Economic Modelling 38 (2014) 555–563

Contents lists available at ScienceDirect

Economic Modelling

journal homepage: www.elsevier.com/locate/ecmod

A recovery mechanism for a two echelon supply chain system under supply disruption

Hawa Hishamuddin [b,*], Ruhul A. Sarker [a], Daryl Essam [a]

[a] School of Engineering and Information Technology, University of New South Wales Canberra, Northcott Drive, Canberra 2600, Australia
[b] Department of Mechanical and Materials Engineering, Faculty of Engineering and Built Environment, National University of Malaysia (UKM), 43600 Bangi, Selangor, Malaysia

ARTICLE INFO

Article history:
Accepted 3 February 2014
Available online 28 February 2014

Keywords:
Supply disruption
Lot sizing
Recovery model
Serial supply chain

ABSTRACT

Supply chains are becoming increasingly competitive in order to meet customer demands. The task of optimizing highly evolved supply chains is not easy, especially when it is particularly sensitive to unexpected disruption. This paper presents a newly developed real-time recovery mechanism for a two stage serial supply chain system, consisting of one manufacturer and one retailer, where the production is disrupted for a given period of time during the production up time. The model is capable of determining the recovery schedule for the manufacturer and the retailer, and ensuring that the total relevant costs are minimized, while seeking to recover the original schedule by the end of the recovery time window. The model was solved using an efficient heuristic developed in this paper, which performed well in giving quality solutions within reasonable time. It can be shown that the optimal recovery schedule is dependent on the shortage cost parameters, as well as on the extent of the disruption. The presented model is useful to assist decision makers to take a pro-active approach for maintaining business continuity in the event of a disruption in the supply chain system.

1. Introduction

Supply chains are becoming increasingly competitive and complex in order to meet customer demands. Current developments, such as "just-in-time" and lean operations, contribute to a more risk-sensitive environment. The task of optimizing highly evolved supply chains is not easy, especially when it is particularly sensitive to unexpected disruption. Supply chain disruption is defined as an event that interrupts the material flows in the supply chain, resulting in an abrupt cessation of the movement of goods. It can be caused by internal or external sources to the supply chain, including natural disasters, transportation failure, labor dispute, terrorism, war and political instability. In recent years, there have been many disruption occurrences that have severely affected supply chains. For example, the 2011 floods that hit Thailand had a significant impact on firms' supply chain operational capability in the region, which resulted in total damages of 100 billion baht (Fernquest, 2011). 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. Toyota was severely affected, where an estimated production of 20,000 cars, equivalent to $200 million worth of revenue, was lost due to parts shortages (Sheffi, 2005).

Without a proper response to such events, a manufacturer would have to incur considerably higher additional costs to recover from the negative impacts of disruption. Therefore, it is crucial that firms seek cost effective solutions to minimize their adverse effects. Realizing the potential losses from such events, enterprises have recently shown a growing interest in incorporating risk management into their operations. Two common strategies to manage the risk of disruptions are those of mitigation and contingency tactics (Tomlin, 2006). The former strategy requires a firm to act in advance of a disruption, while the latter takes action only during the occurrence of a disruption. Implementing mitigation and contingency tactics is not free; rather it involves a cost that influences the attractiveness of an optimal strategy for a given firm.

The research topic of Disruption Management (DM) has gained significant attention of academicians during the past few years. 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 et al., 2004). 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 and Arreola-Risa, 1994; Li et al., 2004; Parlar and Berkin, 1991; Parlar and Perry, 1995, 1996). Under the periodic review framework, Parlar et al. (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 (Ross et al., 2008; Weiss and Rosenthal, 1992; Xiao and Yu, 2006).

