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Identification of Weak Links in the ECDIS - Operator System Based on Simulator Training

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ABSTRACT: Statistics, based on grounding incident investigations, is not always sufficient for retrieving objective information and designing comprehensive solutions for improving the ECDIS training process for deck officers and development of methods aimed at reducing the grounding incident rate and improving the effectiveness of navigation. The research studies statistics on deck officers` errors made during training on bridge simulators equipped with ECDIS and provides an analysis of errors distribution among navigators of different ranks. The study shows that in event of the EPFS (Electronic Position Fixing System) failure the likelihood of grounding increases dramatically for all deck officers, irrespective of rank and experience, despite having fully functional radar and ECDIS in dead reckoning mode.

1 INTRODUCTION

Since 2002, Electronic Chart Systems (ECS) have gained legal status and became widely used on ships. According to the requirements of SOLAS regulation V/19-2.14, ECS could be used together with navigational paper charts. The situation changed significantly in 2009. Scientific and technological progress is not standing still and at the IMO Maritime Safety Committee meeting in May 2009, it was decided to introduce ECDIS (Electronic Chart Display and Information System), as a compulsory part of navigation equipment, on all vessels of more than 10,000 GT. Risks associated with this early implementation stage are outlined in [17], which highlights the importance of system integrity monitoring, operators' training, and, generally, spreading awareness of system limitations and errors in order to reduce the potential of over-reliance.

The introduction of electronic charts was gradual, from 2012 to 2018. During this period navigators had to learn to work with new equipment and use ECDIS. At the same time, paper charts were replaced by electronic ones. ECDIS EHO [2] and further surveys [4] allowed to extensively elaborate the end-user feedback in transition and fully paperless periods noticing the drastic change of paradigm between conventional PNC (paper navigational chart) and ENC (electronic navigational chart) navigation experience. ECDIS EHO survey revealed that 60% of respondents have problems of different nature when operating the system (usability, access to information, system software/hardware reliability, sensors, chart handling, knowledge, and skill), and 19% of respondents notify inconsistencies in system operation.

The analysis of accidents in recent years keeps revealing overreliance on ECDIS trait. The study of causes of grounding accidents and analysis of possible preventive measures [15] shows that "…obligation to have Electronic Chart Display and Information Systems (ECDIS) and compulsory ECDIS training for watchkeeping officers" and "…improvement of education and training" are the top alternatives proposed to prevent grounding accidents involving human errors. IMO has adopted the Guidance for Good Practice for the use of ECDIS [8], which emphasizes the importance of the operator's ability to act in the event of failure, display data interpretation and identification of possible errors. The trend of ECDIS related groundings necessitates a more detailed analysis of the accidents' causes, as well as further development of passage planning methods adopted for paperless navigation.

Data obtained in the process of training and assessment of deck officers on the mini-bridge simulator equipped with ECDIS (Wartsilla Navi-Sailor 4000) allowed to perform a more detailed analysis of direct and indirect factors that increase the probability of vessel grounding.

2 ECDIS SAFETY PARAMETERS AND DISPLAY SETTINGS

The principal difference between ECDIS and paper charts is that the operator can adjust the way the system displays the nautical chart on the screen, as well as the way the system notifies users of potential hazards. This is done with a series of display settings (filters) on one hand and safety parameters on the other. Even as this feature can be very advantageous in capable hands, misuse of display and safety settings can lead to misjudgment and incorrect assessment of the navigational situation.

For instance, the SCAMIN value of an object determines the display scale below which the object is no longer visible on ECDIS. The purpose of SCAMIN is to reduce the amount of clutter displayed to the ECDIS user. Depth soundings are usually the first to disappear. In figure 1 you can see a comparison of the same ENC with the current display scale slightly smaller than the ENC compilation scale. What is important, is that soundings, which are less than Safety Depth disappear as well, when SCAMIN is ON.

