Interface design for prognostic asset maintenance

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1. Scope

We report here part of a project funded by INNOVATE-TSB (UK) concerning the implementation of a prognostic (that is, predictive) maintenance system for escalator assets on the underground railway. The present approach to asset maintenance is primarily based on scheduled maintenance and repair at regular intervals which is wasteful in terms of both human and physical resources. Although humble in machine terms, escalators are essential for moving passengers around underground stations at an appropriate rate of flow and their good maintenance is essential for public safety and the wider life of mass transit systems as a whole (Campbell, 2002). Maintaining them is a demanding task owing to their typical placement, accessibility and limited scheduling windows for work and their sheer ubiquity escalators in various settings around the world means that interventions concerning them have considerable economic implications. The project aimed instead to demonstrate the use of condition monitoring data processed via prognostic computational intelligence to move to a system where maintenance occurs on the basis of identified Condition Indicators and a time-risk based assessment of Remaining Useful Life. Arguably the success of this project hinged upon solving Human Factors challenges in designing interfaces to convey the output of computational intelligence in such a way that it can be used to support a new engineering decision making paradigm. In this context, user interfaces serve as the critical ‘last mile’ in terms of delivering on the potential of investments into sensor technology and computational intelligence in decision making. We anticipate that as digital sensing and the “Internet of Things” become ever more widespread, there will be significant future demand for similar interventions combing data representation with support for changing decision making processes across a range of industries.

2. Project organisation

The project involves the stakeholders themselves (as integrated members of the project team), technical partners concerned with digital architectures for condition monitoring data, the developers of prognostic computational intelligence and academic partners concerned with Human Factors elements in terms of interface design (in terms of delivering useful, actionable alerts) and organisational change.

3. Human Factors topics covered

Our position on developing a strong and appropriate Human Interaction specification was based on the view that it should rather reflect how that decision making is situated: what people do, how they do it and why they do it. The issues of the context in which decision making takes place are particularly important in that one ambition of the present work is to explore the potential for a transition from planned/reactive to predictive maintenance ethos. This led us to adopt a participatory orientation to the present work where the specification was produced through engagement with workers via a combination of observations, interviews, small workshops and the use of an online prototyping tool to collect feedback on specific aspects of UI design. However, we judged that the complexity inherent in (i) the physical asset itself and its failure modes, (ii) the relationships between sensors and the physical state of machine, (iii) presenting a human interface to computational intelligence and (iv) the maintenance decision making process itself, called for a solid methodological backbone to guide analysis and design. To this end we combined two related but distinct techniques: Cognitive Work Analysis (CWA; Rasmussen, Pejterson & Goodstein,1994; Vicente, 1999) and Ecological Interface Design (EID, Vicente, 2002; Burns & Hajdukiewicz, 2004). As work progressed, we also found that issues of trust and technology acceptance would have a significant bearing on both the success of the project and therefore some of our design choices.

4. Project phases
Our approach consisted of four main phases. The first concerned identification of human contextual information needs. In order to understand the context in which decision making took place we took a set of interviews and observations to produce a Work Domain Analysis of asset maintenance that defined through abstraction hierarchy the ‘how’ and the ‘why’ within maintenance decision making and where a prognostic approach would fit in (Figure 1). We also employed another element of CWA, the Decision Ladder (Rasmussen et al., 1994) as a tool for analytically represent maintenance narratives and to map the involvement of different role holders from first report to resolution of issues.

Figure 1. Analysis of the maintenance Work Domain.
The second and third phases concerned identifying user interface requirements; this began with further interviews concentrating on interface design specifically. Together with interviews from stakeholders that emphasised to us the centrality of issues of trust and technology acceptance to effective system integration, we initially designed interfaces using the EID method which involves mapping the physical constraints portrayed in an equipment-focused Abstraction Hierarchy to a set of interface forms that reproduce those constraints visually. Given that the task before us concerned not merely interface design but also some element of change to decision making practices themselves, we were able to use our prior analysis of the maintenance domain to supplement a physical abstraction hierarchy (mapping the physical nature of the escalator itself and the relevant sensors positioned upon it) with additional intentional constraints. The effect of combing the two at this level was to produce an integrated analysis directly relating the physical properties of the asset with the functional properties of the maintenance system itself. Initial interface design was then carried out through matching constraints within the combined abstraction hierarchy with a set of standard interface forms. One particular highlight in this design process was bridging the divide between a requirements for a condition indicator that both reflected the physical form of the system (mimic) at the same time as affording easy detection of indicators across multiple machines which implies a configural form (see Figure 3).

