

Which Radar and ECDIS Functionalities Do Nautical Officers Really Need in Certain Navigational Situations?

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ABSTRACT: Today's navigation systems risk information overload and display clutter due to the multitude of available functionalities and information. Different navigational situations present differing challenges to the navigator, because of varying traffic or maneuvering conditions. This suggests that the need for information and functionalities on ECDIS and radar systems depends on the navigational situation, which was investigated by means of an online questionnaire. A sea voyage was divided into three situations, ranging from narrow maneuvering in port areas, to confined navigable waters, and open sea. N = 80 navigators completed the questionnaire. A compound priority measure was calculated to express the need for each functionality. Approximately half of the functionalities were prioritized in a situation dependent manner and substantially more functionalities were prioritized higher on ECDIS than on radar systems. The results have strong implications for aligning navigation systems more with user needs in the sense of a human-centered design approach.

1 INTRODUCTION

Modern ship bridges comprise complex and highly automated human-machine systems [9]. The crew's safety and capability to accomplish core navigation tasks strongly depends on interacting effectively with machines, as is characteristic for complex sociotechnical systems. Effective interaction is most likely to be achieved when the information flow between humans and machines is optimally attuned to human capabilities and skills [17, 18]. One way to enable this adaptation is to adopt a human-centered approach when designing the interactive system. Human centered design aims to maximize the usability of interactive systems by focusing on the users, their needs and requirements [7]. This is achieved by applying human factors and ergonomics methods. For instance, users should be included in all phases of the design process of the interactive system.

As a result, the users' effectiveness and efficiency, but also their satisfaction and safety when using the interactive system, will likely be enhanced.

Unfortunately, human-centered approaches are rarely employed in the design process of bridge systems [2] with user needs being rarely the primary focus [9], although the e-navigation concept strives to do so [13]. As a result, ship bridge design is not well aligned with human skills and abilities, which in turn likely leads to impairments in efficient execution of core tasks such as collision avoidance and navigation. This can potentially have severe consequences. Consistent with our reasoning, poor design has already been identified as a contributing factor to accidents [9, 17, 21, 23].

The concept of situation awareness comes into play when investigating the link between poor design and the prevalence of accidents [9, 23]. Situation

awareness describes the ability to perceive events in the current environment (level 1), to understand their current meaning (level 2), and to be aware of what they imply for the future (level 3) [6]. Thus, situation awareness is highly dependent on information about the current situation [3]. Such information is gathered in two ways, by looking out the window and by precisely examining bridge systems. In the latter case, information is usually not directly available, but only through selecting certain functionalities. If functionalities and corresponding information are presented inadequately or if simply too many information and functionalities are displayed, nautical officers may experience information overload and retrieve relevant information too slowly [24]. This in turn may cause impaired situation awareness [5] which has often been directly linked to accidents as a causal factor [23].

In the last years, a strong increase of modern information systems and thus of available information on ship bridges has been observed [23], well above and beyond the scope of information and functionality required by current performance standards [11, 12]. Therefore, we assume that there is a serious risk of current systems impeding the establishment of adequate situation awareness due to their sheer volume of information and functionalities. Furthermore, the findings of a study suggest that not all functionalities displayed are used frequently in practice [24]. In this study, navigators completed an online questionnaire indicating how frequently they use selected functionalities and information on integrated navigation systems (INS) during a watch. They were additionally given the opportunity to comment on their responses. Many navigators used this opportunity to report that the functionalities' frequency of use often depends on the navigation situation.

The findings of [24] have two major implications. First, they suggest the feasibility of reducing the number of functionalities and presenting them according to the navigators' needs. Only information and functionalities that are really needed should be available on bridge systems to reduce clutter and information overload [5]. The necessity of rarely used functionalities is therefore questionable. On the other hand, the findings of [24] also hint at how the number of functionalities could be reduced – by presenting only those information and functionalities that are needed in the current navigation situation. Therefore, in different navigational situations, different functionalities and information could be presented according to the navigators' needs.

