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Integrated maintenance and control policy based on quality control ☆

Radhoui Mehdi [a,*], Rezg Nidhal [b], Chelbi Anis [c]

[a] CEREP, Ecole Supérieure de Technologie et d'Informatique, 4, Rue des Entrepreneurs Charguia II – 2035 Tunis-Carthage, Tunisia
[b] LGIPM COSTEAM-INRIA, Université Paul Verlaine Metz, France
[c] CEREP, Ecole Supérieure des Sciences et Techniques de Tunis, 5 Avenue Taha Hussein, BP 56, Bâb Manara Tunis, Tunisia

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ABSTRACT

In this paper, we develop a joint quality control and preventive maintenance policy for a production system producing conforming and non-conforming units. The considered system consists of one machine which must supply another production line operating on a just-in-time basis. According to the proportion $\boldsymbol{l}$ of non-conforming units observed on each lot and compared to a threshold value $\boldsymbol{l_m}$, one decides to undertake or not maintenance actions on the system. In order to palliate perturbations caused by the stopping of the machine to undergo preventive maintenance or an overhaul, a buffer stock $\boldsymbol{h}$ is built up from the instant when the rejection rate reaches a threshold level $\boldsymbol{l_A}$ in order to ensure the continuous supply of the subsequent production line. Our objective is to determine simultaneously the optimal rates $\boldsymbol{l_m^*}$ and $\boldsymbol{l_A^*}$, and the optimal size $\boldsymbol{h^*}$ which minimize the expected total cost per time unit including the average costs related to maintenance, quality and inventory.

1. Introduction

In several production systems, buffer stocks are built between consecutive machines to ensure the continuity of supply during interruptions of service caused by breakdowns or planned maintenance actions.

Several authors proposed and discussed various strategies to deal with this buffer stock sizing problem in presence of maintenance activities (Groenevelt, Pintelon, & Seidmann 1992a,1992b; Meller et al., 1996; Salameh et al.,1999; Van Der Duyn Schouten et al., 1995).

Chelbi et al. (2004) analyse, using an analytical approach, an integrated production/inventory policy for a randomly failing system made up of a single machine and having to feed a subsequent production unit at a constant rate. They present a mathematical model to determine simultaneously the optimal size of the buffer stock and the period according to which preventive maintenance actions should be undertaken, minimizing the total unitary average cost. In the same context, Chelbi and Rezg (2006) consider, instead of a periodic maintenance strategy, a policy based on the age of the equipment. They determine the optimal age of the system at which it should be submitted to preventive maintenance, and the optimal size of the buffer stock, so as to minimize the total cost per time unit, taking into account a minimum required system availability level.

Rezg, Chelbi, and Xiaolan (2005) deal with the same problem using another approach based on simulation and experimental design.

It is clearly shown in all these works and in many others that the equipment condition plays a crucial role in controlling the buffer or lot size. In other respects, it is also well known that the equipment state plays an important role in controlling quality of produced items. Despite the strong link between production, quality and maintenance, only few research works have attempted to catch their underlying relationship through a single integrated model.

For example, Ben Daya (1999) developed an integrated model for the joint optimization of the economic production quantity, the economic design of *x*-control chart, and the optimal maintenance level, for a deteriorating process where the in-control period follows a general probability distribution with increasing hazard rate.

Wang, William, and Meckinley (1999) treaded the case of a production system in which some of the products made are defective. They assumed that the distribution of such defective products depends on the total number of products made since the last maintenance action.

Salameh et al. (2000) developed an inventory situation where items received are not of perfect quality (defective) and after 100% screening, imperfect quality items are withdrawn from inventory and sold at a discounted price.

Ben Daya (2002) proposed an integrated model for the joint determination of economic production quantity and preventive maintenance level for imperfect production process. He proved

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* Corresponding author.
E-mail addresses: radhoui.mehdi@planet.tn (R. Mehdi), rezg@univ-metz.fr (R. Nidhal), anis.chelbi@wanadoo.tn (C. Anis).

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that performing preventive maintenance gives way to a reduction of quality control related costs.

El-Ferik (2008) proposed a numerical procedure to determine simultaneously the economic production quantity and the preventive maintenance (PM) schedule. The considered manufacturing system is assumed to deteriorate while in operation, with an increasing failure rate. The system undergoes PM either upon failure or after having reached a predetermined age, whichever occurs first.

Chelbi, Rezg, and Radhoui (2008) deal with the lot-sizing problem for a production system which may randomly shift to an out-of-control state and produce non-conforming units. The system is submitted to an age-based preventive maintenance policy. As soon as the shift to the out-of-control state is detected, a restoration action of the system is planned for L time units later. A mathematical model is developed for the joint determination of the economic production quantity Q and the age T for preventive maintenance.

