the alert itself or used other input methods such as double-clicking whereas one participant asked for assistance.

Whereas the short alert description provided concise information about the type, the expanded section communicates a slightly more extensive explanation of the cause. In the prototype, the alert description said “CAMERA MALFUNCTION”, while the expanded section included “Camera: STERN CAMERA 02” and “Cause: HDMI Cable detached”. When this expanded section was eventually produced, participants expressed a greater understanding of how crucial this alert was, as well as potential strategies of remedying the problem. This indicates that the expanded description in this prototype supported Level-2 and Level-3 SA.

5.3.2 Semi-structured evaluation interviews

Each interface element will be presented in relation to the resulting SA support as found through interviews with five SMEs after using the prototype (see section

4.4.2). Following the six phases of thematic analysis [58], seven themes emerged revolving around SA support, connected to sub-themes and interface elements (see figure 5.13).

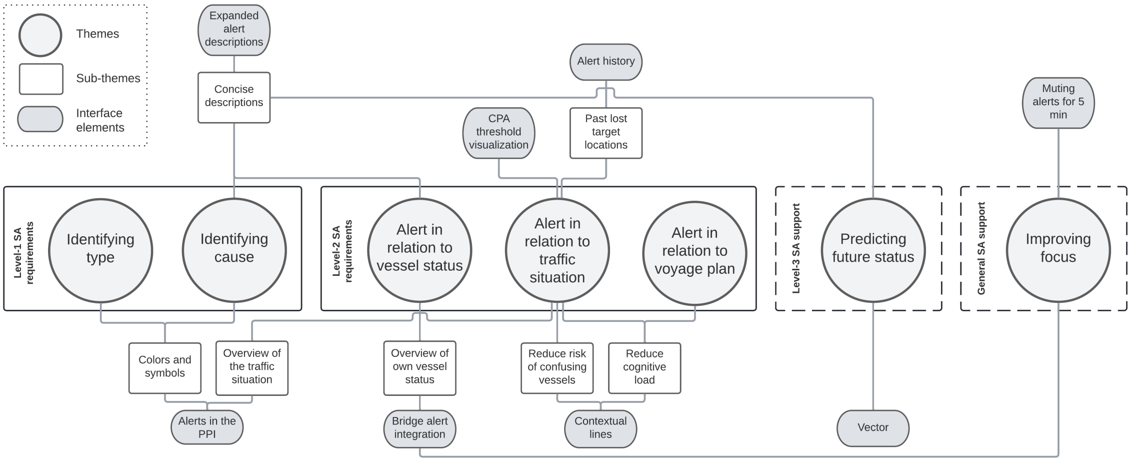


Figure 5.13: The seven themes emerging from the thematic analysis of the evaluation interviews.

5.3.2.1 Alerts in the PPI

The colors differentiating between objects causing alerts aided operators in understanding what the cause of alert was, which was expressed by P3 as *"... the echo [caused by the radar] up ahead is red, already there I understand that it is dangerous in some way"*.

Regarding the route alerts, participants preferred to always see the intended route directly visualized in the PPI rather than just the deviation when hovering over the alert because "... then I can see, visually, how my position is in relation to the intended route. I would know how to keep my heading if, for example, coming back after a maneuver for vessels ahead of me" (P4).

Having alerts in the PPI did also give participants an overview of the situation at a glance, guiding them in *"understanding which [vessels] I need to gather more information of"* (P2). Such an overview can be important in crowded situations. P4 expressed: *"Because in complex situations with many other vessels interacting with each other that you have to navigate through, it can be important to form an understanding around which ones [vessels] are critical and which ones are not"*. However, three participants repeated the importance of separating vessels that were based on an AIS or ARPA. ARPA targets are based on the radar's own signal, while AIS is communicated by the other vessel. P4 expressed *"The radar is a primary tool for anti-collision while ECDIS [main system to communicate AIS information] is navigational aid. The ARPA-function [housed by the radar] is the important function to keep an eye on to assess if there is a risk for collision with another vessel"*.

5.3.2.2 Contextual lines

The ability to hover over either alerts in the list or vessels in the PPI to see direct connections between a vessel and its alert was thought to aid comprehension of relationships between vessels and the alert list. P1 expressed: *"It is simply the case that you just hover over it [a vessel] and you see a connection to the list. The list is then sorted after what is seen as the most dangerous [highest priority alarm]. If I think that one [a vessel] is the most dangerous, then I just hover and see "No, that one is not the most dangerous, that is wrong"."*.

Contextual lines also decrease the risk of confusing ships. P4 expressed: *"This way you quickly see in case you are unsure about what is what. In some situations that require you to interact with several vessels it can be easy to lose which target is which"*. Existing systems sometimes number alerts in the list and display the corresponding number in the PPI next to the vessel that caused it, but P1 expressed that this solution might not be optimal: *"it happens that you [think]... "what boat is it in this list?". You have to sit down and think. "Number one, is this number one? Yes it is number one. All right"*. The contextual lines does aid this process by reducing cognitive resources required to understand the relationship between alerts and vessels: *"It does require an extra bit of cognition. Not because it's hard but I need to double check so that it really is correct [the relationship]. Is this right? Is it that one [vessel]? Yes, it is that one"* (P3).

5.3.2.3 CPA and vector visualizations

The visualized CPA threshold was argued to represent a sort of safety-zone that in many situations is kept free of other vessels. P5 argued for the benefits of using a visualization instead of a number which is often used in many systems: *"It is absolutely easier to visualize than having a number saying "one nautical mile", because what is one nautical mile in relation to the currently displayed radar range?"*. However, similar functions of displaying safety-zones do exist, namely Variable Range Markers (VRMs) which are easily adjustable rings visualized around the own vessel. Thus, several participants expressed that visualizing the CPA threshold might be redundant because of existing functions. If it does exist it should be hide-able or only showed when changing the threshold.

Although a function that exists in modern systems, the ability to visualize your own vector based on speed and heading was argued to aid predictions of a future position in relation to surrounding vessels. P4 formulated it this way: *"I always want to see that. I want to know where I am after 6 minutes, after 12 minutes, or which ever time I choose. It is also a way of handling close-quarters situations and assess distance. [..] By seeing how far I travel in 6 minutes, I can see how close I am to another vessel that also has a vector of 6 minutes without having to plot the target. I can then see that I will be very close [to the other vessel] and that I need to do something"*. A vector in modern systems many times consists out of two elements, a tip marking the predicted location at the exact time set by the operator (for example 6 minutes), but also increments for each 1/2/3 minutes. In general, four participants preferred to just use the tip as increments, especially when a larger number of minutes are set, are cumbersome to count and introduce a risk of miscalculation when doing so.

5.3.2.4 Bridge alert integration

When asked how integrating alerts from the whole bridge into one system would affect their situation on a bridge, all participants agreed that it would provide an overview, thus reducing the requirement to leave the main bridge to acknowledge alerts. P3 expressed it the following way: *"I don't need to leave my post. I don't need to turn my attention away from a situation monitored through my radar to acknowledge that camera alert, right? That is something good. I know that everything that happens around me is channeled to one system"*. Although all participants saw benefits of having a centralized alert management system, the radar itself might not be the best option for it. *"One one hand, I like to have everything important in one place. On the other hand, I've said that the radar should be clean"* (P3), referring to previous statements of keeping the radar separate from other systems. Several participants expressed a preference of reserving the radar just for navigation. P4 expressed it this way: *"The radar is one of the most important tools you have. I would probably perceive it a bit distracting to receive alarms on the radar that don't have anything to do with the handling of the radar"*. P1 expressed worries about the radar becoming a *"bin for all different kinds of alerts from all directions"*, a concern expressed by P5 as; *"The drawback is the risk of an excessive amount of alerts"*. Some alternatives were presented, for example implementing a similar system into the conning display or a separate panel.

