Usability aspects of eMaintenance solutions

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ABSTRACT

As technological development progresses in society, there are several new possibilities to make the maintenance process in industry more efficient. Today, eMaintenance solutions facilitate data management in maintenance activities; data can easily be integrated and shared between sources in heterogeneous environments. This enables systems used in maintenance, such as Computerized Maintenance Management Systems (CMMS), to base decisions on various data, e.g. data produced in other processes. These systems often fulfil the technical requirements (e.g. data consistency control) required to support activities in the maintenance process (e.g. management, support planning, and assessment), but the human interaction with the systems is still essential to the quality of the work performed. Since many maintenance activities require manual input of data the interaction between user, e.g. technician, and system, e.g. CMMS, has impact on the quality of the data; in order for the data to be right and relevant, the technician may need supporting directives from the CMMS. Hence, the system usability must be considered when assuring the quality of the manually inputted data.

The focus of this paper is to investigate CMMS limitation issues due to usability aspects. Furthermore, the paper discusses the role of context awareness within user interfaces managing data obtained through eMaintenance solutions and presents ideas for future research on context awareness in eMaintenance solutions. Data and conclusions have been conducted through literature studies and case studies within the area.

Keywords

CMMS, Context awareness, motivation, data quality.

1. INTRODUCTION

Technology development is in constant progress and the tools and systems used in maintenance processes are continuously improving. As the tools and technologies get more advanced, the need for high information processing solutions with that can communicate between systems is increasing [14]. Today, ICT-based maintenance solutions, i.e. eMaintenance solutions, support enterprises with effective and efficient decision-making by enabling just-in-time access to maintenance information [13][26]. eMaintenance solutions aim to support maintenance stakeholders with necessary information adapted to their context [14]. A proper eMaintenance solution needs to be able to sense the context of the individual stakeholder in order to properly adapt the information to the stakeholder's current situation [3]. eMaintenance solutions with context-sensing capabilities facilitate the interaction between the system, e.g. Computerized Maintenance Management System (CMMS), and its specified users, which in turn will contribute to effectiveness and efficiency in the maintenance process. The increased availability of data enables accurate and precise decision-making in maintenance, given that the collected data are relevant, used correctly and hold the expected level of quality. The quality of the data is essential in the decision-making process, since inaccurate or poor data may influence the decision incorrectly, especially if the system using the data is not able to verify the quality [24]. Hence, it is important for maintenance tools that are using eMaintenance solutions to be aware of data quality issues and actively reduce them [16][24].

There are many factors that can affect the quality of eMaintenance data and various studies [1][15] have emphasized the importance of the users' interaction with the system. A poorly designed system can actually promote human errors when using the system [19][21]. A system in this paper is defined as the computer programs used for surveillance, storage and analysis of operation and maintenance data. As systems become more advanced, due to e.g. increased automation and greater complexity, it gets harder for the users (or system operators) to keep track of the actions in the system and to fully understand the system capability [21]. A CMMS is most likely capable in executing the task it has been designed for, but it often lacks the capability to assist the user to perform the task, resulting in data quality issues and other criticism [1].

The purpose of this paper is to further investigate the usability of a CMMS and the paper seeks to address the following question: What are the main usability issues within a CMMS and what are the core reasons for these issues?

2. THE INTERACTION BETWEEN USER AND EMAINTENANCE SOLUTIONS

A typical interface between eMaintenance solutions and the user of eMaintenance data is a CMMS. A CMMS organizes many different functions, such as work orders, inventory control, asset management and integration towards other management systems. Operators, technicians, as well as, management may be typical users of a CMMS [15]. A CMMS provides work orders to plan and schedule inspections, preventive maintenances and maintenance of machine break-downs; this includes assigning personnel, reserving materials, recording costs and tracking information history. When appropriately configured, and interfaced, with other systems within a company, such as an Enterprise Resource Planning system (ERP), a CMMS can become a critical and useful tool in handling maintenance organization activities [17]. The capabilities of handling large quantities of data facilitate a thoughtful maintenance approach [15]. However, the ability of handling large amount of data is not much worth if the data is not used correctly. The term black holes in CMMS was introduced by Labib [15] as a description of systems greedy for data input that seldom provide any output in terms of decision support. In general there is a lack of basic user-friendly design in many CMMS and this is a result of the systems being designed for accounting and/or IT rather than for the users specific needs [15].