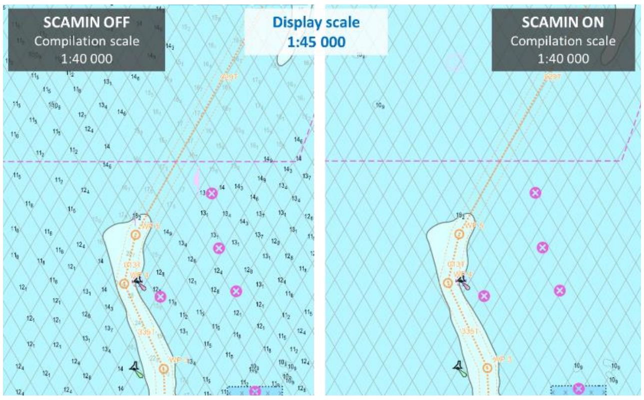

Figure 1. Application of SCAMIN setting on ENC

Generally, a Guide to Safe Navigation issued by Intertanko [5] as well as the work by Becker-Heins [1] and ECDIS Procedures Guide by Witherby [17] provide series of recommendations on proper display and safety settings. As specified in ECDIS performance standards by IMO [9], these settings are: safety depth (D_{safe}), safety contour (C_{safe}), deep contour (C_{deep}), shallow contour ($C_{shallow}$), cross-track distance (XTD) and turn radius (Rad). It is important to understand that these settings affect not only the visual display, but also the behaviour of the alarm and indication system, also known as anti-grounding system.

It is important to define the safety depth from the perspective of navigational risk assessment.

Lemma. The risk of grounding exists if the vessel has a non-zero speed and is heading to an area where the dynamic draft of the vessel may be equal to or greater than the depth.

Hence, the safety depth is the depth above which, considering measurement errors, inaccuracy of cartographic information and dynamic factors (squat, heaving and pitching, etc.), the vessel with a given probability will pass without contact with the bottom.

The most detailed assessment of the safety depth components is given in Harbour Approach Design Guidelines by PIANC [6] shown in figure 2.

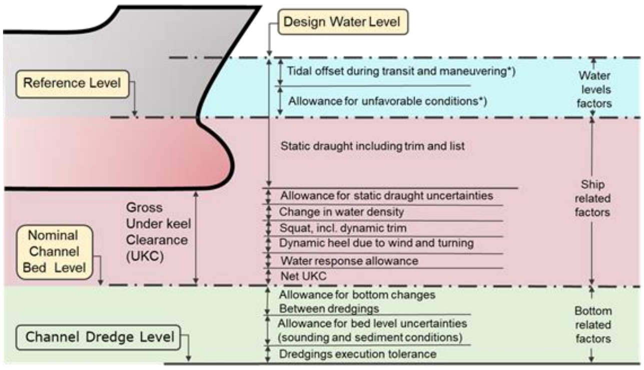

Figure 2. Safety depth components according to PIANC [6]

Basing on the analysis of the publications safety depth and contours can be defined as:

$$D_{safe} = T_{static} + UKC + \Delta_{squat} + \Delta_{ZOC} + \Delta_{\rho} + \Delta_{\varphi} + \Delta_{\theta} - \Delta_{tide} \qquad (1)$$

where: UKC – under keel clearance; T_{static} – ship static draft; Δ_{squat} – ship maximum squat; Δ_{ZOC} – chart accuracy (ZOC) correction; Δ_{ρ} - change of density correction; Δ_{φ} - correction for pitching and heaving; Δ_{θ} - heel correction, Δ_{tide} – tide level.

$$\left.\begin{array}{l} \mathcal{C}_{safe} = D_{safe} \\ \mathcal{C}_{deep} = 2T_{static} \\ \mathcal{C}_{shallow} < \mathcal{C}_{deep} \end{array}\right\} \qquad (2)$$

Safety depth components can be generally defined as:

$$\Delta_{squat} = f\left(\mathbb{S}, \mathbb{C}, U_w\right) \qquad (3)$$

$$\Delta_{ZOC} = f\left(ZOC, h\right) \qquad (4)$$

$$\Delta_{\rho} = T_{static}\left(1 - \frac{\rho_1}{\rho_2}\right) \qquad (5)$$

$$\Delta_{\varphi} = f\left(\mathbb{S}, \varphi_{max}\right) \qquad (6)$$

$$\Delta_{\theta} = f\left(\mathbb{S}, \theta_{max}, w_{max}\right) \tag{7}$$

$$\Delta_{tide} = f\left(\mathbb{G}, t\right) \tag{8}$$

where: S – set of parameters defining ship's hull; C - set of parameters defining the channel or shallow bank configuration; U_w – ship speed through the water; ρ_n – water density; φ_{max} – maximum expected heeling angle; w_{max} – maximum expected heave; θ_{max} – maximum expected pitching angle; G – set describing a geographical location; t – time.