A point raised by both P2 and P4 was the tendency to offload alert responsibility to another crew member. P4 drew an example from a cruise ship: *"You have a lot of alerts connected to the bridge on a cruise ship. You also have two officers on watch, one handling the navigation and one handling alerts. There you almost need to separate it to not disturb the focus of navigation and anti-collision for one of the officers"*. This is also relevant outside of cruise ships, especially in critical situations; *"someone who has to look at, communicate and crosscheck that alerts have been fixed in a critical situation. In those cases, the alerts should not be here [pointing at the alert list in the radar interface]. At that point, maybe those alerts should be disconnected from the pure navigation alerts"*. The core function of an integrated alarm system is to minimize sources of information. This directly limits the number of operators that are able to interact with the system. That in turn means that in situations where many alerts activate the officer who's responsibility it is to safely navigate the vessel, will also become the main receiver of alerts from the whole bridge. Thus, it might be important to provide an ability to delegate responsibility, or for other officers to take responsibility of handling or monitoring alerts that are not directly affecting navigation.

Lastly, a point raised by both P1, P2 and P5 is that in an integrated alert system, there is a greater importance of sufficient prioritization, both by the system in its way of sorting alerts in the list, but also through the support given to the operator.

5.3.2.5 Expanded alert descriptions

The support for SA provided by the extra descriptions of system alerts was discussed by the participants. P1 (16) expressed; *"It is short and concise, because you don't want... You need that information. You need: what is the problem and what is the error type, right?"*. P3 (78) added: *"What I like the most is this drop down list on this alert, so that I, at once, get more comprehensive information about it. I can press the arrow instead of looking through some search function"*. P5 (73) also added: *"This collection of alerts... You don't have to search for what's alerting at the moment. Usually, that's maybe the largest issue, to not know what's causing the alert"*, which both P4 and P5 expressed is a key factor for planning a course of action, and according to P1 some times requires reading manuals to understand the error codes produced by the system. This indicates that the implemented description provided for system alerts does indeed aid operators in understanding the type and cause, thus providing support with how to handle the situation. Although this might not be the case in all situations. Both P4 and P5 expressed that situations exists where one error causes in influx of alerts from various systems, which was worded by P5 in the following way; *"It starts with a faulty sensor, and then the next comes, and the next, which then causes the list to roll [expand rapidly]"*, adding: *"What you would want to know is if it [the alert] affects other systems"*. Situations like these might need further work to properly identify the initial cause of all these errors, and support the operator in understanding how the various types of alerts relate to each other.

5.3.2.6 Muting alerts for 5 minutes

All participants agreed upon that a mute function would be beneficial to reduce disturbances caused by surrounding bridge alerts, either to *"calmly go through the alert list"* (P1) or prioritize a more important situation without blaring alerts around. This was expressed by P2 the following way: *"And then it's about prioritization again. Is navigation the most important thing or is it the other things? Because in that case you can, so to speak, override the other things by muting the sound for 5 minutes at a time"*. Furthermore, P2 gave an example of how this could be beneficial for reducing surrounding noise when communicating with other vessels, which was also mentioned by P1. Such a function also has the potential of reducing stress, which was expressed by both P2 and P4.

Although an ability to mute alert sounds might be beneficial in situations with many active alerts, contexts with fewer alerts might benefit from the extra use of modalities. *"We have sound to raise attention regarding something specific"* (P3). P3 further raised an important point for consideration regarding novel alerts raised during the five minutes that sound is muted: *"Fair enough, I silence these four alerts. They are not a big problem, let them be there, I don't care about them, I have them under control. Then I walk away and do something else on the bridge when a new alert activates. If that new alert doesn't sound, then I wouldn't find out about it until in 5 minutes"*. Another point was raised by P2 regarding a risk of misinterpreting how crucial an alert is before muting it: *"... fire alarms should probably not be waiting for 5 minutes. Those are typical "take care of immediately"* *alerts"*. In an integrated system where the ability to momentarily silence the sound of alerts is just a press of a button away, support must exist to aid comprehension of the alert importance. Although it is worth noting that muting and alert will only turn off its sound, it will still be active on the radar interface.

5.3.2.7 Alert history

The alert history was mostly discussed in relation to lost target alerts, which refers to alerts raised about lost signals of an object or marked position. As was mentioned previously, separating AIS from ARPA targets is important, which is also evident for lost targets. Lost AIS targets generally seen as unimportant while ARPA targets could revolve around targeting buoys or other things of interest. Having lost those are of higher interest than AIS targets which uses a much greater range compared to the radar. For lost ARPA targets, the alert history together with the contextual lines was perceived as a useful tool. One example where it could be useful was raised by P1 when tracking a small vessels in high seas where they continuously disappear and reappear, *"But then you could through the alert history see: "I have a blip here and another there, and one over there", which shows a continuous course. In that case I can be sure that it's the right vessel"*. Another example, although more extreme, where this would be beneficial was raised by P3: *"If you imagine a situation where you are looking for something, and it could be about saving lives, but then you lost your last indication of it. If someone is sinking, the radar might not pick them up"*.

6

Discussion

In the following chapter, findings will be discussed in relation to the two research questions, the process will be discussed, recommendations will be presented as a result of the process and findings, and limitations, future work and ethical consideration will all be examined.

6.1 Information requirements in a target rich environment

To answer the research sub-question "*What situation awareness requirements do bridge operators have in a target rich environment?*", a GDTA was created finding the following requirements.

A majority of goals and SA requirements when navigating in target rich environments revolve around properly perceiving, understanding and projecting the surrounding traffic situation. As seen in the HTA (see section 5.1.2), in a target rich environments, operators rely on a loop of similar tasks alternating between monitoring the surroundings, acting to avoid close situations and observing the effect of their maneuver. A highly similar loop of tasks have also been confirmed by Grech et al. [28, p. 49]. This requires the operator to be aware of the status of their own vessel, its equipment and planned route, as well as the status of the traffic situation. As seen during the observations, the sources for these information types are mainly the radar, the ECDIS, radio communication, the overhead or conning display, and looking out. To get a proper assessment of the situation, operators need to sufficiently be able to identify surrounding vessels (Level-1 SA) and understand their relationship to each other as well as the own vessel (Level-2 SA). As was mentioned in interviews during the phase of specifying user requirements, the tool for doing this is, in many cases, the radar because of its reliability. It is worth noting that not the whole traffic situation needs to be clearly understood, the prioritization lies on vessels that have a direct or indirect influence on the planned route of the own ship. The customizability of the radar allows for fine-tuning informational needs in several ways, allowing operators to receive what information they need from the most relevant vessels. One example is the ability to adjust what range is displayed on the interface which is useful for adjusting the granularity of information. For close situations, the range might be reduced to form, as expressed in the interviews, a "tactical view".

Important types of Level-2 information involves understanding relationships between the own vessel and traffic situation, the voyage plan and contextual restrictions such as shallow waters, as well as how other vessels relates to the safety boundaries of the own vessel as these relationships determine which parts of the whole traffic situation will have an effect on planned route. The dynamic nature of vessel navigation involving a constant weaving of executing proactive maneuvers and monitoring their results will likely entail several changes to what vessel relationships have to be prioritized before the particular traffic situation is surpassed.

Projection (Level-3 SA) is also crucial to provide an aspect of proactivity in a traffic situation which entails predicting position, bearing and distance of both the own vessel as well as others. Modern radar do provide tools for this as well, such as target vectors displaying a predicted position of vessels based on current speed and heading. Another radar-based function mentioned during the initial interviews was trial maneuver, which essentially is a simulation of the close future where different outcomes can be briefly tested live. Although these tools might be beneficial in many cases, the radar only executes predictions based on the current information it has, which is not enough for fully reliable predictions. Thus, operators strive to understand intentions more thoroughly which entails personal calculations based on the information provided. The greater the amount of relevant information, the more reliable the prediction might be. For example, a target crossing the own intended route which might raise questions but seeing that the vessel's bearing is pointed straight towards a port allows the operator to infer that their intention is to dock. It becomes apparent that the more vessels that are involved in the current traffic situation, the higher the cognitive load of solely relying on system information when inferring intentions of others. Thus, operators might turn to radio communication which provides information directly from another vessel to supplement the currently predicted intention.