2.1 System usability

The awareness of the importance of system usability is constantly increasing and the European Parliament and the council of the European communities has established a directive that requires employers to ensure usability when designing, selecting, commissioning or modifying software. The following requirements are listed in the directive; (i) the software must be suitable for the task; (ii) the software must be easy to use and, where appropriate, adaptable to the user's knowledge or experience; (iii) the systems must provide feedback on performance; (iv) the system must display information in a format and at a pace that is adapted to the user; and (v) the system must adapt to the principles of software ergonomics [5][6].

Since a CMMS is very complex, containing information of the whole production process, such as, financial information, logistics, parts and services, maintenance schedules, etc., it is not a simple system to build. Because of its complexity there is a risk in the system becoming error prone, especially for the users. Therefore it is important that the system users are active in the design of the system. Rather than being the cause of an error; "operators tend to be the inheritors of system defects created by poor design, incorrect installation, faulty maintenance and bad management decision" [21]. Therefore it is important that the designers of complex systems need to assume that every mishap will happen and their job is to design against it. To assist in this three principals are recommended [19] for the design of complex systems:

1. Use common knowledge, found in the real world, for actions to be used in the operation of the system. Usage should not require unique knowledge to operate.
2. Use functions that help the user to make natural decisions based on both natural and artificial constraints.
3. Make options readily visible to execute actions and make the results of each action readily available for evaluation.

To make a system easier to learn and use is to allow the users to explore, experiment and learn different possibilities of the system. To make a system explorable and decrease the risk for user errors it needs to: (i) allow for the user to know what state they are in the system and readily see what they need to do, (ii) the effect of the action must be both clear and easy to understand and (iii) undesirable actions should be reversible [19]. This is necessary to increase the usability of complex systems, e.g. CMMS.

A system with a high level of usability should be easy to learn, engaging to use, and support the user to efficiently and effectively complete tasks and goals [25]. ISO 92441 describes usability as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" [12]. This definition includes objective measures, such as specified user context and the goal, of how usable an application is. Goal-oriented actions are often connected to motivation and in order to help the user to achieve a specific goal, the goal must be clear and the system should be able to motivate the user. Having the usability definition in mind, the following two sections discuss the impact of user motivation and context awareness.

2.1.1 The impact of user motivation

The usability of a CMMS is a challenge and it is important to consider the users' level of motivation to know how to work in improving system weaknesses like usability. Motivation can be divided into autonomous extrinsic motivation, which is based on importance and outer goals, and intrinsic motivation, which is based on interest and inner goals. Both types are related to the performance, satisfaction, trust and well-being at the workplace [8][27]. Autonomy, stimulating tasks and decision authority are important aspects to consider when talking about work motivation. The job characteristics model, illustrated in Table 1, is based on the idea that the task itself is the key to employee motivation. The model identifies five characteristics and the fundamental principle of the model is that engagement derives from inside in order for the work to feel satisfying and self-rewarding.

Table 1. The job characteristics model

Characteristic	Degree of…	Description
Skill variety	…skills required.	Describes different skills and talents needed for a given task.
Task identity	...clarity of task definition.	Clear definition of beginning, middle, end and visible results.
Task significance	…"Substantial impact".	Describes how meaningful a given task is.
Autonomy	…freedom.	Includes the ability to schedule work, as well as, finding a solution for a given task.
Job feedback	…relevant feedback.	Keep the employee informed about the performance.

