Condition-based maintenance for complex systems

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Summary

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COORDINATING MAINTENANCE AND LOGISTICS PLANNING FOR THE PROCESS INDUSTRIES

Maintenance planning in the process industries is extremely complex for various reasons. Plants are expected to yield a continuous, high output, which is generally achieved by running the plant nonstop. Limited time is available for performing preventive maintenance, but failures should be prevented as they can lead to system downtime and high losses of revenue. Corrective maintenance strategies, such as failure-based maintenance, are thus not suitable. Moreover, preventive maintenance strategies, such as age-based maintenance or block replacement, are generally too conservative, by scheduling maintenance more often than strictly necessary. Condition-Based Maintenance (CBM) therefore offers a lot of potential, as it bases the maintenance decisions on the actual system condition.

For systems consisting of a single component, CBM can be successfully implemented through a deterioration threshold. Under such a control-limit policy, preventive maintenance is initiated as soon as the deterioration level reaches the threshold. In the process industries, however, systems generally comprise multiple components subject to various inter-component dependencies. In such cases, the optimal policy for one component may not result in a close-to-optimal solution at the system level.

As research is shifting to more complex systems that better match practice, we found that existing classifications of types of dependencies (structural, stochastic, and economic) are no longer sufficient. We thus proposed a more complete classification in this thesis, in which we extended the notion of structural dependence to cover the cases where the system performance depends on the system structure (e.g., series or parallel). Moreover, we added resource dependence as the case where multiple components share for instance a set of tools or spares, or where the maintenance of multiple components is done by the same maintenance workers. Based on this new classification, we reviewed the advances made with respect to CBM. We focused on the effects of different types of dependencies on the optimal

CBM policy structure, and highlighted current gaps in the literature that formed the basis for this thesis.

We focused on obtaining insights into the optimal CBM policy structure for systems subject to various types of dependencies, thereby focusing on decisions such as when to inspect, when to maintain, when to add a redundant component, and when to order spares. For systems subject to economic dependence and structural dependence (through either a series or a parallel setting), we found that significant cost savings can be obtained by applying an aperiodic inspection schedule, in which inspections are scheduled more frequently as the system is approaching the end of its life. Furthermore, we observed for various complex systems that components are not necessarily replaced at their individual optimal replacement moments. Economic dependence forms an incentive to cluster maintenance actions, which can either be achieved by performing maintenance at an earlier stage or by postponing maintenance actions. Redundancy (i.e., structural dependence), even allows maintenance on failed components to be postponed without affecting the system availability, to further achieve clustering opportunities. Load sharing (i.e., stochastic dependence), however, can form an incentive to perform corrective maintenance as soon as possible. The effects of these types of dependencies are thus heavily intertwined. Moreover, we observed that adding a redundant component to the system will increase the maintenance costs, but decrease the probability of a system failure. Load sharing forms an additional incentive to add a redundant component. Resource dependence (through a shared set of spares) is also shown to affect the maintenance decisions. Furthermore, we found that a condition-based inventory policy can significantly outperform the commonly applied (s, S) inventory policy, as holding costs can be reduced by postponing an order for spares if the components are in good condition.

Our key finding is that CBM planning extends beyond merely using monitoring information to schedule maintenance right before component failure. Component dependencies can severely complicate the (maintenance) decisions at the system level. Many complex systems require a custom-fit, dynamic CBM policy, as classical maintenance policies or threshold CBM policies can be significantly more expensive. The insights obtained in this thesis constitute an important step towards such customized CBM policies.