An important source of information for navigating in target rich environment is the voyage plan, which as is the standard towards which most decisions are compared. Details of the voyage plan are implemented in the ECDIS-system, allowing the operator to see the planned route and contextual restrictions. Some of this information can also be overlayed on the radar through AIS. Although the voyage plan is tailored to avoid contextual restrictions such as shallow waters, the maneuver might entail a large enough deviation from the planned route, thus requiring the operator to be aware of the exact extent of surrounding confined waters and how potential maneuvers to avoid it will affect the relationship to the intended route.

As a form of reactive support in a traffic situation, alerts of various kinds are set to different thresholds. Operators need to properly perceive the cause and type of alerts (Level-1), as well as, be able to comprehend their relationship to relevant factors such as safety, other vessels or the voyage plan (Level-2) to understand what action is needed. As such, alerts can be seen as aid for the goals of monitoring and acting (1. and 2. in figure 5.4). Some support for comprehension is given through the brief description provided for each alert, but its relationships with broader aspects such as the traffic situation has to be inferred by the operator. For example, an alert notifying about another vessel breaching the CPA-threshold is less relevant in a situation where close proximity is required, such as passing a vessel in confined waters.

Table 6.1: Interface elements in relation to their SA requirements support, as found through the final evaluation.

Elements	Level-1 SA	Level-2 SA	Level-3 SA	General SA
Alerts in PPI	X	X		
Expanded description	X	X	X	
Bridge alert integration		X		X
Contextual lines	X	X		
CPA visualization		X		
Vector own vessel			X	
Alert history		X	X	
Mute 5 minutes				X

6.2 Discussion of final evaluation results

The following section will discuss findings in relation to the research question: *What interface elements can aid operator situation awareness during active alerts in a target rich environment?*.

The sub-goals related to alerts are understanding the cause and type (1.1.6 and 1.1.7 in figure 5.5) which build on both Level-1 and Level-2 SA information requirements to be fulfilled. When Level 1 SA and Level 2 SA requirements are fulfilled, then the sub-goal of resolving an alert (2.4 in figure 5.6) can be fulfilled by properly understanding the alert and what the course of actions should be as a result of it. Going forward, the implemented interface elements will be discussed in their capabilities of supporting SA requirements as discovered by the final evaluation methods.

6.2.1 Supporting Level-1 SA requirements

The two requirements for Level-1 SA are identifying type and cause of an alert.

Identifying type

To aid the identification of alert type, i.e. the priority of an alert, colors and symbols were used, both for the alerts integrated into the PPI but also for alert descriptions. Alerts in the PPI refers to the element of directly tying alerts to objects in the plan position indication. Two different symbols together with different colors were used in the PPI, representing either vessels or lost targets, a separation that all participants expressed understanding of when interacting with the prototype. The color red symbolized alerts of highest priority while yellow a lower priority which was the same standard used in the alert list.

Identifying cause

Identifying cause was found to also be supported by the implemented alerts in the PPI by the use of color. Participants agreed that this provided an overview of relevant targets while separating those that had active alerts from other vessels, which could be especially beneficial in target rich environments. However, a need was expressed by several participants to separate between AIS and ARPA. AIS information have indeed been associated with a lower trust, and is, in isolation, often not enough to produce a sufficient level of SA [92, pp. 36-37]. Although not directly related to alerts, increasing transparency of what source the surrounding vessel information is based on will aid operators in ensuring that what they see on the screen is based on their most reliable signal source.

The element of expanded alert descriptions, support for identifying cause was provided by short and concise descriptions with the most crucial information. However, it was expressed that there currently is a need to better understand how alerts from one system might affect another because of the level of integration of modern systems where one system relies on input from another. While supporting Level-1 SA, two issues were observed regarding the usability of the element. Four out of five participants struggled with finding the button that produced the drop-down description. A reason for this might have been its placement on the left while operators read from left to right. The most essential information was placed on the right side of the alert description, so operators just looking for this information would end up with their gaze on the right side of the list when done reading. At this point, after reading this information, operators would realize if they needed more comprehensive information or if what already was presented was enough to understand the alert fully. Thus, given that their gaze would be on the right side of each alert description, and that in this moment they would realize if they wanted further information, the location of the button producing the drop-down section of expanded information should be located on the right side rather than the left. Furthermore, two participants did try to acknowledge alerts in the list that were already acknowledged. This was indicated by its symbol only having a border, while the unacknowledged alerts have solid colors and continuously flash. This indicates that clearer distinctions are needed between acknowledged and unacknowledged alerts.

6.2.2 Supporting Level-2 SA requirements

The requirements for Level-2 SA are understanding an alert in relation to three aspects; the own vessel status, referring to safety and functionality, the traffic situation and the voyage plan.

Alert in relation to vessel status

Understanding an alerts relationship to vessel status was found to be supported by two interface elements; bridge alert integration and expanded alert descriptions. Starting with bridge alert integration, which is the overall concept of integrating alerts from the whole bridge into one interface. This interface element was found to support Level-2 SA by providing an overview of the whole situation, thus aiding assessment and diagnosis of multiple alarms. Several points were also raised regarding the potential importance of transferring alert responsibility to other crew members, thus offloading individual SA to focus on navigation. Lastly, a coherent preference was expressed to keep the radar focused on navigation while other alerts could still be integrated but in a separate panel. Some participants did express awareness of this duality; seeing benefits of an integrated alert system but still preferring the radar to be free from non-navigational alerts.

As was mentioned in section 5.1.4.1, fulfilling the sub-goal of understanding the cause might in some cases require Level-2 SA support. One such example is the implementation of an expanded alert description. For more complex alerts, there is a greater need for understanding relationships between the alert and related system factors. When interacting with the prototype, reading the expanded alert description lead to participants discussing specific strategies of solving the cause, indicating that the description did indeed aid them in understanding relationships between the error, implications for safety and potential amendments to remedy the problem. These specific suggestions of strategies were not presented until the description was read, likely because the un-expanded alert on its own did not present enough information to support such relationships to be understood.

Alert in relation to the traffic situation

Understanding an alerts relationship to the traffic situation was found to be supported by four interface elements; visualization of CPA threshold, contextual lines, alert history and alerts in the PPI. By visualizing the threshold of the CPA (supporting Level-1 SA), a better understanding can be achieved of the current threshold in relation to the currently set radar range. As was observed, mainly during simulations (see section 5.1.1), the range of the radar is often adjusted. Thus, a visualization that adjusted depending on the current radar range was expressed during the interviews to be more effective than relying on a number. However, it was also mentioned that such a visualization can be replicated using alternative existing functions, in turn reducing the need for this element.

Referring once again to the notion in section 5.1.4.1 that to understand alert cause might in some cases need Level-2 SA support, this is also relevant for the element of contextual lines. The contextual lines were found to increase participant understanding of which vessels had caused what alerts by participants verbally confirming relationships while exploring the alert list by hovering over alerts and looking at the contextual lines leading to the PPI. In one case, however, a participant could explain the whole situation without hovering, indicating that the prototyped scenario might have been too simple for SMEs. During the interview, participants expressed that such an element will reduce the risk of confusing ships, essentially aiding perception, which indicates that following the SA design principle of presenting Level-2 information directly (G2 in section 2.2) has the potential of successfully offloading cognitive processing that is otherwise required for understanding relationships. Contextualizing alerts this way might therefore be an effective way of reducing some of the Level-1 SA errors, which as reported by Grech et al, is the level that a majority of maritime SA errors can be attributed to [16].

The interface element of alert history was mostly referred to in relation to lost targets together with the contextual lines. Participants expressed that the ability to see past lost targets and their location through the contextual lines might be beneficial in situations where current systems are not able to track targets efficiently. By hovering over lost target alerts in the alert history, the contextual lines would point towards past locations, giving participants an understanding if several lost target alerts were from the same or different vessels by relying on the gestalt principle of proximity [93] (see figure 6.1) .

