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The Role of the ECDIS on the Development of Situational Awareness – a Study on Grounding Accidents

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ABSTRACT: Vessel grounding accidents can potentially cause catastrophic marine accidents with environmental pollution and loss of life and economy. New systems introduced to improve safety of navigation should not be cause them. Today, the ECDIS is the main cartographic system and must therefore be an appropriate aid to support seafarers in building situational awareness with the relevant information needed for safe navigation. This paper describes the development of situational awareness and its features after which the maritime grounding accidents, in the period from 2008 to 2019 are analysed. Due to importance of the ECDIS, only ECDIS related accidents were considered. The aim of this paper was to determine which error ceased the development of good situational awareness and to determine whether there is a certain pattern by which to predict future errors and thus act preventively on them. This study shows at which situation awareness level those errors occurred and which SA demon affected the seafarers to perform an error.

1 INTRODUCTION

The role of Situational Awareness (SA) has become very important due to the increased cognitive nature of the tasks that operators are asked to perform. Failure in such complex cognitive tasks due to loss of SA can have devastating results. According to Asyali studies indicate that SA has a significant causative factor in 88% of aviation accidents, where human error was indicated. Other studies have found that SA errors count for over 50% of air traffic control errors. In the maritime sphere, Sharma et al. have analysed maritime accidents which showed that human error is responsible for 71% of accidents due to SA losses.

During watch-keeping, the seafarer performs important tasks such as collision avoidance, navigation and other administrative duties. For performing each of these tasks, a high level of SA is required. An important part of the seafarer's job is developing SA to the highest level and keeping it up to date in a rapidly changing and complex environment especially in coastal areas, congested waters, ports and channel approaches. In recent years, great progress has been made in technology related to navigation. This primarily refers to the mandatory implementation of the Electronic Chart Display and Information System (ECDIS). In addition to the installation of the ECDIS on board, a great burden has fallen on seafarers and their training and familiarization with new technology. ECDIS has become the primary means of navigation, but not the only one. Accidents continued to happen even as technology advanced. There was a need to determine the causes of those accidents. In this paper grounding accidents related to ECDIS were analysed in order to find out which error led to the grounding and their connection to SA. In addition to the cause of the errors at the certain SA level, it is necessary to determine which SA demon affected the seafarer to make a certain error, so that preventive actions could be taken in the future.

2 LITERATURE REVIEW

Situation awareness is a term that, according to Asyali, originated from aviation psychology and was recognized as a crucial role for military aircraft crews as early as World War I. It is being widely used in other complex and dynamic working environments where a huge amount of data and information is processed by the operator to make accurate, safe, effective, and timely actions. Sharma et al. state that expansion of Situation Awareness (SA) to an operator's comprehension of a complex system has extended SA research to other domains in which the environment is dynamically changing and in which the operator is responsible for maintaining or achieving particular states. Author Endsley state that the operator must collect, aggregate and interpret information in order to know what is happening in the environment and to be aware of the situation in the surrounding.

As in many high-risk jobs, developing and maintaining a high level of situation awareness in maritime watch keeping is the most critical and challenging task. During watch keeping, Officers of the Watch (OOWs) gather huge amounts of data and information from aids to navigation (ECDIS, Radar, etc.), other team members, other vessels (ARPA, AIS), VTS, etc. Combining these data and information together, they create an integrated "whole" which we call a "Mental Picture or Model" on which his/her decisions and actions will be based. According to Francis et al., a person's perception of the relevant elements in the environment, as determined from system displays or directly from senses, forms the basis for his or her situation awareness.

According to Asyali several major factors are shown to influence this process. First, individuals vary in their ability to acquire SA, given the same data input. This hypothesized is a function of an individual's information-processing mechanisms, influenced by innate abilities, experience, and training. In addition, the individual may possess certain preconceptions and objectives that can act as a filter and interpret the environment in forming SA. As second, it is very important that the individual has well-presented information. Even the best-trained decision-makers will make the wrong decisions if they have inaccurate or incomplete SA. Conversely, a person who has perfect SA may still make the wrong decision (from a lack of training on proper procedures, poor tactics, etc.) or show poor performance (from an inability to carry out the necessary actions).

