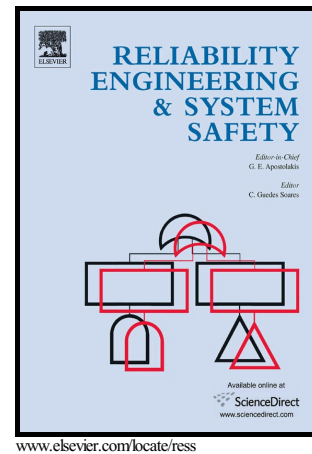


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Timely Condition-Based Maintenance Planning for Multi-Component Systems

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Abstract

Last-minute maintenance planning is often undesirable, as it may cause downtime during operational hours, may require rescheduling of other activities, and does not allow to optimize the management of spare parts, material, and personnel. In spite of the aforementioned drawbacks of last-minute planning, most existing methods plan maintenance activities at the last minute. In this paper, we propose a new strategy for timely maintenance planning in multi-component systems. As a first step, we determine for each system component independently the most appropriate maintenance planning strategy. This way, the maintenance decisions can be tailored to the specific situations. For example, conservative maintenance decisions can be taken when the risk tolerance is low, and maintenance decisions can be made timely when we can accurately predict future degradation behavior. In the second step, we optimize the maintenance plan at the system level. Here, we account for economic and structural dependence with the aim to profit from spreading or combining various maintenance activities. The applicability of the method is demonstrated on a railway case. It is shown how the different cost functions (e.g. costs of maintenance, downtime, and failure) influence the maintenance decisions.

Keywords: Condition-based maintenance; Optimization; Sequential decision making; Multi-component systems; Economic dependence; Structural dependence; Dynamic maintenance grouping; Railway networks.

1. Introduction

For many systems, like manufacturing and transportation systems, maintenance activities have a major influence on the availability, safety, and operational costs of the system. The ideal maintenance strategy prevents failures without resorting to over-maintenance. Such a strategy depends on the current and the future health of the system, which are never completely known in practice. However, if the right system variables are measured and processed adequately, good estimates and predictions of the system health can be obtained, based on which the maintenance can be planned. This is the motivation behind *condition-based maintenance*.

Although much research has been devoted to maintenance planning based on real-time condition monitoring, most existing methods use only diagnostic information, consider planning of individual components, and focus on last-minute planning. Such approaches are sufficient for systems for which it is convenient to perform maintenance shortly after the decision to do so has been made. Last-minute maintenance planning is however often undesirable as it may cause downtime during operational hours, may

require rescheduling of other activities, and does not allow to optimize the management of spare parts, material, and personnel. Furthermore, in multi-component systems, like road and railway networks and wind farms, it may be beneficial to combine or spread maintenance activities. This is not possible when maintenance needs are known just in time.

Motivated by the shortcomings of last-minute maintenance planning, we propose a two-stage bottom-up approach¹ for timely maintenance decision making based on real-time condition monitoring in multi-component systems. A bottom-up approach is preferred over a top-down (aggregate) approach, because of its applicability to heterogeneous systems, i.e. systems consisting of multiple types of components [1–4].

The *first stage* consists of determining the need for maintenance on each of the individual system components. If maintenance is required, based on the nature and urgency of the problem, the most appropriate type and time of maintenance have to be decided. As information regarding the system health is available in real time, it is not obvious when to settle on the decision regarding the time and type of maintenance. Generally, the more data are available, the better we can estimate the current and future system health, allowing a better decision on the time

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¹In a bottom-up approach, optimal maintenance strategies for the individual system components are determined first.

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