Pride of being responsible and feeling ownership with one's work is also an important aspect to be considered when dealing with motivation. It is also true that a sense of ownership of the equipment affects how one treats the equipment and that maintenance will directly affect its reliability and performance. As employees develop this sense of ownership there is an increased sense of pride, motivation and self-esteem. The long-term impact is increased productivity [7][18]. When the users feel alienated to the equipment they will not be motivated to exert themselves in improving the equipment nor taking any extra steps to maintain them.

2.1.2 The impact of context awareness

A necessary, yet difficult, task for system design is the aspect of context awareness. As mentioned before, to make a system easier to use one should know where they are in the system. The system should also be able to allow each user to access relevant information and actions. The CMMS needs to provide users involved in a certain context of the maintenance process with functionality providing accurate maintenance-related information at the right time and adapted to the actual maintenance context

[14]. The context can be described as a template providing any information that can be used to characterize the situation of an entity [4][26]. This entity can be a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves [19]. Context awareness are then using the context template to provide task-relevant information and/or services to a specific user [4][26].

Thus context awareness can be described as the ability of a system to adapt the operations to the current context without explicit user intervention [2][23] and thereby respond to changes in the environment in order to make the system behave more relevant to the current situation. The aim for systems with context awareness is to increase usability and effectiveness by taking the actual situation and the respective user context into account [2].

The actual context or environmental context can be divided into an external and internal dimension [9][11][19]. The external dimension handles attributes, such as location, light, sound, movement, touch or temperature, which can be measured by hardware sensors. The internal dimension handles attributes that is mostly specified by the user or captured by monitoring user interactions, e.g. the user's goals, tasks, work context, business processes or the user's emotional state.

3. METHOD

Two case studies were conducted in order to find the core reasons for usability issues within a CMMS. The base for the study was the usability definition provided by ISO 92441 [12] described in section 2.

The first case study was conducted to gain insight into the main usability issues of the CMMS, while the second case study was conducted to find out how the CMMS could be improved. Semi-structured interviews were chosen for both case studies since the goal of the studies was to "pick up" as many different ideas concerning the CMMS as possible without hindering the interviewees from speaking freely about the system.

The interviews of the first study were conducted at several companies; two mining, five pulp and paper and an airplane manufacturer. The goal of this case study was to gain a more complete understanding of how users of the CMMS find the system helpful in their work. The 10 individuals interviewed had the following roles in the organizations: section manager, foreman for mechanical maintenance, maintenance mechanic, foreman for electrical maintenance, electrical maintenance mechanic, maintenance engineer, maintenance technician, maintenance mechanic for preventative maintenance, production operator and an automation systems designer. The interviewed were experienced and had a good understanding of the system.

The second case study was conducted to gain more specific information concerning the usability of the CMMS and how it could be improved. It was conducted as a group interview with a team of four aircraft service personnel who had different roles in using the CMMS. This was done to learn as much as possible from the individuals on how the whole system functions. The questions used in the open-ended interview were: "How easy is it to use the CMMS?", "How does one get help if needed?", "What limitations are the most frustrating?" and "What improvements are recommended?".

The interview responses were recorded and analysed. For the first case study, the results were categorised in accordance to the types of problems the respondents brought forth. In the second case study, the responses were categorised based upon the research questions used. Everything was controlled and compared to the original material.

4. RESULTS

The two case studies found in this paper look at user issues of the CMMS in several areas and this section presents the collected data.

4.1 Case study 1

The following problems were identified as issues relevant to the ICT solutions in maintenance activities.

(1) Lack of compatibility: The CMMS was not connected with production, material management or spare parts storage and purchasing. These together are required for operative and strategic decision making in the maintenance phases. One reason for this problem is that the data were not comparable and difficult to combine. This complicated maintenance related operative and strategic decision-making.

(2) Data Multiplicity: The CMMS did not collectively store technical documentation and drawings. Certain information regarding technical documentation and drawings was sometimes stored in multiple sources. Since some of the stored information was not regularly updated or maintained it was difficult to know if it could be trusted and sometimes the sources also contained conflicting information.

