Human-Centered Interfaces for Situation Awareness in Maintenance

Allan Oliveira[1], Regina Araujo[1], and Andrew Jardine[2]

[1] Federal University of São Carlos, São Carlos, São Paulo, Brazil
{allan_oliveira,regina}@dc.ufscar.br
[2] University of Toronto, Toronto, Ontario, Canada
jardine@mie.utoronto.ca

Abstract. In Maintenance, a vital activity in industry, ineffective Situation Awareness (SAW) is responsible for 13-17% of accidents. Therefore, a successful SAW has the potential of leveraging safety and efficiency, especially in field work. Bibliographic revision shows that the main gap to develop this idea is the conflict between the structure of Maintenance (procedural) and that of SAW (dynamic). Using a holistic study to elaborate a conclusive definition of SAW in the field, our work was able to solve this dichotomy of structures by developing a conceptual framework which maintains the task-oriented nature of field operation while clustering SAW inputs into entities to outline their potential effects. This Conceptual Framework of Situation Awareness in Maintenance (CFSAM) acknowledges the link between SAW and UIs, and creates a definitive list of multiple factors/entities that supports responsiveness and improves reliability and resilience. The seven entities identified are: task, equipment, system, environment, team, enterprise and personal. To each of these entities, CFSAM assigns a role in the UI design, and analyses challenges and solutions. This new approach of considering SAW-oriented design is a multidisciplinary effort and so far the results are promising: it facilitates an efficient design of SAW in maintenance field work, increases the focus on safety and efficiency and leverages the potential of developing a coherent system with high level of adherence.

Keywords: Situation Awareness, Human Centered Computing, User Interface Design, Maintenance.

1 Introduction

60-80% of errors in industry are attributed to humans [1] and 15-20% of these errors involve maintenance [2]. A widespread practice in all industries, the processes of Maintenance is developed in order to keep the physical assets suitable for fulfilling their function.

This routine, has an impressive impact in overall finances, personnel safety and the product quality. Because of its importance, it has received a big focus from industry and academia and has evolved with technologies such as Condition Based

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Maintenance, Prognostics and Health Management, E-Maintenance and Internet of Things. Nevertheless, this area still lacks further studies in User Interfaces (UI) for field personnel.

A UI designed for maintenance field operators could prevent part of the human errors involving maintenance, by presenting information in a goal-driven mode, while filtering data and adapting their presentation layout according to the user situation, mental model and hardware (the device in use). The goal-driven information UI is developed based on the understanding of the work process, thus being able to select from a range of information and display only what is necessary, when it is necessary. By doing this, the UI supports the user Situation Awareness (SAW). To be adaptable to the real world, this UI must be also integrated with the E-maintenance system (to provide coherent and updated solutions) and it must provide request-driven access to information, becoming a part of the industrial workflow.

This breakthrough approach differs from most studies for field personnel developed nowadays, because they focus on Augmented Reality [3], applied in laboratories with ideal conditions, disregarding the user Situation Awareness in real work contexts. This approach is misleading, because it ignores the fact that 88% of human error is due to problems in Situation Awareness [1], giving a roughly 13-17% of errors in industry caused by lack of Situation Awareness in maintenance.

Situation Awareness (SAW) is one of the cornerstones of human-centered systems. Currently applied in many industries, such as aviation [4][5], mining [6], oil/gas [7], rails [8] and others [9], it involves the perception of elements in the environment, the comprehension of these elements and the situation and the projection of future consequences and elements' status [1]. SAW enhances the decision making capacity of users by providing a framework to assist displaying the right information in the right time. By doing so, it prevents errors and improves the levels of efficiency and safety.

New display technologies (e.g. Augmented Reality Head Mounted Displays) are expected to provide access to the desired information more easily whenever requested. However, safety and reliability are not improved through more exposure to data and technology [9] and the optimal use of SAW is influenced by the way information is presented [1]. Therefore, the best process for UIs to work when selecting data are the SAW guidelines. Ignoring these rules would cause the UIs to backfire, increasing the occurrence of human errors and ultimately causing a rejection of such displays in industry. Consequently, maintenance, as well as others field work areas, demand studies specifically in SAW, anticipating solutions to reduce the large amount of errors this area faces and developing feasible ways to use the new visualization technologies available.