A ship's voyage can be roughly divided into three navigational situations [19, 20]:

1. a maneuvering phase at the beginning of the voyage in port or in very restricted areas,
2. a phase of navigating on the open sea without much traffic or restrictions due to shallow waters, and
3. a phase between the port and the open sea, which is characterized by dense traffic, traffic separation schemes and shallow waters.

Due to the three situations' different characteristics, the specific tasks of nautical officers vary with the situation. In phase 3, the attention of

nautical officers is focused on the close-range situation (3-5 nautical miles) and on orientation between all available aids (RADAR, AIS, VHF, Echo Sounder) that serve to clearly identify the traffic situation. In phase 2 however, more emphasis is placed on an assessment of the situation in a large range (12-24 nautical miles) and especially on efficient and economical movement. In phase 1, coordinating events in the immediate vicinity of the own ship is most important, for example when coordinating along tugs or shore lines, or managing the interaction between the own ship, which is moving very slowly, environmental influences, as well as fixed installations such as piers. Phase 1 is also characterized by very restricted areas, where sensor technology is primarily needed for depth measurement and to determine the ship's drift. Those diverse situational requirements therefore likely cause the ship's bridge systems to be used differently across situations. In line with this reasoning, the range of the radar system, for example, is used differently depending on the navigation situation [14].

Hence, there is a strong need to examine the situation dependent demand for functionalities in order to enable future navigation systems to be optimally aligned with user needs in different navigational situations. The aim of the current study is to shed light on this important issue by inspecting the effect of the navigational situation on the perceived importance of functionalities and information and their frequency of use. For this purpose, nautical officers were directly consulted in the sense of a human-centered design approach [7] to identify their specific needs and requirements. Based on the current body of research [14, 24], the following hypothesis was formulated: The need for functionalities and information on ship bridge systems depends on the navigation situation. To tap more into measuring the need for functionalities, and not only their frequency of use, the importance of functionalities was additionally enquired.

2 METHODS

2.1 Participants

Navigators were recruited for participation with the support of international organizations involved in shipping. Recruitment was carried out online primarily by email. To be included in the analysis, navigators were required to have at least one year of experience at sea as a nautical officer. This was to ensure that all participants were familiar with the navigation systems and their functionalities.

A total of $N = 80$ participants completed the online questionnaire, with $n = 25$ for open sea, $n = 27$ for confined waters, and $n = 28$ for restricted areas. On average, participants possessed $M = 13.87$ ($SD = 9.85$) years of sailing experience and most of them (66%) had been sailing during the past six months prior to the study. The navigators were most acquainted with tankers (56%), bulkers (16%) and containers (15%), and were employed as second officer (35%), master (28.7%), third officer (15%), and first officer (2.5%), or

possessed another nautical position (18.8%) at the time of data collection.

2.2 Measuring and Assigning the Priority of Functionalities

In this study, our aim was to investigate how to arrange functionalities on navigational displays for different navigational situations to be optimally in line with human skills. For this purpose, navigators were asked to indicate how frequently they use 169 ECDIS and 168 radar functionalities and how important they consider them when navigating in a certain situation. We selected the functionalities for the questionnaire based on simulator investigations of three ECDIS and radar systems. See Table 1 for a list of categories and a selection of example functionalities.

Table 1. Categories and example functionalities

Categories	Example functionalities
Own ship information	Heading, ROT
Environmental information	Wind speed, direction of current
Display presentation	Select ship centered mode, change range/scale indication and setting
Cursor location	Cursor position, cursor bearing from own ship
Tools	Select and display range rings, select and display VRM1
Route information	Route name, next WPT number
Route monitoring	Set cross track distance, display bearing to next waypoint
Targets and other objects	Acquire Radar target, activate AIS target
Chart settings	Select safety depth, show deep contour
Display of environmental data	Select tidal data, select surface currents
Own ship settings	Select show stern line, select show past track for own ship
Radar setting	Select S- or X-band, set gain
Functionalities	Set a trial maneuver, perform parallel indexing
Alert handling	Acknowledge alerts, temporarily silence alerts

The same online questionnaire served as the basis for a previous study by our research group, in which the task dependency of functionalities was investigated [10]. In this previous study, we examined the interaction effect of the task a functionality belonged to (route monitoring vs. collision avoidance) and the device on which the functionality was available (radar vs. ECDIS). To analyze this interaction, a subsample of 210 of the 337 surveyed functionalities was examined, which included only those functionalities that could be clearly assigned to one of the two tasks.