(3) Manual data input and transfer: The CMMS required manual input and transfer of data into the system. Manual data entry resulted in data of varying quality; some personnel enter detailed and descriptive failure reports, while others unknowingly omit compulsory data. Some automation based upon work orders, production stops, etc. could also have been helpful.

(4) Not user friendly: The CMMS user interface and the systems functionality were not intuitive. Several of the participants shared the opinion that the usability of the maintenance systems could be improved. At times it could be difficult to find relevant information and the user guidance was lacking.

(5) Lack of guidance: The CMMS lacked user instructions that were easy to use. There was no common practice for what kind of information that was needed and by whom and in what form it should be collected in the different phases of the maintenance process. Several different methods to collect data existed and, therefore, information in the database was not compatible. This made it difficult to do systematic data analysis and to produce key performance indicators.

(6) Limited strategic use of CMMS: The CMMS data were not generally used for operative and strategic decisions. Thus, the CMMS was mainly used for information transfer and communication between people of different positions and organizations, e.g. sending and receiving work orders or accessing information from the system. Since the data were not collected for operative and strategic decision making, the CMMS users were not always aware of what purpose the data were to be used for and the user motivation to collect and enter good quality data in the system was thereby lowered.

(7) Low competence: The CMMS was not used proficiently by the people it was intended for because only a few were able to use the system. Even though the maintenance personnel mainly used the CMMS, the operative personnel conducted a lot of maintenance actions but did not have access to the CMMS. This led to the situation that only part of the actual maintenance actions were recorded in the CMMS and a great deal of data was lost. Finally, when the operative and strategic decisions were made, they were based on the recorded data, which only showed a part of what had occurred. Therefore, the strategic decisions were often not well grounded.

4.2 Case study 2

The following CMMS issues were identified in this case study.

(1) Better training needed: No course was held on the CMMS, all training needed was performed online as a self-study course prior to the introduction of the CMMS. This placed a lot of responsibility on the user to plan and prioritize the training. Due to this the user acceptance of the CMMS was thereby lowered.

(2) Informative feedback is needed: The CMMS did not produce informative feedback to the user. The CMMS should clarify the action and should not only say e.g. “Wrong input data, keyword is missing”. A suggestion was to add feedback that will explain the purpose of the keyword.

(3) Orientation within the system is needed: The feeling of being a part of a whole process was somehow lacking and the significance of the work performed could therefore sometimes be questioned. The following information was pointed out as important for the case study participants:

- “Visualization of actions before and after me in the chain.”
- “Visualization of the importance of my effort and my part in the process.”
- “Visualization of what has been done, not only what is about to come.”
- “Visualization of the number of completed actions of the team. (Important that this is not presented as a stress factor, but as positive feedback.)”

(4) Intuitive Interface is needed: Many minor interface restrictions created irritation. The CMMS interface was not intuitive and did not help the user to find the most likely action in a specific situation. The following examples were mentioned:

- “Need to click twice in a text field before editing.”
- “Little or no feedback from the system.”
- “It is not possible to switch text field with the arrows, must use TAB.”

(5) Flexibility: The work process was not always aligned with how the CMMS was designed, e.g. there was no natural or consequential process. A lack of flexibility in the system also forced the users to develop work arounds.

(6) Simplify common actions: Necessary work arounds ended up with time consuming phone calls with other departments to solve issues due to that the CMMS did not support actions that are commonly used by the operators.

(7) Interface should reflect end-customer solutions: The CMMS was implemented in 2010+, but the interface was a reminder from the mid 90’s. Many of the actions required and solutions given to the users did not reflect common interfaces. This resulted in lowering the users’ motivation to use the system.

5. DISCUSSION

The results of the two studies were compiled and analysed based upon the seven groupings from case study 1. Beginning with Lack of compatibility, data multiplicity, manual data input and transfer, not user friendly, lack of guidance, limited strategic use of CMMS and, finally, low competence.