Maintenance was selected as the basis for this study because it encompasses the three traits below, whereas other industrial processes do not comprehend them entirely:

- Complexity: the need to comprehend equipments, identify a problem and fix it, while having a procedural (manuals) and non procedural (diagnosis) aspects;

- Safety: the importance of safety for the worker (human life), for the equipment (may cost millions of dollars) and for people interacting with the equipment afterward (an airplane defect may risk several people lives);
- Efficiency: the response time to reduce downtime of equipments.

This paper introduces a conceptual framework to SAW that can be applied in UI systems for maintenance field personnel. The framework defines the entities of importance of Situation Awareness in maintenance field work and how they affect SAW. The objective is to fill the gap of current studies in the area and assist designers to create human-centered User Interfaces that provide SAW to their users. This framework can be futurely replicated to other less complex procedures (such as Operation and Production).

The paper is structured as follows: Section 2 is a review of Situation Awareness, mostly applied to maintenance; Section 3 explains the Conceptual Framework for Situation Awareness in Maintenance; Section 4 discusses the entities of SAW in maintenance and some problems and solutions; Section 5 is discussions and conclusion.

2 Situation Awareness in the Maintenance Process

Situation Awareness in maintenance field work has not been extensively explored, compared to Command & Control, because of the strong procedural element in this scenario, which contrast to the situational nature of SAW. However, whenever reliability and resilience are important, such as it is in maintenance, there must be a focus on being responsive to situations [8]. Also, poor SAW is an acknowledged source of errors in maintenance [2]. Finally, SAW is directly correlated to the UI [1].

Coherently to these assertions, in order to improve SAW through User Interfaces, static information/context must be considered a part of a user SAW, regardless of their non-situational nature, because of their effect on users' perception of their situation. For instance, even though the risks of maintaining and testing the speed regulator in a power generator unity are always the same (electric shock, height fall, high pressure, oil leaking), keeping them in the user working memory through UIs may reinforce the mindset to assure a safe and effective work. Moreover, such information will also assist the user's decision-making process by providing comprehensive context for an analysis of the situation.

Besides the implications of displaying static and non-static information, a comprehensive study of SAW in maintenance must consider that a system/domain [8] may contain multiple types of Situation Awareness, as stated by Golightly et. al, and, furthermore, awareness itself could be composed of several factors, as identified by Carrol et al. [10].

Three areas of application of SAW were identified as important for maintenance: field maintenance, industrial field operation and UIs. The works of Endsley and Robertson [4] and Golightly et. al [8] identified four elements as the basis of SAW in maintenance field work: understanding the equipment, to identify problems (diagnosis) and predict failures (prognosis); maintaining team synchrony, to collaborate and coordinate tasks to achieve a common goal; comprehending the environment and their risks, to avoid accidents; having a good corporate environment, to have a standardized work routine and terminology and good communications with other areas for shift scheduling and provisioning of assets.

Considering SAW in industrial field operations, Nazir et al. listed several factors influencing an operator's SAW, mainly environmental, team work and personal factors [11]. Sneddon et al. exposed that the most significant impact in SAW is caused by stress, and not fatigue/workload and sleep disruption [7]. They also proved that Situation Awareness is associated with safety indicators, such as unsafe behavior, near misses and accident history. Likewise, Bullemer analyzed major incidents from industry, discovering that 50% involved failures associated with SAW [9]. According to him, team work and awareness could be improved with better communication, supervision, pre-job briefing and User Interfaces.

Chinoy and Fischer also appointed the need to improve UIs in SAW [5]. They listed several design and system guidelines, such as "Show radar coverage especially in light" and "Information tailored to user need", with a focus on a net-centric approach that integrates several databases.