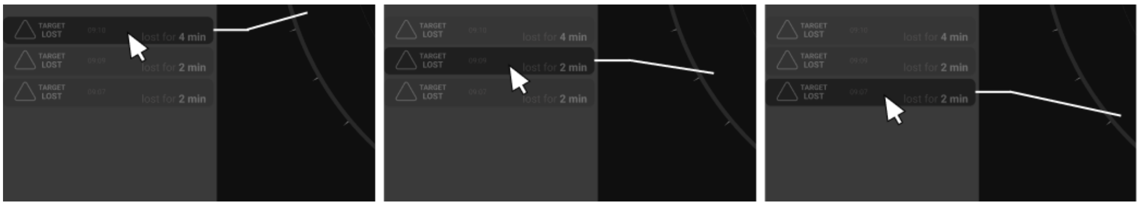


Figure 6.1: An visualized example of how the alert history can be used to track position of past lost target alerts.

While providing plenty of support for Level-1 SA, the overview over the traffic situation provided by the implementation of alerts in the PPI is related to Level-2 SA. An overview in its essence entails a broad picture of relationships between surrounding vessels, in turn aiding operators to prioritize targets. Thus, it can be argued that the overview provided by this element provides input into Level-2 SA requirements.

Alert in relation to the voyage plan
Understanding an alerts relationship to the voyage plan was found to be supported by one interface element; contextual lines. Only one alert related to the voyage plan was implemented in the prototype, namely regarding deviation from a planned route. When hovered, a visualization was shown in the PPI showing the intended route as well as how far the own vessel had deviated. While it was expressed that the visualization did aid understanding of the relationship between current position and planned position, a constant visualization of the route would be preferred as it would provide that information proactively rather than reactively as in the current implementation. This notion can be supported by literature, most notably by arguing that constant visualization of relevant information will support global SA [15]

6.2.3 Supporting Level-3 SA

While no direct Level-3 SA requirements were identified for alerts, there were some indications of support for this level by some interface elements. Implementing a vector for the own vessel was expressed by participants to increase their capabilities of predicting future positions in relation to other vessels. It was also expressed that the element of the expanded alert descriptions might be, together with experience, a powerful tool for predicting future status.

6.2.4 Interface elements supporting general SA

Some elements were found to provide more general support for SA. For example, integrating bridge alerts into one interface was thought to reduce risk of losing focus of the current situation, but there are risks of excessive amount of alerts. The ability to retain attention of what is deemed important is a large factor for SA by both allowing perception to tend to the necessary stimuli, but also by aiding decision making when sufficient stimuli have been perceived [15]. However, attention is limited, and an overload of information, such as an excessive amount of alerts, will risk SA degradation [1]. The interface element of muting alerts for five minutes was expressed to support SA by reducing the risk of such an information overload, allowing operators to focus on more important things, such as radio communication or solving a traffic situation, but then be reminded again after five minutes had passed. One issue, because of the easy access to the button, is the risk of misinterpreting the severity of an alert before muting it. New alerts should likely be let through the mute to not risk the operator missing it. While participants did in general find the button for muting alerts, it was not clear to everyone that the button did in fact not acknowledge them. It is possible that a more comprehensive prototype would make this clear as unacknowledged alerts would still be active and potentially flashing in the list.

6.2.5 SA challenges on a ship bridge

Even though the currently used systems on a bridge might provide sufficient information in most situations, one type of information that was expressed by SMEs to be insufficiently covered was speed changes. P3 in the initial interviews explained this by comparing speed changes to turning; *"you never see the tendencies [of speed changes] as easily as when you see a vessel turn. You have to monitor very closely on the data expressing speed"*, adding that noticing such changes requires quite some time from the navigator. This was also seen to be a problem during the simulation observations, where during one session, participants were totally unaware of an approaching ship until it was in front of them, thinking that the instructor had simply placed the vessel there out of nowhere.

Another information requirement was also expressed during the final evaluation; how alerts from one system affected another. Two SMEs expressed that some situations do produce a cascade of alerts resulting from a single error in one system. Thus being able to identify this initial problem would greatly support fulfilling the goal of resolving alerts (2.4 in section 5.6).

A majority of the time spent on a bridge is dedicated to monitoring the situation which poses two challenges for SA; vigilance and being out-of-the-loop. Vigilance refers to the ability to remain attentive in response to a certain stimuli over a longer period of time [94]. Historically, vigilance has been studied in relation to radar monitoring, finding that operators' ability to accurately detect signals were severely diminished over time [94]. Contrary to traditional beliefs that this decrease in performance was due to passiveness, Warm, Dember and Hancock found vigilance tasks to be directly associated with high workload because of increased task demands [95], which can lead to severe degradation of SA

Long periods of time allocated to monitoring will eventually risk a loss of ability to effectively take action if a critical situation occurs [96]. This has been argued by Endsley to be caused by a loss of SA, which then takes time to rebuild when the situation calls for it, which she refers to as the *"out-of-the-loop"* problem [97]. This gradual degradation of SA might become crucial when a call to action is eventually needed. Relating this to the three level model of SA [15], the operator needs to perceive the relevant information, comprehend it and choose an action accordingly. Conclusively, warnings and alarms can be seen as a call to action which is prone to forcing operators into rapidly assessing the current situation to decide a feasible action. This requires interfaces that are display relevant information in a comprehensive manner so that an assessment of the context can be both accurate and within a feasible time frame.

It was found that alerts are in many cases associated with distractions, many times requiring a shift in attention or being outright overwhelmed. Relatedly, an overwhelming numbers alarms and warnings have been found to cause confusion, distraction and loss of SA [96]. Similarly, Sharma et al. found in their GDTA of vessel navigation that a shift in focus was the largest factor of SA disruption [20]. Attention is often related to perception, i.e. Level-1, in the three levels of SA presented by Endsley [98, p. 214]. This poses a great challenge in designing alerts to complement situation awareness rather than disrupt it by designing alert interfaces that provides crucial information in various ways to increase understanding or severity and relevance as well as support acknowledgements [1, pp. 164-168].

6.3 Process discussion

The observations carried out did provide important insights but their ability to match or validate those originating from interviews was limited. This can be attributed to two factors. Firstly, voyages related to a higher expectancy of alerts are harder to access as a researcher because of their increased complexity. Handling alarms in target rich areas, especially some extreme situations that were mentioned by interviewees, are highly specific contexts which might not be as accessible for observations. Accessing these context for field studies requires a greater level of willingness to allow a researcher to be on the bridge in a potentially stressful situation where vessel safety is the number one priority. As regards to simulators, while being able to create tailored scenarios to be observed, they only partly replicate real bridges, require a substantial monetary investment, and might not fully reflect true behavior. Secondly, even if access to real life bridges would be granted, the produced insights might be limited because of the requirement to be as distant as possible to allow the crew to perform at maximum performance. Thus, interviews with SMEs having experience with such scenarios remained a feasible alternative for the scope and budget of a thesis. However, this introduces their own limitations, one being direct access to experts with marine experience, especially for a researcher that is new to the domain. Although an extensive number of experts were contacted, only a handful responded, and an even smaller subset had time to participate.

The reason for only including SMEs in interviews was their extensive experience with target rich environments, giving them a solid understanding of various factors affecting such a situation and how a potential solution might alter those factors. However, extensive experience with one set of systems might also introduce reluctance towards new technologies. Samuelson and Zeckhauster proposed the status quo bias, referring to a preference of upholding a current situation and a reluctance towards things that might change it [99]. Other factors affecting a reluctance towards new technologies have been found to be perceived needs of the technology [100] and the effect on operator performance [101]. The interface element of presenting all on-bridge alerts through the radar would likely entail a large change to how the dynamics on a bridge crew would play out, thus making it a threat to the status quo. Interface elements associated with smaller impacts however, such as the contextual lines or the expanded descriptions, could have been seen as complement to the current status quo and better fulfill existing needs, and thus were seen in a more positive light.