In contrast, the main purpose of the present study was to investigate whether the navigational situation had an influence on the evaluation of all 337 functionalities. As in the previous study, the variable of interest was coined as the priority of a functionality, consisting of an integration of the two factors surveyed: frequency of use and importance. Frequency of use is established as a valid indicator of whether users really need a feature (see [24]). As a

rule, the more frequently a feature is utilized, the faster it needs to be accessible. Yet, there are functionalities that need to be rapidly accessible, even though their frequency of use is low. The POB function for example is allegedly almost never employed but may become extremely important in a person overboard situation. Therefore, functionalities' frequency of use was complemented by surveying functionalities' importance. These two ratings were obtained using 5-point scales. The frequency of use scale covered ratings from "never" (1) to "always" (5), whereas importance was classified from "extremely unimportant" (1) to "extremely important" (5). See Figure 1 for example questions.

ECDIS: Frequency
How often do you use this functionality on ECDIS?

never always
1 2 3 4 5

Set display brilliance ○ ○ ○ ○ ○

Display AIS targets ○ ○ ○ ○ ○

ECDIS: Importance
How important is this functionality on ECDIS?

extremely unimportant extremely important
1 2 3 4 5

Set display brilliance ○ ○ ○ ○ ○

Display AIS targets ○ ○ ○ ○ ○

Figure 1. Example questions for ECDIS and two functionalities

To create the priority measure that accommodates both types of information, we integrated the two ratings on a global 5-point scale. On this scale, a high priority rating indicates a high overall need for the functionality, whereas a low rating corresponds to a low need for the respective functionality. We employed expert ratings of importance, frequency of use and priority for developing our global priority measure. These established the following rules: first, if a functionality received the highest possible importance or frequency of use rating, or both, it was given a priority rating of five, resembling the highest priority. Second, if the frequency of use and importance ratings coincided, the corresponding rating was adopted for the priority scale. Third, if the frequency of use and importance ratings deviated by one point, the higher rating from both scales was taken for the priority. Fourth, if the frequency of use and importance ratings featured a two-point difference, the mean of both ratings was calculated and adopted as the resulting priority. The remaining cases were classified with a priority of three.

2.3 Situation Dependency of Functionalities

In this study, our aim was to investigate whether the need for functionalities depends on the navigational situation. For this purpose, three navigational situations were defined: open sea, confined waters and restricted areas. Open sea was described as a situation without any land, water depth, or traffic separation restrictions and with little traffic (e.g. the middle of the Atlantic Ocean). Confined waters was

characterized by opposing features, as it was marked by the presence of land, water depth, traffic separation restrictions and heavy traffic (e.g. the English Channel). Lastly, restricted areas were described as areas with very limited maneuverability due to the presence of land, port, water depth, and height restrictions (e.g. port areas).

To quantify situation dependency, mean priority ratings were first calculated for each functionality and then trimmed by 20%. Trimmed means were used to account for possible deviations from the normal distribution, as they are less sensitive towards outliers than untrimmed means and thus more robust [8, 16]. Trimmed means were then rounded, which enables precisely assigning the functionalities to one of the five priority levels. Finally, functionalities were classified as either situation dependent or situation independent, based on the assigned priority level. Only if functionalities received equal priorities in all three situations, they were coined as being independent of the situation. Otherwise, functionalities were classified as situation dependent.

2.4 Experimental Design

We employed a 2 x 3 mixed design with navigational device (radar and ECDIS) as within-subjects factor and situation (open sea, confined waters, restricted areas) as between-subjects factor. The questionnaire measured the frequency of use and importance of each functionality for each device in each situation. Those ratings were combined to a compound priority rating. The dependent variable of interest consisted of the trimmed and rounded means of functionalities' priority ratings. The two independent variables are described in more detail below.