An essential requisite to improve UI and maintain SAW over interruptions is defining design guidelines. John and Smallman created four design principles to this situation [12]. They are: 1) UIs should provide an indicative of changes automatically; 2) UIs must use unobtrusive notifications; 3) UIs should provide summary descriptions of each change, allowing users to choose priorities; 4) For busy displays, UIs should make information about changes be accessed only on demand, to avoid clutter.

Also concerned with SAW in UIs, Endsley and Jones developed fifty design guidelines [1], going from how to organize and present information, to dealing with alarms, automation and multiple and distributed operators.

Finally, Carrol et al. devised design strategies focused on notifications, to support Activity Awareness, a concept similar to SAW, but with an emphasis on project work that supports groups in complex tasks [10]. They structured Activity Awareness around four entities, situation, group, task and tool. Then, they evaluated the information requirements for each factor and created design strategies to support their awareness.

Improving upon literature for SAW in maintenance and operations field work, combined with at-work analysis, this paper uses the strategy of structuring Situation Awareness around seven entities, each one of those with its respective requirements and design strategies. These entities compose the Conceptual Framework for Awareness in Maintenance, presented in the next section.

3 Conceptual Framework for Situation Awareness in Maintenance (CFSAM)

The first of its kind, CFSAM was defined based on a holistic study of the maintenance process, which included mapping of the different types of information essential to the field operator of maintenance and their categorization into seven entities. To each of these entities it was attributed its own "awareness", a set of information that should ensure the best service-level possible. To respond to a broad range of contexts, these entities are combined to generate the user Situation Awareness in maintenance. This approach by CFSAM demands a different definition of SAW in maintenance field work, because it recognizes the need for understanding and knowledge of the ongoing procedure (and other static information connected to the surrounding context) to form a user Situation Awareness. Thus, it differs from Command & Control, in which SAW is based only in dynamic information.

The goal of CFSAM is to better define SAW in industrial field work, particularly maintenance, providing an up-to-date framework that can be used to identify the main SAW problems and point potential solutions related to each entity. The framework will help understand the entities in the maintenance work and assist UI designers knowing at any time, what information is useful to users. It will also leverage users' adherence level by providing a dependable source of information with optimized display according to the surrounding environment.

To establish the set of entities that compose CFSAM, the initial step was mapping the information typically required by operators to ensure an effective maintenance in the field. This material was used to understand the maintenance activity and the main inputs for the decision-making process. The flowchart generated, together with the works of [2,4,5,6,7,8,9,10,11], was the basis for devising an initial structure of SAW in maintenance. To proof-read this method, this proposal was revised according to interviews with specialists.

As a result of the mapping, the inputs of CFSAM were clustered into seven entities, named after the focus of their assessment, as demonstrated in figure 1: personal, task, equipment, system, environment, team and enterprise. Each entity is composed by singular elements which influence the perception of awareness to them, further explained later in this paper.

