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Integrating noncyclical preventive maintenance scheduling and production planning for a single machine

Mohamed-Chahir Fitouhi, Mustapha Nourelfath *

Interuniversity Research Center on Enterprise Networks, Logistics and Transportation (CIRRELT), Mechanical Engineering Department, Université Laval, Quebec (Qc.), Canada G1K 7P4

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ABSTRACT

This paper deals with the problem of integrating noncyclical preventive maintenance and tactical production planning for a single machine. We are given a set of products that must be produced in lots during a specified finite planning horizon. The maintenance policy suggests possible preventive replacements at the beginning of each production planning period, and minimal repair at machine failure. The proposed model determines simultaneously the optimal production plan and the instants of preventive maintenance actions. The objective is to minimize the sum of preventive and corrective maintenance costs, setup costs, holding costs, backorder costs and production costs, while satisfying the demand for all products over the entire horizon. The problem is solved by comparing the results of several multi-product capacitated lot-sizing problems. The value of the integration and that of using noncyclical preventive maintenance when the demand varies from one period to another are illustrated through a numerical example and validated by a design of experiment. The later has shown that the integration of maintenance and production planning can reduce the total maintenance and production cost and the removal of periodicity constraint is directly affected by the demand fluctuation and can also reduce the total maintenance and production cost.

1. Introduction

1.1. Motivation

Harmony between maintenance and production departments is necessary for the success of modern companies. These two activities are clearly linked and, together, contribute to the improvement of the profit margin and the company's effectiveness. However, in many cases, their relationship may become conflictual, since they share the same equipments. The production department has to satisfy customer demands within promised delays and service levels. If a production manager promises to a customer the satisfaction of his demand with a given service level, it is important to honor her/his promise in a timely manner. Thus, the production department pushes for the maximal use of the production equipments. However, the maintenance department should try to keep these equipments in good conditions through preventive actions. This antagonist environment promotes the lack of communication and internal conflict during the planning process. The synchronisation between the production planning and preventive maintenance (PM) activities may avoid failure, production delays and re-planning problems. The maintenance planning should be simultaneously planned with the production planning and scheduling in order to decrease the costs generated by the production interruptions.

1.2. Prior literature

There are a lot of papers in the literature dealing with tactical production planning issues. For example, in Argoneto et al. (2008), the authors cover the majority of advancement in this research area. The problem consists generally in minimizing inventory, production and set-up costs under machine capacities and demand satisfaction constraints. Solution methodologies for corresponding multi-product capacitated lot-sizing problems vary from traditional linear mixed integer programming, and associated branch and bound exact methods to heuristic methods.

Similarly, several maintenance planning models can be found in the literature. The advancement in this area is covered, for example, in Garg and Deshmukh (2006) where the authors present an interesting classification, based on the modeling approach used for the problem formulation, such as Bayesian approach, mixed integer linear programming, fuzzy approach, simulation, Markovian probabilistic models and analytic hierarchy process. These models are generally solved using optimization techniques

* Corresponding author. Tel.: +1 418 6562131x12355; fax: +1 418 6567415.
E-mail addresses: mohamed-chahir.fitouhi.1@ulaval.ca (M.-C. Fitouhi), Mustapha.Nourelfath@gmc.ulaval.ca (M. Nourelfath).

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to minimize equipment maintenance costs, or to maximize the equipment availability. Many preventive maintenance models are presented in a cyclic (or periodic) context. In Grigorieva et al. (2006), the authors present a literature review about periodic preventive maintenance problems. The periodic aspect of PM consists in a repetitive execution of the same optimal maintenance service (for the optimal preventive maintenance interval) in the time horizon. There is only a relatively limited literature on models presenting a general (*i.e.*, not necessarily periodic) preventive maintenance policy. The objective of these models is to determine either the best time for doing preventive replacements by new items, *i.e.*, perfect PM (Yao et al., 2004), or the optimal sequence for imperfect maintenance actions (Levitin and Lisnianski, 2000).

