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THE CHANGES FROM PREVENTATIVE TO PREDICTIVE MAINTENANCE: THE ORGANISATIONAL CHALLENGE

Luminita Ciocoiu, Carys E. Siemieniuch & Ella-Mae Hubbard

Engineering Systems of Systems Research Group, School of Electronic, Electrical and Systems Engineering, Loughborough University

The ‘Health and Prognostic Assessment of Railway Assets for Predictive Maintenance’ (HPA) project is developing a Prognostic tool, aiming to enhance the existing capability of London Underground escalators’ Remote Condition Monitoring (RCM) system, with the purpose of facilitating change from preventative to predictive maintenance. This paper investigates the organisational challenges associated with the introduction of this tool into the organisation. The paper will describe the approach adopted to model the extant maintenance processes and associated organisational structures which revealed issues to do with unclear processes, poor communication and data sharing links and problems with delineation of responsibility for decision making. It will go on to describe the development of a new maintenance process model that incorporates the additional functionality provided by the newly developed Prognostic Tool, which necessitate changes of roles responsibility, organisational processes and activities.

Introduction

Maintenance is critical over an asset life-cycle due to the need to maintain and improve the asset availability over its lifetime (Iung et al., 2005). In today’s environment there is a growing demand for maximising asset availability and safety, maintaining the operational quality and customer satisfaction, all whilst minimising costs (Al-Najjar and Alyouf, 2003). As a result, maintenance planning and activities have grown increasingly in importance across many industries, the focus being on optimising resource allocation and use, as this is where a competitive advantage can be gained (Marais and Saleh, 2008).
One way that can enable organisations to work towards achieving better resource allocation for maintenance purposes is to gain knowledge about on-going asset health during asset operations and hence develop the capability to act before a failure has happened. This approach towards maintenance indicates a need to change maintenance practices from reactive to predictive maintenance.

Within this context, the HPA project was created. Its purpose is to develop a Prognostic Tool to enhance the existing RCM capability in monitoring London Underground escalators and enable the shift in London Underground maintenance practices from reactive and preventative towards predictive and preventative maintenance.

With the number of passenger journeys predicted to reach half a million daily by 2021, keeping the Underground system in a safe and efficient operational mode is a major challenge. Even scheduled works are disruptive for passengers and costly for the organisation and customer, so knowing when and where to deploy maintenance resources to maximum effect is critical in minimising disruption.

While the advantages that the Prognostic Tool can bring to the organisation are obvious, it is reported in the literature that many of the projects that seek to introduce and implement a condition monitoring maintenance regime fail to achieve their objective (Mobley, 2002; Mitchell, 2007; Koochaki and Bouwhuis, 2008). Previous research indicates that a key element for the success of these programmes is the understanding of human and organisational factors involved (Koochaki and Bouwhuis, 2008; Jonsson et al., 2010).

This paper investigates the organisational challenges associated with the introduction of the Prognostic Tool, with the purpose of facilitating change from reactive to predictive maintenance. The paper describes the approach adopted to identify the organisational challenges specific to the integration of the Prognostic Tool within the maintenance processes and discusses the implication of the findings.

**Remote Condition Monitoring (RCM) systems**

RCM systems are innovative e-maintenance solutions that make use of emerging technological advancements to offer a revolutionary change in the way maintenance is conducted (Jonsson et al., 2010). Traditional maintenance is based on physical proximity to the asset (e.g. hearing, seeing the asset) to achieve either monitoring of the asset condition or maintenance intervention. As some assets cannot easily be physically inspected, either because of access issues, health and safety concerns or because of costs of undertaking such activity, some incipient defects remain hidden and undetected until a failure occurs. RCM offers a hands-off alternative to condition monitoring, eliminating some of the issues associated with hands-on condition monitoring.
RCM systems primarily collect and display data that is received from sensors attached to the assets, and there are a multitude of RCM systems that cover a variety of maintenance related services ranging from diagnostic to quality assurance (Kajko-Mattsson et al., 2010). In essence, these systems automatically monitor the health of an asset during operation (no need to stop the asset for inspection) and identify any deviation from normal performance. This information then can be made available on demand to various decision makers, thus offering decision-support regarding appropriate maintenance activities independent of time, location or organisational position (Karim and Soderholm, 2009). The use of RCM systems broadens the capability spectrum of organisations by offering a new insight into asset performance while the asset is in operation. The use of such systems can lead to new maintenance practices and rules (Jonsson et al., 2010) by enabling proactive maintenance actions to be taken in advance of failure.

