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COMMENTARY

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Discussion of signature-based models of preventive maintenance

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1 | DISCUSSION

First of all, I congratulate the authors in Reference 1 for the pleasant and pedagogical tone in which they exhaustively describe most of the maintenance strategies found in the literature. This fact is a value in itself because it allows both novel researchers and experts having a conceptual map of many types of maintenance policies which go from the seminal work of Reference 2 to the most recent techniques based on the notion of the signature of a coherent system. Specifically, this article is highly recommended for researchers who are interested in maintenance management strategies for the first time because the authors sequentially list the most relevant results and approaches in the literature, as well as provide a large number of bibliographic citations.

Broadly speaking, the authors frame maintenance techniques into two broad classes, namely time-based maintenance (TBM) and condition-based maintenance (CBM). The former are based on the analysis of failure time data to determine a programmed calendar and the latter are based on condition monitoring in which the system is continuously monitored by some covariates as indicators, sensors or warning lights that allow to control the deterioration of the system. For those strategies there are two types of maintenance actions, corrective maintenance (CM) and preventive maintenance (PM). The CM action is clearly not advisable as it involves unplanned and unpredictable maintenance actions that can lead to high costs. However, the PM strategy allows maintenance to be planned, improving the useful life of the systems through an adequate schedule. Obviously the schedule must be optimized avoiding wasted expenditure. Additionally, each of the maintenance techniques are in turn classified according to the restoration degree of the components that fail: minimal repair, perfect repair and imperfect repair, where the complexity of the system also influences. Furthermore, the authors made special mention to plan a finite or infinite horizon and how that affects the optimization methods. Another key concept described by the authors concerns the scenarios for the failure of the system which can be split into two groups: the scenarios assuming that system failures occur due to wear out by aging over time and those where failures are due to fatal shocks arriving at the system from external or internal sources. All these techniques, actions and strategies aim to obtain the optimal PM. To conclude the general framework the authors recall the two most classical criteria for evaluating optimal models based on the cost and on the system availability indices, namely the expected long-run cost per unit of time and the availability criterion, respectively. Both criteria are used along the paper as the backbone to evaluate particular models.

After the general view of PM actions, the main purpose of the paper is focusing on describing recent optimal PM models on complex multi-component coherent systems where the reliability function is expressed in terms of the signature of the system. As described in Reference 3 "computing a signature is associated with the fact of capturing the essence of a coherent system to simplify the quantification of its reliability that leads us to better understand the nature of each system". Here the authors start by describing the classical signature introduced by Samaniego[4] and after that also the two more recent concepts of survival signatures and t-signatures. Throughout the literature, the authors show how we can take advantage of having a signature to optimize the criteria based on the cost or on the system availability. Concerning the signature, one of the most useful contributions made by the authors is the elaboration of the Table 16 in their paper. Such a table provides a good summary of the most recent works about maintenance study under signature-based PM of coherent systems where we can see different approaches, strategies and assumptions. As a criticism, the signature seems to be only presented as a tool to facilitate the representation of the reliability handling. I do miss a better description of how the signature provides extra knowledge for PM actions. Finally, the authors do not address the most critical and polemical point of the signatures: the assumption of i.i.d. components or just i.d. for components having a joint exchangeable distribution.

I do agree with the authors in Reference 5 about the convenience to extend the application of the different notions of signature for CBM. The authors only focus on PM techniques but predictive maintenance (PdM) techniques are a type of CBM that supply data in real-time and those are used to predict when maintenance is required and to prevent a future failure. Due to the use of big data and artificial intelligence, the PdM is one of the most popular type of maintenance in these times, where it is only scheduled when specific conditions are met and before the failure, see for example, Reference 6. As a specific case, it would be nice to explore what conditions affect the components of the system and which ones the signature, that is, the structure.

Respect to random shocks, I do like the discussion of the overall damage of some models by the number of shocks and its signature taken from Reference 7. It is proposed a discrete scale based on the number of the shocks instead of a classical time scale. However, I think that discrete scale could be difficult to put into practice because it could represent in some sense a decision not planned in time that can cause a certain degree of uncertainty. For example, it seems to be not practical for the classical vehicle inspection. I do think this topic warrants further investigation.

The authors explicitly mention the restoration degree of the components that fail but do not pay attention to constraints about the number of repairs. Clearly inspired in the concept of signature, the authors in Reference 8 address the problem of describing the reliability of a coherent system whose n independent components can be repaired a fixed number of times. The system starts operating at time zero, and each component can be just repaired m_h times, for $h = 1, \dots, n$. It would be challenging to obtain optimal PM actions based on the representation of the reliability function described in Reference 8 which takes into account the number of repairs before the system failure.

Although the authors provide a large number of research papers on optimal PM planning of systems, I would like also to pay attention to papers that deal about the stochastic comparison of the reliability function under different stochastic orderings as the usual stochastic order, the hazard rate order, the likelihood ratio order, the median residual life order, and so forth. In a formal way, the stochastic orderings deal about the comparison of two random behaviors and the kind of comparison depends on what we are looking for, see Reference 9 for more details about stochastic comparisons. Given a specific system, this comparison can be made by considering different replacement policies. For example, the authors in Reference 10 obtain optimal strategies by comparing stochastically three different options based on the minimal repair of the first failed component, on the component which causes the system failure and on a fixed component. Likewise the authors in Reference 11 determine the optimal allocation of spare parts under a minimal repair policy. It would be also challenging to combine the classical optimal PM actions with optimal allocation policies in a stochastic sense to obtain a better maintenance strategy.

By going deeper into the concept of stochastic orders, many papers in the literature compare systems by relying on the signature concept, see for example, References 12 and 13. Given two different systems having lifetimes T_1 and T_2 and signature vectors $\mathbf{s}_1$ and $\mathbf{s}_2$, those papers mainly study the relationship between stochastically ordered signatures and system lifetimes. In the context of evaluating optimal PM, it would be nice to study how those relationships are connected with the expected long-run cost per unit of time, denoted by $\eta(\cdot)$, and the availability criterion, denoted by $\mathcal{A}(\cdot)$. For example, given a specific PM action, if $\mathbf{s}_1$ and $\mathbf{s}_2$ are stochastically ordered in some sense and this order implies that T_1 and T_2 are also ordered, a natural question arises about the comparison between $\eta(T_{PM_1})$, $\eta(T_{PM_2})$ and $\mathcal{A}(T_{PM_1})$, $\mathcal{A}(T_{PM_2})$. Obviously, that kind of comparisons would put light on the classical relation between reliability and cost.

To conclude my discussion, I think the authors have made a nice work concerning the current state of the art. On one hand, it seems clear that the notion of signature can be useful for a better understanding of PM actions. On the other hand, the exhaustive overview described by authors opens avenues to be explored for further research.

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DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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