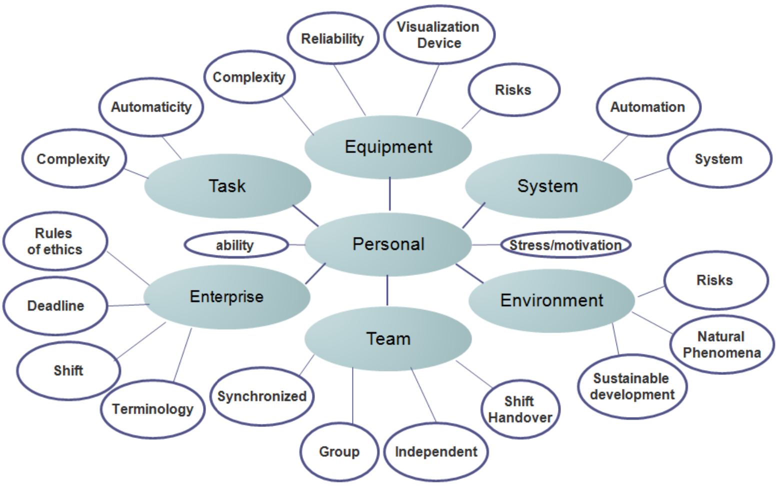

Fig. 1. Main entities affecting users SAW in maintenance field work

Furthermore, figure 2 demonstrates how different kinds of information can be combined with CFSAM to form an UI. In the figure, the information pool is on the left side, structured with the entities from CFSAM and with examples and a visual abstraction. On the middle part, information is being filtered according to CFSAM, which considers the seven defined entities and their Situation Awareness. Finally, in the right side, both users, red and blue, have information displayed to them to assist in their work. Even if both users are performing the same procedure, different information could be displayed to them, to improve their current SAW.

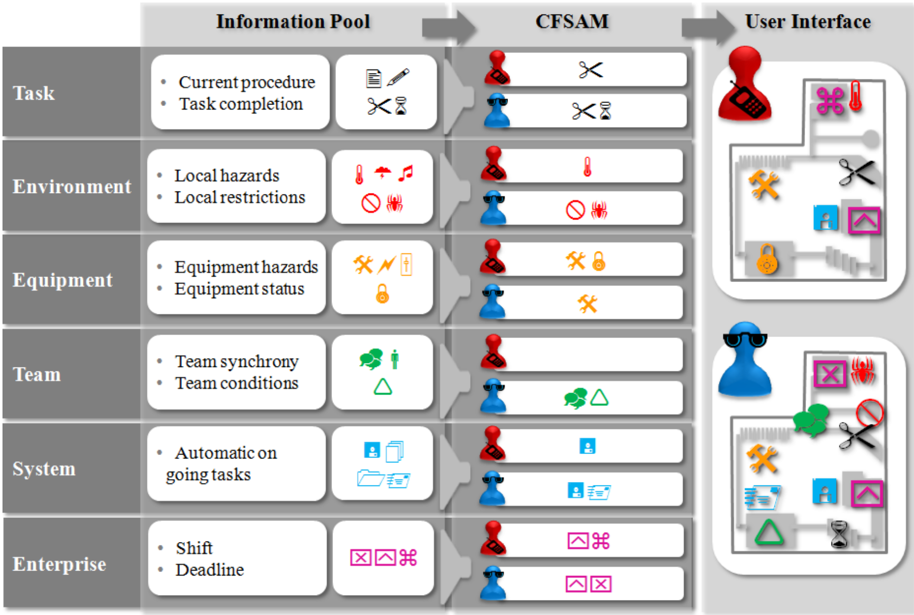

Fig. 2. An example of CFSAM influencing Situation Awareness in Maintenance

All the entities are presented below, in addition to the definition of their awareness and identification of some common problems of awareness in each.

4 Entities of Situation Awareness in Maintenance

4.1 Task Awareness

Task Awareness is the understanding of the procedure and comprehension of how does it have to be executed. This awareness is the one that most benefit from experience, but also one that can be increased by complexity and occupies a great deal of the working memory.

Experience helps develop automaticity, but, according to Endsley and Jones [1], human working memory is a big limitation in SAW and systems need to consider it in their design, or else errors are possible to occur.

A solution to maintain Task Awareness is using Interactive Electronic Technical Manuals augmented by Augmented Reality, so that it is possible to view projected in the equipment instructions and CAD/CAE data.

Some of the common problems to SAW related to Task Awareness are:

- The task tends to take all the focus from situation assessment [8];
- In the end of a task, the focus is even more reduced in situation assessment [8];
- Repetitive task results in complacency [7];
- Not understanding the work/task proposed [8];
- Distraction/lack of focus during work [8].

4.2 Equipment Awareness

Equipment Awareness is the understanding of the equipment and its behavior. It is generally considered the most important Awareness in maintenance, even defined as the concept of SAW in maintenance [4] and is particularly useful to assist in diagnosis of problems. Two important aspects of this awareness are risks and reliability.

Risks should ideally be treated as an event with: association, duration, area-of-effect and priority.