Device. Participants rated the frequency of use and importance of 176 functionalities available on radar and ECDIS navigation systems (within-subjects factor). Since 161 of the 176 functionalities (91%) are available on both systems, whereas 8 functionalities are available on ECDIS only, and 7 functionalities on radar only, each participant rated a total of 337 functionalities.

Situation. Participants were randomly assigned to one of three navigational situations in order to reduce the questionnaires' length. At the beginning of the questionnaire, participants were asked to focus on the indicated situation while answering the questions. Thus, situation was employed as a between subjects factor with three levels.

2.5 Procedure

Data was collected by means of an online questionnaire, which was programmed using the online survey tool SoSci Survey [15]. First, navigators were provided with general information regarding the research aim and gave their informed consent for participation. General questions were displayed concerning the navigators' occupational background. Then, information about one of the three possible situations was given, after which a control question was asked to assure that participants were aware of the assigned situation. Finally, participants rated the

functionalities' frequency of use and importance on 5-point scales. They were given the opportunity to leave additional comments regarding the presented functionalities at each page of the questionnaire. Overall, completion of the survey took approximately 90 minutes.

2.6 Data Analysis

We performed both descriptive analyses and inferential statistical tests with the help of IBM SPSS and R. To avoid extensive α -error accumulation, we did not apply inferential statistics to investigate the situation dependency individually for each functionality. However, inferential statistics were applied to examine the global effect of situation and device and possible interactions on trimmed priority ratings. For this purpose, a mixed model ANOVA was set up with the two factors device and situation, including only the trimmed priority ratings of functionalities available on both devices ($n = 161$ functionalities per device). Testing the assumptions of the mixed model ANOVA revealed that group variances for ECDIS were heterogeneous, as assessed by Levene's test ($p = .001$), whereas they can be assumed to be homogenous for radar ($p = .273$). Inspection of the Q-Q-plots suggested a deviation from the normal distribution of trimmed priority ratings. However, our sample consisted of $n = 161$ functionalities per cell and mixed model ANOVAs are considered to be robust against normality violations and heterogeneous variances, when sample size is large and equal in all cells [22].

A one-way ANOVA with situation as factor and trimmed priority ratings of all functionalities included ($n = 337$ per situation) was conducted to follow-up the mixed model ANOVA. Again, Q-Q-plots indicated deviations from a normal distribution and Levene's test was significant ($p = .014$), but sample size is sufficiently large for the ANOVA to be considered robust [22]. The one-way ANOVA was followed by three independent samples t-tests. For all inferential statistical tests, an alpha level of $\alpha = .05$ was employed and Bonferroni adjusted if appropriate. As a measure of effect size, Cohen's d , η^2 and η_p^2 were utilized and interpreted according to [1].

3 RESULTS

Descriptive statistics of trimmed priority ratings are displayed in Table 2. Untrimmed priority ratings were included to illustrate the difference between untrimmed and trimmed ratings. The means of trimmed priority ratings were consistently higher than the corresponding means of untrimmed priority ratings on both devices and in all three situations. Our priority scale consists of five levels, with the third level representing the scales' midpoint. All means were well above a value of 3, suggesting that most functionalities received a rather high priority. This also explained why trimmed means were always higher than untrimmed means, since the lowest 20% of priority ratings that were excluded then had a greater impact on the mean than the highest 20% of priority ratings that were excluded.

Table 2. Means (and standard deviations) of untrimmed and trimmed priority ratings for 169 ECDIS and 168 radar functionalities

Device	Open Sea (n = 25)		Confined Waters (n = 27)		Restricted Areas (n = 28)	
	untrimmed	trimmed	untrimmed	trimmed	untrimmed	trimmed
Radar	3.63 (0.85)	3.72 (1.03)	3.36 (0.86)	3.41 (1.12)	3.53 (0.84)	3.58 (1.03)
ECDIS	4.14 (0.52)	4.37 (0.61)	3.83 (0.67)	4.01 (0.84)	4.08 (0.58)	4.28 (0.66)

