Experimental Design for Buffer optimization of unreliable production system with transportation delay based on Salameh Model

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Abstract: The work reflects the study of a manufacturing system composed of a single unit production operating according to a just-in-time configuration, buffer and a constant demand. The production machine is submitted to preventive maintenance actions for each time T. In order to study the impact of the transportations durations constraints between the production unit and the warehouse and between the warehouse and the customer, we developed a mathematical model to determine the optimal just-in-time stock level S* which guarantees the minimisation of total average cost per unit time. A numerical example is presented to illustrate the results found.

Keywords: just-in time, preventive maintenance, buffer inventory, transportation delay.

1. INTRODUCTION

The current industrial environment is characterized by a sharp economic slowdown and widespread global competition. The implementation of production systems has often led to the use of manufacturing processes at pulled flows with constitution of a stock buffers, as Just-in-Time (JIT), and methods of valuation and management these stocks such as FIFO. Thus we have seen appear in the workshops, transfer lines and flexible manufacturing systems. The high automation of these new production systems puts equipment maintenance at the heart of production constraints. In general, contributions observed in literature on performance optimization for production systems may be classified into two main families: the production control is dealt separately from the issue of preventive maintenance of the equipment. In this case, the use of models built must be done with reservations about regarding monitoring and compliance with production indicators such as Map Production Manager or peak industrial and commercial plan. Due to their use or age, these manufacturing devices are in reality susceptible to undergo failures. In doing so, they often move randomly in a control state to a state out of control, with the risk of causing customer dissatisfaction, production losses or even additional operating costs. And, on other hand, the second family of models proposes the coupling of preventive maintenance with production control. In this case, the models allow to ensure better availability of manufacturing means, but also increase their service life and to substantially reduce the operating costs. The adoption of this type of model places the maintenance at center of the productivity and profitability of the company.

A lot of research has been done in this regard on the combination of production control, incorporating a buffer stock policy and maintenance of the facilities. In this section we look at some relevant models. The pioneers in the field of control of production and maintenance policy are Duyn Schouten et al. (1995). In their work, the authors consider a production system consisting of a machine that is powered through an intermediate inventory put in place to deal with downtime of production. The preventive maintenance program of the machine is age type and takes into account buffer level. The objective function to be optimized is the minimization of the average stock level and the average number of pending or lost orders. The optimal control policy is found using Markov chain process.

Since the year 2000, there has been renewed interest in the work integrating control of production to maintenance policies. Kyriakidis et al. (2006) generalized the study done by Van der Duyn Schouten et al. (1995). The authors analysed a production system taking into account its operating conditions, age and the buffer level. For the total cost of production optimization, authors adopted the Markov chain process in discrete time model. Salameh et al. (2001) consider a type production system "Supplier - Buffer - Customer", composed of a single machine that is operational throughout the period of production. Their strategy consists, in a first step, to produce on demand. Then the machine produces to fill the buffer stock until the date of preventative maintenance. The preventive maintenance period corresponds to the period of safety stock consumption. If out of safety stock, customer demands are lost; and this loss of customer demand generates a cost of shortages. The model developed by Salameh et al. (2001) sets the optimum level of inventory that minimizes average total cost per unit time. To always continue in the enumeration of approaches that integrate joint maintenance policy issues with the production controls; Ouali et al. (2002) studied a system composed of a single machine providing a single product type. By taking into account of inventory costs and out of stock, the authors have defined the total unit cost of preventive maintenance, the optimal level of inventory and the optimal date of maintenance actions. In the same meaning, the model of maintenance policy and production control developed by Radhaoui et al. (2009) also assumes that the system can producing randomly the conforming and nonconforming units. The production system

