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A myopic policy for optimal inspection scheduling for condition based maintenance

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Abstract

In this paper, we propose a decision policy for condition-based maintenance that schedules inspections according to the current health of the system, optimized myopically over the next inspection interval. In traditional condition-based maintenance practices, regular inspections are considered a given requirement. Most measurements, however confirm that the machine in question is in good working order and that no maintenance is necessary. We consider the possibility that there are savings to be had in the number of inspections that are undertaken. As such, we use a proportional hazards model for risk of failure and a Markovian process to model the system covariates. The cost and time of inspections are incorporated into our model, and an optimal decision for one interval is made. This process can be repeated for each decision point, resulting in a decision policy that produces an inspect-or-replace result and an optimal time for the next inspection. Applied over the life of an asset, this policy can be used as a complete condition monitoring program supporting evidence based asset management.

Keywords: Condition-based maintenance, condition monitoring, condition-based inspections, proportional-hazards model, inspection intervals

1. Introduction

Condition-based maintenance (CBM) is the practice of diagnosing the health of an expensive long-life asset by condition monitoring, and following with an appropriate maintenance action. By inspecting an asset, it may be possible to obtain a better understanding of the health of the item, and thus intervene with an appropriate maintenance action prior to failure [1]. CBM's roots are in Barlow and Proschan's early works, whose seminal research discusses foundational maintenance models, such as block replacement policies [2, 3].

Inspections are measurements of the condition of an asset, and can range from low-tech visual inspections, to high-tech oil analysis and vibration monitoring. The data from inspections is processed for use in decision support systems to justify maintenance activities and their scheduling [4, 5].

As the name suggests, CBM is driven by the inspections that are made. It is impossible to know the condition of a machine without inspections, and the results of the measurements are the primary source of information used to make maintenance decisions. In industry, the measurements are mostly made periodically, and many resources are spent on obtaining the observations [6–8]. These inspections cost money, time, creates downtime, and occasionally causes machine failures in and of themselves [9, 10]. Unfortunately, the number of measurements that are non-critical and indicate that no maintenance is necessary largely outnumber the critical measurements indicating a need for preventive maintenance. This implies that many resources are being used to maintain the status quo, and that there is room for improvement.

Consider a machine with increasing hazard rate. This indicates that as the machine ages, its reliability decreases and experiences a degradation process. There have been considerable work in maintenance scheduling for deteriorating systems, such as in [11, 12] in which the environment is taken into account, and in [13–15], where degradation is assumed to be monotonically increasing over time. Alternatively, [16] uses piecewise deterministic Markov process. The range of studies can be reviewed in [17].

We propose that in cases with deteriorating machine health, a possible inspection policy could include less frequent inspections in the early stages of operation, and more frequent inspections as the machine ages. In the case where machines have long lifetimes and complex inspections, this sort of non-periodic inspection policy could add up to significant cost savings.

In the practice of CBM, inspections are made, and various measurements of the health of an asset are entered into decision support systems to acquire information about the hazard of machinery. Support systems generate maintenance policies that optimize criteria, such as minimizing total cost or maximizing availability based on the hazard that is evidenced through the data [18, 19].

There have been several studies into the practice of non-periodic inspections for CBM [20–23]. However, prior

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