Table 3. Descriptive statistics of trimmed priority ratings for the 161 functionalities applicable to both devices

Device	Open Sea (n = 25)		Confined Waters (n = 27)		Restricted Areas (n = 28)	
	M	SD	M	SD	M	SD
Radar	3.71	1.05	3.42	1.14	3.57	1.04
ECDIS	4.37	0.62	4.00	0.85	4.27	0.67

As shown in Table 2, radar functionalities received lower mean priority ratings than ECDIS functionalities in all three situations. Furthermore, irrespective of the device, the priority of functionalities in confined waters is on average lower than the priority of functionalities in the other two situations. Functionalities received the highest mean priority ratings on open sea. A mixed model ANOVA was set up to investigate whether these observed differences in trimmed priority ratings are statistically significant. Only those functionalities available on both devices were included in the mixed model analysis, leading to an elimination of 15 functionalities (n = 161 per device). The descriptive statistics of these do not differ substantially from those with all functionalities included (see Table 2) and are displayed in Table 3.

The mixed model ANOVA yielded a significant main effect of device ($F(1,480) = 111.83, p < .001, \eta_p^2 = .19$) as well as a significant main effect of situation ($F(2,480) = 11.50, p < .001, \eta_p^2 = .05$). The interaction between device and situation was not significant ($F(2,480) = 0.30, p = .739, \eta_p^2 < .01$), indicating that the main effects can be analyzed and interpreted separately. Since the main effect of device was significant, the above observations regarding the device dependency were underpinned statistically. Trimmed priority ratings of radar functionalities were indeed significantly lower than trimmed priority ratings of ECDIS functionalities with a medium effect size ($d = 0.69$).

The significant main effect of situation was investigated further by conducting a one-way ANOVA including all functionalities (n = 337 per situation). The ANOVA model with situation as factor and trimmed priority rating as dependent variable reflected a significant difference in trimmed priority ratings between situations ($F(2,1008) = 10.24, p < .001, \eta^2 = .02$). Consequently, three t-tests were conducted to examine the difference. After applying a Bonferroni correction to adjust for multiple testing ($\alpha = .017$), there were significant differences in priority ratings with small effect sizes between confined waters and open sea ($t(661) = -4.40, p < .001, d = -0.34$) and between confined waters and restricted areas ($t(665) = 2.81, p = .005, d = -0.22$). The difference between open sea and restricted areas was non-significant ($t(672) = 1.64, p = .101, d = 0.13$). Therefore, trimmed priority ratings were significantly lower for confined waters than for the other two situations, confirming the descriptive observation above. However, trimmed priority ratings for open sea were not significantly higher than ratings for restricted areas.

3.1 Device Dependency

As the inferential statistical tests described only address the global means across all functionalities, the device dependency effect was examined more closely in the following. On each device, the functionalities' distributions over the five priority levels after rounding the trimmed priority ratings were observed and are displayed in Figure 2 and in Figure 3. Radar functionalities (Figure 2) seem to be more evenly distributed over the five priority levels than ECDIS functionalities (Figure 3). On ECDIS, one can observe a descending order: the two highest ratings (levels 5 and 4) were predominantly given, while some functionalities received a priority of 3 and even less functionalities received a priority of 2. No functionality was evaluated with a priority of 1 on ECDIS. On Radar, three functionalities received a priority rating of 1 in confined waters. Therefore, navigators very rarely classified functionalities as "extremely unimportant" and as "never used" at the same time, while a majority of functionalities were rated as either "extremely important", "always used", or both.

