Usability-based eMaintenance for effective performance measurement

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Abstract— **Today's providers of eMaintenance solutions for maintenance and support related to complex technical systems are facing increasing amounts of information flow with the increased complexity of managing data. Organizations developing and providing maintenance support solutions and services also need to improve their capability to efficiently and effectively exploit the increasing amount of data presented to the users'. Subsequently the amount of maintenance data is increasing constantly, thus, human factors issues need to be considered in development of eMaintenance solutions so that performance quality, productivity, and profitability are maintained. Since humans make critical maintenance decisions based upon system performance measured by use of available data, it is necessary that the users understand the underlying data correctly in the correct context. To address the challenges that arise in complex information environments providers need to adapt usability-centred methodologies, technologies, and tools that enable utilization of the advantages eMaintenance solutions can give. In turn this would also reduce situations where too much or incorrect information would decrement the users cognitive capabilities to make good decisions. The usability challenges faced by eMaintenance are complex and need to be taken seriously. Hence, the purpose of this paper is to explore eMaintenance design challenges based upon user issues in complex system environments. This paper will present an overview of the challenges that need to be considered for further research within the field of eMaintenance.**

***Keywords*— User-centred design, Human factors, Usability, eMaintenance, Maintenance,**

I. Introduction

More and more advanced tools are being used to assist in maintaining operation and management of maintenance processes. Since maintenance is composed of a complex set of activities it is difficult to find procedures and information support systems that are capable of assisting in all areas [1]. To combat this difficulty in the maintenance processes, the field of eMaintenance has evolved. The goal of eMaintenance solutions are that they are to take into consideration all limitations and constants and then integrate requirements from stakeholders and facilitate correct decision making on a single platform [2]. Since the complexity of technical systems is growing and also the requirement of system sustainability is increasing, there is a need of developing frameworks that approach challenges related to the development of eMaintenance solutions [3].

Since maintenance activities are most often conducted in cooperation between humans and machines, usability issues need to be considered [4]. In short, if a system can assist operators by quantifying and clarifying the condition of a process it can substantially decrease the operator's physical and mental workload. By implementing user-centred design methods usability can be improved and this will help decrease the risk for detrimental errors. A proper eMaintenance solution will provide a seamlessly integrated and fused service, such as, data visualization and context-sensing [3]. With this the users of the system can be more focused upon finding a solution and not waste time and energy on trying to figure out the context of the problem.

Even though the users of the system are assisted by the eMaintenance solutions there are several issues that need to be considered, since humans are prone to error and mistakes [5], and this is because they have limited physical and cognitive resources [6]. This means that too much stimulus can be distracting, that is, if there is too much to keep track of or maintain it can be stressful and lead to mistakes. On the other hand, even too little stimuli can lull one into a condition of unpreparedness so that when an emergency arises one is not mentally capable of responding appropriately [6]. Therefore, factors such as human error, statutory requirements, accidents, etc. are important considerations in the development of maintenance and support concepts [4]. An overview concerning usability considerations for the design of eMaintenance solutions will be presented in this paper.

II. Maintenance

Maintenance can be perceived as the process that compensates for deficiencies in the original design [4] and it includes all the technical, administrative, and managerial actions during the lifecycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function [7]. The operation of maintenance is complex and it includes; objectives or priorities, strategies, and responsibilities and the implementation of them by means, such as, maintenance planning, maintenance control and supervision [1]. This increases in highly automated plants there the integrated nature of the equipment and process separates the operator from the process making it even more difficult to diagnose and solve problems, while making the operator a more integral part of the process [8] and when problems arise they are difficult to diagnose and solve [9].

The technical complexity and variety of technical systems make efficient maintenance more difficult because the task of identifying, tracing and diagnosing has become less transparent [10].

And today's maintenance often is based upon "trying to solve immediate emergencies…. This kind of "work process disturbances" will exist as long as unplanned and unpredictable product failures can occur and the customers do not have the required competence to resolve the problem themselves. A more "proactive" approach would be to try to reduce the consequences of such disturbances for both the customer and manufacturer, by planning and accommodating for such activities [4].

More specifically operators of the system are often presented visual cues, of which, they need to place the cues in the correct context before they can respond correctly. Since too much information or the wrong information in the wrong place at the wrong time can lead to distraction and mistakes [6], of which, in some case can lead to detrimental results.