Most researchers have approached SA from a position between these two extremes. These middle positions typically remain very general, but some kinds of cognitive activity are assumed to be outside of SA. A representative definition is proposed by Dominguez, where author defined SA as an "individual's continuous extraction of environmental information, and integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing future perception and anticipating future events". Endsley defined SA 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". Dominguez stated that term extraction is more tied to actively perceiving than using the term perception. Both terms lead to an understanding of the situation through sampling the environment. Both definitions have three hierarchy phases and primary components that can be represented as three levels of SA.

Author Endsley comprised SA in three levels:

10. Level 1 - Perception: perceiving critical factors in the environment.
11. Level 2 -Comprehension: understanding what those factors signify.
12. Level 3 -Projection: anticipating what will happen with the situation in the near future.

These levels are cumulative, as projection cannot occur without comprehension, and comprehension cannot occur without perception.

3 SA DEMONS

Achieving and maintaining situational awareness on the highest level is a challenging process affected by the individual, task, systemic factors, and environment. The difficulty occurs in the interaction between the characteristics of the human information processing abilities of operators and technologies' design. Author Endsley labelled these difficulties as "SA Demons". SA demons are factors that weaken the SA in every environment. Eight major SA demons need to be considered when designing the SA-oriented system according to Wickens. SA demons are:

1. Attentional tunnelling,
2. Requisite memory trap,
3. Workload, Anxiety, Fatigue, and other stressors,
4. Data overload,
5. Misplaced salience,
6. Complexity creep,
7. Errant mental models,
8. Out-of-the-loop syndrome.

The high level of SA depends on the constant shifting between different features of the environment. In a dynamic environment, multiple tasks are simultaneously performed, and multiple pieces of information are processed. Such a condition is called attention sharing. Operators cannot access all the relevant information simultaneously. They establish information sampling strategies, so they can update SA. Scanning across the environment may take a second or an hour. A high level of SA is achieved by appropriate switching the attention between different features of the environment. Attentional tunnelling or narrowing occurs when operators cannot process a certain aspect of the environment and they lock their attention on that certain feature. In that case, overall SA is decreased because they ignore other aspects of the environment. It is happening unintentionally. In their minds, they are attending to the most important feature of the environment. For example, the OOW can focus on avoiding collision with the other vessel but can ignore shallows in the vicinity and find himself in greater danger.

During the time, operators extract information from the environment and store it in the working memory. Working memory is limited and easily disrupted. SA failures occur when that limit is reached or due to the natural decay of information in the working memory. Depending on the sensor we use, information cannot be retrieved. Auditory information has the same value for achieving SA as the visual but often visual information can be revisited on the visual display. This "demon" can be reduced if the operator actively works to keep the information in the memory by repeating or revisiting it. Another way to keep the information for a while longer is to connect the information to another information or a mental model in long-term memory.

Except for the complex dynamic environment, operators must perform their duty under the conditions that are often stressful. Those stressors can be psychological or physical in nature. Stress or anxiety can occur when it comes to big stakes, like human lives. Psychological stressors may also include mental workload, time pressure and uncertainty. Physical stressors occur in the environment with extreme cold or heat, poor lighting, high level of vibrations or noise, etc. Working against the operator's circadian rhythm and physical fatigue significantly reduces the capacity of, already limited working memory. In these conditions, the operator has difficulties to form SA because of reduced cognitive functions for processing and holding information in memory. Also, the operator becomes less organized in scanning information, less capable to efficiently collect information and more liable to attentional tunnelling.

To achieve good SA in a dynamic environment, in which data is rapidly changing, the operator must constantly scan and collect new information. Quick information intake can outpace the cognitive ability of the operator. In such conditions, attention cannot be evenly shared among the relevant aspects of the environment and SA soon becomes outdated. The operator will likely have gaps in projecting the near-future situation. To overcome this problem, the data presented to the operator should already be processed. If the operator gets simple, naked data, that he needs to process and combine with each other to get some practicable information, it will occupy his limited working memory. This is accomplished with the supporting systems transition to user-centred designs rather than technology-centred designs.