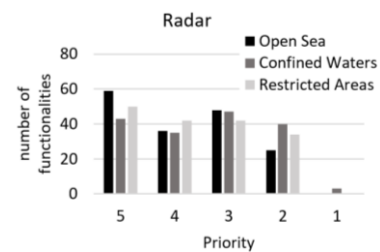


Figure 2. Number of functionalities in each priority level by situation on radar

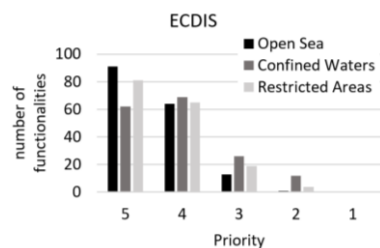


Figure 3. Number of functionalities in each priority level by situation on ECDIS

Table 4. Examples of functionalities in the respective situation dependency categories

Situation dependency	Example functionalities on radar	Example functionalities on ECDIS
OS ↑	<ul style="list-style-type: none"> - Alphanumerical position - Rudder angle - Set curved heading line - Select display of unknown objects - Enter geographical coordinates of any position and display that position 	<ul style="list-style-type: none"> - Alphanumerical position - Select display orientation North Up/Head Up/Course Up - Select true/relative motion mode - Enter geographical coordinates of any position and display that position - Set alert escalation (unacknowledged warning escalation time)
CW ↑	--	<ul style="list-style-type: none"> - change displayed chart area manually
RA ↑	<ul style="list-style-type: none"> - Remove chart data - Select safety depth - Select video emphasis - Distance to "TO-WPT" - ETA 	<ul style="list-style-type: none"> - Select align by heading or course over ground for heading line - Select show 2nd past track for own ship - Temporarily silence alerts/alarms - POB function
OS ↓	<ul style="list-style-type: none"> - Show time labels - Time to go to "TO-WPT" - Radius 	<ul style="list-style-type: none"> - Toggle past positions on/off - Set target vector length (time) - Perform manual update
CW ↓	<ul style="list-style-type: none"> - COG - Set and load user configurations - Set filters for AIS target information - Select Display Base/Standard Display/All Information - Calculate rise/set sun and moon 	<ul style="list-style-type: none"> - Set own ship track length (time) - Set filters for AIS target information - Add/remove information from standard display - Plot own ship position manually (dead reckoning) - Set AIS settings (transmitter, select auto/manual for channel A/B, ...)
RA ↓	<ul style="list-style-type: none"> - Water depth under keel - Water depth (chart datum) - Show shallow contour - Add/remove information from standard display - Time to go to cursor position 	<ul style="list-style-type: none"> - Water depth under keel - Select default ECDIS settings - Set curved heading line - Time to go to cursor position - Wind speed

3.2 Situation Dependency

Similar to the device dependency effect, the situation dependency effect was also examined more closely by looking at the individual functionalities. While the priority of some functionalities appeared to be situation independent, the priority of other functionalities differed by situation. In total, 77 radar functionalities (46%) and 86 ECDIS functionalities (51%) were classified as situation dependent according to the rules specified (see section 2.3). Consequently, 91 radar functionalities (54%) and 83 ECDIS functionalities (49%) received the same priority ratings in all three situations, i.e., were classified as situation independent. Therefore, the priority ratings of approximately half of the radar and ECDIS functionalities can be viewed as depending on the navigational situation.

To explore how exactly situation dependency manifested itself, further analyses were conducted. As the mixed ANOVA model already showed, situation dependency stemmed mostly from the fact that functionalities were evaluated differently in confined waters than in the other two situations. This difference was most pronounced with respect to priority ratings of 5, 3 (ECDIS) and 2, but not for ratings of 1 and 4, in which the number of priority ratings was approximately the same in each situation, as displayed in Figure 2 and Figure 3. In confined waters, less functionalities received the highest priority rating compared to the other two navigational situations, complemented by a higher number of lower priority ratings (i.e., ratings of 3 and 2).

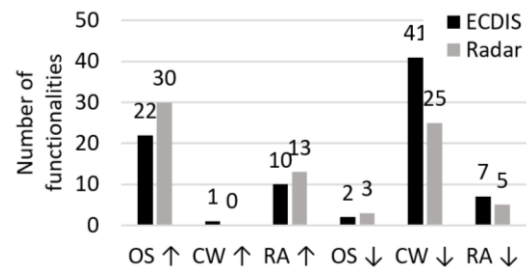


Figure 4. Number of situation dependent functionalities categorized by the situation in which they received the highest priority (indicated by ↑) or the lowest priority (indicated by ↓). Functionalities received the same priority in the unmentioned situations. OS = open sea, CW = confined waters, RA = restricted areas