- Association: useful to determine the entity responsible for this risk, so that an UI for a risk can be designed once and used for every procedure related to the entity;
- Duration: important for the process of maintaining awareness during a task;
- Area-of-effect: specified so that coworkers can be aware of the range of a risk;
- Priority: mostly used to avoid information overload, since higher priority risks should have better salience (such as the color red or a flashing light).

Besides, whenever possible, Augmented Reality is the best media to display risks, because it can lessen the cognitive processing by displaying a risk on top of its source.

Reliability is how close the equipment is to a breakdown, verified through age (Reliability-Centered Maintenance), prognostics and reading of sensors (Condition-Based Maintenance). If the status of the equipment being worked points to an imminent or close breakdown, UIs should inform users and display risks associated with it.

To keep Equipment Awareness, besides using risks and reliability, UIs should allow users to view on demand information about equipment and they should focus on assisting diagnosis of problems, with a list of general problems and their visual cues.

Finally, another particular aspect of Equipment Awareness is the visualization device. Comprehension and ability to use this device can influence a user Situation Awareness, thus users need to be trained in the device before engaging any activity.

Some of the common problems to SAW related to Equipment Awareness are:

- Confusing translation of documentation of imported equipments;
- Specialists failing to understand the functional relationships of equipment when problem solving [5], normally by use of incorrect mental model [16];
- No documentation update [5][8];
- Equipment too complex and risks not known to user.

4.3 System Awareness

System Awareness in maintenance is being aware of the computational, electrical, mechanical and hydraulic systems and how they control the process, in simpler terms, the automation in the system. Automation is the smart management of a system using technology, so that it operates without human direct control [6], and there is a high potential in automations to distract, overcharge and confuse operators, instead of supporting them. Therefore this awareness is centered on users understanding systems controlled actions and how they influence his/her work.

With the growth of automation, a new set of human factors have arisen, such as: how is information displayed in automated systems, how is the system controlled, do the operators accept the system, what happens when the system fails, boredom associated to a change in work from execution to monitoring, how does the system deal with SAW, disqualification and behavioral changes in operators depending on the level of automation and how this impact in risks.

UIs should focus on keeping user aware of automation by informing actions of the systems, as if the system was a coworker, and supporting direct system control.

Some of the common problems to SAW related to system awareness are:

- User “out-of-the-loop” with automations [1];

4.4 Environment Awareness

Environment Awareness is being aware of the surrounding considering the risks and consequences of the work and it is essential for keeping a high level of SAW. This awareness is considered by Nazir et al. as the Situation Awareness in industrial field work [11] and defined as the perception of changes in the physical parameters, the comprehension of the changes and anticipation of consequences.

In some domains, barriers are an important tool for safety, because they can prevent dangers in the workplace. Therefore UIs should take advantage of Barriers and inform users when they are present, to assist maintaining Environment Awareness.

UIs should also be designed to with the following principles:

- Avoid risks: in an industrial ambient, dangers caused by high temperatures, electricity, radioactivity, etc, are common and human-centered interfaces should focus on keeping users aware of them when they are present;
- Adapt to visibility issues: in case of diminished visibility (fog) Augmented Reality is a good technology for path guidance, being able to display the factory layout;
- Noise limiting UIs: workplaces with heavy machinery have loud sounds or noises that make it impossible to use sound/speech based interfaces. Therefore, they must not be used in this scenario, even with the increase in processing capabilities;
- Provide sustainable development: correct and ecological procedures of waste disposal should be ensured by a human-centered interface.

Also, some of the common problems to SAW related to environment awareness are:

- Unexpected leaking;
- Lack of organization and cleanliness and unclear procedure of waste disposal;
- Mistakes on understanding the factory layout (access to the wrong equipment) [11];
- Lack of visibility, because of darkness (night) or weather (fog) [8][11];
- Risks not known to user.

4.5 Team Awareness

Team Awareness is an essential element in a maintenance process, important for coordinating and maintaining a collective awareness as a group with the same goals and because 40% of accidents in industry are caused by lack of Team Situation Awareness [9]. As stated by Endsley and Robertson [4], errors frequently occur in team work because information is not shared or passed between teams. Therefore, individuals need not only to comprehend the task they are doing, but also what the team is doing, because this will influence their decision making and performance.

