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A proactive event-driven decision model for joint equipment predictive maintenance and spare parts inventory optimization

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Abstract

Manufacturing operations can take substantial advantage of the proactivity concept by utilising event-driven information systems, able to process the sensor data and to provide proactive recommendations. Despite the recent advances in technology and information systems and the variety of methods for prognosis, decision models for joint maintenance and inventory optimization on the basis of real-time prognostic information have not been explored. We propose a proactive event-driven decision model for joint predictive maintenance and spare parts inventory optimization which addresses the Decide phase of the "Detect- Predict- Decide- Act" model and can be embedded to an Event Driven Architecture (EDA) for real-time processing in the frame of e-maintenance concept. The proposed approach was tested in a real manufacturing scenario in automotive lighting equipment industry and proved that maintenance and inventory costs can be significantly reduced by transforming the company's maintenance strategy from time-based to Condition Based Maintenance (CBM).

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Keywords: proactivity; joint optimisation; predictive maintenance; inventory; e-maintenance; decision making; Condition Based Maintenance

1. Introduction

Manufacturing failures cause significant problems in human safety, environmental impact and reliability of industrial processes. The fact that unexpected failures deal with uncertainty and stochastic degradation process of manufacturing equipment leads to high uncertainty in the decision making process as well [1]. Thus, there is an increasing demand of maintenance management policies as well as associated information systems in order to reduce unexpected failures, eliminate unscheduled downtimes, and minimize maintenance-related costs [2]. Since maintenance and inventory management are strongly interconnected [3], an accurate reliability evaluation is essential for taking reliable maintenance modelling and spare parts inventory planning decisions [1-8]. The decision about the predictive maintenance of equipment requires a balance between the cost due to premature replacement and the cost of unexpected failure. Moreover, the ordering time of spare parts and their stocking quantities should be planned so that holding costs are minimized by avoiding, at the same time, stock-outs [1]. Due to the recent advances in technology and information systems and the plethora of methods for prognosis, decision models for joint maintenance and inventory optimization on the basis of prognostic information (e.g. Remaining Useful Life (RUL), Remaining Life Distribution) coming from real-time data (e.g. through sensors) have just started to emerge [3]. To the best of our knowledge, the most representative research work for such kind of problems was proposed by [1] who transformed the decision model proposed by [5], so that it is updated continuously in real-time according to the RUL estimation each time a sensor measurement is gathered. To do this, it takes into account the sampling time and follows the "Sense and Respond" concept.

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However, the availability of a multitude of data generated in the form of very high frequency events by various sources, paves the way for coupling prognostic-based decision methods with sensor-based, event-driven architectures that can support efficient processing of events and improved scalability, while having the ability of handling probability distributions functions instead of parameters (e.g. RUL). In this work, we are advancing the state-of-the-art by developing a joint predictive maintenance and spare parts inventory decision model that can be deployed in a sensor-based, real-time big data industrial environment using an Event Driven Architecture (EDA) and taking into account the Condition Based Maintenance (CBM) framework [9], the e-maintenance concept [10] as well as the principles of proactive event-driven computing [11-12]. More specifically, the proposed decision model contributes to the Decide phase of the "Detect-Predict-Decide-Act" cycle of the proactive enterprise [11-12] by providing proactive maintenance and inventory-related recommendations on the basis of real-time, event-driven prognostic information.

2. Literature Review

2.1. Proactive Event-driven Decision Making

The evolution of Internet of Things (IoT) supports the monitoring of business processes with the use of sensors generating huge amounts of data that enable the identification and prediction of deviations in the production process in comparison to the scheduled performance and the recommendation of the appropriate actions at the appropriate time. In this way, there is the possibility to decide and act ahead of time, i.e., to resolve problems or exploit opportunities before their actual appearance. This requires the development of event monitoring and data processing systems that are able to handle real-time data in complex, dynamic environments in order to develop predictive models and provide meaningful insights about potential problems or opportunities [12,13]. The term 'proactivity' in information systems indicates the capability to avoid or eliminate the impact of a future undesired event, or to take advantage of a potential future opportunity and is leveraged with novel prediction and automated decision making algorithms as well as information technologies [11]. Currently, there are only conceptual models for proactive event-driven decision making, while its capabilities have not been examined in real application domains, such as the manufacturing field, due to several challenges related to the real-time big data, sensor-based enterprise environment and the lack of appropriate algorithms that can be embedded in an EDA. The contribution with decision methods with different inputs, outputs and other characteristics are of outmost importance for the evolution of proactive event-driven decision making. The proactive decision making approach extends the reactive one, referred in literature as sense-and-response [1] or detect-and-act [14], to a new model of situational awareness, based on the Observe-Orient-Decide-Act (OODA) cycle [15]. This model consists of four phases [11-12]: **Detect** situations; **Predict** future undesired events; **Decide** recommendations are going to be provided; **Act** by enacting the decision taken in order to adapt the operational system. Due to the concept of proactivity, CBM can be significantly evolved by being implemented with the appropriate technologies, information systems and computational methods (e.g. data mining, machine learning, operational research, etc.) under a suitable framework [9,13].

2.2. Condition-Based Maintenance

Maintenance engages a large proportion of companies' total cost, while it affects reliability, safety and environmental impact [16,17]. Therefore, it is a key operation function in manufacturing companies and there are several attempts for a holistic approach for maintenance management taking into account the advances in technology, computer science and management [9,18]. According to CBM strategy, real-time data are collected through condition monitoring, prediction models about the manufacturing equipment future health state are developed and appropriate actions are recommended and implemented [17]. In this sense, it is a proactive maintenance strategy, so it can take advantage of new information systems and decision methods that implement the proactive event-driven enterprise concept for the full exploitation of its capabilities [18]. Condition monitoring is increasingly realized with equipment-installed sensors, able to generate large amounts of data in high frequency [18], and with data management software, able to store these data [19]. However, there are still challenges regarding the data and information processing as well as the provision of proactive maintenance recommendations. Figure 1 shows a simplified version of the sequence of CBM steps by mapping the framework for CBM implementation [9] to the proactive event-driven principles [11]. Despite the plethora of research works dealing with CBM, decision making step of CBM in sensor-based, real-time big data environments is not a widely explored area [18].

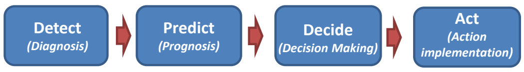

Fig. 1. Simplified sequence of CBM steps

2.3. E- maintenance

CBM and proactive event-driven computing is related to the e-maintenance concept which aims to enable automated proactive decision making [10]. E-maintenance has become important in the last years due to the emergence of technologies which are able to optimize maintenance-related workflows and the integration of business performance, which enable openness and interoperation of e-maintenance with other components of e-enterprise [20]. This support does not include only technology and computer science, maintenance-related operations such as condition monitoring, diagnostics, prognostics, decision making, etc. [10,21]. The implementation of the e-maintenance concept can have a major impact on the implementation of decision models, such as the joint maintenance and inventory models, in an EDA in order to handle and process effectively Big Data. Although e-technologies provide several advantages, optimization of e-