Figure 2. The left panel shows the mapping of an observed maintenance decision making narrative to a Decision Ladder. The left panel represents different stakeholders using the same format.

The layout of “knots in string” reflects the physical layout of monitored parts of the machine while also affording quick ecological detection of an fault (distortion of lines at right angles). When multiple machines are presented in grid form, faults are easily cued as breaks in sets of horizontal and vertical lines.

We were then able to use an online interface prototyping tool to share prototypes (featuring limited interaction) with stakeholders and collect feedback via Facebook-style commenting. The final stage concerned test and final presentation which took a workshop form prior to ongoing final system integration. All these stages of development were undertaken concurrently with the aggregation of condition monitoring data, development of Condition Indicators and the production of suitable software architectures for the delivery of the system.
5. Conclusions

The present work has thrown up a range of lessons. The involvement of stakeholders as a core part of the project team, as opposed to merely as ‘customers’, proved highly valuable both in terms of practical aspects such as access to people and materials, but also in terms of understanding wider cultural issues in the organisation. The concurrent staging of design with the development of the underlying technical system (software, computational intelligence) was also useful in as far as different elements could be adjusted responsively to demands arising in other parts of the project (e.g., specific interface requirements requiring the provision of extra datasets).

Second, close participatory engagement with stakeholders has emphasised to us the importance of context in decision making and the wider issues surrounding organisational adaptation to envisaged new processes. Introducing new forms of data into organisational decision making is a challenging issue. Our initial view of our role in the project was that the main challenges we would face would be in the area of interface design specifically and would mostly concern issues of presenting complex information legibly. However, discussion with stakeholders strongly emphasised the importance of design as a cue for implementable action, as a support for a new decision making process and also for trust and acceptance. Trust emerges as an issue at multiple levels when a system is based upon a data product; the level of the data itself (do we trust it is accurate?), the level of its analysis (do we trust the algorithms processing it?) and finally at the level of its presentation (do we trust the accuracy of the representation and what it implies?).

What makes addressing this particularly challenging is that computational intelligence systems, by their very nature, are unlikely to be cognitively penetrable: their workings are not readily understandable by human beings thus there is the implication that the processes involved cannot as such be monitored, checked or narrated. We found that one way to deal with this was to present computational intelligence outputs alongside machine histories to provide some sort of context for verification (e.g., predicted failure event vs. deteriorating temperature). Furthermore, integrating elements of decision support allowed the computational output to be understood within a clear decision making context (see Figure 4) rather than as an otherwise disembodied fact. In terms of the persuasive design paradigm (Fogg, 2003) this could be seen meeting dual requirements that information is seen as trustworthy (corroborated) and demonstrating expertise (directly useful in relevant decision making).

Figure 4. Remaining Useful Life calculated by computational intelligence mapped against potential costs of repair, replacement intervals and impact on customers at different action points.

Our methodological approach was also useful here. While the distinction between CWA and EID is not necessarily a strict one as use they use comment elements, we found combining two distinct ways of mapping the system, in terms of the work domain’s ‘hows’ and ‘whys’ and in terms of physical system (effectively, how an escalator works), highly useful in bridging across this complex of issues though a common set of analyses as it allowed physical and organisational issues to be plotted in compatible forms.
While the Abstraction Hierarchy and the Decision Ladder might be viewed as initially slightly foreboding analytic graphics, using them for multiple forms of analysis from representing observations through to depicting stakeholder roles and mapping the system as a whole and forming the basis for interface design reassured stakeholders that there was a coherent process behind the design activity that represented their views, concerns, activities and inputs alongside hard technical facts and holding at least equal weight.

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References
Vicente, K.J. 1999. Cognitive Work Analysis. LEA.