In this paper, considering SAW and HCI in maintenance, team work was structured in three types:

- Synchronous: procedures with actions performed in a fixed order;
- Group: unrelated procedures with the same goal on the same set of equipments;
- Independent: unrelated procedures with different goals but on the same equipment/location.

In case of Synchronous work, the order of tasks, and dependencies among tasks, could be mapped and UIs should display accomplished tasks of coworkers and their current task. In case of Group work, UIs should display beginning and end of tasks of coworkers. Notifications are a possible UI solution, and they could be integrated to the UI in case of Synchronous work or unobtrusive in case of Group work.

Considering only the guidelines above, in cases of teams with 5 or more members, information overload will be inevitable in synchronized and group work. Therefore a guideline was introduced for this case. In Synchronous teams, only tasks blocking the user should be displayed, and the current task of coworkers should be hidden, but possible to access when desired. In case of Grouped teams, only one message about coworkers should be displayed at a time (others messages could enter a queue and be displayed in order).

Another important aspect considered in team awareness is shifts handover during a task. Logs are generally used for this, informing events that happened during the last user turn. However, the new user should also be informed of: current progress of the task, current step to execute, current state of teammates.

Some of the common problems to SAW related to Team Awareness are:

- Poor communication with the team [4], especially of critical information [5];
- Poorly prepared planning and last minute changes [8];
- Shift handover trades a user with developed SAW for another with low initial awareness [9];
- Number of stakeholders too high for a manageable communication [5].

4.6 Enterprise Awareness

Enterprise Awareness is being aware of company controlled factors that influences the work, such as shift scheduling, workload/deadlines, assets, standards/ terminologies and ethics rules of the work place.

Shifts, deadlines and workload can influence a person awareness ratio. Small deadlines or big workloads can cause stress, night shifts changes the circadian cycle and both can diminish cognitive capacity, impairing SAW. Also close to the end of a shift, users tend to focus only on the task and forget their surroundings, therefore UIs should further highlight events in this period (such as risks).

Additionally, because of the importance of the social component in the interface, studying the ethics and behavior rules of the work place are essential for guiding the design of a behavioral awareness interface. For instance, in some work places silence is mandatory, thus speech interfaces are not a good choice.

Finally, another cause of problems in Enterprise Awareness is the lack of use of standards and the different terminologies among stakeholders. Both can be ensured by an UI designed to standardize processes and nomenclature in a corporate environment.

Some of the common problems to SAW related to enterprise awareness are:

- Smaller attention to details and situations when close to the end of shift [8];
- Inconsistent documentation and terminology among stakeholders [5];
- Pressure to solve problems in short periods of time [7];
- Constant disruption of the circadian cycle due to 7days-7nights shifts schemes [7];
- Unavailability of spare parts [4].

4.7 Personal

Personal Awareness is related to the user and his/her characteristics and should be taken into account to create UIs that are compatibles to each user mental model. Factors such as ability (experience, training and skill), general cognitive level, motivation and stress should be considered to interfaces adaptations.

A simple manner to use these and others personal factors is to create profiles (similar to Personas) and adapt UIs to them, instead of each factor. Thus, a stressed experienced user could be fitted in the same profile of a novice user.

Some of the common problems to SAW related to Personal Awareness are:

- Lack of experience, preparation and training in the work and evaluating risks [1][5][7];
- Lack of motivation [2];
- Long work shifts with no rest [7].

5 Conclusion

This paper presents a conceptual framework to structure effective User Interfaces for maintenance field operators using Situation Awareness. In this sense, SAW is structured around seven entities, each requiring specific information to ensure awareness. The combination of these entities creates a context to analyze and perform operational maintenance processes, improving their efficiency and efficacy (leading to a higher level of safety), and also decreasing the number of errors and their criticality.