III. Usability

The usability context of this paper is based upon the idea that usability is ''the capability to be used by humans easily and effectively'' [11]. ISO standards on usability state that usability is ''the effectiveness, efficiency, and satisfaction with which specified users can achieve goals in particular environments'' [12]. For usability in control rooms or even with smart devices, often used by operators in highly automated plants, one of the key questions is how to work with and improve the usability of interactive systems. Research addressing this question has led to guidelines for improving the usability of systems [13], methods for predicting usability problems [14] [15], techniques to test the usability of systems [16], and discussions on how to measure usability, e.g. [17] [12] [18].

The ISO 9241 standard for usability [12] breaks down usability into three groups; effectiveness, efficiency, and satisfaction, in further, effectiveness is the ''[a]ccuracy and completeness with which users achieve specified goals''; efficiency is the ''[r]esources expended in relation to the accuracy and completeness with which users achieve goals''; and satisfaction is the ''[f]reedom from discomfort, and positive attitudes towards the user of the product'' [11].

Although usability cannot be directly measured but by the use of several measures, e.g. effectiveness, efficiency, and satisfaction, aspects of usability that can be measured [19]. The usability benefits in system thinking and system design are accuracy and completeness in response time. How quickly the task is completed and how correctly it is completed. Flaws and errors need to be reduced and through design work based upon the users capabilities. Therefore the goal is to "design out maintenance or try to optimize the design with respect to maintenance issues" [4]. The manufacturer should carefully design the work processes for design, manufacturing, assembly, etc., and, not least, for supporting product use, to avoid errors in use and reduced reliability and quality, and, finally, for better service delivery performance [4].

IV. Usability and eMaintenance

Crespo Marquez and Gupta [1] when writing about Maintenance Management they argue that an IT solution there managers, planners, and production and maintenance personnel would have access to all equipment data to help them prioritize actions and make better decisions. To support the role of keeping and improving maintenance system availability and safety, as well as, product quality the development of information and communication technologies and their application to the maintenance framework has led to the development of e-maintenance [20].

Globalization and fast growth of communication technologies, computer and information technologies have changed the pattern of maintenance. A new maintenance has emerged and has been gradually replacing the traditional maintenance [21]. Along with that are new variables being added to the maintenance processes, e.g. business plans, financial plans, real-time production and process information, etc. The definition of eMaintenance is that eMaintenance takes into consideration all limitations and constants and then integrates requirements from stakeholders and facilitates correct decision making on a single platform [2]. "This is called e-maintenance in which the maintenance system is dependent upon coordination, co-operation and negotiation through the use of Internet and tether-free communication technologies. This enables manufacturing operations to achieve near-zero-downtime performance on a shareable, quick, and convenient platform through integrating the advanced technologies distributed through the manufacturing process" [21].

With all this information, and the relevant alerts and warnings that are also involved, a looming concern is the use of visual information and how it is to be presented to the users. In many cases, if not all, visual cues are used to alert, warn, and inform users of the system of changes in the status quo. This is a challenge for the designers of these highly automated systems. eMaintenance solutions are used to assist in decision-making [3]. A central problem for those in the aircraft industry is to manage the rapidly increasing information flow [22]. The problem is that for example in aircraft systems the parameters, as well as, the tolerances are becoming more and more context specific. Cutbacks in available aircraft and aircraft technicians are used to cut back on excessive costs, and at the same time the complexity of the aircraft systems are increasing greatly. On top of that the tolerance levels are increasing. This can be a problem for service technicians or personnel in that individuals need to know more, have less time to conduct the task, and must be available at all hours of the day. The risks for mistakes, which can lead to errors, and even possibility a catastrophe, are much greater today. Similar problems arise in manufacturing and process industries where the systems are becoming more complex and at the same time greater demands are being placed upon the personnel.

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As shown earlier, more and more complexity is being adopted to maintenance systems. On top of that complexity eMaintenance solutions place greater demands on the users, there the integrated nature of the equipment and process separates the operator from the process making it even more difficult to diagnose and solve problems, while making the operator a more integral part of the process [8] and when problems arise they are difficult to diagnose and solve [9]. The technical complexity and variety of technical systems make efficient maintenance more difficult because the task of identifying, tracing and diagnosing has become less transparent [10].

James Reason [5] defines human error "the failure of planned actions to achieve their desired ends without the intervention of some unforeseeable event" Training and awareness-creating activities are therefore necessary to avoid such errors.

V. Design concerns

Present eMaintenance projects are testing "smart" devices on service personnel to assist them in their service rounds and repair tasks. These devices allow for real-time communication with the control room personnel and databases to assist in repair work. eMaintenance is an important context for usability because "for complex products, there is a problem in making the available information accessible and understandable to the user" [4].