First, the lack of compatibility of the interface showed a need for familiarity in the interface and improved CMMS functionality. The interface should reflect common end-user solutions of today, both mobile and stationary computer operative systems have standardized order of operations, in which, users can identify with. Therefore the proposed solution would be to improve the user interface so that it reflects commonly used solutions.

Secondly, data multiplicity pertains to the patchwork of solutions used to help and guide the user when needed. Work processes are constantly changing and the systems that are used in the processes must be flexible and cooperate with the user in order to avoid work arounds. To avoid time consuming work arounds, the participants in case study 2 asked for a flexible CMMS that is able to adapt to the current situation. This would not only save time but also reduce frustration in the work process. This pertains to context awareness within the CMMS. The operators need to receive the right information at the right time in the right context.

Thirdly, manual data input and transfer was a bottleneck in the system. To solve this, the participants in the case study 2 asked for a system that simplified common actions. This pertains to the user interface and the need for interface improvements.

Fourthly, the CMMS was not perceived as user friendly or intuitive due to complexity of the required actions and the fact that relevant guidance was lacking. The participants in case study 2 expressed the need for an intuitive interface and this pertains to interface improvements. Many problems could be solved by an intuitive interface, reducing user error.

Fifthly, lack of guidance pertains to the CMMS’s lack of necessary information when operating the system. To combat this, the participants of case study 2 expressed the need for usability solutions that reflect common end-user solutions found in the marketplace today. And on top of that each action in the system should be confirmed by a sound or change in the interface giving relevant feedback on what action was taken so that the user knows exactly what has been done and what the next action should be, reducing incorrect actions. The job characteristic model lists relevant feedback as an important influence on the engagement of the employee [10]; by using positive and explanatory feedback the system can motivate the user to perform even better the next time data is fed into the system. This will increase intrinsic motivation [8][27] instead of just telling what has been done wrong and thereby only using extrinsic motivation to get the user to do the task correctly next time. Finally, the users need to know where they are in the system and where they are in the work process in relation to other tasks being completed. In this way they could plan their work more effectively and be able to quickly come up to speed.

Also, the cooperation between different teams would improve if other teams work actions are visualized. This is an important, if not necessary, part lacking in the CMMS. Being a part of that bigger picture and work together with different skills towards a common goal will increase the motivation and the sense of pride of the work. It can also reduce unhealthy competition between groups within a company. The job characteristic model suggests that all different skills required for a task should be added to the task. This can encourage collaborations between teams [8]. The job characteristic model also describes the importance of task significance and task identity [8] that can be emphasized by the visualization of the whole work process. The system should be aware of the user context and able to visualize the context and the significance of the task. The users need to know the context so that they can be more effective in their work, as well as, reduce the chance for mental slips and mistakes caused by loss of context.

Sixthly, even though the CMMS is a powerful tool it was often only used in limited degrees for making strategic business decisions. The reason for this was the fact that the system was difficult to understand and use. Also, there was little transparency to the users what the result of the user actions actually could or should be used for in the complexity of the CMMS. The role of the user during each action should be known by the CMMS in order for the CMMS to be able to provide the purpose of what to be entered in the system. This would result in more accurate and relevant entered data. This pertains to the need of context awareness in the system. The users should be able to quickly orientate themselves by a glance or through a quick action request.

Lastly, the general lack of competence amongst the system users is a great concern. As noted in earlier studies, se [1], it is not unlikely that finances are expended in the implementation of the hardware and software, while training is not given the same level of importance. The participants in the case study described the CMMS training as an online self-study. Although this solution was most likely cheaper than a regular, hands on course with teachers and the actual equipment and system, relevant training is needed in order to gain user acceptance of a system.. To gain user acceptance, the purpose of why the new system is introduced must be thoroughly known of task significance and task identity are important for the user motivation [10]. If the training is a positive experience and performed in near time to when the user will start using the system, acceptance is more likely to occur. Therefore training should be considered as an important part of the system implementation.