We will omit the detailed safety depth calculation here, as it is a subject for a separate research and analysis, however, components of equation (1) can be estimated by methods suggested by Becker-Heins [1] or PIANC [6].

On the basis of the analyses of industrial recommendations and research publications, particularly [1, 5, 11, 12], industry-recommended limits and alarm settings are compiled in table 1.

Table 1. Summary of industry-recommended limits and alarm settings

Parameter	Setting		
Display	Standard + Custom layers		
Ship as	Contour		
Turn radius	To satisfy recommended RoT limit (10-20°/min)		
Safety Depth	Draft + UKC Policy		
Safety contour	= Safety Depth		
Deep contour	= 2 × Draft		
Shallow contour	Next smaller than Safety Depth		
	Harbour approach	Coastal sailing	Open Sea
Cross-track limit	≥Breadth – 0.1 nm	0.1 nm – 1.0 nm	≥Tactical Diam.– 2.0 nm
Safety frame	6 min ǀ XTL	12 min ǀ XTL	18 min ǀ XTL
Track time labels	≤6 min	12 - 30 min	30 – 60 min

Regardless of the ECDIS manufacturer ECDIS performance standards by IMO [9] prescribe certain layers of information to be available and adjustable in any software model. Therefore, the generic approach to display settings for planning and monitoring stages was suggested in [11].

During the planning stage, when setting the track, the user shall check that the present display is in the best scale mode (coincides with the largest scale ENC on the selected route leg), keeping the display in custom mode, with certain layers being ON/OFF as needed (table 2).

Table 2. ECDIS display setup for voyage planning

Parameter	Setting
Display	Standard
Custom layers	ON
If there is too much clutter, temporarily:	
Highlight Info	OFF
Text	OFF
Accuracy (ZOC)	OFF
Full light lines	OFF

On the monitoring stage Highlight Info, Accuracy (ZOC) and Text layers can be kept OFF, if not needed at the time. Additional information shall be brought up, as shown in table 3.

Table 3. ECDIS display setup for monitoring

Parameter	Setting
Display	Standard
Custom layers	ON
If there is too much clutter, temporarily:	
Highlight Info	OFF
Text	OFF
Accuracy (ZOC)	OFF
Full light lines	OFF
Other parameters	
Route mode	Monitoring (Active)
Safety Frame	ON (can be invisible)
Past Track	ON
RADAR / AIS	Propper filter settings and ALARMS
Primary + Secondary source of position	ON
Position Difference alarm	ON

3 ERROR STATISTICS – PASSAGE PLANNING

To find out the common traits in deck officers' errors during the passage planning stage, statistics over the 2018-2020 period based on ECDIS proficiency assessments of 875 deck officers of various ranks (master, chief officer, 2nd officer, 3rd officer) in different coastal navigation and harbour approach areas was collected. All deck officers have previously completed ECDIS generic training as required by Table A-II/1 of the STCW Code between 2012 and 2020. Deck officers were required to create a short route (5-6 legs) which included the following: route assessment for hazards, safety depth calculation, setup of ECDIS display and safety settings, and plotting of "No-Go" areas (figures 3, 4 and 5).