Figure 4 provides a clearer picture of functionalities' situation dependency by displaying the number of functionalities that differed by one priority level when comparing one situation to the other two. If a functionality received the highest (indicated by ↑) or lowest (indicated by ↓) priority rating in one situation, it received the same priority in the other two situations. There was only one functionality on ECDIS ("change displayed chart area manually") that received the highest priority in confined waters. Again, most situational differences originated from functionalities that received a lower priority in confined waters than in the other two situations. This was true for 25 radar and 41 ECDIS functionalities, supporting the trend seen in Figure 2, Figure 3 and the mixed ANOVA results. The second most frequent origin for situation dependency was a higher priority rating of functionalities on open sea than in the other two situations, which accounted for 30 radar and 22 ECDIS functionalities. Functionalities

receiving the highest or lowest priority in restricted areas, or the lowest priority in open sea were by far less frequent. Table 4 displays examples of functionalities classified in the respective situation dependency category.

Table 4 and Figure 4 only include those functionalities with a situational difference in priority ratings of one level. Additionally, a difference of two priority levels between at least two situations were obtained in the following four functionalities: “rudder angle” (ECDIS), “propulsion engine RPM” (ECDIS), “select S- or X-band” (ECDIS), “set AIS settings” (Radar).

4 DISCUSSION

The design process of ship bridge systems rarely adheres to a human-centered design approach [2] and seldom addresses users’ needs [9]. In our current study, we aimed at changing this by surveying navigators about how frequently they use functionalities on ECDIS and radar systems and how important they consider these. These two measures were used to derive navigators’ overall need for the functionality on the respective system by assigning them to one of five priority levels. As previous research suggests that functionalities’ use depends on the navigational situation [24], we specifically surveyed the need for functionalities in three separate navigational situations: open sea, confined waters and restricted areas.

4.1 *Summary, Interpretation and Practical Relevance of Study Results*

Our analyses revealed that for about half of all 337 functionalities, the priority depended on the situation, although the difference in priority between the situations consisted only of one priority level for the majority of functionalities (98%). Situation dependency was mostly due to functionalities receiving a higher priority on open sea or a lower priority in confined waters than in the respective other two situations, as confirmed by the inferential statistical analysis. On average, functionalities received a significantly lower priority in confined waters compared to the other situations, regardless of the considered navigation system.

One possible explanation for the higher prioritization of functionalities on open sea than in the other two situations is that on open sea, navigators may have to rely more on navigation systems because looking out of the window might not reveal much information there. On the contrary, in confined waters and restricted areas there is rather high traffic density and a proximity to the shore. Thus, most events happen within a close range of the own ship and navigators retrieve most situational information by simply looking out the window. Another plausible explanation is that events on open sea are relatively rare, allowing navigators to take the time to modify routes and to prepare impending entries of busier confined waters by adjusting limits and other settings optimally to the circumstances in confined waters. As

a result, the need for such settings is higher on open sea than in confined waters. The navigators’ comments underpin this assumption (see [10]).

Further, priority levels were given more distinctively in confined waters. The need for functionalities may thus be more differentiated in confined waters than in the other two situations. On open sea and in restricted areas most functionalities were classified in only two of the five possible priority levels, which was more pronounced for ECDIS than for radar functionalities. In these two situations almost all functionalities were assigned to the two highest priority levels for the ECDIS. Therefore, navigators are reluctant to dismiss functionalities as extremely unimportant and never used, in line with a central tendency bias often observed in questionnaires, which states that participants prefer scale midpoints over extremes [4]. However, for higher priority levels, a central tendency bias was not observed on the ECDIS, since most functionalities were assigned to the two highest priority levels. Hence, ECDIS functionalities are classified either as extremely important, always used or both.

These findings are somewhat surprising, as one would expect that some functionalities are not needed due the high number of functionalities available on the navigation systems. According to the survey results, a large amount of ECDIS functionalities is needed. This highlights the importance of optimally adapting the ECDIS design to navigators’ skills and capacities. All functionalities need to be accessible quickly and effortlessly to allow for efficient execution of core tasks.