Although providing plenty support for answering the research sub-question, the HTA and GDTA were limited in how much valuable insights it gave to the main question. As discovered, these methods, especially the GDTA provides a holistic approach of SA requirements. One issue might have been that the context of the methods were not sufficiently limited as they covered navigation in target rich environments and not just alert management. However, limiting the GDTA for a narrow context such as alert handling in a target rich environment might have reduced its effectiveness of capturing potential SA problems which would affect the context in focus. One such example is the main loop of tasks alternating between monitoring and maneuvering, requiring the operator to be positioned at one place during most of the time, which has in turn been used as an argument for integrating all bridge alerts into an interface close to their mostly used position on the bridge. Without a broader scope on the HTA and GTDA, this insight might not have been discovered. A point can also be made regarding the use of a broad scope, not only to define what information a potential solution should communicate but also to set boundaries for what it should not do. One example of this is the voyage plan. When creating the plan, the whole voyage is calculated according to certain factors, and thresholds for certain alerts are set already at this stage. However, even though this is inside the scope of alert management, these plans are sometimes made weeks in advance using other system features than those during navigation. The route and parameters set during the plan have to be followed to the best of the capabilities of the crew when the voyage eventually takes place. Thus, the GDTA and HTA defines, in this case, a clear boundary for what is relevant to focus on if creating a solution to be used during navigation.

Another point related to the GDTA is its normative nature of focusing on goals, decisions and information requirements. The core purpose is to focus on what an operator requires in an optimal scenario to provide a greater understanding for designers of what is needed to build SA [1, p. 63], but relying on just this method misses out on potential pain points not related to required information. To counter this, the initial interviews with SMEs did not only focus on information requirements, but also on potential pain points, and eventually discovered that alerts were seen as disturbances. This is one example of an insight that would likely be either missed, or not emphasized if a GDTA was the only outcome expected from these interviews.

During observations, the researcher adopted the style of a recognized outsider, this might produce the *Hawthorne effect*, i.e. a tendency to change behavior as a result of being observed [53, p. 117]. Forming rapport with participants and assuring that performance will not be judged are two recommendations proposed by Harell et al. to reduce the Hawthorne effect in simulation studies [102]. In line with these recommendations, the researcher presented himself and the purpose of the observation to the participants prior to each observation session, and pointed out that performance would not be assessed.

As seen during the process, the value provided by the technology analysis was less than what is generally expected. Endsley proposed the method to act as a survey of existing products or technologies as support for the conceptualization of a solution [1, p. 48]. The application of the method is expected to be rather extensive to explore possibilities, however as mentioned in section 6.5, documentation or direct access to these technologies were problematic.

6.4 Recommendations

Following, a set of recommendations will be presented based on the findings from this thesis.

1. **Keep alert management activities around the main bridge.**
   Although integrating bridge alerts into the radar was criticised by SMEs, the concept of integration was seen as highly beneficial as it would allow operators to effectively understand and manage alerts with less of a requirement to step away from the main systems used during navigation. As found during bridge observations of simulations and on a ferry (see section 5.1.2), the main loop of operation revolved around using the radar, ECDIS, overhead display and lookout for monitoring, and ship controls for maneuvering, creating an iterative loop of monitoring, maneuvering and back to monitoring the result of the action. A similar loop has been confirmed by other sources [28, p. 49]. All crucial systems to maintain this loop are located on the main bridge in close proximity of each other. Thus, keeping alert management around the same area was expressed to be beneficial, especially in situations where the demands of the main loop was high.

   (a) **Provide an ability to offload alerts to other crew members.**
   In certain situations, for example target rich environments where navigation is top priority, there might be a need for offloading alert responsibility to other crew members while one operator is responsible for solving the traffic situation. This was expressed by P4 in the following way: *"You have a lot of alerts connected to the bridge on a cruise ship. You also have two operators on watch, one handling the navigation and one handling alerts. There you almost need to separate it to not disturb the focus of navigation and anti-collision for one of the operators"*. Such solutions would benefit from using theory and principles regarding designing for shared SA [1, pp. 213-218]. One example is providing different key information of the same problem to different operators, allowing them to fulfill their current goals while reducing informational load [1, p. 215], which has been found to reduce numbers of errors while keeping the performance intact [103]. This way, the operator responsible for navigation

could, for example, receive information how this alert affects his ability to maneuver, while another operator is presented with a more thorough explanation of the cause.

2. **Keep the integrated alert system separate from the radar.**
   SMEs did express a preference for the radar to be separated from alerts not directly relevant for navigation, which was expressed by P4 in the following way; *"The radar is one of the most important tools you have. I would probably perceive it a bit distracting to receive alarms on the radar that don't have anything to do with the handling of the radar"*. This does entail that the radar, although a central part of the main loop on a bridge, is perceived to serve a specific purpose which might be best served if separate. It has been proposed by some regulators that the conning display should be used for centralized alert management systems [46, pp. 1662-1663]. A conning display is often located close to the main systems, and would thus still provide a control over alerts in close proximity of where operators are most often positioned. It might also be beneficial in the sense that a lot of screen space might be required to provide enough context about cause for certain alerts. One such example is fire alarms. Currently, a separate computer on the bridge is used to display all decks and the status of fire sensors on each one, allowing an operator to see directly where an active fire sensor is located. Providing such a detailed display might be more fitting in a conning display as to not risk covering important information related to navigation in the radar.

3. **Provide information to support alert-related goals.**
   Strategies of accessing needed information might vary between operators, or the existing technology might outright be unable to provide required information to fulfill a goal. Relying on goal-defining methods such as the GDTA, allows designers to specify goals and SA requirements no matter the technology used by operators [1, p. 63]. This way, satisfying the SA requirements to allow operators to fulfill the goals will assure that the information that is optimally needed, no matter current practises of reaching it, is provided to users, in turn increasing their SA [1, p. 63]. In this thesis, three goals were identified in relation to alerts; understanding type, cause and resolving alerts. By examining what information is required for each goal to be fulfilled, SA requirements can be specified and used as direct input into the design process. This thesis has shown how such a process might be carried out in a maritime domain, from conceptualization to evaluation.

4. **Provide an overview of the surrounding situation.**
   A common problem for maintaining SA is focusing on just a subset of the relevant information [19]. Systems are thus encouraged to provide a wide overview of relevant information types, also referred to as *Global SA* [15]. Although the radar in itself is a tool for producing such an overview of the surrounding traffic situation, its ability to integrate information specifically for alert-related goals has been limited. SMEs expressed that implementing alerts into the

PPI supported prioritization by, as P2 expressed, aiding *"understanding which [vessels] I need to gather more information of"*. This in turn supports assessment and diagnosis of multiple alarms, which is another SA design principle proposed by Endsley [1, p. 167].

(a) **Provide an ability to visually contextualize alerts, even for simple situations.**
When an effective overview has been presented, another SA design principle suggests to visualize Level-2 information directly to show relationships between different relevant types of information [1, pp. 79-81]. Some attempts at this already exists for integrated bridge systems. One example is a proposal of a route exchange feature between vessels, allowing operators to directly compare, and also predict, their own route and heading in relation to the route of a target [5]. Another example is an attempt of visualizing safe headings in relation to surrounding vessels [104]. The concept presented in this thesis attempts to provide direct relationships between surrounding vessels and active alerts, which is done through the contextual lines interface element. This was perceived by SMEs to be beneficial for reducing the risks of confusing vessels, especially in situations where there are numerous in the surroundings. For example, P3 expressed the benefits of contextual lines by comparing it to how alerts are otherwise perceived in commonly used systems: *It does require an extra bit of cognition. Not because it's hard but I need to double check so that it really is correct [the relationship]. "Is this right? Is it that one [vessel]? Yes, it is that one""*

(b) **Separate ARPA and AIS targets.**
Referring back to the notion of supporting global SA, SMEs did express that vessels on the radar should be differentiated depending on if they are based on an ARPA or AIS signal. The reason was explained by P4 in the following way: *"The radar is a primary tool for anti-collision while ECDIS [main system to communicate AIS information] is navigational aid. The ARPA-function [housed by the radar] is the important function to keep an eye on to assess if there is a risk for collision with another vessel"*. This poses a need for understanding what data the surrounding vessels are based on, which should be communicated through the interface.