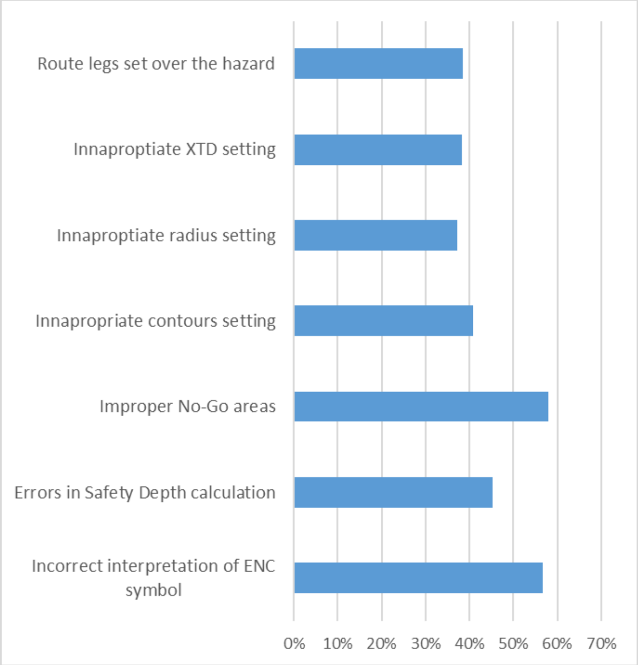

Figure 3. Distribution of errors by type

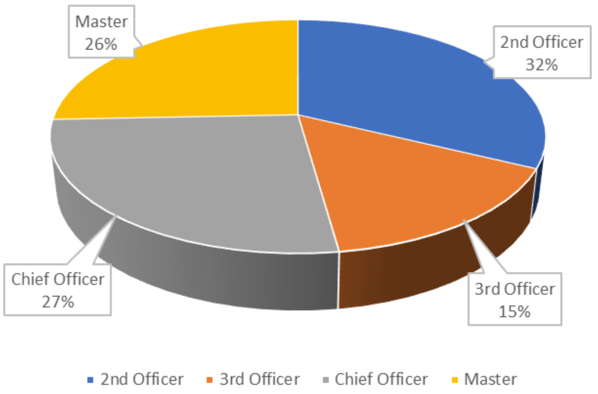

Figure 4. Distribution of deck officers by rank

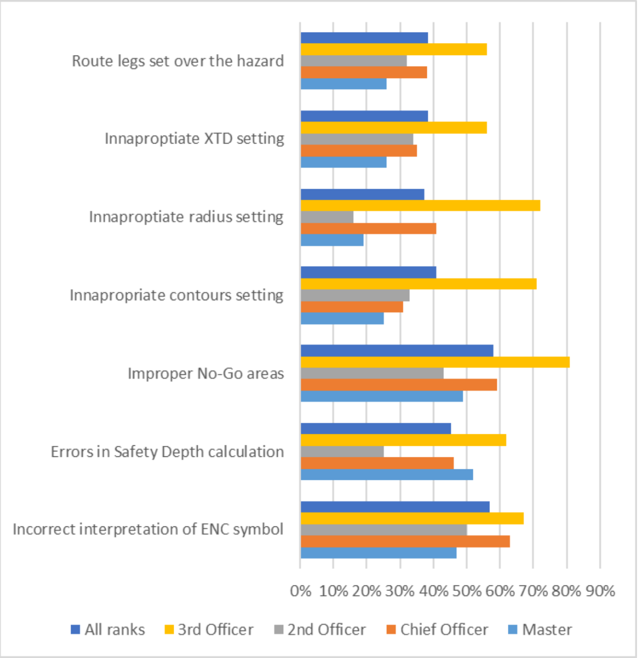

Figure 5. Distribution of errors by type and rank

Distribution by ranks (figure 5) shows that the least number of errors are made by 2nd officers whose direct responsibility is passage planning. 3rd Officers are usually better than masters and chief officers in using the software, however, they lack risk assessment skills and often make mistakes, when it comes to route safety assessment. At the same time, the contributing factor to a lot of masters' and chief officers' mistakes is the computer literacy and knowledge of specific software.

The most common error is the misinterpretation of ENC symbols observed among all ranks, regardless of their work experience and, most alarmingly, the misinterpretation of navigation hazard symbols. Discussions with the trainees after the assessments showed that often deck officers either do not see the hazard or do not recognize it. The same result was observed for the No-Go areas concept. Often No-Go areas were simply repeating the safety contour or were missed in necessary areas.

ECDIS anti-grounding alert and display appearance are mainly dependent on the safety contour value, correct calculation of which makes it particularly important for safe navigation. As per Intertanko [5] and other industry recommendations the Safety contour is normally set equal to the Safety depth. Therefore, incorrect Safety depth calculation directly affects the Safety contour. Errors in the Safety Depth calculation often occur as a result of incorrect ZOC (Zone of Confidence – IHO [7]) application, incorrect assessment of the minimum depths on the route and incorrect calculation of tidal levels.

Improper track location (setting legs over the hazard or shallow contour, incorrect assessment of distance to the hazard or depth), which may lead to grounding. Radius and XTD settings affect the route safety check, as a safety corridor is built and checked with regard to those parameters. Therefore, hazards could often end up within the safety corridor, or XTD and radius were too small for normal ship operations in the specific area.

Also, insensitivity to alarms was observed quite frequently. Audible alarms are often turned off too fast without checking the actual cause or meaning of the alarm.

The results obtained during error analysis correlate with the results published in MAIB reports on marine casualties related to improper use of ECDIS and [13], and conclusions made by Lusic et al. [10], Turna et al. [14]: lack of knowledge and understanding of safety parameters, alarms, and especially Safety Frame and XTD functions.

