A Component Selection Method for Prioritized Predictive Maintenance

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Abstract. Predictive maintenance is a maintenance strategy of diagnosing and prognosing a machine based on its condition. Compared with other maintenance strategies, the predictive maintenance strategy has the advantage of lowering the maintenance cost and time. Thus, many studies have been conducted to develop a predictive maintenance model based on a growth of prediction methodology. However, these studies tend to focus on building the predictive model and measuring its performance, rather than selecting the appropriate components for predictive maintenance. Nevertheless, selecting the predictive maintenance policy and target component are as important as model selection and performance measurement. In this paper, a selection method is proposed to improve component selection by referencing current literature and industry expert knowledge. The results of this research can serve as a foundation for further studies in this area.

Keywords: Predictive Maintenance, Condition-based Maintenance, Component Prioritization, Machine Condition, Intelligent Manufacturing.

1 Introduction

Regardless of how well a manufacturing machine is designed, the machine degrades over time because operation causes stress to each machine component and random event causes machine degradation (Jardine, Lin, & Banjevic, 2006). As a result, maintenance is an inevitable endeavor of most manufacturing industries. It can be classified into three types of strategies: corrective, preventive, and predictive (Bertolini & Bevilacqua, 2006).

Corrective maintenance is a run-to failure or reactive maintenance strategy (Ahmad & Kamaruddin, 2012). This strategy thus leads to considerable machine downtime and high maintenance costs (Ahmad & Kamaruddin, 2012). However, corrective maintenance is used as an adjunct operation because it is impossible to respond to all failures before a machine fails.

The second strategy is preventive maintenance, which is also known as preventative maintenance. In this strategy, maintenance is performed to each component on a

adfa, p. 1, 2011.

specific unit interval (e.g., x cycles, y hours) and it is widely used in the manufacturing industry (Coats et al., 2011).

Predictive maintenance is the third maintenance strategy. It is similar to the condition-based maintenance approach. It employs condition and performance data, which are captured from the machine to indicate when maintenance should be performed (Byington, Roemer, Kacprzymki, & Galie, 2002). Compared with the first two maintenance strategies, the predictive maintenance strategy has the advantage of reducing both the maintenance cost and time. Thus, many studies have been conducted on building a reliable predictive maintenance model to minimize maintenance costs and time.

The remainder of this paper is organized as follows. In Section 2, a literature review on existing predictive maintenance approaches is provided. A process of identifying appropriate components for predictive maintenance is proposed in Section 3. In Section 4, the characteristics relating to a component's criticality are analyzed for component prioritization. A component selection method for prioritized in predictive maintenance is then proposed in Section 5. Our conclusions and future work on component prioritization in predictive maintenance are presented in Section 6.

2 Research Background

In this section, existing literature is briefly reviewed to introduce predictive maintenance before addressing component prioritization. Predictive maintenance was introduced in 1975 to maximize the effectiveness of maintenance decision making (Ahmad & Kamaruddin, 2012). Its development was driven by the fact that 99% of machine failures are preceded by certain signs, conditions, or other indications that a failure will occur (Zhang, 2014). Analyses of some study results have shown that, in most cases, the goals of the model are reached by choosing the predictive maintenance policy (Bertolini & Bevilacqua, 2006). Owing to the potential advantage of predictive maintenance, many studies have served to develop a predictive maintenance model. Moreover, the growth of a prediction methodology has accelerated the development of predictive maintenance.

In predictive maintenance, condition data and performance data are matched. From that point, the relation between them is identified. This approach provides an opportunity for improving failure predictability and machine reliability (Elwany & Gebraeel, 2008). Several studies focused on building a prediction model for bearings, gears, shafts, pumps, and alternators using various algorithms, such as the Fourier transform, Wavelet energy, Principal component analysis, Logistic regression, Kalman filter, and Neural network (Lee et al., 2014). However, researchers have tended to emphasize building a predictive model, not selecting a predictive maintenance policy and target component. On account of high data collection costs (Ahmad & Kamaruddin, 2012), it is impossible to collect all data from all components. Therefore, target component identification should precede predictive maintenance. In this paper, a selection method is proposed for selecting and prioritizing components to which predictive maintenance is selectively applied.

3 Appropriate Component Identification for Predictive Maintenance

Predictive maintenance is not always the best strategy when strategic and data analysis aspects are considered. Therefore, before applying predictive maintenance, it is important to find appropriate component that is better to apply predictive maintenance than corrective maintenance or preventive maintenance. Applying predictive maintenance requires an additional investment in machines (e.g., sensors, gateways, and servers). Furthermore, data should be in adequate form to build predictive maintenance. Thus, depending on the condition, a suitable maintenance strategy should be selected before applying any kind of maintenance strategy. When the maintenance objective is not operating well, but is enabling the machine to merely function—or, if alternate machines are adequate so that a machine failure is not a critical issue—predictive maintenance is not required. Consequently, strategic decision making should be first performed. If the strategic aspects of the maintenance do not indicate adopting a predictive maintenance strategy, then other maintenance strategies should be considered.

