Predictive Maintenance as a Case for Intervention

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Predictive maintenance is a core topic of smart factory visions and adds further automation, digital processes, and new ICT-systems to industrial settings which are already highly automatized on the manufacturing level. It will change how maintenance is carried out, reduce breakdowns and stall times – thus impacting the factory's inner workings and the work experience of the maintenance personnel and the plant operators in specific. We will highlight some of the key challenges we identified in our case study and their impact on the work experience. Further, we will show how the concept of intervention and exploration can be employed to mitigate several problems. We will also highlight that apart from technical measures communication and social process are needed to resolve the issues.

CCS CONCEPTS • Information systems~Information systems applications~Collaborative and social computing systems and tools • Human-centered computing~Interaction design~Interaction design process and methods~Participatory design • Human-centered computing~Interaction design~Interaction design theory, concepts and paradigms

Additional Keywords and Phrases: Predictive Maintenance, Intervention User Interfaces, Work Experience

1 INTRODUCTION

Predictive maintenance is at the heart of many smart factory visions. Insights into the current and recorded sensor values help to anticipate defects before they occur. Thus, reducing breakdown and stall times but also increasing the quality of the goods produced by keeping the machinery in optimal condition [5, 7]. Traditionally, factories or production plants have been inspected and/or maintained physically on-site according to a schedule – preventive maintenance. Some conduct inspections on machines and their surroundings only once minor or major defects emerge – corrective maintenance. The move away from “fail-and-fix” to “predict-and-prevent” schemes has been fostered by the availability and integration of modern ICT within the factories [6].

Predictive maintenance provides a new point of view on the plant through its current and recorded sensor values allowing for new forms of support, planning, and work distribution. This data-centric and forward-looking view may become the dominant one in the future. Plant operators until now have been able to see and understand what happened recently or now either by using information systems to display or aggregate sensor data or by conducting an actual inspection on-site in the plant. With predictive maintenance systems, an additional view becomes available: predictions of what will happen in the future and warnings regarding feared events [6].

The introduction process poses many challenges – technical, organizational, and social alike. Special attention is needed when such a system is introduced and has to adjust to its context. The users have to observe the system’s

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notifications and compare them with the plant's status. They have to maintain the coherence between the predictive maintenance system's notifications and the real status of the plant. Thus, they have to provide feedback for the system to learn and adapt and provide fixes for any rough edges. The process of learning here is twofold. On the one hand, the predictive maintenance system has to be trained, but also on the other hand, its users have to undergo a learning process. Besides, the plant runs through a continuous process of change with varying requirements, new production lines, and machinery. Therefore, the question arises whether the improvement of the predictive maintenance system will also be an ongoing challenge.

If the system is reducing defects and downtimes it can at the same type reduce stress for the maintenance staff. Breakdowns putting the whole plant on hold are less likely to occur. Anticipated downtimes can be scheduled, sufficient and qualified personnel will be available, and needed parts will be present. That reduces the need for workarounds and reduces the pressure on the maintenance personnel. In the predictive maintenance project which we have investigated in the context of the body assembly of a car manufacturer, if-this-than-that-hypotheses were drafted. The hypotheses are based on the fluctuations or outliers in the stream of sensor data. If certain thresholds are violated, a warning is issued. We will employ the concept of intervention user interfaces [3] to selected problems of this case and discuss how intervention and exploration can contribute to mitigating them.

2 EMPIRICAL BACKGROUND

We have accompanied the introduction of a predictive maintenance system at a car manufacturer's body assembly plant. Before the introduction of the system, incidents have been handled in an ad-hoc manner. There were no scheduled maintenances. All replacements of parts only happened on incidents or breakdowns. Such breakdowns put a whole assembly line or even the whole plant on hold. Thus, replacing the failed parts and resolving the issue puts the maintenance staff under severe pressure – the incident has to be resolved as fast as possible.

The plant operator is responsible for this process. He operates and monitors individual production islands or robot groups and, if necessary, stocks magazines with supplies. He is responsible for troubleshooting these systems. In doing so, he can use his experience with the plant. The plant operators are familiar with the details and peculiarities of the plants and can therefore rectify faults quickly. They carry out most of the necessary repairs themselves. If needed, specialized workshops are called in for larger repairs. Plant operators are overseen by a foreman or a highly experienced master craftsman.