The analysis reveals an alarmingly low level of knowledge and understanding of ECDIS capabilities, which directly threatens the safety of navigation. The results obtained indicate the need to make appropriate changes to the training process and stress the attention on the elements of knowledge where deck officers show the worst results.

4 ERROR STATISTICS – EPFS FAULT

The STCW Code, Ch. VIII states: "… Fixes shall be taken at frequent intervals, and shall be carried out by more than one method whenever circumstances allow. When using ECDIS, appropriate usage code (scale) electronic navigational charts shall be used and the ship's position shall be checked by an independent means of position fixing at appropriate intervals."

The introduction of paperless navigation did not cancel this requirement. However, the methods fixes done on the chart changed substantially. The dead reckoning and manual position fixing functionality are compulsory for type-approved ECDIS software. Although position-fixing (or verification) requirements vary from company to company, mainly it turned into a "paperwork exercise", where deck officers plot positions on ECDIS display not to verify where the ship is, but to fulfil the requirement.

Due to modern bridge design, radar is the only equipment that can serve as the independent source of LoP's (Line of Position). With dominating satellite positioning system reliability modern deck officers' radar navigation skills started to degrade. A group of instructors at NU "Odesa Maritime Academy" recorded the results of 105 deck officers' assessments performed on Wartsilla Navi-Trainer 5000 mini-bridges. As in the previous experiment all deck officers have previously completed ECDIS generic training as required by Table A-II/1 of the STCW Code between 2012 and 2020.

Task description: car carrier (length - 236 m, max draft – 9.2 m) is on the eastbound transit via Singapore strait (daytime; visibility – 10 nm; wind – NW/5 Bft; current SSE – 1 knot). Within several minutes after the exercise has begun both available EPFS sensors are set out of order without a warning, i.e., no data is displayed on ship's position, course over ground (COG) and speed over ground (SOG). During the task, 5 active vessels are moving along the strait, leaving and entering the port of Singapore. Other vessels are at anchor and do not interfere with the passage (figure 6).

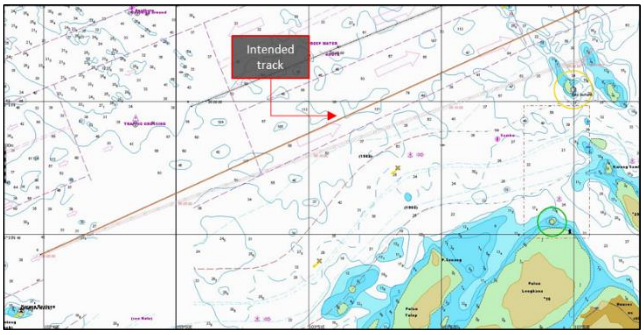

Figure 6. Vessel drift-off and consequential grounding as a result of EPFS failure

Near-miss was defined as an approach to navigational hazard or vessel closer than distance given by equation:

$$CPA_{min} = \frac{SF_L \times L \times \sin(\alpha) + SF_B \times B \times |\cos(\alpha)|}{L} \quad (9)$$

where CPA_{min} – minimum allowed closest point of approach; L – ship length; B – ship breadth; α – approach angle, °; SF_L – longitudinal safety factor; SF_B – transverse safety factor.

The choice of variable CPA is based on the fact that when approaching in narrow waters on opposite or following courses it is quite difficult and due to the limitations of the navigational nature not always possible to maintain a large distance between vessels. On the other hand, if the sea room allows vessels to approach at angles close to perpendicular, the navigators shall maintain a certain margin over the distance to leave room for manoeuvre.

An example of the variable CPA calculated using the mentioned method is shown in Fig. 7.

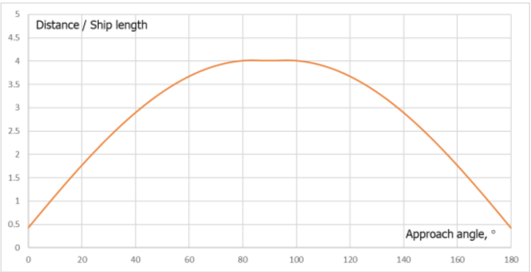

Figure 7. Minimum CPA as a function of ship dimensions and approach angle

The experiment summary is given in table 4. The deck officers, in their majority (88%), until the very last moment did not pay attention to the fact that the GPS did not work and continued to proceed unless the ship ran aground or passed too close (near-miss) to Batu Berhanti after 15 minutes (Fig. 7).