When determining through strategic decision making that predictive maintenance should be applied, additional decision making should be performed in terms of data analysis. Lee et al. [8] suggested use of a maintenance transformation map to guide appropriate maintenance strategies for data analysis (Fig. 1.). As shown in Fig. 1, predictive maintenance can be applied to systems in which complexity is intrusive and uncertainty is continuous. Depending on the machine component, the system can differ and increase in size, including with additional components. Thus, the complexity is non-intrusive and uncertainty is dynamic.

If a component is strategically identified and the related data are analytically appropriate to applying predictive maintenance, then component prioritization follows. Fig. 2 summarizes the steps of applying predictive maintenance.

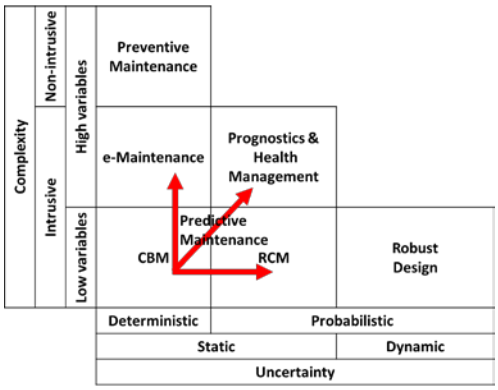

Fig. 1. Maintenance transformation map.

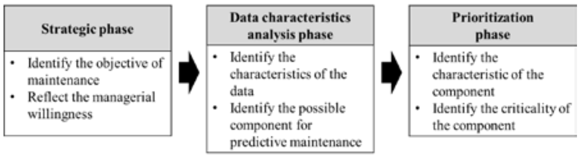

Fig. 2. Decision-making process for applying predictive maintenance.

4 Components Failure Criticality Measurement

To prioritize components, criticality analysis for each component's failure should be conducted. Criticality analysis is based on the component characteristics. In the manufacturing industry, the component criticality may relate to the cost incurred by the component's absence. However, it is difficult to quantify the cost that reflects the component absence itself (Zha, Lim, & Fok, 1998) (Kennedy, Wayne Patterson, & Fredendall, 2002). Thus, the criticality measurement is conducted in terms of severity, frequency of occurrence, and detectability. These three criteria—severity, occurrence, and detectability—are widely used to measure criticality in failure, mode, effect, and criticality analysis (FMECA). (Bowles & Peláez, 1995) Using the same criteria, component criticality analysis can be performed to prioritize the components.

4.1 Severity

According to (Depeartment of Defense USA, 2012), "severity" is defined as "death, injury, occupational illness, damage to or loss of machine or property, damage to the environment, or monetary loss." From the definition, we can recognize that, if the severity is high, the result of the component failure leads to a significantly negative impact. Therefore, if the severity is high, predictive maintenance should be first applied. The definition includes three issues: cost, time, and regulation. We determined the characteristics of components related to the above three issues through a literature review.

4.1. 1 Cost

One of the most important characteristics relating to component failure severity is the cost. Many studies that addressed spare components management or machine prioritization used cost as a decision variable for developing an optimal procurement and management policy (Hamdi, Oweis, Zraiq, & Sammour, 2012)(Taghipour, Banjevic, & Jardine, 2011). The cost related to component severity can be classified into four types, which are outlined below.

Repair cost refers to the cost required to return a component to normal condition. This cost is only incurred when the component can be repaired, and it is better in terms of cost and time than replacing the component. Repair is a widely accepted concept to managing a component. To minimize the total cost of inventory (S.G. Allen, 1968), components are classified as repairable or non-repairable (Gross & Pinkus, 1979). If the repair cost of a certain component is higher than the repair cost of another component, it is better to monitor the component with the higher associated cost. The component for which the repair cost increases if degradation occurs should be monitored before the repair becomes impossible or the repair cost remains low.

Replacement cost is the second type of cost that affects the component criticality. Replacement is needed when the component no longer can be used because of degradation or a random incident. As mentioned above, the replacement cost should be considered with the repair cost for estimating criticality. In addition, replacement is inevitable; hence, it is necessary to consider the replacement cost to measure the component criticality.

Ordering cost (regular/emergency) is the expense involved in processing an order to suppliers. Depending on the order type, the ordering cost can be classified as a regular or emergency ordering cost (Zohrul Kabir & Al-Olayan, 1996). The regular ordering cost is lower than the emergency ordering cost. Therefore, if the gap between the two different costs is high, the severity of an unexpected component failure increases and the positive effect of the predictive maintenance will be greater.

Spare component cost/holding cost affects decisions of whether the company should have a spare component, and, if so, how many spare components the company should hold. In practice, it is difficult to maintain expensive spare components, especially when the spare component requires extra care in its holding. On the other hand, inexpensive components, such as bolts, nuts, screws, and cables, which do not require extra care, are not burdensome to the manufacturer. In this case, it is reasonable to hold an adequate amount of spare components because the holding cost is much lower than the ordering and shortage costs. Thus, if spare components of this type exist, the severity of the component failure is limited.