The operator, as a human, has natural salient properties. That means that certain forms of information that are determined by physical characteristics will draw the operator's attention. For example, movement, red colour, flashing light, things that are physically nearer, loud noise, or larger shapes will catch the operator's attention much more than the other feature. A similar situation will be if we hear the word "Fire" in the crowd. A human perceptual system is more sensitive to particular signal features. Those salient properties are used to improve SA, but also may diminish it. Properties like colour or movement are used to draw attention to the most important information, and this is used as a tool to design a supporting system. Misplaced silence occurs when this tool is overused or used improperly. For example, less important data may be presented on a larger display than an important one, and this can draw attention away from crucial information.

With the development of new supporting systems, their complexity grows. Designers do that unwittingly. It is difficult for people to form a mental model of how the system works. Training, as the most vital solution to this problem, should prepare operators and give them sufficient knowledge about the system. However, in reality systems are constantly getting more complex and there is more chance that operators will have insufficient experience with system performance in situations that occur rarely.

With the complexity and errant mental models, another problem occurs in automated systems. Automation helps to process the collected information but also take the operator out-of-the-loop. In this condition, the operator develops poor SA, as he is not aware of the performance of the automation and features the automation is supposed to control. Being out-of-the-loop does not present such a problem when automation is performing well, but when it fails, the operator will not timely detect the problem. This can be solved by properly designed automated systems.

4 ECDIS AS A SUPPORTING SYSTEM

In many domains, the main goal of SA is to detect abnormal or unusual events that can lead to dangerous or undesired situations. Perceiving and alerting to such anomalous situations in the vast amounts of information is then important while filtering out normal situations. In most domains, computer-based support is necessary for reaching the highest level of SA. A support system for situation awareness helps with gathering, processing, and interpreting the vast amounts of relevant data. According to Francis et al. such a system presents its output to a human operator. With the help of such a system the operator will get a better overview of what is happening, and consequently, can make better decisions and take more effective actions. A system supporting SA must present its output in an appropriate and practicable way to a human user. Using only textual output is not a good option for providing vast amounts of vessel information. Great visualization methods are required to enable the operator to quickly recognize and understand the current situation, which is required to build event projection and reach a high level of SA. In a dynamic environment, it is hard for the operator to have up-to-date SA. Such an environment provides large amounts of diverse information and monitoring it without the assistance of a supporting system, is almost impossible. The good supporting system design provides support for individuals' limitations and helps to overcome known problems (SA demons) for cognitive processing.

In maritime, during watch keeping, an effective support system today is an Electronic Chart Display and Information System (ECDIS). According to SOLAS Chapter V, Regulation 19 - Carriage requirements for shipborne navigational systems and equipment, section 2.1.4., all ships irrespective of size shall have: nautical charts and nautical publications to plan and display the ship's route for the intended voyage and to plot and monitor positions throughout the voyage. The ECDIS is also accepted as meeting the chart carriage requirements of this subparagraph. Certain benefits of the ECDIS have already been recognized before official use. Mandatory implementation of the ECDIS had been carried out from July 1, 2012, to July 1, 2018. After July 1, 2018, all merchant vessels should be fitted with Electronic Chart Display and Information System (ECDIS). The main purpose of the ECDIS is to contribute to safe navigation. The idea of developing such a system was to reduce the navigational workload of seafarers, comparing to using a paper chart.

Not only has that ECDIS replaced "paper" navigation but changes the way of maritime navigation. ECDIS becomes the main hub for the "Integrated Navigation Bridge". All relevant voyage data and information from other sources can be presented on the ECDIS display. The implementation of the ECDIS has been challenging in two major aspects. There have been great requirements for technically designing the system and train up all the operators. The ECDIS should be designed to support the SA. Good design can benefit SA by attracting attention to important stimuli that might otherwise go unnoticed. Human factors specialists have made considerable efforts designing alarms, warnings, and alerts. ECDIS is a user-centred designed system, where technology is organized around the user's tasks, goals and abilities. Endsley et al state that opposite to user-centred designs, technology-centred designs are designed in a way that every sensor has its display. As technology upgraded, more displays were added. The human has limited attention and cannot follow so many displays in limited time. In such designs, displays are often scattered and do not support human tasks. A system designed in this way involves more human error. To avoid those situations, a philosophy of user-centred design was developed. For a system to be effective, it must be designed to include the needs and capabilities of the operator. In user-centred designs, pieces of information are integrated in a way that fits the goals and needs of the end-user. For example, besides direct information about the course and speed, ECDIS also presents the ETA to some critical point on the route or average speed required to a particular position. Thus, relieving the working memory of the OOW.

