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Managing disruption in an imperfect production–inventory system

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ABSTRACT

In this paper, a disruption recovery model is developed for an imperfect single-stage production–inventory system. For it, the system may unexpectedly face either a single disruption or a mix of multiple dependent and/or independent disruptions. The system is usually run according to a user defined production–inventory policy. We have formulated a mathematical model for rescheduling the production plan, after the occurrence of a single disruption, which maximizes the total profit during the recovery time window. The model thereby generates a revised plan after the occurrence of the disruption. The mathematical model, developed for a single disruption, is solved by using both a pattern search and a genetic algorithm, and the results are compared using a good number of randomly generated disruption test problems. We also consider multiple disruptions, that occur one after another as a series, for which a new occurrence may or may not affect the revised plan of earlier occurrences. We have developed a new dynamic solution approach that is capable of dealing with multiple disruptions on a real-time basis. Some numerical examples and a set of sensitivity analysis are presented to explain the usefulness and benefits of the developed model. The proposed quantitative approach helps decision makers to make prompt and accurate decisions for managing disruption.

1. Introduction

Batch production systems are very common and popular in advanced manufacturing environments. In these production systems, the products are produced and delivered in batches, because that helps to reduce costs and increase profitability. However, in real life cases, the production process may not be perfect and they may face production interruptions, such as: machine breakdown, raw material shortage or any other type of system failure. In an imperfect production system, it is expected that a certain percentage of products will be defective. As a result, process reliability is considered as an important factor in real production environments. Hence, the consideration of production interruption with process reliability, in any production inventory system, will make the research problem closer to those in the real-world.

Over the last half a century, one of the most commonly studied research topics, in applied operations research and industrial engineering, is the analysis of production inventory system. A few examples of such studies include: a single item inventory system with a non-stationary demand process in a single stage production inventory system (Graves, 1999), a periodic review stochastic inventory system (Chan & Song, 2003), determination of lot size and order level for a single item, single stage inventory model with a deterministic time-dependent demand (Dave, 1989), a single item and single stage inventory system with stochastic demand in a periodic review where the system must order either none, or at least as much, as a minimum order quantity (Kiesmüller, De Kok, & Dabia, 2011) and to analyse three inventory models; a replenishment batching policy, a production batching policy, and an integrated replenishment/production batching policy (Rau & OuYang, 2007).

Recently, a few studies have considered some important practical issues while analysing production–inventory system, such as: machine breakdown, process interruptions and supplier reliability. Lin and Gong (2006) analysed the impact of machine breakdown on an EPQ model for deteriorating items in a single stage production system that considered a fixed period of repair time. Later, Widyadana and Wee (2011) extended the model of Lin and Gong (2006) for deteriorating items that incorporated random machine breakdown and stochastic repair time with uniform and exponential distribution. An EPQ model with a Poisson distributed set of machine breakdowns was considered by Chiu, Wang, and Chiu (2007). They developed a total inventory cost function for EPQ models with both breakdown and without breakdown for a single stage production system. They also assumed some portion of the products produced were defective and had to be scraped or reworked. Jaber (2006) developed a mathematical model for

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analysing the lot sizing problem for reduction in setups, with reworks, and interruptions to restore process quality under an imperfect production process. Zeynep Sargut and Qi (2012) considered random disruption at both the retailer and supplier, and assumed that unserved customer demand was lost in a two-stage supply chain consisting of retailer and supplier. Schmitt and Snyder (2012) developed an inventory model that considered two options: (i) an unreliable supplier and (ii) a reliable, but expensive supplier. For both cases, they considered disruption and recovery probabilities with yield uncertainty to find the optimal order and reserve quantities. Recently, another model for a multi-echelon supply chain was developed, that also considered two supplier options to manage supply disruption, where the lot-size was considered as the decision variable (Pal, Sana, & Chaudhuri, 2012).

In the literature, most of the previous studies were conducted under ideal conditions and only a few of them considered practical issues, such as: supplier reliability, machine breakdown and process interruption. Production disruption is a very familiar event in real-life production environments. A *production disruption* can be defined as any form of interruption that may be caused due to material shortage, machine breakdown, or any other form of disturbance (either accidental or man-made). Without a proper response to those disruptions, the entire system can be imbalanced and the organization can face huge financial loss, as well as reputation damage. The development of an appropriate disruption recovery policy can help to minimize financial loss, and also maintain the goodwill of a company. As of the literature, there exist limited quantitative studies that consider disruptions in a production system, or that developed approaches to obtain a recovery plan.