The predictive maintenance system to be introduced at this plant uses sensor data to predict where malfunctions may occur at the plant before they lead to any (critical) incidents. These predictions are based on predefined hypotheses build on the workers' experience with parameter values. The plant operator oversees all warnings produced by the predictive maintenance system during his shift and has to take every notification into account. He schedules the maintenance on the weekend or other planned production pauses and supervises the completion. Besides doing this himself, he can forward the maintenance tasks with the coordination committee – the committee consists of other plant operators and experienced workers. It will be led by the master craftsmen. This committee can be called in for special workshops and serves as a steering body for the whole project and the introduction of the predictive maintenance system.

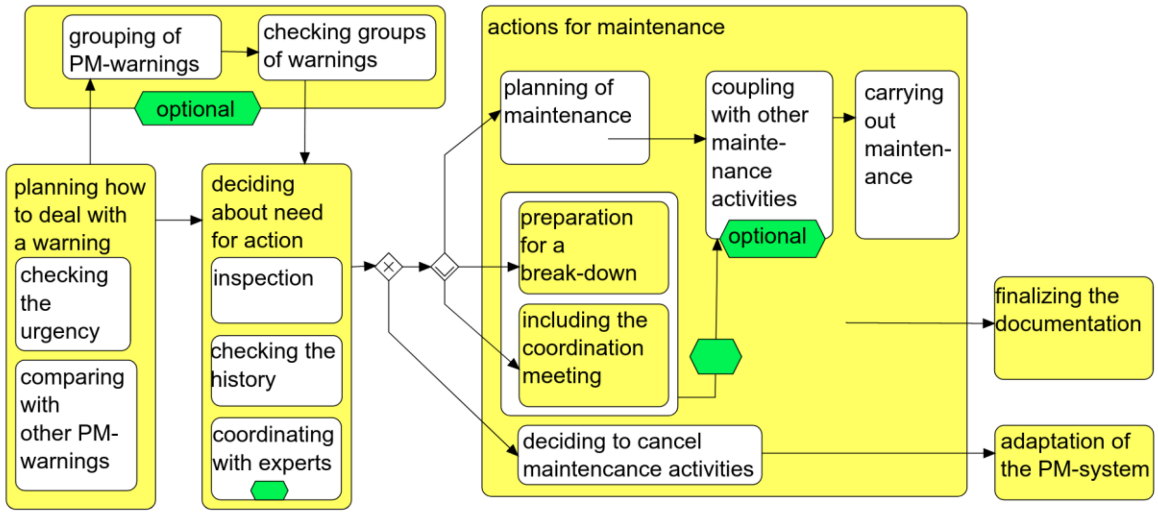

Figure 1 Handling of predictive maintenance warnings from the plant operator's point of view.

For example: If a warning occurs that the tensioner on the conveyor belt has too little tension, the operator must plan how to deal with this warning (see Figure 1). He has to compare it to other warnings and check how urgent it is. Tension issues are very frequent and mostly can go unhandled for larger periods. The plant operator can decide to pool the warning and act once enough tensioner issues have accumulated. In case of a more urgent warning, e.g. low pressure in a hydraulic pipeline he might act immediately.

The plant operator can take several actions to handle warnings and notifications. He can check the history of the offending machine or its parts to improve his decision-making or better prepare his inspection. Inspection on the factory's work floor is the most common action. In some cases, he might already know that experts need to get involved or consultation is necessary to decide on further action, e.g. opening large machinery. Finally, he has to decide whether a maintenance action needs to be performed or whether he wants to delegate this decision to others. If the decision is to reject the warning, further action is necessary to document the false positive and to decide whether an adaption of the predictive maintenance system has to be initiated.

However, if actions for maintenance are due, these can be coupled and scheduled together with other maintenance activities and will be carried out accordingly. Apart from doing nothing or repairing before an actual defect, the plant operator can decide to prepare for a future breakdown by ordering the necessary spare parts upfront. In case of a breakdown, repairs can be carried out faster. If a forced production pause occurs it can be used to carry out other non-urgent but already planned maintenance activities.

