



Joint integrated production-maintenance policy with production plan smoothing through production rate control



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ABSTRACT

We consider a production system that has to satisfy a random demand during a finite planning horizon under a required service level. This study consists in developing an analytical model in order to determine a near-optimal integrated maintenance-production plan which takes into consideration the influence of the production rate on the system's failure rate while attempting in the same time to smooth the production plan through the production rate control between periods of the planning horizon. A numerical example is presented in order to illustrate the contribution of the proposed modelling approach and discuss the different trade-offs that are considered.

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1. Introduction and literature review

Manufacturing companies must manage several functional areas successfully, such as production, maintenance, quality and marketing. One of the keys to success consists in treating all these services simultaneously. In order to ensure an efficient coordination between them, managers and decision makers have to consider a global systemic approach integrating the interactions between parts or all of those complementary functions. In this perspective, several researchers have investigated ways of integrating maintenance and production after decades during which those two functions had been studied separately. Works on maintenance policies started with Barlow et al. [1] and continued with a huge number of contributions as it can be seen in a survey on maintenance models by Wang [2]. During the last two decades, several companies have realized that strategies dissociating maintenance and production were ineffective. The need for developing new integrated maintenance-production strategies became evident. Brandolese et al. [3] proposed a strategy for maintaining a multiple machines

production system. The planning consists in programming the execution date of each task and the machine that should perform it. They integrated preventive maintenance tasks in the planning placing them as close as possible to the optimal maintenance periods. Chelbi et al. [4] developed a mathematical model in order to determine both the buffer stock size and the preventive maintenance period for an unreliable production unit which is subject to regular preventive maintenance of random duration. The optimization of the preventive maintenance period and the buffer size was also the problem addressed by Pal et al. [5] in the context of an imperfect production system that may shift to an 'out-of-control' state after a random time. Non-conforming products are reworked incurring an additional cost. They also considered the situation where both the buffer size and the production rate are the decision variables. Rezg et al. [6] developed an analytical model and a numerical procedure which allow determining a joint optimal inventory control and age-based preventive maintenance policy for a randomly failing production system. Recently, Tambe and Kulkarni [7] developed a selective maintenance and quality control decision optimization framework considering the production schedule of the machine. They derive an optimal maintenance decision, consisting in one of three actions (repair, replace or do-nothing) for the system components along with the optimal sample size, the acceptance number

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and the time between samples, taking into account the optimal production schedule. The authors used a genetic algorithm in order to solve the problem.

In the same framework, some researchers have taken into account several external constraints. In fact, integrated maintenance-production strategies which take into consideration subcontracting have been studied by Dellagi et al. [8]. They developed and optimized a maintenance policy incorporating subcontractor constraints. They demonstrated through a case study, the influence of the subcontractor constraints on the optimal integrated maintenance-production strategy. Dealing also with the same subject, Dahane et al. [9] studied analytically the problem of the integration of subcontracting activities and determined the optimal number of subcontracting tasks to be performed during a maintenance cycle. Recently, Nourelfath et al. [10] dealt also with the same problem of integrating preventive maintenance and production planning, for a production system composed of a set of parallel components. A subsequent work by Nourelfath and Châtelet [11] assumed the presence of economic dependence and common cause failures in the production system. Mifdal et al. [12] considered the same problem in the case of multiple-products manufacturing systems.

Looking at the literature on integrated maintenance-production policies, we noticed that the influence of the production rate on the system degradation in presence of a random demand over a finite planning horizon was rarely addressed in depth. Very few works dealt with this issue. For example, the study of Hajej et al. [13] which presents an analytical stochastic optimization model based on the operational age concept, revealed the significant influence of the production rate on the deterioration of the manufacturing system and consequently on the integrated production-maintenance policy. Later, Hajej et al. [14] dealt with the same problem by integrating a subcontracting constraint in order to recycle a certain quantity of returned products. In these two studies, the authors started by establishing an optimal production plan which minimizes the total inventory and production cost taking into consideration the subcontractor constraint. Then, using this optimal production plan, they derived an optimal maintenance schedule which minimizes the total maintenance cost. Their approach is sequential. Moreover, they do not consider the influence of having differences between quantities produced in successive periods and the impact of such differences on labour and set-up related costs.

The approach adopted in this study favours the fact of smoothing the production rate between periods in order to avoid the disadvantages of a significant variation (mainly in terms of set-up costs).

This paper is organized as follows: In the next section we specify the targeted contributions of this work. Then the problem and the working assumptions are described in Section 3. Section 4 is dedicated to the working assumptions and the development of the analytical model. A numerical example is presented in Section 5 to illustrate the proposed modelling approach and discuss different trade-offs that are considered. Finally, conclusions and potential future work are provided in Section 6.

2. Targeted contributions

Several industries such as steel production exhibit fluctuation of the production rate between production periods. This yields a great deal of set-up and preparation work like unloading and loading raw materials using special equipment and human resources. Moreover, in the case of production lines, generally buffers with finite capacities are present between machines. The variation of the production rate between periods brings the necessity of changing the buffers' levels involving a certain handling and logistics cost.

Hence, it is clear that the production rate fluctuation between periods may have a significant impact on the set-up cost incurred at the beginning of each period. To the best of our knowledge, this issue has not been considered in the literature. The adopted approach in this study favors the fact of smoothing the production rate between periods in order to avoid the disadvantages of a significant variation (mainly in terms of set-up costs). We also propose an integrated (and not sequential) optimization of the maintenance schedule and the production plan in order to derive a near-optimal integrated maintenance-production strategy taking into account the penalty induced by excessive variation of the production rate between periods of the planning horizon. To do so, we express the set-up cost as being proportional to the production rate variation between successive periods of the production plan. Besides, we propose new modelling features in the total integrated cost modelling, particularly when dealing with the shortage and inventory holding costs by considering them separately contrarily to the previous studies mentioned above.

The proposed model allows the investigation of different trade-offs. The first one is between the smoothing penalty and the production plan, the inventory, and the preventive maintenance schedule. We also consider the effect of the demand variability on the smoothing penalty, the production and maintenance plans, and on the total expected cost.

3. Problem statement

We consider a single machine M subject to degradation and random failures. It produces one type of product whose demand is random and characterized by a Normal probability distribution with known average and standard deviation. The demand is satisfied from a stock (Fig. 1). Production is planned over a finite horizon divided in H production periods of equal length Δt . It is assumed that the quantity produced at every period is added to the stock at the end of the period and the demand of every period is satisfied at the end of the period. The machine failure rate increases with both time and the production rate. Periodic preventive maintenance actions have to be scheduled to reduce the probability of failure.

We are in presence of a production control problem with a state variable, namely the inventory level, together with the following control variables: the production rates for every period and the number of preventive maintenance actions to be performed over the time horizon $H\Delta t$.

The objective is to minimize the total expected cost over the production planning horizon made of H periods. This cost integrates production costs, inventory and shortage costs, preventive and corrective maintenance costs and an additional cost related to a penalty due to the production rate variation between successive periods.

As it will be shown in next section, compared to previous works dealing with the same subject, the first contribution of this study consists in the total integrated cost modelling. On one hand, the shortage and inventory holding costs are formulated separately, and on the other hand, the average number of failures is modelled differently considering an increasing failure rate according to both time and production rate.

The second feature consists in the integrated (and not sequential) optimization of the production plan and the maintenance schedule taking into account the influence of the production rate variation on the system degradation. Finally, the third main contribution is the control of the production rate variation between successive periods in order to smooth the production plan by reducing the penalty induced by excessive variation of the production rate over the planning horizon.

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