Dimitrakos et al. (2008) use a semi Markov decision algorithm to deal with the preventive maintenance period problem of a deteriorating installation (I) that transfers a raw material to a production unit and a buffer, which is built between both units. They assumed that the repair times follow some known continuous distributions. They determined the optimal policy based on control-limit type, i.e. it initiates the preventive maintenance of the first installation if and only if the degree of its deterioration exceeds a critical level.

In Panagiotidou and Tagaras (2007), the authors present an economic model for the optimization of preventive maintenance in a production process with two quality states. The equipment starts its operation in the in-control state but it may shift to the out-of-control state before failure or scheduled preventive maintenance. The two states are characterized by different failure rates and revenues.

Jaber, Goyal, and Imran (2008) proposed to extend the work of Salameh et al. (2000) assuming the percentage of defective items per lot decreases according to a learning curve. The developed model was compared with the model of Salameh et al. to illustrate the importance of learning.

Radhoui, Rezg, and Chelbi (2009) proposed a new maintenance strategy based on quality control. They considered that every produced lot is subject to quality control, and according to the observed rejection rate, one decides which kind of maintenance action to undertake. They supposed that at the beginning of each production cycle, a buffer stock is built to supply the demand during production interruption.

In the same context of integrating production, maintenance and quality, we propose here to extend the work of Radhoui et al. (2009) by allowing the buffer stock to be built at any instant during the production cycle to be optimally determined jointly with quality and production parameters.

We consider a single unit production system which must satisfy a constant and continuous demand d. We propose a joint quality control, preventive maintenance and production policy for randomly failing systems producing conforming and non-conforming items. The machine lifetime cumulative distribution function is not known. Each lot produced by the machine is subject to a quality control and according to the observed percentage of non-conforming units found, one decides to perform or not maintenance actions and which type of maintenance to carry out.

Production has to be stopped while the machine is submitted to preventive or corrective maintenance. In order to palliate these perturbations, a buffer stock is built up after a lap of time to minimize the holding cost. A mathematical model is developed in order to determine the optimal values of the three decision variables which characterise the proposed strategy and which are: the threshold level of the rate of non-conforming units on the basis of which maintenance actions are to be performed, the size of the buffer stock, and the threshold level of the rate of non-conforming units which corresponds to the instant at which the buffer stock should be built. The optimal values are those which minimize the average total cost per time unit including inventory cost, maintenance cost and quality cost.

In next section, the proposed policy is defined; the working assumptions and the necessary notation are stated. In Section 3, we develop the mathematical model. Section 4 shows an illustrative numerical example. Finally, the main conclusions of this work are presented in Section 5.

2. Strategy definition

Consider a production unit subject to a deterioration process with an increasing failure rate, and producing conforming and non-conforming items. This production unit is considered as a single machine which must satisfy a constant demand. Each produced lot is entirely subjected to a quality control in order to determine the number of non-conforming items. According to the observed rejection rate $\boldsymbol{l}$, one decides to undertake or not maintenance actions. As shown in Fig. 1, if the rate of non-conforming units $\boldsymbol{l}$ is found higher than a certain threshold $\boldsymbol{l_m}$ and lower than a maximum value $\boldsymbol{l_{max}}$ ($\boldsymbol{l_m < l < l_{max}}$), the machine is stopped to undergo a preventive maintenance action. If $\boldsymbol{l}$ is found higher than $\boldsymbol{l_{max}}$, the machine is considered to be in a quasi-failed state and consequently a major corrective maintenance (overhaul) is performed. Finally, if $\boldsymbol{l}$ is found between a minimum level $\boldsymbol{l_0}$ and $\boldsymbol{l_m}$, no action is undertaken. After a maintenance action (preventive and overhaul), the system's state is considered as good as new and rejection rate starts again at $\boldsymbol{l_0}$. We suppose in this paper that maintenance actions guarantee that the probability of breakdown of the production unit before the next maintenance action is approximately zero (see Fig. 2).

To ensure the continuous satisfaction of the demand while the production unit is stopped to undergo maintenance actions, a buffer stock of $\boldsymbol{h}$ units is built as soon as the rejection rate reached a threshold level $\boldsymbol{l_A}$. The buffer stock is renewed each time it is totally consumed.

Other assumptions are made as follows:

- The production unit lifetime cumulative distribution function is not known.
- The cumulative distribution functions associated to preventive maintenance actions and overhauls durations is known.
- The demands which can not be satisfied are lost.
- The produced items are imperishable with time.
- The non-conforming items are not reinserted in the production process.
- All costs related to maintenance, quality and inventory are known and constant.
- The resources necessary for the achievement of maintenance actions are always available.
- The size of the lot subject to quality control is known and constant.

The following notations will be used:

- C_s: Holding cost per item per unit time.
- C_p: Shortage cost per item.
- C_{nc}: Cost incurred by producing a non-conforming item per unit time.
- $\boldsymbol{h}$: Size of the buffer stock.
- δs: Total holding cost.
- δq: Total quality cost.