Either way documentation of the whole issue is necessary from the sensor readings to the triggered hypotheses with its thresholds, the produced warnings, the actions taken upon this or these warnings as well as the final outcome. All messages produced by the predictive maintenance system need to be assessed manually – regarding its priority and reliability. If a false or unreliable message is based on a predefined hypothesis the respective parameters have to be adjusted accordingly. Also, non-anticipated breakdowns and incidents have to be fed back to the system – hopefully mitigating the incident through a timely warning.

3 IDENTIFIED PROBLEMS

To identify problems that have to be considered when introducing a predictive maintenance system, we have conducted an exploratory study that was based on four interviews. The interviews were prepared based on presentations of the project leader, by studying the underlying documents including a complex process model, and by deliberated discussions. We interviewed various roles in the project (for example plant operators, master craftsmen, quality assurance). From the interviews, we developed a better understanding of the tasks to be carried out in the context of predictive maintenance and we identified 77 problems to be considered. The interviews were guided by addressing various aspects that were derived from a literature analysis of socio-technical principles, guidelines, and heuristics[1, 2, 4]. The most relevant heuristics dealt with visibility, flexibility and evolution, communication support, information exchange, or balance between effort and benefit in this case.

In the following, we present some selected problems. One main theme was the fear that the predictive maintenance system would produce too many false warnings or notifications with low priority. Thus, important and urgent warnings might go unnoticed leading to severe incidents. This has been a real issue as the predictive system started out with hundreds of false warnings per day in its initial stage.

Plant operators know their equipment and robots extremely well and have a deep understanding of all the parts involved and their inner workings. They expressed the fear of unreliable or false positive warnings because they believe the predictive maintenance system with its hypotheses could never *understand* these inner workings and therefore could not generate insightful warnings. They also stressed that each machine and robot needs to be considered individually and planning or anticipating repairs requires a lot of experience.

> Predictive Maintenance Case-6: We cannot simply transfer knowledge from one robot in the production line to another – even if it is the same robot. The installations are too different and require individual adjustments to their thresholds. Therefore, managing the predictive maintenance system becomes a daunting effort.
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> Predictive Maintenance Case-22: The system cannot explain the underlying reasons for the messages, the user needs to understand them from his or her own experience.

Keeping the plant running is a personal challenge for the plant operators and they feel responsible for their respective areas. They want to apply their skills and knowledge. Therefore, it is important to maintain their perception of control and allow them to apply their knowledge to uphold their work experience. While the overall goal of predictive maintenance is to increase the efficiency of maintenance personnel and improve overall plant productivity, the current pilot system requires more documentation, which makes employees feel like they are being distracted from their actual work.

> Predictive Maintenance Case-14: Work does not really get easier. In the initial phase after the introduction of predictive maintenance, it is unclear whether predictive maintenance means more or less work.

Besides the additional documentation to be carried out the system will also change the roles of the plant operators and will lead to new coordination tasks. If adjustments are made they might be reverted by the next shift's plant operator. These cases of disagreement need to be handled.

> Predictive Maintenance Case-12: It must be handled when different plant operators do not agree on how to adjust a threshold value

The predictive maintenance system will support the plant operators and help them be prepared in case of a breakdown or even avoid such breakdowns. Currently, they are allowed to ignore messages even if this leads to a breakdown without consequences. In the long run, if messages are ignored and breakdowns happen that lead to quality issues, increased costs, or liability issues employees will need good reasons for such ignored messages. So, handling the messages in one way or the other will become the norm and determines how work is carried out.

> Predictive Maintenance Case-67: You have to trust the system – and let the system tell you how to coordinate your work

This is a distinct change of perspective – previously the “needs of the machines” became apparent physically, now “notifications/warnings of an information system” of what might take place are displayed on a screen. The plant operator’s role will also change with this new mechanism of work distribution. The plant operators have been the first responders in case of any issues and have tried to repair small defects right away on their own. With predictive maintenance in place, they become coordinators and schedule repairs into production pauses. They must also decide which messages are grouped together and handled within the same maintenance shift.