The results from both case studies show that improvements need to be made within the area of user training, interface improvements and context awareness. The first, user training, shows that the case study participants did not feel that they were given the proper tools to work with the CMMS. The second, interface improvements, shows that there is a need for user-friendly design in many CMMS. As Labib described in [15], the systems seem to be accounting and/or IT oriented rather than engineering-based. The third area, context awareness, shows that the case study participants are in need of a system that understands the complexity of the task that is about to be executed and the role of the current user of the system. The CMMS needs to have a context awareness solution and be able to sense what the user needs to accomplish a specified task [2][4][23]. Table 3 illustrates the relationship between the three identified core areas for the CMMS usability issues and the two case studies.

Table 3. Relation between core areas and case study results

Case study 1	Case study 2	Core area
Lack of compatibility	Interface should reflect end-customer solutions	Interface improvements
Data Multiplicity	Flexibility	Context awareness
Manual data input and transfer	Simplify common actions	Interface Improvements
Not user friendly	Intuitive interface is needed	Interface Improvements
Lack of guidance	Informative feedback is needed	Context awareness
	Orientation within the system is needed	
	Interface should reflect end-customer solutions	
Limited strategic use of CMMS	Allow for simple modifications	Context awareness
	Orientation within the system is needed	
Low competence	Better training needed	Better training

The need for user interface improvements points to the need for increased usability. As of today the CMMS interface is not intuitive and in some situations it can be rather difficult to use. There are EU directives [6] on how “useable” software programs should be and the main point of this directive is that the user should know what to do in each situation. This was not the case for the CMMSs studied. The greatest problem is not that the level of usability is low but that the users were prone to conduct errors because of the low level of usability. On top of that the users in several cases chose not to even use the CMMS but “push” the task of entering in, reading and using the data upon someone else. Design recommendations for complex systems are clear in that the user should see the system as enjoyable to use and not a threat [19].

Due to the complexity of the maintenance systems found in large industries, not just a better interface is necessary. Therefore it was stated by the users that they would like to work with a system that was able to know who was using the system and allow them to work with task relevant actions. Context awareness is necessary in assisting users in very large and complex systems like the CMMS of the companies that have been analysed in the studies.

Depending on who is using the system, different techniques might be used to raise the user motivation to add good quality input data. A typical user in this paper refers to e.g. a technician that is interacting with a CMMS and manually adding e.g. work order data, which will be used for further analysis and maintenance, to the system. However, usability aspects and context awareness are important for all interfaces, regarding if the user is a human or another system in the front or back end of a process.

5.1 Limitations

Several different CMMS manufacturers were used in the study. Since the user interfaces of these CMMS differ, there could be a conflict in the responses given by the case study participants. Although, the reported responses in these case studies were the general consensus of the personnel and the reported results congruent.

6. CONCLUSIONS

The conclusions of this paper are based upon how the CMMS can be improved. To improve the CMMS it was found that (i) interface improvements are necessary for the users to use the system more effectively, (ii) a greater focus needs to be placed on the training of the personnel and finally, (iii) the CMMS needs to have an intelligence that understands the context of the user situation and be able to sense what the user needs to accomplish a specified task.

The user aspects must be considered in relation to the current user. Different users of a CMMS may have varied expectations and needs and it is important to make the interface flexible and able to adapt to the user context. By implementing context awareness into a CMMS users are presented with information and allowed actions that are relevant to the goals they are to perform. Since the individual becomes an integral part in the maintenance process, with context adaption they are apt to a higher level of motivation and would be more likely to use the system to a higher degree.

7. FUTURE WORK

The interface improvements and training issues can be solved with an increased focus in those areas by the system designers and the businesses that implement the CMMS. It has been shown with today's end-users solutions, in both mobile and stationary solutions, that these issues can be reduced to a minimum. The area of context awareness is rather young and much research needs to be done so that industrial solutions reduce the risk for human error.

Usability aspects and context awareness are important for all interfaces, regarding if the user is a human or another system in the front or back end of a process. A subject for future work is to find a model or process describing of how a system interface can adapt to the user context in order to get good quality eMaintenance data.

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