5. **Design alert descriptions to be concise.**
Alerts should provide the right information to fulfill the current goals but at the same time avoid extraneous information as to not overload the operator [15]. This requires a balance that might differ between alert categories. For example, it has been found that target rich areas area able to produce upwards of 40 alerts per hour, most of them being navigation related [30]. For these types of alerts, there is a need to quickly be able to assess its relevancy and severity, thus requiring that these alerts are effective but minimalistic in their

information density. However, non-navigational can be more complex, in part because they require attendance elsewhere on the bridge, and in part because their errors require amendments beyond ship maneuvers. Thus, rather than expressing error codes that require physical manuals, information should be supporting the decisions of the operator [15]. The current implementation of expanded alert descriptions for ship equipment was an attempt at that which was expressed by SMEs to produce essential information about cause and type in a concise manner. P1 expressed it in the following way: *It is short and concise, because you don't want... You need that information. You need: what is the problem and what is the error type, right?"*

6. **Provide an ability to temporarily silence alerts.**
   Alerts on a ship bridge have been linked to distraction and loss of SA [96, 20]. In early interviews, SMEs did express a concern of alerts disturbing the main tasks of an operator (see section 5.1.3.4). It has been found that the best time for interruptions to occur is between coarse break points between tasks [83], which then requires less cognitive effort and raise less frustrations, as well as, time pressure [82]. In complex systems such as ship bridges, tasks and their natural break points will vary largely between contexts. The interface element of muting alerts for five minutes was an attempt at giving operators a greater freedom in adjusting alert sounds according to their current tasks, providing a greater capability to postpone interruptions until a natural break point occurs. SMEs did express that the element will have potential by allowing the operator to prioritize more important matters, and take up the alerts when those tasks are completed. P2 summarized it in the following way: *"And then it's about prioritization again. Is navigation the most important thing or is it the other things? Because in that case you can, so to speak, override the other things by muting the sound for 5 minutes at a time"*. Although worth noting is that the power of such a feature in combination with its accessibility require careful design around notifying the operator exactly what alerts are muted. Designing such feature requires careful consideration what alerts should be able to be muted and how to make the operator aware of the severity of alerts before they decide to silence them.

7. **Balance normative and descriptive findings.**
   The core purpose of a goal-directed task analysis (GDTA) is to provide normative insights regarding goals, decisions and information requirements in a particular context to provide a designer with an understanding of what information is required in an optimal scenario [1, p. 63]. While this is an effective method that explores beyond current contextual restrictions, it might miss out on important insights that are external to information requirements. Thus it has been beneficial during this thesis to supplement the GDTA with descriptive insights, either by observations or through the same interviews that the method is based on. This has in turn produced insights that might not have been discovered would the focus only be on information requirements, such as alerts being perceived as disturbing in certain target rich environments (see

section 1.2).

8. **Provide clear indications of what is interactable.**
Acknowledging alerts is a highly common type of interaction on a bridge used to communicate to systems that the operator is aware of the alert that was raised [11]. Therefore, it is important to signify what elements are interactable, especially in a solution that might present novel implementations. As discovered during the think-aloud protocol, some of the interactable elements of the proposed concept in this thesis were not immediately obvious for SMEs. The most prominent example was the button for expanding the extended alert description (see section 5.3.1.6). To communicate where interactions are possible, Norman presents the concept of a *signifier*, referring to a *"perceivable indicator that communicates appropriate behavior to a person"* [105, p. 14]. These can come in many forms in digital interfaces, such as the use of *static hinting* by designing elements to look interactive, or implementing visual cues when hovering over objects, either through *dynamic hinting* referring to changing appearance of the object, or through *cursor hinting* by changing the visuals of the pointer [106, p. 312].

6.5 Limitations

Given the range of various alerts that could activate on a bridge [46, p. 1659], there might be those that are not feasible to implement in an integrated alert system. The concept is based on the understanding of alerts by a researcher that lacks maritime domain experience and the concept would need to be revised in relation to the full set of possible alerts. Although it is, in theory, possible to find documentation about the full range of alerts that can be expressed on a bridge, domain experience is required to understand how they affect a crew in practice. An example would be the active alerts found on the observed ferry, which were left unattended because they were deemed unimportant. The system, however, consistently showed these alerts which implies a dissonance between what the system designers planned to be important alerts and how important they were in that particular context.

The expanded alert description did present information to support strategies to be formed by participants. However, one reason for participants not expressing these strategies previously to expanding the alert description might be because it was an alert that SMEs had no experience with. Thus, the effectiveness of an expanded alert description, although appreciated by participants, might vary for alerts that are commonly understood by operators. Although its usefulness might be higher for alerts that rarely occur.

CPA visualization was deemed redundant as a similar function already exists. Other aspects of the final prototype might also already exist in modern systems. This might be attributed to an insufficient understanding of modern systems before conceptualizing the prototype. Modern radars and ECDIS systems do house a certain degree of customizability, leading to observations of those systems only catching the narrow range of possible setups and options that was configured by the operator at the time. To get a comprehensive understanding of the full range of features and options, a researcher needs to either interact with the system on their own, or read their manuals. For systems in complex environments such as bridge systems, both these options are sub-optimal. To directly interact with these systems, one needs access to them in a context that allow exploration. One such context might be simulators, but even then the researcher needs to have access to someone who can explain what each feature does and when it might be relevant. Regarding reading manuals, for systems such as the radar and ECDIS, manuals are often hard to come by if one hasn't purchased the system on their own.

Several limitations do exist in the current application of the final evaluation. One being the use of a think aloud to evaluate SA, which only provides as good insights as the participant is able to verbally communicate [1, p. 261]. One evaluation method developed to account for this is SAGAT, which involves moments where the system freezes and questions are posed to the participant to evaluate if SA requirements have been fulfilled [107]. However, as SAGAT has been developed for aviation contexts, the method has been criticised for not being adapted to the slower dynamics of the maritime domain [108]. Two alternative SA evaluation methods have been developed specifically for the maritime domain; SATest which involves the same types of freezes as SAGAT [109]. Although there are some discrepancies between what the SATest requires to efficiently measure SA and what the scope of this thesis could provide. Some of the requirements posed for SATest are: a realistic simulation scenario, a long enough scenario to allow participants to build sufficient SA between freezes and a prototype of a similar level of interactivity as provided by the systems usually used by participants to complete their tasks [109]. This would require the current prototype to be highly interactive and implemented into a simulator, which would entail a larger cost and a longer time frame than was possible in this thesis.

The inability to implement the prototype into a simulator could itself be seen as a limitation as this reduces the generalizability of the results. Although experts are deemed knowledgeable of the contexts they work in, thus providing credibility to the results emerging from the methods they participate in, what they say might still differ from how a real situation would unfold [56]. In an evaluation context, relying on a think aloud protocol outside of a bridge using a prototype and complementing that with an interview might not be enough to evaluate what difference to SA the interface elements would have on a real bridge.

A third limitation would be the use of a homogeneous sample of only including Scandinavian men. Relatedly, the sample size was five SMEs for the evaluation, and only three for the initial interviews, introducing various problems of not fostering a heterogeneous perspective. Although, as previously mentioned, even though expert knowledge might be of high quality, getting access of SMEs can be complicated. It was seen in the initial interviews with SMEs during requirement specification that even though it only included three participants, the third interviewee did repeat much of the previous findings from the other two. The reason for this might have been that goals, decisions and information requirements in target rich areas are general enough to be specified with only a few participants. Pain points, however, are likely not as general between SMEs.

A fourth limitation of the final evaluation would be the lack of standardized question during the interviews as there was a need of covering a broader set of interface elements.