Cole at al. research showed that use of the ECDIS has more impact on improving SA level 1 (perception) and SA level 3 (projection) than SA Level 2 (comprehension). Van de Laar et al. share opinion that ECDIS decreases the navigational skill of the OOW. Those attitudes were expressed in 2012 when the ECDIS was not fully implemented on all the ship, and it was something new for seafarers. OOWs are obligated to attend the mandatory, 40 hours, ECDIS Generic Course, and Type Specific Course, which is a specific ECDIS model familiarization course. Brcic et al. research have already shown the shortcomings of the ECDIS generic course. Although most consider that the time for the course is sufficient, the ECDIS should not be important in itself, but the background knowledge should accompany the new navigation equipment. With the rise of automation, seafarers showed overreliance in new technology, without getting fully familiarized with it. In paper Car et al. even 55% of respondents answered that they took over the duty without sufficient time to familiarize themselves with the ECDIS on board. This should not happen, but today, vessels stay very short in ports, and sometimes there is not enough time for the complete familiarization of seafarers, so they are forced to take up duty under such circumstances. Another shortcoming that occurs is the lack of standardization of the ECDIS. In the future, this problem should be solved with implementing the "Guidelines for the standardization of user interface design for navigation equipment".

5 RESEARCH METHODOLOGY

In this paper, ECDIS-related grounding accidents were analysed from the aspect of situational awareness. Methods used in this research are methods of abstraction, compilation, analysis, and the inductive method. The aim of this study was to determine at which SA Level, a loss of SA occurs, i.e. at which level, the development of sufficient situation awareness ceases. Also, there is a need to find out which errors of seafarers are most often involved in the loss of SA so that preventive action can be taken in the future.

The data used in this study are based on the accident investigation reports published by Marine Accident Investigation Branch (MAIB), The Federal Bureau of Maritime Casualty Investigation (BSU), The Marine Safety Investigation Unit (MSIU). The Dutch Safety Board (DSB) and The Transportation Safety Board of Canada (TSB). Analysing grounding accident reports in the period from 2008 to 2019, 25 cases were found to be ECDIS-related.

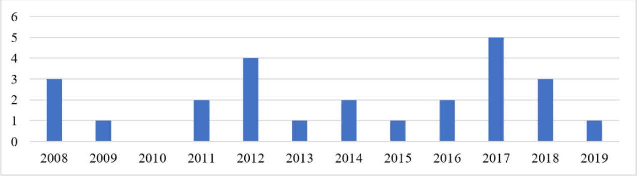

Figure 1. Distribution of grounding accidents in the period from 2008 to 2019

Marine accident investigation reports published by MAIB, BSU, MSIU, DSB, and TSB contains all facts related to the accident. Re-analysing them, it was found that in the same cases the cause of the accident is the loss of SA at some point. SA is comprised of 3 levels, which are cumulative, which means that Level 2 cannot be achieved without previous achieving Level 1, and Level 3 cannot be achieved without achieving Level 2. Grounding accidents occur when Level 3 is not achieved. That means that the Master, OOW, or the pilot cannot project the vessel's future movement, or this projection is inaccurate.

Analysing grounding accident reports, several causative factors related to ECDIS were found, that to some extent affected accidents. They are listed into three parts, where each part represents one of three SA level. Accident causative factors, assigned to certain SA levels are shown in Table 1.

Some cases had more ECDIS-related causative factors but in those cases, as a representative factor is taken the one that is assigned to the lowest SA Level. For example, avoiding high traffic and heading into shallow water but ECDIS safety alarms were switched off and could not warn the OOW. Or the ship drifted off the route and found itself in shallow waters without triggering the XTD Alarm. In that case, the fact that the ECDIS safety alarm was switched off is used in this study. With alarm, switched off, the OOW was not warned and all relevant data was not provided to him, which he or she should know to develop sufficient SA. Those representative ECDIS-related causative factors are listed in Table 2.

Table 1. ECDIS related accident causative factors listed by SA levels.

