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Intermediate buffer analysis for a production system

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ABSTRACT

In this paper, a production system consisting of two serial machines and an intermediate buffer is studied. A shortage cost is incurred when the upstream machine is down and the buffer is exhausted. The practical example for this type of system can be an automated work center or an automobile general assembly.

Researches on a similar two-machine system have been done in some articles where maintenance and an intermediate buffer are considered, but the spare parts are not involved. Nevertheless, spare parts are essential for maintenance implementation, and there is interaction between the buffer inventory and the spare parts due to maintenance activity. This paper is aimed to investigate three types of cost related to the intermediate buffer inventory, and obtain their expectations as functions of several decision parameters on maintenance, buffer, and spare parts during a renewal cycle, by using mathematical analysis. The proposed method can be an important basis for further study of system cost calculation and decision making optimization.

1. Introduction

In a production system with buffer built between machines for coping with unexpected interruptions, the influence caused by machine failure and maintenance duration can be neutralized [1]. It is obvious that performing preventive maintenance (PM) frequently will need large buffer size and cause high inventory holding cost. Nevertheless, too low frequency of PM may decrease machine reliability and make it vulnerable to breakdown, which will also lead to frequent interruptions that make necessary high buffer levels. To deal with the interaction between maintenance planning and buffer inventory holding cost, two kinds of research are developed: the first kind is maintenance optimization with the buffer size predetermined; the second kind is joint optimization of maintenance planning and buffer sizing.

Among the first kind of research, a series of papers dealt with one type of system consisting of two units and a size-predetermined intermediate buffer. Van der Duyn Schouten and Vanneste [1] proposed a class of control limit policies which are nearly optimal for the PM of the upstream machine, and provided a characterization of the overall optimal policy for a particular optimization criterion. Meller and Kim [2] determined the optimal buffer inventory level, b^*, which triggers PM on the first production operation, under the assumption that periodic PM will decrease the first production operation's failure rate in the long run. Then in recent years, focused on this type of system and with some assumptions about maintenance time distribution, the same conclusion that the optimal policy is of control-limit type is obtained under different deterioration situations of the two units [3–8]. Differing from the papers on this type of two-unit system, in the article of Zhou and Xi [9], an opportunistic PM policy was proposed for multi-unit series with integrating the intermediate buffers for the purpose

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of maximizing the short-term cumulative opportunistic maintenance cost savings. In the above literatures, Markov decision theory is the most usual method for optimization, some other methods like dynamic programming and the usual regenerative argument are also applied.

The second kind of research focused on the joint optimization of maintenance and buffer size can be seen in the following papers. Chelbi and Ait-Kadi [10] developed a mathematical model to determine the value of buffer stock size and the PM cycle for a repairable production unit, in which the buffer stock is built at the beginning of each PM cycle. Kenné et al. [11] proposed the policy named "the multiple threshold levels hedging point policy", which determines the optimal safety stock levels taking into account PM policies and machine age. The system studied by Ribeiro et al. [12] is similar with that studied by Van der Duyn Schouten and Vanneste [1], which consists of two units and an intermediate buffer. However, Ribeiro et al.' research developed joint optimization of the buffer size and the maintenance of two units. In the paper of Zequeira et al. [13], with the possibility of imperfect production in a manufacturing facility considered, the optimal maintenance policy and the optimal buffer inventory are determined. Murinom et al. [14] presented a simulation model, based on which a cost optimization was used to determine the thresholds of wear for different maintenance interventions.

In this paper we study the intermediate buffer inventory which is built for coping with the unexpected interruptions due to failure or maintenance. A production system consisting of two machines and an intermediate buffer is investigated. It is similar to the type of two-unit system with an intermediate buffer referred above, but differs from that in considering spare part ordering additionally and in regarding the buffer size as a decision parameter. The reason for taking into account spare parts is that there is non-negligible interaction between intermediate buffer and spare parts due to maintenance activity. Taking the situation of seat assembly as an example, where the downstream machine represents the seat assembly line and the upstream machine is the machine that produces seat covers and sends them to a large buffer that feeds the seat assembly [2]. If the upstream machine fails and there are not enough spare parts for maintenance, much more seat covers in the intermediate buffer will be needed to prevent the interruption of the seat assembly line. Some seat covers in the buffer are for meeting the need of the seat assembly line during maintenance activity, and the others are for coping with spare part lack (i.e. for meeting the need of the seat assembly when waiting for ordered spare parts arriving). This problem makes the intermediate buffer very difficult to analyze.

In this paper, the deterioration of the upstream machine is considered and an age-dependant maintenance policy is applied. The PM and corrective maintenance (CM) for the deteriorating machine are assumed to be perfect. Consequently, the interval between two maintenances is a renewal cycle. The paper is focused to analyze three types of expected cost related to the intermediate buffer during a renewal cycle, including the expected buffer inventory holding cost, expected shortage cost due to buffer exhausted, and expected surplus buffer disposing cost, and then obtain them as functions of decision parameters on buffer, maintenance, and spare parts. The considered decision parameters include the buffer size, the time to initiate the buffer accumulation, the predetermine age for PM, and the time when the spare parts arrive in a renewal cycle. The order lead time of spare parts is assumed to be constant to reduce complexity in this study. Then for the convenience of derivation process, the spare part arrival time rather than the spare part order time is adopted to be a decision parameter.

The rest of this paper is organized as following. In Section 2, the system and applied policy are described. In Section 3, based on the renewal cycle analysis, the three expectations related to intermediate buffer are derived by mathematic analysis. Finally the conclusions are given in Section 4.

2. The system and policy

2.1. Nomenclature

Decision parameters	
B	buffer size
T_B	the time when the buffer inventory accumulation is initiated
T	the age arranged for machine a_1 to undergo a PM
T_s	arrival time of ordered spare parts
System parameters	
A_1	the upstream machine
A_2	the downstream machine
T_1	the time when the maintenance of machine a_1 should be initiated due to failure or PM planning
T_a	the actual time when the maintenance of machine a_1 is initiated
T_2	the time length of a renewal cycle
T_f	failure time of a_1
T_m	maintenance duration time
T_{r1}	the shortage time length
T_{r2}	the maintenance delay time length due to spare part lack