This method allows the framework proposed to streamline UI design by: 1) categorizing entities of interest in maintenance; 2) identifying important information in each entity; 3) presenting the common problems of SAW and possible solutions to them. The conceptual nature of this framework grants it flexibility to be used in any domain. Additionally, this method can be easily combined with other design solutions, which increases the value it adds in scenarios with high equipment costs or great risks.

However, the conceptual nature of this framework implies in leaving problems of SAW in UI design for maintenance unsolved and they will be addressed in a future work. For instance, it does not assist in determining priority of information, or defining a fixed criteria to select which information should be displayed to avoid information overload. Moreover, this conceptual framework does not specify how to display each type of information (according to their entity category), nor the ideal method to design UI for maintenance.

These shortcomings will be addressed by defining a methodology to design and develop User Interfaces for maintenance field work considering the Situation Awareness guidelines presented in this study. We also intend to propose a solution to increase Motivation in maintenance, because this is a lever to increase the level of awareness [7].

Concluding, today insufficient SAW is one of the main causes of errors in industries. Therefore, this cognitive model should be the basis of any system design process, especially if it involves complexity, safety and efficiency (such as maintenance field work). However, the present SAW-oriented design methodologies ignores the necessity of combining the principles of Physical, Social and Applied sciences, such as psychology, ergonomics, information management and HCI. This problem is addressed by this study by developing the foundation for SAW in industrial field work: the CFSAM, based on a theoretical and practical analysis of maintenance and a holistic study of SAW in maintenance. This innovation accelerates the UI design process, ensures that it provides adequate SAW to users, makes certain that developers/designers consider every area of knowledge relevant for maintenance and provides guidelines to increase the level of coherency and adherence of the system developed.

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References

1. Endsley, M., Jones, D.: Designing for Situation Awareness: An Approach to User-Centered Design, 2nd edn. CRC Press (2011)
2. Dhillon, B., Liu, Y.: Human error in maintenance: a review. Journal of Quality in Maintenance Engineering 12(1), 21–36 (2006)

3. Henderson, S., Feiner, S.: Exploring the Benefits of Augmented Reality Documentation for Maintenance and Repair. IEEE Transactions on Visualization and Computer Graphics 16(1), 4–16 (2010)
4. Endsley, M., Robertson, M.: Situation Awareness in aircraft maintenance teams. International Journal of Industrial Ergonomics 26(2), 301–325 (2000)
5. Chinoy, S., Fischer, D.: Advancing Situational Awareness for Technical Operations. In: Annual Air Traffic Control Association Conference Proceedings, pp. 16–27 (2011)
6. Lynas, D., Horberry, T.: Human factor issues with automated mining equipment. The Ergonomics Open Journal 4(S2-M3), 74–80 (2011)
7. Sneddon, A., Mearns, K., Flin, R.: Stress, fatigue, situation awareness and safety in offshore drilling crews. Safety Science 56, 80–88 (2013)
8. Golightly, D., Ryan, B., Dadashi, N., Pickup, L., Wilson, J.R.: Use of scenarios and function analyses to understand the impact of situation awareness on safe and effective work on rail tracks. Safety Science 56, 52–62 (2013)
9. Bullemer, P., Reising, D.: Improving the Operations Team Situation Awareness: Lessons Learned from Major Process Industry Incidents. In: American Fuel & Petrochemical Manufacturers Annual Meeting, pp. 1–12 (2013)
10. Carroll, J.M., Neale, D.C., Isenhour, P.L., Rosson, M.B., ScottMcCrickard, D.: Notification and awareness: synchronizing task-oriented collaborative activity. International Journal of Human-Computer Studies 58(5), 605–632 (2003)
11. Nazir, S., Colombo, S., Manca, D.: The role of Situation Awareness for the Operators of Process Industry. Chemical Engineering Transactions 26, 303–308 (2012)
12. John, M., Smallman, H.: Staying Up to Speed: Four Design Principles for Maintaining and Recovering Situation Awareness. Journal of Cognitive Engineering and Decision Making 2, 118–139 (2008)