SA Level 1	Safety Contour/Depth Alarm settings wrong
	Route Check feature not used
	Route Check alarm ignored
	Outdated chart used
	XTD Alarm off
	Safety Contour/Depth alarm off
	Wrong Look Ahead Settings used
	Unsuitable Chart Scale used
	Safety Alarm Ignored
	Wrong buoy position in ENC
	Wrong reef position in ENC
	Insufficient ECDIS Training
	Insufficient ECDIS Voyage procedures
SA Level 2	Safety Alarm Ignored
SA Level 3	Wrong usage of Ship predictor feature

Table 2: Representative ECDIS related accident causative factors listed by SA levels.

SA Level 1	Wrong Safety Contour/Depth Alarm Settings
	Route Check feature not used
	Route Check alarm ignored
	Outdated chart used
	XTD Alarm off
	Safety Contour/Depth alarm off
	Wrong Look Ahead Settings used
	Unsuitable Chart Scale used
SA Level 2	Safety Alarm Ignored
SA Level 3	Wrong usage of Ship predictor feature

6 RESULTS

The results of the study are divided into two parts. The first part consists of an analysis of errors committed by OOWs operating the ECDIS. Analysing those errors, they are assigned to a certain SA level. The aim of the study was to determine at which SA level development of good situational awareness ceases and which error OOW made, that affected the loss of SA. The second part consists of an analysis of SA demons that have affected OOWs. Analysing the circumstances in which the error occurred, an SA demon, which affected the OOW to make the error, was identified for each case.

To find out on which SA Level, development of Situation Awareness ceases, accident reports were analysed. In every case, several factors that caused the accident were identified. In this study, only ECDIS-related causative factors were considered. They needed to be assigned to one of three SA Levels, and the one that was assigned to the lowest SA Level presents the SA Level at which development of Situation Awareness ceases. Those causative factors first occurred on a time basis.

Of all 25 cases, 22 cases were found in which the development of SA ceased at SA Level 1, in two cases ceased at SA Level 2, and in one case at SA Level 3. ECDIS-related grounding accidents causative factors are listed in three categories where each category presents one of three SA Levels. The number of each causative factor is presented in Figure 3. It can be noticed that the most occurred causative factor is "Safety Contour/Depth Alarm off". In addition to this causative factor, two other causative factors, "XTD Alarm off", and "Safety Alarm Ignored" deviate from the majority. Other causative factors occurred only once.

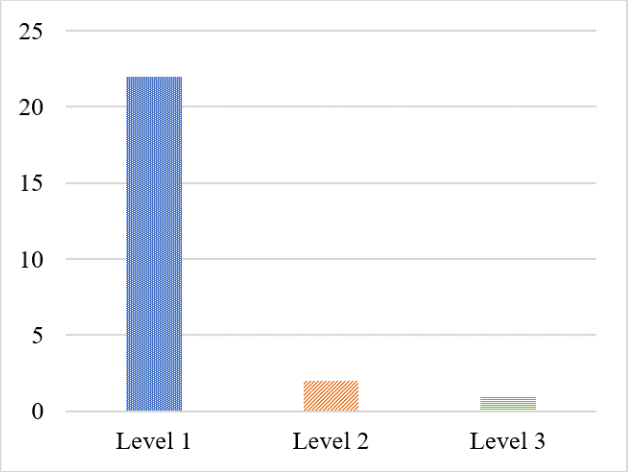

Figure 2. The distribution of ECDIS related causative factors by SA Levels

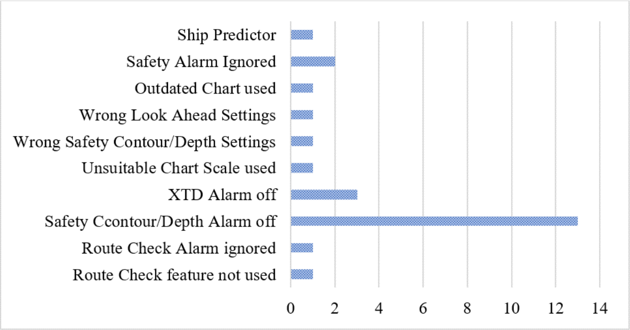

Figure 3. The number of individual ECDIS related causative factors.

SA demons are certain difficulties that represent an obstacle in the interaction between the operators' cognitive abilities and designs of the technologies. Analysing accident reports, several SA demons were recognized, affected the grounding accident. Figure 4 shows the distribution of grounding accidents quantity against SA demons, which affected them.