6.6 Ethical considerations

As has been seen, a majority of the time spend on the bridge is revolving around the same systems and position around the main bridge (see section 5.1.2). While an integrated alert system would allow the operator to keep focus on the main tasks to a greater extent, it might also have a drawback in the form of increased vigilant behavior. As vigilance has been associated with high workload [95] and degradation of SA [1, pp. 34-35], integrated systems that removes the requirement to move around the bridge might actually affect performance negatively.

During 2020, the size of the world's trading fleet, referring to seaborne transports of cargo and passengers, was estimated to be 62,100 vessels [110]. This entails a world-wide domain housing operators from all continents. However, the SMEs included as participants in this thesis were all Scandinavian men, representing only a small subset of the domain.

6.7 Future work

The proposed concept is compatible with a fully integrated bridge system where fewer screens contain several systems. In those cases, the alert management system proposed here could present alerts from all systems, allowing the operator to navigate between systems to see the integrated information. For example, such an interface could present alerts regarding deviations from a planned route (which originate from the ECDIS) and simply display the deviations on the radar interface or allow the operator to switch to the ECDIS-interface briefly.

Although current conventions and regulations lack clear acknowledgement of autonomous shipping, the notion is already well developed in certain maritime sectors [111]. For example, Yara Birkeland is a fully autonomous container vessel put into service in the current year of 2022 [112]. A related notion is also unmanned vessels that are remote controlled from shore-based stations [113]. Various degrees of automation might pose challenges to the operators who are still kept in the chain of activities in one way or the other. One such challenge is being out-of-the-loop which entails rebuilding an understanding of the situation in case intervention is required by an operator [114]. Being out-of-the-loop can be seen as a direct loss of SA, requiring time and effort to build it up if needed [97]. Relating this to the three level model, Level-2, i.e. understanding of the situation, has found to be the level that is mostly harmed by increased automation, thus requiring sufficient feedback of systems states to rebuild SA [97]. Indeed, providing visual information regarding the state of the automated system has been found to increase SA in pilots and drivers [33, 3]. Thus, further work is encouraged to examine SA-supporting strategies in contexts where degrees of automation is higher and challenges such as being out-of-the-loop are more prominent.

Given that operators on a bridge often work in tandem with overlapping goals and tasks, future work might explore capabilities of sharing situation awareness between crew members. Some attempts of this have been made by using shared visual information to complement verbal communication. Bolstad and Endsley found that sharing abstracted visual information between operators might effectively fulfill individual SA requirements and keep errors low [103]. Parush et al. constructed a screen of information to support team situation awareness in an operating theatre [115]. Shared visual information has been found to provide a common ground and support situation awareness [103, 116, 117], thus requiring less verbal communication for effective collaboration [117]. However, the degree to which visual information might aid collaboration depends on the used technology [118] as well as the task [119]. For example, visual information is more effective in tasks where objects are harder to verbally describe [120, 121]. Efforts have also been made to create procedures of designing for increased performance in complex automated systems where out-of-the-loop problems might be an issue [122, 123]. Attempts such as these might aid in designing solutions that not only increase the shared SA of a crew, but also alleviates offloading alert responsibilities. Better ways of sharing a common understanding between vessel crews might also be explored, given that interpretations of target intentions is a crucial goal during navigation (see section 5.1.3.3). For this purpose, work such as the ship route exchange function presented by Aylward et al. might alleviate both comprehension and prediction of intentions between vessels [5].

As the action of acknowledging alerts is a common form of interaction communicating to the system that the operator is aware of the alert [11], alternative types of interactions could be explored. One alternative could be the use of eye-tracking given its large advancement in precision during the past years.

Endsley presents three reasons of why alerts in general fail to fulfill their purpose of increasing operator awareness of a developing situation [1, p. 147-148]. Firstly, a sheer abundance of alerts limiting the SA capabilities of an operator. Secondly, a high number of false alerts, in turn affecting the reliability and a risk of inaction. Lastly, a tendency to deactivate alerts because of the two previous reasons. While the first reason of an abundance has been addressed in this thesis, some SA design principles which were outside of the scope might be used to further develop the multi-modal informational transfers of alerts. These two principles are: "Utilize parallel processing by taking advantage of several modalities" [1, p. 83] as well as "use multiple modalities for alerts but insure that they are consistent" [1, p. 166]. Relying just on a single modality such as vision might reach a bottle neck of information processing capabilities in a complex system. Audio is already, by IMO standards, implemented into the on-bridge alerts, first and foremost to raise awareness of unacknowledged alerts [12, p. 26]. Modern integrated bridge systems would likely benefit from alert signals that would differentiate between alert types to a greater extent. Lloyd's register is a maritime classification society with standards used in vessels world-wide[1]. In their rules for ship classification, integrated bridge systems are suggested to use audio signals such as a buzzer, bell, chime or a tone for different levels of alert severity [46, p. 1660]. Evaluating the effectiveness of such a solution would require operator training to build a foundation for "priming from contextual cues to which a goal is linked" [31, p. 117]. This would require a more

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[1] https://www.lr.org/en/who-we-are/

longitudinal approach of getting used to the different alert sounds to understand their meaning, and thus required a larger scope than was available for the thesis.

The second reason of false alerts can also be addressed by SA design principles. By tailoring sensors and algorithms, a system's capability can increase its performance of producing reliable alerts [1, p. 165]. Another way of tackling this issue is by introducing alert thresholds, increasing the control that operators have regarding alert activation [1, p. 165], although as mentioned below, this might introduce its own issues.

The third reason of deactivating alerts has also been addressed in this thesis, and could be related to customizable thresholds of some on-bridge alerts which some operators use to effectively disable the alert (see section 5.1.3.4). Baldauf et al. also observed the same behavior on vessels, in some cases this low threshold was kept for the whole voyage [29]. A large increase in activated alerts have been observed in target rich environments [30], and reducing a threshold can thus be seen as a proactive measure for such contexts. However, it also introduces a safety risk by rendering the anti-collision alerts useless. Given that anti-collision alerts fully depend on the thresholds that are set, it might be fruitful to explore interactions regarding increasing or lowering them. A form of interaction that is highly accessible might induce a greater willingness to dynamically adjust thresholds as they are originally meant to. Although this would mostly be relevant for anti collisions alerts such as CPA or TCPA as many on-bridge alerts lack thresholds. Thus, future attempts of designing alert management systems are encouraged to apply a holistic approach of building systems to reduce false alerts, utilize multi-modal information and increase accessibility of threshold adjustments.

7

Conclusion

The purpose of the thesis was to define situation awareness (SA) requirements during navigation in target rich environment and address the needs and pain points of alerts in this context. The main research question targeted alerts: *What interface elements can aid operator situation awareness during active alerts in a target rich environment?*, which was supported by the sub-question: *What situation awareness requirements do bridge operators have in a target rich environment?*.

By using a situation awareness oriented design process, the SA requirements of a target rich environment were mapped out in a goal-directed task analysis (GDTA) by observing simulations, a ferry and SME interviews to answer the research sub-question. Requirements for Level-1 SA revolve around being aware of the status of the own vessel, its equipment and planned route. It also requires awareness of the traffic situation, which form the Level-2 requirements of understanding how position and speed of surrounding vessels relate to, not only the own vessel, but also to each other. SA requirements for Level-3 revolve around a need to project information, such as position of other vessels to aid proactive behavior. In a target rich environment, these requirements are mainly filled by using bridge systems in close proximity, allowing the operator to receive crucial information without moving around much.

However, alerts pose a risk for operator SA, leading to some situations being sub-optimal in regards of fulfilling SA requirements. Thus, the main research question attempted to address the issue by introducing interface elements to reduce the shortcomings of alerts in current system. By relying on a situation awareness oriented design process, SA requirements specific for alerts, together with insights gathered from SME interviews and established SA design principles, created a foundation for eight interface elements to be designed and implemented into a prototype. The presented interface elements aimed at integrating surrounding bridge alerts into the radar, provide crucial information to increase understanding of an alert, reduce auditory distractions, and visualize relationships between crucial factors. Although evaluations with SMEs implicated that SA was generally supported by these elements, some usability issues were found during the think aloud protocol, mostly regarding ambiguity of what was interactable where some elements were harder for participants to locate. There were strong preferences of separating the radar from non-navigational alerts, one reason being that having both navigational and non-navigational alerts in the same interface might cause information overload and thus degrade SA. However, participants were open towards integrating it in other systems in close proximity to the radar.