Budai et al. (2006) reviewed the majority of integrated maintenance and production models, and subdivided the research area into four categories: high level models, the economic manufacturing quantity models, models of production systems with buffer and finally production and maintenance rate optimization models. Cassady and Kutangolu (2005) proposed an integrated maintenance planning and production scheduling for a single machine, in order to find the optimal PM actions and job sequence minimizing the total weighted expected completion time. This model was solved by using genetic algorithms by Sortrakul et al. (2005). In Ashayeri et al. (1996), a mixed-integer linear programming model is developed to simultaneously plan preventive maintenance and production in a process industry environment. The model schedules production jobs and preventive maintenance jobs, while minimizing costs associated with production, backorders, corrective maintenance and preventive maintenance. The performance of the model is discussed and a branching solution procedure is suggested. Chelbi et al. (2008) proposed an integrated production and maintenance strategy for unreliable production system. The presented model focused on finding simultaneously the optimal value of the production lot size and the optimal preventive replacement interval, while considering the possibility of producing non-conform items. Song (2009) considered the problem of production and preventive maintenance control in a stochastic manufacturing system. The system is subject to multiple uncertainties such as random customer demands, machine failure and repair and stochastic processing times. A threshold-type policy is proposed to control the production rate and the preventive maintenance operation simultaneously. Jin et al. (2009) introduced a new methodology based on the financial stock options principles to maximize the average profit under uncertain demand, by generating the optimal number of PM works during the production plan. Chung et al. (2009a, 2009b) used the reliability acceptation function to minimize the production makespan in a multi-factory context. Berrichi et al. (2010) presented a mathematical model minimizing the production makespan and the system unavailability for parallel machine systems.

At the tactical level, there are only a few papers discussing the issue of combining preventive maintenance and production planning. Weinstein and Chung (1999) examined the integration of maintenance and production decisions in hierarchical planning environment. In Aghezzaf et al. (2007), the authors present a production and maintenance planning model for a production system modeled as a single component, subject to cyclical PM with minimal repair at failure. An approximate algorithm based on Lagrangian decomposition is suggested in Aghezzaf and Najid (2008) to solve this problem for both cyclical, and noncyclical PM policies. In Nourelfath et al. (2010), the authors develop an integrated model for production and PM planning in multi-state systems.

1.3. Objective and outline

The present paper contributes to this small literature body on the integration of PM and production planning at the tactical level. The maintenance policy suggests possible preventive replacements at the beginning of each production planning period, and minimal repair at machine failure. This PM policy is said to be general, in the sense that it can be either cyclical or noncyclical. The production planning part corresponds to a multi-product capacitated lot-sizing problem. At this level, the decisions involve determination of quantities of items (lot sizes) to be produced in each period. Lot-sizing is one of the most important problems in production planning. Almost all manufacturing situations involving a product-line contain capacitated lot-sizing problems, especially in the context of batch production systems. The setting of lot sizes is in fact usually considered as a decision related to tactical planning, which is a medium-term activity. In aggregate planning, the lot sizing models are extended by including labor resource decisions. Tactical planning bridges the transition from the strategic planning level (long-term) to the operational planning level (short-term). Clearly, the time horizons may vary for each planning level depending on the industry. Typical values are one week (or less) for operational planning; one month (or more) for tactical planning; one year (or more) for strategic planning. In several modern production systems, the components are usually reliable and PM decisions should be integrated at the tactical level.

Unlike Weinstein and Chung (1999), we are not dealing with this problem in hierarchical planning environment. While the models in Aghezzaf et al. (2007) and Nourelfath et al. (2010) deal with cyclical PM, the present paper takes into account the possibility of noncyclical PM. To the best of our knowledge, the only existing model that deals with the same problem is the model in Aghezzaf and Najid (2008). The later assumes that maintenance actions carried out on the production system reduce its capacity without calculating this reduction. The model developed in this paper is different, and a method is proposed to evaluate the capacity reduction, the times and the costs of PM and minimal repair and the average production system capacity in each period.

The remainder of the paper is organized as follows. The next section describes the problem. Sections 3 and 4 develop, respectively, the mathematical model and the solution method. An illustrative example is presented in Section 5. A design of experiment is realized in Section 6, and conclusions are in Section 7.

2. Problem description

2.1. The preventive maintenance scheduling problem

Let us consider a single machine in a manufacturing system that is subject to random failures. Planned preventive maintenance and unplanned corrective maintenance can be performed on the machine. Whenever an unplanned machine failure occurs, a minimal repair (MR) is carried out, *i.e.*, the machine is restored to an operating condition without altering its age. In practice, MR happens when the machine operator does just enough maintenance to make the machine operable. Furthermore, we consider that the machine's hazard rate increases with the time, so that preventive maintenance is used to decrease the risk of failure. It is assumed that PM either restores the machine to "as-good-as-new" condition (perfect PM), or replaces the machine by a new one. We will sometimes refer to such perfect PM as preventive replacement (PR). We consider a general model, in the sense that it is possible to apply cyclical or noncyclical PR. The machine is considered as a binary-state system. It is characterized by its own nominal production rate, and its expected preventive and corrective maintenance times and costs. The expected maintenance cost during the planning horizon is the sum of preventive and