A disruption recovery model for a single-item single-stage production system was developed by Hishamuddin, Sarker, and Essam (2012). The model was formulated for a single disruption, for recovering within a given time window, while considering back order as well as lost sales options. Recently, a transportation disruption recovery model in a two-stage production and inventory system was also developed by Hishamuddin, Sarker, and Essam (2013). It considered back order, as well as the lost sales option, and determined the optimal ordering and production quantities during a recovery time window. Recently, a real-time recovery plan for managing demand fluctuation in a two-stage supply chain system was developed by Paul, Sarker, and Essam (2014a), which also considered both back orders and lost sales options. A few years earlier, Xia, Yang, Golany, Gilbert, and Yu (2004) formulated a quadratic mathematical programming problem for managing disruption in a two-stage production and inventory control system that incorporated a penalty cost for deviations of the new plan from the original plan. Later, another disruption recovery model for a manufacturing plant was developed by Yang, Qi, and Yu (2005). They proposed a dynamic programming method that involved both cost and demand disruptions, and also developed a greedy method to solve the model. In production and inventory modelling, several studies that considering supply disruptions have been performed. Parlar and Perry (1996) developed inventory models that considered supplier availability with deterministic product demand under a continuous review framework. A production–inventory model that considered back orders under random supply disruption was developed by Özekici and Parlar (1999), and was modelled as a Markov chain. Over the last few years, some other models of supply disruptions, that considered deterministic product demand, have been studied by Mohebbi and Hao (2008), Qi, Shen, and Snyder (2009), and Tomlin (2006).

Process reliability is another important factor in imperfect production environments and has a significant impact on company' costs and profits. So it should be taken into consideration in developing production inventory models. Production process reliability can be defined as the percentage of non-defective products produced in a system (Cheng, 1989). There are some previous studies, where the reliability of the production process has been considered. 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, Chakraborty, and Roy (2009) to consider product demand as a fuzzy random variable. In recent years, process reliability in an imperfect production process, was used: to determine the optimal product reliability and production rate that could achieve the biggest total integrated profit (Sana, 2010), to study unreliable suppliers in a single item stochastic inventory system (Mohebbi & Hao, 2008), to develop a new inventory model with two warehouses and imperfect quality simultaneously (Chung, Her, & Lin, 2009) and to develop an integrated production–inventory model for supplier, manufacturer and retailer supply chain (Sana, 2011). Some other inventory models for imperfect quality products can be found in Sana (2012a), Sarkar (2012), Sana (2012b), and Masud, Paul, and Azeem (2014).

In this paper we have dealt with disruptions on a real-time basis. That means, the current plan is revised after experiencing any real disruption. Such a disruption is not known in advance and it is impossible to be predicted. It is assumed that both the disruption and the period of disruption will follow a stochastic process. In this paper, we assumed that the production disruption scenarios followed a uniform random distribution. From the literature review, it is clear that the previous disruption management studies, in production–inventory systems, were mainly focused on managing single a disruption. In real life, production processes can face multiple disruptions, one after another, as a series. These disruptions may or may not affect the recovery plans of the previous disruptions. If a new disruption occurs during the recovery time window of a previous disruption, a new recovery plan that considers the effect of both disruptions must be derived. So it could be a continuous process that must be dealt with on a real-time basis. This real-time disruption management, in an imperfect production–inventory system, is considered in this study. The most closely related paper, to our current study, is the one published by Hishamuddin et al. (2012), where they assumed that the production system produces 100% accurate items. Moreover, they developed the recovery model for managing only a single occurrence of disruption. The problem presented in this paper is much more complex because we have developed a mathematical model and solution approach that deals with both single and multiple (mix of dependent and/or independent) disruptions on a real-time basis. We also consider process reliability because imperfect production processes are very common in real life. The objective of our model is to maximize the total profit as the revenue varies with production process reliability. The total profit function includes the revenues from the sale of non-defective items and the relevant costs.

Here, we first developed a constrained non-linear mathematical model for dealing with a single occurrence of disruption and solved the mathematical model to obtain a recovery plan by using both a pattern search and a genetic algorithm. We have generated a good number of disruption test problems by using a uniform random distribution and the results, obtained from both a pattern search and a genetic algorithm, are compared. We have also considered a series of disruptions that occur at different points in time. If a new disruption occurs during the recovery time of another disruption, a revised recovery plan incorporating the effect of both disruptions must be derived, which makes the algorithm more complex. In this case, a new revised plan must be derived after the occurrence that considers the effect of both disruptions. So it is a continuous process that must be dealt with on a real-time basis. In this paper, we have developed a new mathematical model and dynamic solution approach to deal with a mix of multiple dependent and/or independent disruptions, as a series, on a