In contrast to ECDIS functionalities, considerably more functionalities on radar were assigned to lower priority levels (see Figure 2). Accordingly, the mean priority of radar functionalities was significantly lower than the mean priority of ECDIS functionalities, regardless of the situation. Consequently, the need for radar functionalities is more nuanced than the need for ECDIS functionalities. Results from our other analyses underline this finding, indicating that radar systems are mainly seen as collision avoidance tools, whereas a less clear task allocation emerges for the ECDIS [10].

Taken together, these results indicate that the need for a functionality both depends on the navigational situation in which it is used and on the device, on which the functionality is displayed, with most functionalities receiving a high priority rating. These results include important insights into how ECDIS and radar functionalities should be presented. On the one hand, a situation dependent presentation would be plausible, in which functionalities are presented differently in the three situations according to the navigators’ needs (which is in line with [13]). However, different situation modes should be employed with caution. According to [5], the number of modes should be limited in order to prevent mode confusion. Navigators may receive training to understand and use the different modes correctly, so that mode changes are expected and self-initiated only. Future studies need to investigate whether ECDIS and radar designs would benefit from incorporating multiple situation modes when navigators receive sufficient training. It would be

particularly interesting to see, if these new ECDIS and radar designs perform better than traditional designs in simulator tests, for example. In general, it would be interesting to know, in which aspects the new ECDIS and radar designs differ from traditional designs.

Further, the results offer implications on how functionalities can be presented efficiently in the navigational situations. For example, the functionalities' priority could be used as an indicator of how quickly accessible the functionality should be in the respective situation [10]. This offers a feasible approach for radar systems, since on the radar, different functionalities were assigned quite heterogeneously to priority levels. On the ECDIS, however, due to the largely homogeneous prioritization, the accessibility measure alone will not be sufficient to guide display design. Further investigations and iterations with users actively participating in the design process according to [7] will be necessary.

4.2 Study limitations

We employed a between subjects design to investigate the effect of the navigational situation on the priority of functionalities. For this reason, it is not completely clear whether the same navigator would have prioritized functionalities differently in the three navigational situations. However, we believe that the between subject design was necessary to avoid extending the already very long online questionnaire even further. Furthermore, the relative ranking of the functionalities' priority within one situation is not affected by the chosen method and is thus still sufficient to guide display design. Nevertheless, we will carry out further studies to investigate whether the situation dependencies observed are solely attributable to the design employed.

Another limitation is that we rounded the trimmed means of priority ratings to be able to assign them to different priority levels unambiguously and to quantify situation dependency. Rounding sometimes creates arbitrary differences. For instance, a trimmed mean of 4.4 would be assigned to a priority of four, while a trimmed mean of 4.6 would receive a priority of five, although the difference in trimmed means is very small. Furthermore, the practical relevance of our obtained situational differences might be questioned, since most situation dependencies (98%) resulted from a difference of only one priority level. For this reason, it is important to test a design guided by the results of this questionnaire extensively before establishing it in practice.

5 CONCLUSIONS

This study investigated the research question of which functionalities nautical officers really need in which navigational situations. Nautical officers regarded almost none of the functionalities (< 1%) as never used and extremely unimportant. Thus, the aforementioned question must be answered in the following way based on the study's results. Nautical officers need almost all functionalities to a certain extent regardless

of the navigational situation. However, differences in the intensity of the need between the navigational situations and the considered devices have been observed. About half of the functionalities could be classified as being used in a situation dependent manner. Functionalities received overall higher and more homogeneous priority ratings on the ECDIS than on the radar, where priority ratings were on average lower and more heterogeneous. These results offer implications for ECDIS and radar design and provide an important step towards a more human-centered design approach. For instance, functionalities might be presented in different situation-dependent modes. Priority ratings may serve as sufficient indicators of how fast a respective functionality should be accessible on the radar. For the ECDIS, where priority ratings were quite high and not as diverse, future studies may investigate how functionalities can be presented to avoid information clutter and overload, allowing for an effective user-centered navigation.

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