The goal of eMaintenance solutions is to provide decision support to the maintenance process and its related processes (e.g. operation process and business process) [23]. eMaintenance solutions also maintain or improve upon performance quality, productivity, and profitability by integrating the whole maintenance platform. This is why usability aspects need to be considered and implemented into the design of eMaintenance support systems. eMaintenance solutions need to take into consideration the user and the context of the user. It is not reasonable to expect the user to be an expert in all parts of the system but a good eMaintenance solution would be able to recognize the situation and present appropriate information to the users. "Often reasons for product failures can be traced back to design engineers' and managements inability to foresee problems" [4]. "Traditionally, software products designed for the information technology industry put more focus on feature richness than on ease of use, the assumption being that IT professionals are expert users who should be able to figure out the functionality of the application regardless of how complex of poorly designed the user interface is" [23].

However, recently discussions recur on which measures of usability are suitable and on how to understand the relation between different measures of usability. These discussions of usability are in part fueled by concerns on the limitations of commonly employed usability measures. Take as an example Dillon [18], who has argued that users, designers, and owners of a system may not equally weight the importance of a usability measure such as time. Thus, the importance of time as a measure of usability may be overestimated. Another example comes from Hassenzhal et al. [24]. They argue that commonly employed usability measures ignore what they call hedonic quality, that is ''quality dimensions with no obvious relation to the task the user wants to accomplish with the systems, such as originality, innovativeness, beauty, etc.'' [24].

eMaintenance usability solutions can be incorporated in maintenance decision support provided by fulfilling the goals of usability engineering [25]. This is based upon of working quantitatively with usability and also application of the measures of usability. "it is now an accepted and common practice to purchase products whose sole purpose is to help us master products that we own, but cannot use properly" [26]. It is probably more important to find solutions for the user needs, hence, produce new solutions than try to adapt them to the user [27].

A. *User-centred design*

"As the industry has matured, there has been an increasing shift in focus towards ease of use" [23]. In order to understand the problem of human error one needs to consider what increases the risk for errors. This includes; too much information, improper information, improper grouping of information, and improperly located information. By measuring usability, flaws while interacting with the user interface can be detected and, hopefully, corrected before they result in a mishap.

The role of user-centred design, focuses upon four principals developed from Gould and Lewis [28] user involvement, empirical measurement, iterative design, and multi-disciplinary teams that are used in three phases, concept formation, prototype development, and evaluation. The user involvement principal maintains that an understanding and knowledge about the user(s) is necessary, that an empirical measurement or validation of the design is required, design iterations should be used and take into account the insights gained in the empirical validation, and multi-disciplinary teams should be used so to have a broad knowledge base of the users, technologies, and the context of the design problem.

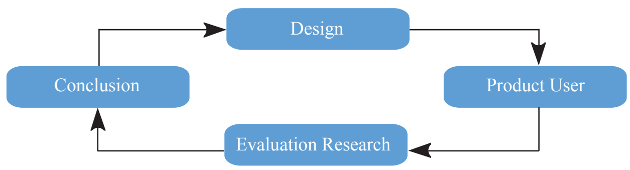

Fig. 1. User-centred design model

The standpoint of user-centred design is that the designer uses the feedback and knowledge of the user to analyse the different steps in the design process (Figure 1). Jordan [29] explains this in the three levels of user needs, which are functionality, which shows that a product needs to function properly. If it does not function properly then it cannot be usable and if it does not have the right functionality it will cause dissatisfaction. For artefacts to be complete in this level the designer must have an understanding of what the product

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will be used for and the environment it will be used in. Usability takes into consideration that the first level is fulfilled.

Usability is a qualitative attribute that assesses how easy artefacts are to use. This is defined by five components; learnability, efficiency, memorability, errors, and satisfaction [30] [31]. Pleasure is the third level and usability is a key component to pleasurability for without usability pleasure is hard to come by. The difference between usability and pleasure is that objects are not just usable tools, but they also are objects that one has a relationship to. As stated by Markeset and Kumar [4] there is a greater need than just having a function but also users need to feel a certain level of satisfaction in using the eMaintenance system. Customer satisfaction is not only decided by value and performance of hardware purchased but by the total value received and by the quality of interaction and relationship experience throughout the service life of the product [4].

Finally, proposals for new measures of usability are continuously emerging. The HCI literature now contains discussions of, for example, fun, aesthetics, apparent usability, sociability and flow [19]. These proposals all seem to suggest that common conceptions of how to measure usability may need revisiting.

B. Customers goals

A main task of good usability is to reduce errors that lead to downtime, thus, increasing of system availability and reliability. The better the operator understands the system and its interface the lesser of a chance they will make incorrect decisions. A usable system satisfies its users and increases their efficiency, which leads to increased system availability. The trend that maturing markets has competing products with similar feature sets. Thus, ease of use and overall use experience are becoming more important to the buying decision.

