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A recovery model for a two-echelon serial supply chain with consideration of transportation disruption ☆

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ABSTRACT

Supply chains are becoming increasingly competitive and complex in order to effectively meet customer demands. These characteristics make supply chains vulnerable to various risks, including disruptions. In this study, a recovery model is explored for a two-stage production and inventory system with the possibility of transportation disruption. This model is capable of determining the optimal ordering and production quantities during the recovery window, and ensuring that the total relevant costs are minimized, while seeking to recover the original schedule. An efficient heuristic was developed to solve the model. The results showed that the optimal recovery schedule is highly dependent on the relationship between the backorder cost and the lost sales cost parameters. In addition, the heuristic was able to give quality solutions for the model, with very small deviations of the heuristic solutions from the optimal value. Such tools are useful in assisting managers towards effective decision making, particularly in determining the optimal recovery strategy for the longevity and sustainability of their firms undergoing disruptions.

1. Introduction

The nature and complexity of today's supply chains (SCs) make them vulnerable to various risks. These risks may fall into different terms, such as disruptions, uncertainties, and disturbances. SC disruption, particularly, is defined as an event that interrupts the material flows in the SC, resulting in an abrupt cessation of the movement of goods. SC disruptions can be caused by internal or external sources to the SC, including natural disasters, transportation failure, labor dispute, terrorism, war, and political instability. In recent years, we have come to see many disruption occurrences that have severely affected SCs. For instance, the 1995 earthquake that hit Kobe left vast damage to all of the transportation links in Kobe, and nearly destroyed the world's sixth-largest shipping port. The 7.2 scale Richter quake substantially affected Toyota, where an estimated production of 20,000 cars, equivalent to $200 million worth of revenue, was lost due to parts shortages (Sheffi, 2005).

SC disruptions are costly and it is crucial that managers take appropriate measures of response to reduce its negative effects. Disruption Management (DM) is a line of study that has recently gained the interest of researchers. One of the goals of DM is to implement the correct strategies that will enable the SC to quickly return to its original state, while minimizing the relevant costs associated with recovery of the disruption (Qi, Bard, & Yu, 2004). Two common strategies to manage the risk of disruptions include mitigation and contingency (or recovery) tactics (Tomlin, 2006). The former strategy requires a firm to act in advance of a disruption, while the latter is taking action only during the occurrence of a disruption. Implementing mitigation and recovery tactics is not free; rather it involves a cost that influences the attractiveness of an optimal strategy for a given firm.

Transportation disruption, in particular, is slightly different from other forms of SC disruptions, in that it only stops the flow of goods, whereas other disruptions may stop the production of goods as well. It is distinctive in that the goods in transit halt, even though the other operations of the SC are intact (Wilson, 2007). Giunipero and Eltantawy (2004) noted that a potential transportation disruption is a source of risk and that it could quickly cripple the entire SC. Transportation disruption can cause late deliveries, which may lead to production stoppages costs, lost sales and lost of customer's goodwill (Guiffrida & Jaber, 2008). Furthermore, a transportation disruption may affect the condition of the valuable goods in transit. Due to the rise of organized crime and terrorist activities, the cost of goods lost during transportation is estimated at billions of dollars per year, with manufacturers suffering losses amounting to approximately five times the value of those goods

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damaged or stolen. The floods that hit Bangkok in 2011 caused vast damage to inventories in sugar mills and firms faced increased raw material cost and shortages, partly due to transportation disruption (Fernquest, 2011). Managers are forced to seek cost effective ways to react to these unexpected occurrences, mainly to alleviate the damaging impact it could bring to the firm. The model that we have developed in this research thus addresses this vital aspect of transportation disruption.

This paper proposes a newly developed real-time rescheduling mechanism for an economic lot sizing problem of a two stage supply chain system subject to transportation disruption. A recovery duration known as the recovery time window (Hishamuddin, Sarker, & Essam, 2010, 2012; Xia, Yang, Golany, Gilbert, & Yu, 2004) is allocated after the disruption to allow changes in the production and ordering schedule. The objective is to determine the new optimal recovery schedule that minimizes the overall recovery costs of the system. Similar to other DM models, the original production schedule is restored by the end of the recovery time window, focusing on the attempt to preserve the original operational plan as much as possible.

The contents of the paper are organized as follows. Section 2 presents the related literature review. Section 3 discusses the model development and analysis. This section includes derivation of the cost functions. Section 4 deals with the solution approach for the model. Section 5 addresses the related computational results and analysis. Lastly, Section 6 summarizes our research findings and offers potential directions for future research.

