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Predicting the unpredictable: Consideration of human and organisational factors in maintenance prognostics

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ABSTRACT

Human performance is a major contributor to system performance and maintenance errors can have a significant influence on system reliability. However, existing reliability modelling approaches lack any methodologies to take account of maintenance actions in predicting system failure probability. The primary objective of this work is the development of a methodological framework to enable the integration of human and organisational factors (HOFs) as quantitative metrics within prognostics maintenance models. Inclusion of significant HOF metrics derived from performance shaping factors (PSFs) should reduce the predictive uncertainty of models developed for system failure probability estimation. This research investigates human error during maintenance activities as one variable contributing to system failure events. The hypothesis is that including HOF metrics derived from the performance shaping factors (PSFs) influencing maintenance tasks can reduce the predictive uncertainty of models developed for system failure probability estimation, provided that the PSFs are found to be significant predictors of the failure event. This research uses a case study from the biopharmaceutical industry to demonstrate the industrial application of the developed methodology. Regarding the case study, current field data is unable to isolate a process variable that can reliably predict sudden component failure. Technician error during installation and system maintenance activities is therefore investigated as a potential significant variable. This applied research explores how human errors can be discovered and accounted for within the reliability modelling process. The use of PSFs in this way forms one part of the development of data driven soft-sensors using a knowledge fusion approach. This soft sensor approach utilises a combination of quantitative and qualitative information in the form of laboratory tests, historical industrial process data, and metrics derived from human factors analysis, the combination of which is unique in the literature.

1. Introduction

The ultimate goal of reliability analysis is to accurately predict the remaining useful life (RUL) of systems and components. Although the most reliable approach to lifetime prediction is the use of precise first-principle models, such models are not available in most newly developed processes due to modelling complexity. In particular, it is difficult to build precise first-principle models that explain why defects appear in components. To circumvent this problem, operational data can be used in a data-based approach to monitor and control numerous process variables (Kano and Nakagawa, 2008). To achieve an accurate data-driven prognostic model, failure event model uncertainty must be reduced through the identification and inclusion of as many system variables as possible. However, most modelled systems use only 'machine related' (MR) quantitative information available from sensors to automate the diagnosis task (Kiassat et al., 2013), and almost no use of quantitative or qualitative information derived from human sources is made (Chiu et al., 2004; Devaney and Cheetham, 2005; Varma and Roddy, 1999). One drawback of many modern modelling approaches therefore is the overreliance on MR data, which does not describe the full set of operating conditions in which systems are operating. One often overlooked metric is human related (HR) data which can further contextualise the system environment (Kiassat et al., 2013). This is important, as a significant number of catastrophic incidents in industry occur primarily due to human factors (Palaniappan, 2016). Okoh and Haugen (2014) analysed 183 major industrial accidents in the United States and Europe between 2000 and 2011, reporting that 44 percent of those were related to maintenance activities. However, the practical difficulty of building a common platform to process both quantitative and qualitative data has hindered the use of so called hybrid modelling

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systems. The potential advantages of integrating human and organisational factor (HOF) data within reliability models include uncertainty reduction of the probabilistic system state estimations. These 'human-in-the-loop' models are particularly pertinent where sparse MR data is available and where humans are central to the maintenance and/or operation of the system.

In these circumstances a 'soft-sensor' approach can be utilised. Soft-sensors act as inferential system health estimators via proxy process indices (Fortuna et al., 2007; Vachtsevanos et al., 2006). Soft-sensors are essentially mathematical models which relate operating conditions to component condition using multivariate statistical techniques (Kano and Nakagawa, 2008) (Yan et al., 2004). Designing a soft-sensor exploits the concept of gathering and combining numerous measurable quantities or features as inputs, and outputting the time evolution of a fault pattern. Accordingly, within traditional system health monitoring, fusion technology plays a significant role (Vachtsevanos et al., 2006). The incorporation of external data can yield more information and lower the variance in the parameter estimates of predicted response variables (Jørgensen et al., 2004). The combination of multiple sensors in a multi-sensor data array to validate signals and create features is common in modern industrial applications. At a higher level, fusion may be used to enhance diagnostic information. Developing this methodology further allows for a total knowledge fusion approach. Such an approach would combine experience based information such as legacy failure rates, reliability testing data, and a-priori human knowledge concurrent with traditional signal based information from sensor data (Vachtsevanos et al., 2006). This approach is outlined in Fig. 1. In this work, a soft-sensor methodology is combined with the knowledge fusion approach allowing the development of a 'virtual' prognostic and health management (PHM) scheme, whereby inferential soft-sensor measurements are used in place of directly monitored system health variables used in traditional CBM paradigms.