When measuring usability, we want to select usability parameters based on the business objectives. This means that business objectives should be defined and understand. The usability parameters should be used to contribute to or are relevant for each specific objective and then selection of an appropriate approach and tools can be undertaken. In other words, this means that one needs to fulfil the customer's goals. Then in following a performance indicator system should be used to monitor the effectiveness and efficiency of the implemented operation, maintenance and support strategies [32]. To ensure the desired product performance at a support system for a reasonable cost, one has to develop maintenance and product support concepts right from the design phase [4]. "Enterprise Applications can be both feature rich and easy to use" [23].

C. Customer Satisfaction

Customer satisfaction is crucial to business success and, therefore, product and service strategies should be aligned to meet customers' needs. An important part of that is staying close to customers and providing superior services. This also helps create more loyal customers and increased customer satisfaction [33]. The main goal of a service intended to support a product, is to ensure the expected function and/or to facilitate the clients access to its function and in this case it is the eMaintenance solution and the goal is to produce a functional system where "the user company focuses on core business processes (e.g. production) and need not worry about service/maintenance" [4].

VI. Design Recommendations

One important issue for the need for good design in eMaintenance solutions for highly complex systems is that no matter how perfectly the system functions it is still impossible to design a system that is maintenance free [4]. Surely, the reasons for improper maintenance and maintenance failures can be traced back to maintenance design [34] but the complexity of it makes it almost impossible to find a perfect solution. Therefore, "it is important to understand operators' requirements, performance targets, system attributes, and the competence level of operators and maintenance personnel before the design process is initiated [4]. In order to produce a good design these things need to be taken into consideration:

D. Stress reduction

Stressors that can cause stress are noise, vibration, heat, dim lighting, and high acceleration, as well as psychological factors such as anxiety, fatigue, frustration, and anger along with time pressures [6]. Many stressors impose a distraction and, thus, divert selective attention away from task-relevant processing. Yerkes Dodson Law [35] states that arousal improves performance, while too much arousal or stressors cause performance to decrease. This follows an inverted U shaped pattern. People who are stressed, while performing, chose patterns of self-preservation, that is, they often continue with a plan of action, which, they have used in the past [6].

E. Human Error

According to Reason [36] the primary cause of major accidents and incidents in complex systems, such as, nuclear power, process control, and aviation are due to human error. Many errors committed in operating systems are the result of bad system design or bad organizational structure rather than irresponsible action [5] [37]. Human errors made in experiments are not as detrimental as errors made in real life situations, therefore, are models or guidelines produced to help designers predict and test for errors in both simulated and natural conditions before implementing new changes. In dealing with humans it is difficult to isolate errors of a certain kind because the human, as mentioned earlier, can be affected in many different ways.

Human error can be categorized in several ways and a model that is consistent with the information processing model is the Skill Rule Knowledge Taxonomy (SRK) by Rasmussen [38]. This taxonomy provides "some basic distinctions which are useful in defining the categories of human performance for which separate development of models is feasible". Three levels of human errors, skill-, rule-, and knowledge-based, were developed to be useful in design and evaluation of new interface systems. The skill-based and rule-based levels are automatic responses, while the

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knowledge-based level is slow and a thought process needs to be engaged (Figure 2).

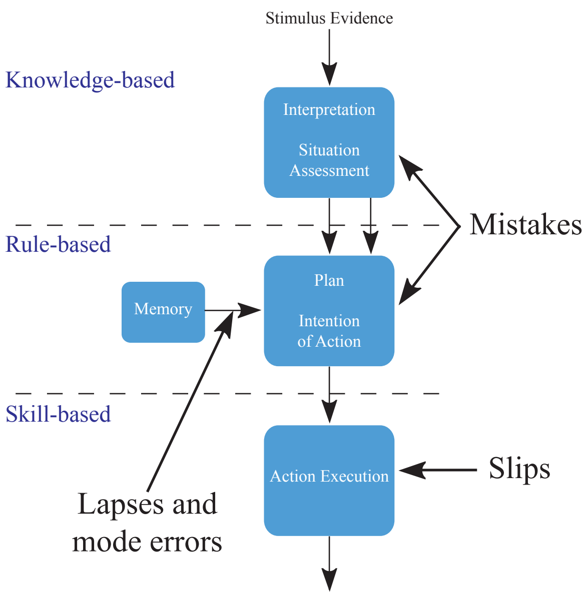

Fig. 2. SRK taxonomy

The skill-based behaviour represents things one is skilled with, e.g. walking, typing on the keyboard. At this level only small errors, called slips, can occur. The rule-based behaviour requires no reasoning in the thought process. One is in a familiar situation, e.g. riding a bike, driving a car, and here can errors of memory lapses or mistakes occur when one is distracted or under stress. While knowledge-based behaviour takes in effect when one comes to an unfamiliar situation there the thought process needs to take into consideration unexpected factors, e.g. uncommon alarms in a system or detour in the roadway. At this level detrimental errors, also called mistakes, can occur. The goal is to design systems that do not allow for knowledge-based decisions when the user is distracted or under stress.