they consider consists of a single-machine designed to fulfil a constant demand. According to the proportion of non-conforming units observed by lot and compared to a threshold value defined in advance, one can decide to undertake or not maintenance actions. Bouslah et al. (2013) also proposed a model integrating production, preventive maintenance and control of conformity of products in a production system subject to random degradation. The production is also carried out in batches, and is managed by a critical threshold type control policy. The objective of the authors is to simultaneously optimize the size of the production batch, the safety stock level and the threshold and maintenance periods. The mathematical model minimizes the total cost of production operations. The article of Gomez et al. (2011), deals with the optimization of a product manufactured in a single-stage and supplied by a constant demand and systematic maintenance policy. The authors believe that the manufacturing system is subject to failure as a function of time and its production rate is given by a hedging point policy. The down time is a random variable with an exponential distribution. Gomez et al. (2011) propose a simulation algorithm based on the technical Infinitesimal Perturbation Analysis (IPA) to determine the optimum buffer stock level and they derive the optimal value of the period of systematic maintenance. In Gan et al. (2014) a production system consists of two serial machines and an intermediate buffer built to cope with unexpected disruptions is studied. The upstream machine system deteriorates with time and working conditions. During the preventive maintenance actions of the upstream machine, the buffer stock are used to prevent breaking production. System complexity appears with consideration of: the level of the buffer stock, the working conditions of the machine, and spare parts. The production system and the decision process are modelled by discrete Markov method. And the limit-control policy is optimized to minimize the total cost of ownership. In Najid et al. (2011), a stochastic model based on Markov chains was developed to monitor the status of the machine and to determine the optimal level of stock buffer depending on the production rate. This model allows the establishment of an integrated policy for maintenance and control of production. Several other studies with the aim of integrating issues of production control and maintenance, in order to minimize the total cost of the inventory / backlog, have been proposed with different approaches and modelling tools.

In which regard to research works that take account of the transportation constraints in the couple formed by control of production and maintenance policy, very few studies have been conducted. To the best of our knowledge only, Turki et al. (2013), developed works in this context. In his work, the authors analysed the impact of delivery delay on production plan, the maintenance policy and safety stock level, production system that must satisfy a random demand. They used a simulation algorithm on a continuous flow model, and determined the optimal inventory levels, which minimizes the total cost.

In this article, we provide an extension to the work produced by Salameh et al. (2001), by taking into consideration all the elements constituting a production system i.e. production

machines or workstation, means handling or transport and buffer stock or storage areas. The proposed model takes into account transport between the buffer and each workstation, and minimizes the total costs associated with the production and maintenance. The outline of the paper is organized as follows: The problem statement and the notations are provided in the next Section. The section 3 focuses on presenting the mathematical formulations and assumptions used for the development of the model. An numerical example applied to the Flexible Manufacturing System (InTelProMIS) of LGIPM is used to illustrate the development of the model in Section 4. The final section includes our conclusions and recommendations.

The notations introduced in the building of analytical model are summarized in **Table 1.** below:

Table 1. Results of the numerical example

S:	Buffer inventory level.
T:	Operation time of production unit per cycle.
t:	Preventive maintenance time per cycle.
$T1$:	Transportation time between production unit and warehouse.
$T2$:	Transportation time between warehouse and Customer.
A:	Inventory build-up starts time.
f:	Probability density function of time to failure for the production unit.
h:	Storage cost of a product unit during a unit of time.
ρ:	Shortage cost of a product unit (unit of time).
α:	Buffer replenishment rate without considering the transportation durations (units/unit time).
α':	Buffer replenishment rate taking into account the transportation time (units/unit time).
β:	Consumption rate from the buffer stock during the preventive maintenance actions without considering the transportation durations (units/unit time).
β':	Consumption rate from the buffer stock during the preventive maintenance actions taking into account the transportation time (units/unit time).
x_α	Number of produced pieces among the periodicities y_α and y'_α.
x_β	Number of pieces demanded by the client during the periodicities y_β and $y_{\beta'}$ y'_β.
y_α:	Production periodicity without integrating the transportation durations.
$y_{\alpha'}$:	Buffer replenishment periodicity taking into account the transportation time $T1$.
y_β:	Periodicity of the client request without integrating the transport durations.
$y_{\beta'}$:	Periodicity of the client request taking into account of the transportation durations.

2. PROBLEM STATEMENT

The production system we consider in this paper is an unreliable unit supplying in just-in time configuration a constant demand. The production unit is regularly submitted to age type preventive maintenance actions, until it reaches T