Although the situation awareness oriented design process was found to provide a useful structure for identifying requirements and design SA-facilitating implementations, the normative GDTA was found to be lacking in its ability to reflect current SA pain points. To amend this, this thesis used the same semi-structured interviews which the GDTA was based on, to also explore pain points beyond information requirements. Limitations are discussed regarding the small sample size of expert users, the final evaluation methods, and potentially redundant interface elements. Ethical considerations are also raised regarding a fully integrated alert system. The following recommendations emerged from the final evaluation as well as the process as a whole:

1. Keep alert management activities around the main bridge.
    (a) Provide an ability to offload alerts to other crew members.
2. Keep the integrated alert system separate from the radar.
3. Provide information to support alert-related goals.
4. Provide an overview of the surrounding situation.
    (a) Provide an ability to visually contextualize alerts, even for simple situations.
    (b) Separate ARPA and AIS targets.
5. Design alert descriptions to be concise.
6. Provide an ability to temporarily silence alerts.
7. Balance normative and descriptive findings.
8. Provide clear indications of what is interactable.

A

Think aloud tasks

1. Increase the CPA-threshold to 1 nautic mile.
2. Turn on the vector for your own vessel.

Scenario A: *You're working on a ferry that travels between Sweden and Germany. You enter the bridge to start your shift and this is what you see on the radar interface.*

3. Use the alarm list to find out what vessels have caused the active alarms.
4. Use the alarm list to acknowledge the alarms.
5. Look at alarm history.
6. Find out what vessels have caused the active alarms without using the alarm list.
7. Acknowledge the alarms without using the alarm list.
8. You can now see an active route alarm, find out what it means and then look at the history for previous route alarms.

Scenario B: *You enter the bridge for a new shift and can hear active alarms all around you. Sound is coming from a panel at the back of the bridge, from a system on the left wing and another system on the right side of the main bridge. This is what you see on the radar interface.*

9. Before starting to investigate the alarms, mute their sound.
10. Navigate to the equipment alarms and try to understand the active alarms.
11. Try to find out what caused the active camera alarm.
12. Acknowledge all active alarms.

B

Semi-structured interview questions for specifying user requirements

1. What is your experience at sea?
2. What is the overall goal when navigating in a target rich environment?
    (a) If the answer consists out of several elements (subgoal X, Y, Z):
        i. Why X/Y/Z?
        ii. How X/Y/Z?
3. What decisions do you have to make to reach subgoal X/Y/Z?
    (a) Do you have any examples of how this decision can go wrong?
4. What information do you need to be able to make that decision?
    (a) What information would be ideal?
    (b) Where is this information coming from?
    (c) What information risk being missed?
5. How do the alarms and warnings of the system affect your decisions?
    (a) What information do they provide?
    (b) What factors affect how you perceive alarms?
    (c) How do you handle alarms in a target rich environment?

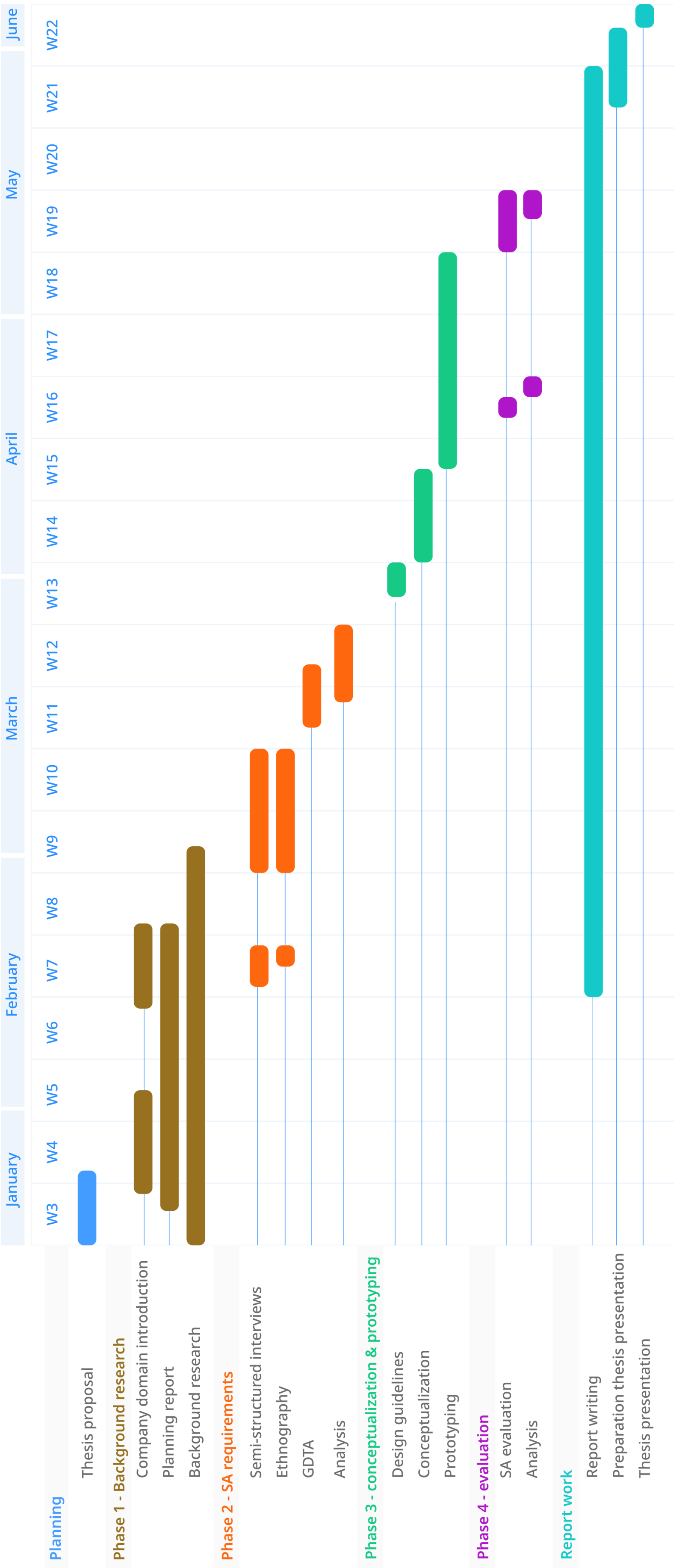
C

Semi-structured interview questions for evaluation

1. What is your experience at sea?
2. How did the presented concept affect your ability to understand what type of alarm was active?
3. How did the presented concept affect your ability to understand what caused an alarm?
4. How does the ability to see active navigation alarms directly on the radar interface affect your situation awareness?
5. How does the ability to see the direct connection between a navigation alarm and what vessel has caused it affect your situation awareness?
6. How does the ability to see the current CPA threshold affect your situation awareness?
7. How does the ability to see the current TCPA threshold of you own vessel affect your situation awareness?
8. How would the ability to acknowledge alarms from other systems affect your situation on a bridge?
9. How would the ability to mute an alarm for X minutes affect your situation on a bridge?

D

Time plan as defined in the planning report


January
February
March
April
May
June
W3
W4
W5
W6
W7
W8
W9
W10
W11
W12
W13
W14
W15
W16
W17
W18
W19
W20
W21
W22
Planning
Thesis proposal
Phase 1 - Background research
Company domain introduction
Planning report
Background research
Phase 2 - SA requirements
Semi-structured interviews
Ethnography
GDTA
Analysis
Phase 3 - conceptualization & prototyping
Design guidelines
Conceptualization
Prototyping
Phase 4 - evaluation
SA evaluation
Analysis
Report work
Report writing
Preparation thesis presentation
Thesis presentation

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