F. Error remediation

The SRK taxonomy is used to help guide the overall design process, while Rasmussen [38] states that quantitative methods can be used to help guide the specifics of the design. This method is not designed to remove human error, but to increase the systems tolerance to errors [39]. Norman [37] says that one is to design for error by assuming that errors will occur, plan for them, and design a system that allows users to make errors and recover from them. The design should allow reversible actions, while preventing irreversible actions through the use of:

1) *Task design*: Simplify tasks by making them similar to natural tasks, but give mental aids to the new method. Certain tasks do not need to be changed, but what the operators is doing has to be made visible and feedback should be given so they can keep control of the situation. Parts of a task could be automated so reduce unnecessary work and if a task is too complex or difficult the nature of the task should be changed [37].

2) *Equipment design:* Equipment should not allow people to misunderstand what is to be done. Let the operator know what actions to take and give feedback to what they are doing. Use constraints that prevent people in making errors. Use reminders so that actions are not forgotten. Avoid systems that require similar actions, which result in different functions in different contexts [37].

3) *Training:* A lack of knowledge and training is a large source of mistakes. Even with training it is important that the immediate and relevant feedback is given. People should also practice at correcting errors so they will know how to deal with them in the actual situation [6].

4) *Assists and rules:* If things cannot be solved by design then develop rules of operation or by standardizing the way things are to be used [6].

G. Usability for Maintenance

Usability is important and essential when developing eMaintenance solutions, since it facilitates maintenance decision-making through provision/enhancement of user-centred design. Since error remediation is an important part of eMaintenance solutions the use of Rasmussen's taxonomy is a helpful tool to use. Recommendations by Rasmussen [39] are used to help reduce human error:

1) A formalized description of the categories of the tasks need to be determined if a plan is to be developed.

2) A task must be described in terms based upon the human mental functions. Subjective preferences and performance in the given environment is necessary for design.

3) Analysis of human performance in real-life situations is necessary to identify strategies and subjective performance criteria.

4) Different types of experiments should be used to evaluate different design concepts. Qualitative evaluation of the peoples' strategy of performance is better suited than quantitative measures.

5) It is also important to continuously measure system usability during the whole system lifecycle since the usability parameters will be change due to changes in the system requirements and the system characteristics.

VII. CONCLUSIONS

Based upon the customer and manufacturers point of view, the human is the most important part of a maintenance system. That is why it is very important that the human can work effectively and safely within the system and its environment. If this is not possible then when the user interacts with poorly adapted and integrated complex technical system, under stress, then system safety, operation reliability and costs will be negatively affected.

eMaintenance solutions assist system users in solving problems, therefore, both subjective and objective measures of usability should be added to the design of the maintenance framework. Just as differences between interfaces may not be found in an objective measure for subjectively experienced duration, and vice versa [19] it is necessary to know what one is measuring and why. Therefore, are user-centred design methods recommended for eMaintenance system design.

In conclusion 11 recommendations are given to assist designers for eMaintenance solutions. These are developed from the results found in this paper and they are necessary reminders for those who develop tasks and interfaces for the maintenance workers:

1. Not too simple, so to reduce boredom.
2. Not too complex, so to prevent unnecessary negative stress.
3. Allow for correct warnings in the correct situation, so to prevent confusion between warnings from different systems/ equipment.
4. Correctly show warnings so that the correct information is shown in the correct situation.
5. Unnecessary or impertinent information can be "hidden" until it is relevant or "asked for" by the user.
6. Use logical groupings of information, so to reduce confusion, of which, may lead to errors in stressful situations.
7. Present information so that the users can quickly orientate themselves to what they are looking at and what they are looking for.
8. Present the most relevant and useful information in easy to use locations.
9. Allow for user-centred studies to be completed in both simulated and natural environments to gain a better understanding of the area of interest.
10. Use redundant information presentation to reduce misunderstanding.
11. Design the system so that the users can make decisions they are trained for.

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