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Replenishment, production and quality control strategies in three-stage supply chain

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ABSTRACT

In this paper, we propose to jointly integrate and coordinate production, replenishment and quality inspection decisions in a three-stage supply chain control problem. The transformation stage produces one final product type and responds to a stable market demand. After a random lead time, the supplier delivers raw materials in batches which may each contain a certain proportion of defective items. When a lot of raw materials is received, a lot-by-lot acceptance sampling plan is applied, and then a decision is taken with regards to a 100% screening or discarding of the sampled lot. In this article, we focus on the existing interaction between the applicable quality control decisions and the replenishment and production control decisions. The objective is to determine a control policy for production, replenishment and quality activities which minimizes the total cost, including purchasing costs, production and quality inspection costs, as well as the inventory/backlog costs. A simulation model and a Response Surface Methodology are used to find the optimal parameters of the proposed policy. The obtained results show that the integration of 100% screening or discarding decisions in a new "hybrid" one is more beneficial, and guarantees a better coordination at a lower cost.

1. Introduction

In today's economy, an adequate management of a supply chain is necessary in order to ensure the survival of industries, and allow them to increase their competiveness. Several recent studies have shown that decision making models incorporating raw material procurement in manufacturing activities perform better in terms of average total cost than those tackling the decisions involved separately (Lee, 2005). In this context, Ben-Daya and Al-Nassar (2008) studied a coordinated inventory and production problem in a three-layer supply chain involving suppliers, manufacturers and retailers. Sawik (2009) developed a mixed integer programming approach where manufacturing, supply and assembly schedules are determined simultaneously. Pal et al. (2010) suggested an integrated procurement production and shipment planning for a three-echelon supply chain. Sajadieh et al. (2013) considered an integrated production-inventory model for a three-stage supply chain in which lead times to retailers are stochastic. All these studies provide valuable contributions to the scientific literature; however, they do not consider the dynamic evolution of manufacturing activities and the impact of this evolution on complete decisions.

Many research studies have tackled the problem in a dynamic stochastic context where the control theory has been one of the most significant approaches used to solve such problems. In the context of the planning problem for unreliable manufacturing systems, several approaches have been developed based on the Hedging Point Policy (HPP) concept (Kenné and Gharbi, 2000). This policy consists in building an optimal safety stock level during periods of excess capacity in order to meet demand when the manufacturing system is no longer available due to machine failure. Sethi and Zhang (1999) suggested a solution for an optimal production planning where multiple distinct part types are produced. Kenné et al. (2003) considered an integrated production and corrective maintenance problem. Pellerin et al. (2009) developed a production control problem for multi-production-rate remanufacturing systems. Rivera-Gómez et al. (2013) studied an integrated production, overhaul and preventive maintenance problem.

Following the works of Lee (2005), Hajji et al. (2009) addressed an integrated production and supply control problem for a three-stage supply chain with one unreliable supplier and one unreliable transformation stage. Hajji et al. (2009) showed that the optimal

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control policy is a "modified state-dependent multi-level base stock policy" (MBSP) for production activities, combined to a "state-dependent economic order quantity" (SD-EOQ) policy for replenishment decisions. The developed policy allows the identification of the best decision to undertake as a function of the whole system state. Berthaut et al. (2009) determined a control policy for both supply and remanufacturing activities, composed of a Multi-Hedging Point Policy (MHPP) and an (s,Q) policy. Song (2009) considered a supply chain with supplier, manufacturer and customer with stochastic lead-time, processing time and demand and determined the optimal integrated ordering and production policy that minimize the expected total cost subject to finite capacitated warehouses. Hajji et al. (2011a) studied a joint production and delayed supply control problem. They showed that the control policy is a combined (HPP) and (s,Q) policy. Hajji et al. (2011b) extended the model of Hajji et al. (2009) to a multiple supplier case. These research studies showed the advantages considering the production and supply activities in a dynamic stochastic context in an integrated manner. Song (2013) studied several stochastic supply chain systems and determined the optimal production control policies and the optimal ordering policies in the case of supply chains with backordering and, a supply chain with multiple products, etc. However, they all assume raw materials to be in perfect quality. This assumption is unrealistic, as has been argued by many research studies (Konstantaras et al., 2012; Khan et al., 2014). In fact, the lot received may contain a fraction of non-conforming parts. Therefore, to identify and separate bad purchased items from good ones, the inspection/screening process becomes an indispensable step.