The Prognostic Tool

The Prognostic Tool developed in the HPA project is designed to be part of the current London Underground RCM system, to enhance the current capability of the organisation to monitor the escalators (initially) and to support decision-makers by providing actionable but advisory information regarding the Remaining Useful Life (RUL) of the assets. The aim of the new capability is to enable the organisation to manage asset degradation and undertake maintenance interventions at optimum time, in advance of failure (Ciocoiu et al., 2015).

The Prognostic Tool is a software-based, decision-making support tool, which calculates the RUL based on asset condition data and failure trends. The tool will enable better use of condition monitoring data and improve the quality of extant advisory information, which results from that data. The main tool functions are: to analyse the condition indicators from the existing RCM database, to detect events in the data, and to calculate RUL. This is depicted in Figure 1.

![Figure 1: The Prognostic tool](image)

As the systems (in this case, the escalators as the assets selected for focus) are monitored, while in operation, the tool outputs are dynamic in nature, which means that the outputs will change as the asset condition changes. Furthermore, the data used for analysis reflects registered symptoms rather than causes. These characteristics define the Prognostic Tool as being primarily a decision-support
tool rather than a decision-making tool. The difference is quite important as this shapes the nature of how primary, secondary and tertiary users will interact with the tool: their perception of the tool; how and when they provide input to or take output from the tool; the range of interactions with the tool to support maintenance decisions etc. The tool also has the potential to impact on organisational structures and responsibilities.

As shown and discussed so far, this type of technology can bring important benefits to the organisation and have a positive impact on the maintenance practices. However, it is also been identified that several questions and issues remain to be answered – for example will users trust the technology and the data it produces?; is the organisation is ready for and capable of implementing any necessary changes in structure, processes responsibilities?; have any training needs been identified? etc. Not getting the organisational and human context right can severely and negatively impact on the implementation and operation of new technology.

Organisational challenges

Previous research shows that technology insertion has wider reaching implications for organisational processes than the immediate benefits that it can bring. From previous work, such as that of Koochaki and Bouwhuis (2008) and Jonsson and colleagues (2010), a number of organisational factors appear to be quite consistent: the importance of shared ontology; effective knowledge sharing, clarity between the roles and responsibilities between those involved, and a clear and shared organisational strategy. Their findings highlight the importance for new systems, like the Prognostic Tool not only, to be built based on cutting edge technology but also on comprehensive organisational models of the current and future maintenance processes, roles and information flows, if the new system is going to be implemented successfully and achieve the intended goals.

It is not just the new context following technology insertion that needs to be understood. The existing organisational culture, context and work practices need to be clear as well, so that the new system is implemented within a well-mapped organisation. Maintenance is often carried out by people relying on physical evidence that indicates an issue and on their experience in assessing and interpreting these observable symptoms. This way of carrying out condition assessment has three major implications for the change towards RCM-based maintenance: loss of tacit knowledge; need for trust in non-physical observable data; and dependence on the reliability and ease of use of the technology.

Maintenance is often carried out by people relying on experience, which is not always clearly captured in formal processes. Based on this experience, people will adapt the way they work. It is important to understand how people have adapted over time, optimising their activity. This characteristic is specific to humans and is a normal process that happens in any activity. Furthermore, it is not necessarily a process with negative impact. Therefore, if a new process,
system, technology or other innovation is to be introduced into the working environment it is important to understand the way people work and the motivation/rationale behind extant or potential adaptive behaviour.

People that have been working in an area for some time may develop their own ‘predictions’ based on experience and familiarity with the asset and based on physical and observables cues. The predictive nature of the new system means that there may be no obvious signs that a maintenance engineer could identify from the asset alone. For example the Prognostic Tool may detect a significant variation in the performance data of a gear box, before the gear box shows any visible signs of failure. People then have to rely on information provided by the RCM system, in order to be able to take timely and appropriate decisions, they have to trust that information.

