Maintenance optimization in complex systems using prognostic information

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1 Introduction

Maintenance is an essential activity to slow down the degradation of components in production systems, and can avoid frequent system breakdown [1]. To the best of our knowledge, maintenance policies for single-component systems have been widely investigated, but complex systems with multiple components that are more practical and complicated also require appropriate maintenance decisions. In this research, we propose effective optimization approaches for multi-component complex systems to support preventive maintenance decision-making.

To implement predictive maintenance, we use component-level *Remaining Useful Life* (RUL) information [2] to achieve system-level availability in generic complex systems. Note that a component's RUL is the currently remaining operation time before it fails. The considered complex system (the main industry) in Figure 1 consists of several operational stages, and each stage contains multiple redundant components [3]. This redundancy allows backup (standby) components to take operating responsibility once an on-working component needs to be maintained. The objective of this work is to coordinate component redundancy and maintenance in different stages to keep the main industry producing continuously such that client demands are satisfied as much as possible in the planning horizon. We also assume that there exist backup industrial sites that can sell products to the main one, but transport and purchase costs are incurred in this case.

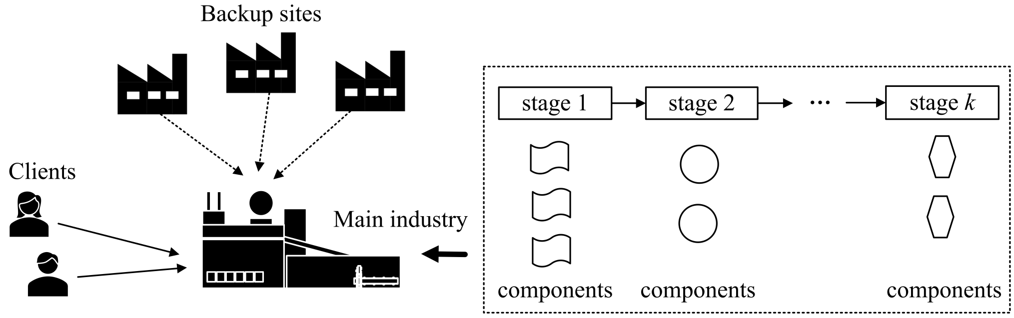

FIG. 1 – Schematic diagram of the studied problem

In summary, we optimize RUL-based maintenance in complex systems, integrating maintenance and production in a single formulation. The objective is to minimize the total cost in the planning horizon. Our contributions are twofold :

(i) A novel maintenance optimization problem in complex systems.

(ii) A mathematical optimization formulation of this problem.

2 Problem description

We consider the following groups of constraints.

(i) *The evolution of a component's RUL over the planning horizon.* Prognostic RUL information is the fundamental basis for deciding maintenance activities in our research. We assume that the variation of the RUL of a component depends on its use within a period. If a component has not been used, its RUL does not change ; if it has been used, its RUL decreases ; if it needs maintenance (its RUL reaches the given threshold), its RUL will recover to another value after maintenance.

(ii) *System availability.* The main industry can operate if and only if all the stages it contains operate. To guarantee this, at least one component in each stage must be working. Obviously, there will be no output of any product in periods of system downtime.

(iii) *Purchase from backup sites or not.* If the main system's production cannot meet client demand or the system breaks down in some period, it can still order products from the backup sites, possibly with a lead time.

(iv) *Inventory and production flow.* We allow some product inventory in preparation (if needed) to meet future demand. We assume that the total of the production, inventory, and purchased amounts is greater than the demand.

The objective function is to minimize the total cost over the planning horizon. It is the sum of the maintenance cost, system-failure cost if the system breaks down, inventory cost, and cost arising from purchasing products from backup sites (transport cost and product price).

A mixed-integer linear programming model is formulated for this problem, and the model is solved to global optimality using the commercial solver CPLEX.

3 Conclusions and future research

We proposed a mixed-integer linear programming approach to cope with small problem instances. Through different experimental results, we not only showed the effectiveness of our approach to find optimal solutions but also provided practical maintenance decision support for this type of generic complex system.

Future research directions include : (i) considering a setup cost when changing components from standby to operating state ; (ii) using other forms of RUL, such as probability or quantiles ; (iii) integrating maintenance decisions for multiple sites.

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