4.1.2 Time

Time has a strong relation with productivity, and productivity is the main indicator of performance in the manufacturing industry. Therefore, time can be used to measure the severity of the component failure. In the same manner as the cost, time can be classified into four types, as outlined below.

Repair/replace time refers to the time required to repair and replace the component when the repair/replacement component ready for use. That is, it does not include delivery time. As mentioned above, the repair and replacement are inevitable and require a certain amount of time to return the component to a normal condition. Before the component repair or replacement is completed, the machine cannot operate; it remains in an idle time, for which the manufacturer incurs a monetary loss.

In practice, if component alternatives exist, a temporal repair or replacement with an alternate component is possible. For example, a key switch has a similar structure as a selector switch. If a key switch fails, a selector switch is used as a temporary alternative. Thus, the cost of a *temporal repair or replace with an alternative* is another cost that is not common.

Delivery time is the time that should be employed to receive the new component for replacement. If no spare component exists, a wait time for the component delivery is involved and a monetary loss from the component failure can also occur. Moreover, in the manufacturing industry, the delivery time can be lengthy if the machine is discontinued or the machine manufacturer is far from the factory.

4.1.3 Regulation

Safety is another key aspect. Workers should be protected from the conditions that can cause any hazardous outcome, such as injury, death, or illness. If the component failure is directly related to a safety problem, it should be maintained in the best possible condition to fulfill the safety requirement and maintain worker safety.

In terms of the *environment*, when the failure of a component results in costs required for cleanup and environmental liability, fines or penalties can be imposed. Hence, it is desirable that environmental aspects are measured.

4.2 Occurrence

4.2.1 Frequency

The *failure rate* is the frequency in which failure events occur in a given time period (Ostrom & Wilhelmsen, 2012). It is a widely used concept in reliability engineering. If the failure rate is high, the frequency of the component failure is likewise high. Thus, the appropriate monitoring system should be installed to manage the component.

Mean time between failure (MTBF) is another representation of frequency. It is calculated by the sum of the time operation normally divided by the number of observed failures. Unlike the failure rate, if the value of MTBF is low, the frequency of the component failure is high. With same logic, *mean time to failure (MTTF)* can be another candidate.

4.2.2 Life time

Desired life time is the expectation of the amount of time the component will last once installed. For components that have short life times, and frequent replacements are needed, the predictive maintenance should be reconsidered. In contrast, if the durability of the component is retained over a long time, and the desired life time is semi-permanent, then predictive maintenance may not be needed.

Of the characteristics compared for assessing component failure criticality, *remaining life time* is a good measurement. It is the estimated remaining time until a failure occurs (Finkelstein, 2008). Depending on the metric use, it can be an alternative to the desired life time or they can be used in combination.

4.3 Detectability

4.3.1 Ease of Prediction

Before the component fails, if the machine state or any *prior signal* from the machine indicates the future failure of the component, it is not severe to assign a priority to a certain component.

In PHM research, for some components, common features applied for PHM are identified. In this case, detectability of that component (*probability to success)* is high, and the risk of applying predictive maintenance is low.

5 Component Prioritization Method

In this section, a method for component prioritization in predictive maintenance metrics is presented (see Figure 2 and Table 1). As shown in Figure 2, the appropriate component for predictive maintenance should be selected first in terms of the strategic and data analyses. After the candidate components are selected, prioritization is conducted by comparing component failure criticality. The criteria for measuring component criticality are severity, occurrence, and detectability. Each criterion has a sub-category (see Table 1). The component characteristic presented in Table 1 may not apply to all machines in all industries. However, the data shown in Figure 2 and Table 1 are only a starting point. This method can hopefully assist researcher efforts in assessing the component criticality for sequential application of predictive maintenance.

Table 1. Characteristics for measuring component failure criticality.

Severity			Occurrence		Detectability
Cost	Time	Regulation	Frequency	Lifetime	Ease of prediction
Repair cost Replacement cost Ordering cost Spare part (holding) cost	Repair time Replacement time Temporal – replacement time Delivery time	Safety Environment	Failure rate MTBF MTTF	Desired lifetime Remaining lifetime	Prior signal Probability

6 Conclusions

Before applying predictive maintenance, the primary issues to be addressed include determining which maintenance strategy is appropriate for a certain component, and which component should be prioritized if predictive maintenance is applied. Thus, the strategic phase and data analysis phase are suggested for identifying the appropriate component for predictive maintenance. In addition, three criteria—i.e., severity, occurrence, and detectability—are used to identify the component failure criticality. With these three criteria and their sub-categories, the component characteristics—i.e., cost, time, regulation, frequency, lifetime, ease of prediction — that affect each criterion are identified. For component prioritization in predictive maintenance, the characteristics are comprehensively considered. However, if the quantitative approach is adopted, then the usability of the method will be enhanced.

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