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Managing real-time demand fluctuation under a supplier–retailer coordinated system

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ABSTRACT

We have considered a supplier–retailer system, that operates under an agreed coordinated policy, with an imperfect production process and a possibility of having demand fluctuation. In this paper, a dynamic planning process is proposed to deal with short-term demand fluctuations. To do this, a mathematical model was first developed for a single fluctuation, either for increasing or decreasing demand rate. The model generates a revised plan, after the occurrence of the fluctuation event. We also propose a new and efficient heuristic to solve the developed model. Secondly, multiple fluctuations have been considered, for which a new occurrence may or may not affect the revised plan of earlier occurrences and we extend the heuristic so that is capable of dealing with multiple demand fluctuations on a real time basis. We have generated a good number of random test problems and also solved the model using a genetic algorithm, in order to compare the solutions with our heuristic. The comparison confirmed the consistent performance of our developed heuristic, and also its lower computational time. Numerical examples and sensitivity analysis have been presented to explain the usefulness of the developed model.

1. Introduction

Any manufacturing organization, connected to any supply chain network, receives inputs or raw-materials from suppliers, transforms those raw materials into finished products, and supplies the products to customers through a distribution network. In any supply chain system, the flow of materials is planned based on certain scenarios. Any variation of the factors in those scenarios, such as delay in supply, delay or disruption in production, imperfect production process, delay or disruption in transportation, or fluctuation in demand, increases the risk of not fulfilling the demand on time (Sodhi and Chopra, 2004). A proper response to those factors, if any occurs, will thus improve the performance of the supply chain operation.

Supply chain operations have been widely studied over the last few decades, for either sub-networks or entire networks. Most of these studies mainly focused on developing coordinated models and incorporating certain fuzzy parameters. For example, a single product, single warehouse and multiple retailers based distribution supply chain system (Petrovic et al., 2008), single manufacturer and single retailer supply chain model with demand and manufacturing cost as fuzzy variables (Zhou et al., 2008), a single period and two-stage supply chain coordination problem (Xu and Zhai, 2010) and a three stage supply chain management consisting of supplier, manufacturer and retailer which produces products with some defective items (Sana, 2011). Recently, Sana (2012) developed a model for a three stage supply chain where the systems may produce defective items. The production rate, order quantity and number of shipments are decision variables, where the objective is to maximize the expected total profit. Pal et al. (2012) developed an inventory model for multiple items produced by a manufacturer that considered multiple suppliers, one manufacturer and multiple retailers with deterministic demand. They assumed that each supplier can supply only one type of raw material and that the finished products are produced by a combination of fixed percentages of various types of raw materials. They maximized the total integrated profit of the supply chain by determining the optimal ordering lot sizes of the raw materials.

There exist a good number of studies that incorporate uncertainty in supply chain modeling. Petrovic et al. (1999) introduced uncertainty associated customer demand, and supply deliveries in supply chain modeling. It was later extended for analyzing supply chain behavior and performance in the presence of uncertainty (Petrovic, 2001). Recently, Chen and Chang (2006) considered multi-product, multi-echelon, and multi-period supply chain models with fuzzy unit costs of raw materials, unit transportation

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costs and demand quantities. They have developed a mathematical model for a four-echelon (suppliers, plants, distribution centers and customer zones) five-period supply chain problem with fuzzy parameters. Peidro et al. (2009) proposed a fuzzy mathematical programming model for a multi-echelon, multi-product, multi-level and multi-period supply network which considered supply, demand and process uncertainties. The proposed model is a fuzzy mixed-integer linear programming model. They tested their approach by using data from a real automobile supply chain with triangular fuzzy numbers. Recently, Xu and Zhai (2010) considered a single period, two-stage supply chain coordination problem with demand uncertainty as a fuzzy variable. They have shown that the profit in the coordinated situation was higher than the same of the non-coordinated situation.

Process reliability is an important issue in imperfect production environments because it has significant impacts on costs and profits. At first, process reliability was considered by Cheng (1989) in a single period inventory system and was formulated as an unconstrained geometric programming problem. Later, it was extended by Bag et al. (2009) by considering product demand as a fuzzy random variable. Recently, process reliability was incorporated to determine the optimal product reliability and production rate that achieves the highest total profit (Sana, 2010), to apply the concept of entropy cost to extend the classical EOQ model under the assumptions of perfect and imperfect quality (Jaber et al., 2009), to develop an inventory model under randomly changing environmental conditions (Mohebbi, 2006, 2008), to study an unreliable supplier in a single-item stochastic inventory system (Mohebbi and Hao, 2008) and to analyze an EPQ model with price and advertising demands under the effect of inflation (Sarker, 2012).