At the other end of the trust in technology spectrum however, it can be said that people can become too dependent on the technology and overlook its limitations. Jonsson and colleagues (2010) reported that ‘’with more online measurements the less people will be walking around by the machines […] In this case the remote diagnostic system led to a local physical distance as the value of a local presence was not realised. To the operator, the phone call from the remote technician had become a work practice that would indicate all problems with the machine and, therefore, the walk rounds were neglected. This shows that through the use of remote diagnostic systems follows the critical issue to manage the boundaries between the remote and local maintenance work.’’

Although an RCM system constantly monitors the asset condition, only data from a specific number and particular types of parameters are collected. As a result, the picture that the Prognostic Tool provides is not total. To have a more complete picture of asset condition, physical monitoring as well as decision-makers assessment is essential to detect things that are not detected by the RCM system. These two maintenance activities need to be integrated to ensure important data is not lost in the interface between them.

**Research approach, methods and tools**

To identify the organisational challenges specifically related to the implementation of the Prognostic Tool within the London Underground escalators maintenance regime, a three-step approach has been devised:

- 1st step: Create process maps to reflect the maintenance processes as they are in practice (‘As is’ model);
- 2nd step: Identify the functionality provided by the Prognostic tool;
- 3rd step: Create process maps to reflect the maintenance processes which incorporates the additional functionality provided by the RCM system (‘To be’ model) and identify the organisational differences between the existing and future maintenance processes. (Ciocoiu et al., 2015)
The data was collected through a series of workshops with London Underground maintenance delivery, planning and condition monitoring experts and a review of formal documentation (e.g. London Underground work instructions). The data regarding the Prognostic Tool functionality was gathered through discussions with the tool developers. In all, 4 workshops were conducted and the roles of the participants ranged from: Condition Monitoring Engineers (CME), Asset Managers, Technical Engineers, Performance Managers and Planners. The workshops were run using collective semi-structured interviews and a series of questions and points of discussions were put forward. In all cases, following the workshops, reports were written and handed to London Underground to validate the findings.

For the analysis of the data the following methods and tools were employed: IDEF0, process flow diagrams, and the Role Matrix Technique (RMT). The IDEF0 is a widely used method for process modelling, for the analysis and modelling of functional aspects of organisations, and is usually recommended to be used for process re-engineering at the strategic level (Vernadat, 1996). The process flow diagrams are commonly used to show the flow of information between different constituent functions within a systems and to capture different types of relationships (eg time dependencies) between these functions.

The RMT is a method developed by Siemieniuch and Sinclair (2002) and involves a four-step process: identification and definition of the roles involved in the process of interest; decomposition of the process into lower level activities and sub-activities; allocation of roles to the various layers of the process; creation of the role matrix, which involves the transfer of the roles onto a two-dimensional matrix where, the horizontal axis represents the discretion that a role has in achieving their goal and the vertical axis represents the degree of freedom that the role has in terms of planning, resource allocation and scheduling the activity to achieve the target (Callan et al., 2006; Henshaw et al., 2011).

The purpose of employing the RMT method is to define and visualise the relationships between the roles in terms of role boundaries, interactions, responsibility and accountability in a given organisational process. The RMT was used not only as an analysis method (Ciocoiu et al., in press) and but also as a means to promote discussions between London Underground maintenance experts regarding the roles that should be involved in the new maintenance regime (based on predictive practices) and the responsibilities and relationships between the involved roles.

Findings

During the first phase of research, formal documentation as well as discussions with London Underground maintenance experts was performed. This analysis revealed inconsistencies between the documentation and individual accounts (Ciocoiu et al., 2015). Further investigation into the observed inconsistencies revealed that due to ongoing organisational changes within London
Underground, some of the documents were either no longer in use or not updated following the changes in processes and/or roles. As a consequence, further analysis was reliant on Subject Matter Experts (SMEs) accounts rather than London Underground documentation.

Based on the data collected during the first stage (1st step) an ‘As is’ model was created to reflect the existing maintenance processes. A high level representation of this model is presented in Figure 2. Condition Monitoring (CM), including RCM activities are located within ‘Deliver Maintenance’.