This paper proposes to study this issue through the integration of production, replenishment and raw material quality control in a three-stage supply (Supplier–Manufacturer–Customer) chain. Upon the lot being received, the manufacturer performs a single acceptance sampling plan. Such a policy has indeed been largely adopted in the industry (Schilling and Neubauer, 2009). Starbird (1997, 2005) analyzed the impact of a buyer's acceptance plan on a supplier's quality and production decisions. Ben-Daya and Noman (2008) established integrated inventory inspection models with and without replacement of non-conforming items. They proposed a comparative study between different inspection policies: *no inspection*, *sampling inspection* and *100% inspection*. Al-Salamah (2011) studied an EOQ model where the quality of the received lot is controlled by a destructive acceptance sampling. Wan et al. (2013) studied the incentive effect of acceptance sampling plans in a supply chain with endogenous product quality. More recently, a few articles have studied supply chain problems with non-conforming raw materials, but however, with the focus solely a full inspection policy (Sana, 2011; Pal et al., 2012; Sana et al., 2014).

It should be noted that when an acceptance plan is applied, the inspected raw materials lot may be refused. However, in all of the previous research studies, only one of the two decisions was taken with respect to the rejected lots: either 100% inspection or the entire lot is returned to the supplier. While this assumption may be reasonable for certain circumstances, it could present limitations if considered jointly with the production process and the customer demand stage. As a three stage supply chain is considered, the quality decision should not be taken independently of the whole system. The question then becomes how the decision maker should proceed in taking such inspection decisions? On the one hand, returning a lot to the supplier reduces the total cost of the inspection operation, but it increases the lead time, and results in an important finished product shortage risk. On the other hand, although a 100% inspection decision may assure the presence of better quality raw materials, the system will face high inspection costs. To arrive at a compromise between the advantages and disadvantages of return and 100% inspection decisions of rejected lot, we propose, in this article, that quality inspection decisions be coordinated with production and replenishment activities to ensure better control at minimal cost.

The rest of this paper is organized as follows. In Section 2, we present a formulation of the production, supply and inspection problem. In Section 3, we propose a control policy of the system. We report a resolution approach in Section 4 and a simulation model in Section 5. In Section 6, we give an example to present the numerical results. In Section 7, we illustrate a comparative study between different inspection policies. Finally, conclusions are given in Section 8.

2. Problem formulation

The purpose of this section is to introduce the considered problem which consists of an integrated unreliable manufacturing system supplied by an upstream supplier with random lead time, using a sampling plan to control received raw materials.

2.1. Notations

The notations used in this paper are summarized as follows:

dem	finished product demand rate (units/time)
u^{max}	maximum manufacturing production rate (units/time)
Q	raw material lot size
s	raw material ordering point
n	sample size
c	acceptance number
d	number of non-conforming raw material items in a sample
p	proportion of non-conforming items in the received lot
P_a	acceptance probability of a lot
δ	replenishment delay
τ_{insp}	inspection delay per unit (time/unit)
τ_{rect}	raw material rectification time (time/unit)
W	ordering cost
c_R	raw material cost ($/unit)
c_R^H	raw material holding cost ($/time/unit)
c_{RF}^T	cost of raw material transformation into finished product ($/unit)
c_F^H	finished product holding cost ($/time/unit)
c_F^B	finished product backlog cost ($/time/unit)
c_{insp}	raw material inspection cost ($/unit)
c_{rect}^R	raw material rectification cost ($/unit)
c_{rep}^F	non-conforming finished product replacement cost ($/unit)

2.2. Problem statement

The system under study (Fig. 1) consists of one supplier, one manufacturer and one customer. The manufacturer (stage 2) orders a batch of products from an upstream supplier, with an ordering cost W and a purchasing price c_R per unit. The supplier (stage 1) delivers the lot after a random lead time δ. We assume that each delivered lot contains a fixed fraction p of non-conforming items and that the manufacturer (stage 2) could be unavailable due to failures and repair operations.

After the raw materials are transformed into finished products, the manufacturer sells them to the final customer (stage 3) and responds to a continuous and constant demand rate dem.

When the lot is delivered, the manufacturer inspects its quality using a lot-by-lot single acceptance sampling plan with attributes. Because a sampling plan is adopted, some unsafe product may pass inspection. These items could be transformed into a finished