The supply chain process usually starts with a static plan, for a given planning horizon, that needs to be updated dynamically for better performance if a parameter change is experienced. However, very little has been done for dynamic updating of a supply chain plan. In this paper, we have considered a two-stage supply chain coordinated system, where a supplier delivers a single product to a retailer based on an agreed coordinated policy (as proposed in Sarker and Khan, 2001). That means the lot-size, as well as the cycle time of delivery, has already been agreed by both parties based on their mutual benefits. However, the demand rate at the retailer end may unexpectedly fluctuate (either increase or decrease) for a period of time, and then return to normal, and it may happen again, and so on. This fluctuation will affect the production at the supplier end. For such a demand fluctuation, a revised plan may be developed to maximize the profit considering the changed situation. After implementation of the revised plan, if another fluctuation happens, that may or may not affect the earlier action. In this situation, both cases must be considered in developing the revised plan. The effect of the demand fluctuation described above is somewhat similar to disruption recovery management due to disruption in production and transportation in a supply chain environment (Li et al., 2004; Tang and Lee, 2005; Qi et al., 2009; Hishamuddin et al., 2012, 2013; Paul et al., 2014). In addition to the demand fluctuation, we have considered that the production process is imperfect, this means it produces a certain percentage of defective items. However, the percentage of defective items can be reduced by improving the process reliability.

In this paper we have dealt with demand fluctuations on a real time basis. That means, the current plan is revised after experiencing any real demand fluctuation. Such a fluctuation is not known in advance and it is impossible to be predicted. It is assumed that both the demand fluctuation and the duration of fluctuation will follow a stochastic process. To do this, we first developed a mathematical model for dealing with a single occurrence of demand fluctuation. The objective in the model is to maximize the total profit as the revenue varies with production process reliability. We have also proposed a heuristic to solve the developed model, which is a constrained nonlinear program. The results of the heuristic were compared with the solutions obtained from a genetic algorithm. We have also considered a series of demand fluctuations that occur at different points in time, where the fluctuations may or may not affect the revised plans of the previous fluctuations. Hence if a new fluctuation occurs during the revised planning window of another fluctuation, a new revised plan must be derived after the occurrence that considers the effect of both fluctuations. So it is a continuous process that must be dealt with on a real-time basis. In this paper, we have extended the heuristic to deal with a series of fluctuations on a real-time basis. This was done by incorporating a modified version of the heuristic that was developed for a single fluctuation occurrence. The solutions for both the single and multiple fluctuations are discussed, and some numerical examples are presented to demonstrate the usefulness of the proposed approach. With the proposed approach, the decision makers can decide on a revised plan in real time, whenever the supply chain system experiences either a single independent fluctuation, or a series of a mix of dependent and independent fluctuations.

The main contributions of this paper can be summarized as follows:

i. Modeling a supplier–retailer coordinated system under demand fluctuation. Here, the demand fluctuation is not known in advance and it follows a stochastic process. So the plan is revised, for a future period, after experiencing the fluctuation, on a real time basis.
ii. Developing a new heuristic to generate the revised plan after the occurrence of a demand fluctuation. The heuristic is able to produce quality solutions with little computational time.
iii. Extending the heuristic to deal with multiple fluctuations on a real time basis. In the multiple fluctuations case, any new fluctuations may or may not affect the revised plans of the previous fluctuations. These two cases may be introduced as dependent and independent scenarios. The extended heuristic is capable of dealing with both scenarios.

For better understanding of the demand fluctuation problem, a definition of the different terms used in this paper is provided below.

***Demand fluctuation*:** Any kind of variation in product demand. Demand can be increased or decreased for a certain period of time, which is known as the fluctuation period.

***Process reliability*:** Percentage of non-defective products produced in the production system (Cheng, 1989).

***Revised plan*:** If the demand variation occurs for a given period of time, it is necessary to revise the schedule for some periods in the future (known as a revised planning window) until the system returns to normal schedule. It is known as a revised plan.

***Backorder*:** If the demand rate is increased for a certain period of time, then the portion of demand that cannot be fulfilled at the scheduled time, but that will be delivered at a later date when available, is known as the backorder quantity.

***Lost sales*:** If the demand rate is increased for a certain period of time and the production process is not capable of fulfilling that demand, then customers will sometime not wait for the stock to be replenished, and so that demand is lost.

***Loss of production*:** If the demand rate is decreased for a certain period of time, then the production process has to reduce the lot size because of the decreasing demand, this will reduce profit. Note that, in this case, there are no backorder or lost sales.

The reminder of this paper is organized as follows. After the introduction, the problem description and model formulation are presented in Sections 2 and 3 respectively. The solution approach and