Findings showed that although there are Condition Monitoring (CM) procedures in place, the current organisational processes are mainly focused around reaction to faults and fault preventative practices. Furthermore, the location of CM and RCM activities within the overall Maintenance process has affected the way the CM output is used. The ‘Deliver Maintenance’ part of the process relies on decisions made by the ‘Plan Maintenance’, which rely in part on the ‘Review faults and fault repair’. However, CM and RCM information is not included formally within the review process and analysis of this information (e.g. review of CM reports) is done in an ad hoc manner. As a result, actions based on CM and RCM knowledge is taken only in critical situations (where something is about to fail).

During the second phase of the research (2nd stage) discussions were held with the Prognostic tool developers (also partners in the project) to identify the tool’s functionality. Following this, a proposed ‘Prognostic Maintenance’ process map was created. A high level version of this map is presented in Figure 3.
The ‘As is’ model and the proposed Prognostic Maintenance process were used further in a workshop with London Underground maintenance experts where there was discussed the placement of the tool within the organisation and the effect that this will have on roles, responsibilities and configuration of the existing activities within the maintenance process (3rd step in the research approach).

The findings following this workshop were quite interesting. Trying to see where the new technology might fit and how the processes and activities should be organised revealed some aspects of existing processes and activities that were not obvious in previous analyses.

The findings showed that some activities migrated from their initial process location towards others. It was observed that some of the activities related to ‘planning’ and some related to ‘reviewing’ were heavily influenced by the delivery part of the maintenance process although the activities are within the intended organisational processes (‘Plan Maintenance’ & ‘Review fault and fault repair’ processes – see Figure 2). The authors understanding is that this observed phenomenon (from workshop participants) is due to geographical location of people.

Furthermore, some interesting aspects related to visibility and decision-making power were also identified. For example, the ‘reviewing’ part of the process has decision-making power over the planning and delivery of maintenance however, that part of the process consists only of reviewing the faults and fault repairs, so they have limited visibility of maintenance works carried out on the asset. The ‘delivery’ part of the process on the other hand has full visibility over carried maintenance works but has limited decisional power over planning of the maintenance interventions.

**Discussions and conclusions**

The findings highlight the importance of having up to date formal documentation regarding the roles and activities within the maintenance process before a technological or structural change is implemented: the documents serve not only as a point of reference for review but are also important in ensuring that the people involved in a process have a clear view of their roles and responsibilities as stated in these ‘formal’ documents. Lack of or unclear documentation can lead to issues such as: shifting of blame and responsibility, loss of accountability, loss of transparency. Likewise where documentation of processes is not clear this can result in poor understanding of the boundaries of one’s own roles and that of other roles, poor communication and data sharing links and problems with delineation of responsibility for decision-making.

It is also worth noting that the position of a sub-process or a set of activities within a process can affect the way the output of those activities is utilised. For example, the CM and RCM activities, from a process point of view, are currently
located within the ‘delivery’ part of the maintenance process. According to this configuration, it is difficult for the CM and RCM output to have the desired impact on the maintenance regime, because, the ‘delivery’ part of the maintenance process does not have the necessary decisional power to act upon the knowledge provided by CM and RCM.

As the Prognostic tool is to be integrated with the current RCM system, the positioning of the RCM and CM is crucial if the organisation is to benefit from the enhanced capability provided by the tool. Outputs of the new, enhanced RCM have not only to be reviewed by people with decision-making power to act on the Tool output, but the processes through which this is achieved and the relevant connecting links have to be put in place by the organisation.

Furthermore, re-engineering of the maintenance processes to benefit from the new technology has to be complemented by decisions regarding geographical location and means of interactions between the roles and the departments. As findings have indicated, in some situations, individual alliances towards certain groups can have an effect on the activities carried out. The effect is not necessarily negative, and in some instances it is actually desirable as it might bring huge benefits. As mentioned in the first part of the paper, this effect may appear also as a result of human optimisation of their work and environment. The point is though that this effect has to be acknowledged and understood as this has an effect on the way the activities within a process are actually carried out.

Having a structured, sound process, which has been resourced with clear roles (each of which will have a role profile) and consensus on, and an understanding of other factors that can affect the running of the process before a change is implemented, can bring huge benefits. Investing in understanding and creating this partial enterprise model and associated process configuration which is suitable for a specific change within a specific organisation could bring that competitive advantage that technology on its own cannot achieve.

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