4 INTERVENTION USER INTERFACES FOR PREDICTIVE MAINTENANCE

For a predictive maintenance system to be successful the plant operators must use and extend it with their experience and their daily observations. Thus, it must be decided how adaptions to the hypotheses are performed and to what extend – by the currently present plant operator, overseeing the messages and the plant, by a coordination body in a review meeting or by special key users or members of the executive level. In the following, we will describe several ways how the concept of intervention [3] can help to improve the work experience of the plant operator and allow the master craftsman and management level to be in charge of the final decisions.

A plant operator should be allowed to postpone messages. E.g. because they occur during a time where other more urgent messages have to be dealt with or the feared event won’t happen in the near future. Plant operators have precise knowledge about their work areas and can make such decisions accurately. If messages are postponed they need to reappear after some time, so that the anticipated incident is considered in time. Messages which are postponed several times or by different plant operators need to be flagged for discussion within the coordination board – either they are faulty or cannot be dealt with by the operators. Postponing is an intervention as its effect is usually limited in time and scope.

However, besides giving the plant operator the option to postpone a message for a period of time or until the next parameter change role-based interventions are necessary. A master craftsman overseeing all the plant operators or a foreman should be allowed to limit the postponing for certain areas or messages and adjust the time intervals. Either to limit the plant operator’s ability to off-load work to the following shift – a big concern of the master craftsman and the management body – or to enable targeted maintenance of special machine parts, e.g. if a special supplier for bearings or welding gear will come to the plant all relevant machinery is considered. This is made possible because messages across different plant areas become available and can be grouped together. The number of call-ins of external specialist workshops can be reduced.

Exploration is a key to successful interventions. Only if the consequences of an intervention are apparent they can be applied with the intended effect. The exploration of new threshold values can serve as a way for plant operators to apply their knowledge and to test or experiment on how their adjustments would play out before being deployed to the whole plant or the respective area. How would this change affect prior warnings and messages?

Does the adjustment reduce the number of warnings that have been considered false positive in the past? How many “new” warnings would have been produced? Are true positive and urgent warnings missing?

This way the person adjusting the threshold can determine if a small change of the threshold values will only result in the desired change of surpassing one or a few false positive warnings or if more warnings are getting lost. Vice versa the user adjusting system will learn upfront if the change would be of any effect. Otherwise, the effect of an improved threshold value would not be experienced. The result of it will be the absence of a false positive warning. But this absence can be caused by other external factors and must not necessarily be caused by the new threshold. This approach allows the plant operator to explore and adapt the system and reduce the experience of a black box interfering with their practices.

5 DISCUSSION AND CONCLUSION

In our case study, we show that this further step of automation in an already highly automated environment challenges the current roles and impacts the worker’s experience in the factory. For information systems supporting the control of industrial plants that deal with the forming or assembling of material, we can differentiate between two tendencies:

1. The information systems are considered as a type of technology that is separated from the machinery that has to be supervised. The information systems and the monitored machinery are considered separate technologies/entities. This separation is particularly evident in the design and especially the maintenance and evolution of the information systems. These are carried out without the involvement of those responsible for the automated machinery to be controlled. Technology suppliers are taking care of the information systems such as predictive maintenance. Practitioners might be included during the initial design of these systems by subsequent cycles of improvement, but the technology developers decide when and how this inclusion takes place.
2. The supporting information systems (including predictive maintenance) are considered an integral part of the machinery to be controlled. The operators feel not only in charge of the material parts but also for the information systems parts and that their control and maintenance job should cover both sides. They are the ones who decide what they can do by themselves and when help from specialists is needed, e.g. in the robot workshop or suppliers of the predictive maintenance system should be involved.

The culture and experiences of the case we have investigated indicate that at least those plant operators that promote the usage of the predictive maintenance system are in favor of the second option. By contrast, the management and the project leader seem to be undecided: While they prefer that management decides on whether, when, and how to customize the system, they also recognize that experienced operators should be continuously involved. Because they have first-hand knowledge of the necessities for customization. We propose the concept of intervention-based exploration of possibilities for customization as a bridge between the two tendencies outlined above.

For further research, it is interesting to discuss how the concept of intervention could be complemented, for instance by organizational measures such as the role of a facilitator. Furthermore, we might ask whether this concept is transferable to other applications such as automated vehicles where the users might have a lower interest of being in control with all kinds of technical details, but might also be able to deal with situations where they feel uncomfortable or might want to temporarily adapt the automated running of processes.

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