2. Literature review

In the literature on supply-disruption where the supplier is not always available, numerous studies have been performed for inventory models under the continuous review framework with deterministic demand, where supplier availability is modeled as an alternating renewal process (Berk & Arreola-Risa, 1994; Li, Xu, & Hayya, 2004; Parlar & Berkin, 1991; Parlar & Perry, 1995). Under the periodic review framework, Parlar, Wang, and Gerchak (1995), Song and Zipkin (1996), and Ozekici and Parlar (1999) have analyzed an inventory model with backorders in a random supply environment modeled as a Markov chain. There also exist works that study both supply and demand disruption in their model (Weiss & Rosenthal, 1992; Xiao & Yu, 2006).

Tomlin (2006) examines the optimal strategy for a single product system with two suppliers: one that is unreliable and another that is reliable but expensive. Schmitt, Snyder, and Shen (2010) and Chen, Zhao, and Zhou (2012) extend the work of Tomlin (2006) to study the system with stochastic demand. Furthermore, Schmitt and Snyder (in-press) conducted a study on the comparison between single period and multiple period settings for an inventory system subject to yield uncertainty and supply disruption. To do this, they extended the paper by Chopra, Reinhardt, and Mohan (2007) which only considered the single period case. Other variations of supply disruptions in stochastic inventory models are also available in literatures (Arreola-Risa & DeCroix, 1998; Li et al., 2004; Mohebbi, 2003; Moinzadeh & Aggarwal, 1997). Snyder et al. (2012) provides an extensive review of supply chain models with disruption.

Most of the works cited above consider inventory mitigation as a DM strategy, in which additional inventory is held in the system for the entire period to protect against disruptions. The majority of the studies are likely to result in stationary higher ordering quantities or bigger stock levels for the entire planning horizon. Carrying additional inventory can be very costly, unless if the disruption is predictable, the items have low holding costs or the products will not be obsolete (Wilson, 2007). Therefore, inventory mitigation tactics may not be of interest for firms that prefer a more lean and cost effective solution to managing disruptions. This in turn justifies the need for more recovery strategies in the presence of SC disruptions.

Studies on optimal recovery strategies for disruptions exist in the literature, but are rather scarce. In the production and inventory literature with regards to the Economic Lot Scheduling Problem (ELSP), Gallego (1994) considered how to schedule production after a single schedule disruption by proposing a base stock policy. His work was extended by Eisenstein (2005) who introduced the Dynamic Produce-Up-To (Dynamic PUT) policies. Tang and Lee (2005) proposed rules for recovering from a machine breakdown or other forms of interruption using relaxation and heuristic methods. Xiao-Feng and Ming (2012) explored the optimal recovery strategies of an assemble-to-order SC subject to supply disruption. Recovery strategies to demand disruptions have also been explored in the work by Qi et al. (2004). In the work by Xia et al. (2004), a recovery strategy was developed for a two-stage production and inventory system subject to disruption in the form of parameter changes. The purpose of their study was to recover from the disruption within a short time window, spanning two to three production cycles, at minimum disruption costs. Hishamuddin et al. (2012) studied a recovery mechanism for a single stage production–inventory system subject to supply disruption, in which a heuristic was developed to obtain the new recovery schedule within the recovery time window. The objective was to seek the optimal production and ordering lot sizes, as well as the optimal back ordering and lost sales quantity, while minimizing the overall recovery costs.

The study of transportation disruption in particular has received much less attention, despite the many harmful effects that it may impose on the SC, as mentioned in the earlier section. Giunipero and Eltantawy (2004) in their study discussed about transportation disruption in general, but did not specify the strategies on how to face it. Wilson (2007) investigated the effect of transportation disruption on SC performance using system dynamics. The work concluded that the most severe impact is experienced when transportation disruption exists between the tier 1 supplier and the warehouse. This disruption location is considered in our study. Zhang and Figliozzi (2010) conducted a survey on the effects of delay and disruption on international freight transport chains. Unnikrishnan and Figliozzi (2011) proposed an online freight network assignment model for network flows experiencing disruptions. Although some mitigation strategies were suggested in most of these papers in general, there is still a lack of computational methods to face transportation disruption in the SC and production–inventory context.

The recovery model proposed in this paper is an extension of the work by Hishamuddin et al. (2012). While the former study only considered the single stage, our work explores a two echelon supply chain, where disruption is in the form of a transportation disruption that is not known in advance. In other words, there is no pre-disruption period in our model. Hence, the firm does not have the opportunity to take mitigation measures before the occurrence of the disruption, which reflects many real world problems that occur without warning.

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

1. The development of a recovery model for a two stage serial SC system with transportation disruption. Additionally, the model considers stock-out costs consisting of both backorder and lost sale costs, as opposed to the penalty costs or complete backlogging/lost sales considered in previous works.