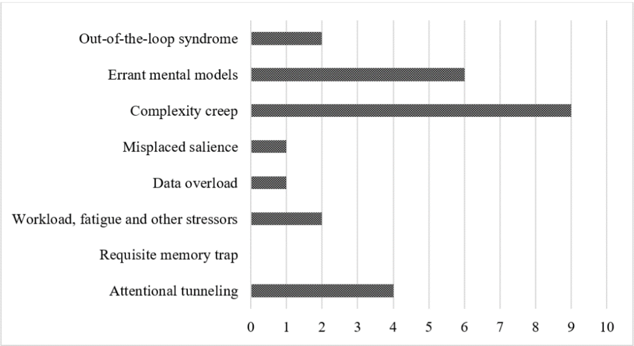

Figure 4. The number of individual SA demon that affected the grounding accident.

7 RESULTS DISCUSSION

Analysing these 25 grounding accident cases, it was found that in 22 cases the development of SA suspends at SA Level 1. SA Level 1 presents the perception of the environment. When developing situational awareness, at SA Level 1, seafarers collect the relevant information required for safe navigation. With inaccurate information, or without any information at all, seafarers cannot develop higher levels of SA. With the loss of situational awareness, they cannot know what is happening with the vessel, and therefore cannot project future vessel movement and environmental conditions. With 88% cases in which situational awareness is ceased at SA Level 1, there is a need to find what went wrong and found some significant cause. Two most occurring causative factors, at SA Level 1 are related to ECDIS alarms. Together, they present 73% of causative factors at SA Level 1 and 64% of all causative factors at which the development of Situation Awareness ceased. The third most occurred causative factor, also related to ECDIS alarms, refers to SA Level 2. Together with causative factors at SA Level 1, causative factors related to ECDIS alarms present 73% of all causative factors.

The distribution of SA demons over certain grounding accidents shows two demons, "Errant mental models" and "Complexity Creep", that had a greater impact than the others. SA demon, "Errant mental models", can be interpreted as the impact of the loss of situational awareness at SA Level 1. With faulty perceiving and data input, seafarers could not create accurate mental models. Thus, it results in the development of incorrect situational awareness and leads to a hazardous situation. "Complexity Creep", as the most prevalent SA demon, with 40 % of the share, signifies that seafarers involved in analysed grounding accidents did not use all the safety functions that ECDIS provides. The ECDIS is a complex, software-based system with multiple options for display and integration. The effective use of the ECDIS requires many stakeholders, who have to be able to understand all the capabilities and role of ECDIS in the navigation. Such a complex system with many functions can be confusing for the operator. In analysed cases, only basic ECDIS functions were used, which may imply that OOWs were not aware of the significance of proper use of all the ECDIS features. This may be a result of a lack of training and insufficient familiarization.

8 CONCLUSION

The main purpose of the integration of the ECDIS into the bridge navigational equipment is to increase safety by reducing the OOWs' workload and relieve his attention. This was achieved by designing the ECDIS as user-centred design. Also, the ECDIS is based on visualization methods, rather than providing the textual outputs, with constant real-time tracking. In a way, we can say that the goal has been achieved. None of analysed grounding accidents did happen under the influence of SA demon "Data overload".

With the introduction of new technology into practice, new difficulties and new SA demons, have emerged, affecting operators. In this paper, the demons that influenced the grounding accidents were detected. "Complexity creep" stands out as the most common SA demon. The influence of SA demon "Complexity creep" could be reduced, by providing the seafarers, more appropriate training.

In most cases a seafarer has become a passive monitor, rather than a participant in the system control. This attitude puts the seafarer out-of-the-loop. Since human has limited cognitive ability there is a need to find if some of ECDIS features exceeds them. There is a lot of monitor sensors and every sensor has his own alarm which is shown on ECDIS screen. In a sensitive situation, like port approach, there can be high traffic, low depth and the vicinity of land which can give multiple alarms at the same time. For seafarers it may disturb them rather than help them. In future ECDIS interface designs, this feature should have great significance. Whenever human is part of a system, there will be errors. Technology will advance and humans as operators will always be challenged. To reduce the number of human errors, adequate training should constantly be provided.

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