Monitoring the health state of systems, subsystems, and components, classifying the different types of faults that may occur in these components, and estimating the RUL is critical to support decision makers in assessing whether maintenance intervention is necessary and the timeframe in which to complete it. Without quantifying the associated uncertainties, remaining life projections have little practical value within PHM systems (Engel et al., 2000). It is the comprehension of the corresponding uncertainties that enables the development of a business case that addresses prognostic requirements (Sandborn, 2005). In practice, the possible sources of uncertainty that may arise in a PHM system are:

- Uncertainty in the signal measurements
- Uncertainty in the models adopted at each data management stage
- Selected model parameters
- Uncertainty due to the inherent stochasticity of the physical processes
- Variability in human decisions relating to the PHM system output

Another source of uncertainty in any PHM model is the uncertainty associated with the human interactions with the system, e.g. maintenance or installation work completed. It is often assumed that when maintenance work is conducted, it is considered that repairs/replacements always restore the system to a 'good-as-new' condition, which, in practice, may not be very realistic (Marseguerra et al., 2002). The effect of incorrect maintenance or installation has sufficient impact for it to be regarded as a separate source of uncertainty, and therefore useful information in its own right. Most reliability models assume that the work done by a maintenance technician has been completed to a requisite standard, thereby allowing predictive analytics a consistent operational performance benchmark from which to operate. However, in practice this is often not the case, with a large variability in numerous aspects related to the ability of a maintenance technician to effectively carry out their work. In an attempt to address this issue there have been systematic methods developed to improve the performance of human-machine systems, such as Human Error Probability (HEP) assessments (Noroozi et al., 2013). Incorporating such HEPs in the development of operational procedures can significantly improve the overall reliability of the system (Brune et al., 1983). This work aims to provide a methodological framework for the collection of qualitatively derived HR data so that it can be assimilated with quantitative MR data enabling a data-driven knowledge fusion approach for the RUL estimation of industrial components. To do this, the Weibull proportional hazards (WPH) model is used as a demonstration model.

2. Literature review

Modern industries, such as nuclear, petrochemical, automotive, and pharmaceutical, consist of complex socio-technical systems which include a vast array of system combinations of software, electronic, and mechanical components, all of which require some degree of human interaction in their operation and/or maintenance. Despite many technological advancements in both industrial plant machinery and process and condition based monitoring methods and techniques, failure and breakdown of industrial components remains a threat which

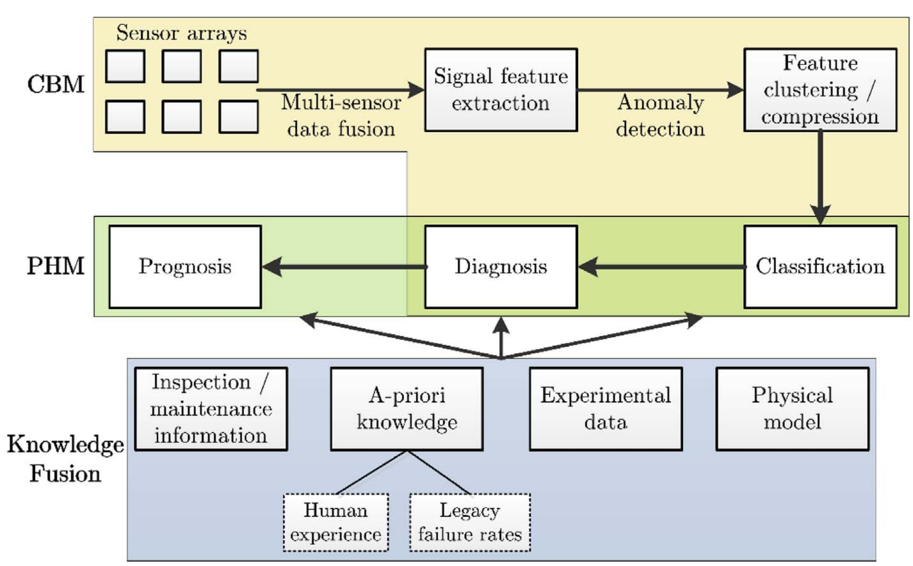

Fig. 1. Knowledge fusion approach to system reliability prediction. Adapted from (Vachtsevanos et al., 2006).