Table 4. Statistics on exercise with EPFS malfunction

Attempt	1st	2nd	3rd
Situation			
1 Collision with a vessel	1	2	
2 Grounding	3		
3 Near-miss with ship or hazard	89	10	2
4 Safe passage (<70% of past track within XTD)	12	46	10
5 Excellent passage (>70% of past track within XTD)		35	
Cause			
6 Hazard was not detected	21	5	
7 Hazard was not realized	71	6	
8 Improper risk assessment	1	19	
9 Ignoring speed manoeuvre		1	
10 Wrong manoeuvre		36	
11 Lack of planning		1	

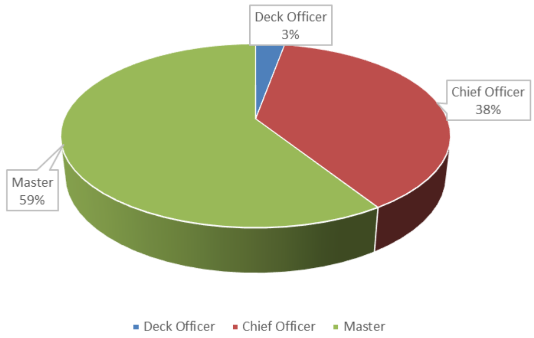

Figure 8. Distribution of deck officers by CoC (certificate of competence)

A small portion of deck officers did not pass the task (2%). They could not use ECDIS without operational EPFS and failed all 3 attempts. Some deck officers were confused when the vessel symbol did not move on the ECDIS display and did not notice other vessels, which led to collision (3%). In total, only 11% of mariners successfully completed the task on the first attempt. They correctly assessed the situation, determined the vessels' position and managed to follow the route.

It is important to notice that the participants for the most part had considerable experience at sea (on average 21.8 years total and 8.4 years in rank) as shown in figure 8.

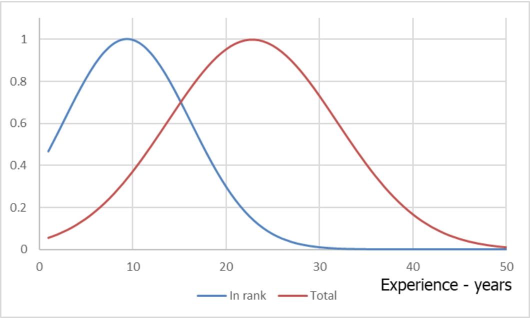

Figure 9. Distribution of experience among participants

Also, there is a wide fleet representation as shown in figure 10, with mainly officers from container and bulk fleet, who took the assessment.

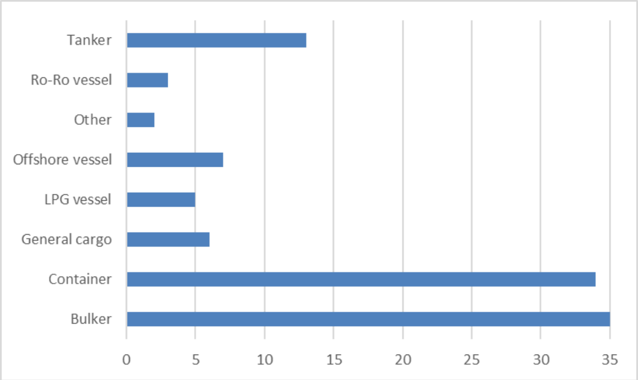

Figure 10. Vessel types the participants work on

5 CONCLUSIONS

Modern ECDIS equipment is a critical navigational instrument that in capable hands can help to significantly increase the safety of navigation. This can be achieved when the safety parameters are determined correctly and appropriately set up in the system.

Since ECDIS almost entirely replaced paper charts in 2018, the risk of overreliance on this equipment and related sensors increased dramatically. Seemingly, the comfort of using ECDIS results in the degradation of radar and visual navigation skills.

Inappropriate passage planning caused by the erroneous determination of such parameters as safety depth, safety contour, cross-track distance and turn radius leads to the inability to recognize navigational hazards. The latter in combination with the lack of computer literacy and overreliance on ECDIS in the unlikely event of EPFS failure creates a serious chance for a high-potential incident.

Therefore, the implementation of proper passage planning routines together with simulator training in equipment failures related to the ECDIS system (EPFS, gyro, log failures) is crucial for the safety of modern-day navigation.

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