* Corresponding author. Tel.: +60 3 89216516; fax: +60 3 89118314.
E-mail address: noorulhawa@gmail.com (H. Hishamuddin).

http://dx.doi.org/10.1016/j.econmod.2014.02.004
0264-9993/

Tomlin (2006) examined the optimal strategy for a single product system with two suppliers: one that is unreliable and another that is reliable but expensive. Schmitt et al. (2010) and Chen et al. (2012) extended the work of Tomlin (2006) to study a system with stochastic demand. Furthermore, Schmitt and Snyder (2012) conducted a study on the comparison between single and multiple period settings for an inventory system subject to yield uncertainty and supply disruption. To do this, they extended the paper by Chopra et al. (2007) which only considered the single period case. Other variations of supply disruptions in stochastic inventory models include Arreola-Risa and DeCroix (1998), Li et al. (2004), Mohebbi (2003), Mohebbi and Hao (2006), Mohebbi and Hao (2008), Moinzadeh and Aggarwal (1997), and Qi et al. (2009). Snyder et al. (2010) provides an extensive review of supply chain models with disruption.

Most of the papers cited above consider *inventory mitigation* as the disruption-management strategy, in which additional inventory is held in the system for the entire period to protect against disruptions. These studies design their inventory models such that supply uncertainty occurrences are included in the original objective function by modifying the original non-disruption models. The majority of the studies are likely to result in stationary higher ordering quantities or bigger stock levels for the entire planning horizon, which may cause a firm to incur unnecessarily high holding costs over the long run. Thus, inventory mitigation tactics may not be of interest for firms that prefer a more cost effective solution to managing disruptions. An alternative solution to this problem would be the use of contingency or recovery tactics.

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 works by Qi et al. (2004) and Yang et al. (2005). Xia et al. (2004) developed a recovery strategy for an Economic Production Quantity (EPQ) system subject to disruption in the form of parameter changes. These studies propose various methods of schedule recovery, but none examines the optimal recovery duration, while minimizing the recovery costs, given a production-inventory system with partial backlogging options. To the best of our knowledge, we are the first to consider this as it has never been reported in the previous literature.

The recovery model proposed in this study is a variation of the work by Hishamuddin et al. (2012). While the previous study only considered the single stage, this research presents a newly developed real-time recovery model for a two stage serial supply chain system, consisting of a single supplier and single retailer. It is assumed that a random supply disruption occurs during a cycle that disables the production from running as scheduled. After the disruption occurs, a specified duration, known as the recovery time window, is allocated for recovery. Like other DM models, the term recovery is defined as restoring the original production schedule within a short time period, while minimizing the relevant costs. The objective of the model is to determine the optimal recovery schedule that consists of the manufacturing and ordering batch sizes for the manufacturer and retailer, as well as the optimal recovery duration, so that the expected total cost is minimized. The model can be classified as a constrained nonlinear programming model and is solved using a set of heuristics that has been developed as part of this study. Given the various risks and potential disruptions that firms face nowadays, the proposed model could prove to be an essential tool for manufacturers who want to make quick and cost effective decisions on an optimal recovery plan, in the aftermath of a disruption.

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

(1) The development of a recovery model for a two stage serial supply chain system with disruption in the form of schedule interruptions that are not known a priori. Additionally, the model considers stock-out costs that consist of both backorder and lost sale costs, as opposed to the penalty costs or complete backlogging/lost sales considered in previous works.
(2) The introduction of an efficient heuristic approach that determines the optimal recovery plan for disruption, subject to the system's costs and constraints. The heuristic we developed can be used as a module for re-scheduling of the production-inventory subsystem, due to disruption, within the company planning process. The module can be run immediately after the disruption happens and the customized output will provide the decisions without further processing of outputs and interpretations.

The remainder of this paper is structured as follows. In Section 2, the model formulation is presented. The solution approach is proposed in Section 3. Section 4 discusses the related computational results and analysis of the quality of the solution. Finally, Section 5 summarizes the paper and provides directions for future research.

2. Model development

In the following subsections, we introduce a mathematical model accounting for disruption in a two-stage supply chain system. First, we provide the system description of the model. This will be followed by the derivation of the cost functions for the model.

2.1. System description

In this study, a two stage production and inventory system that consists of a manufacturer and a retailer is considered. The manufacturer produces a product and maintains its inventory, and thus follows the economic production quantity model, while the retailer only maintains inventory and follows the economic order quantity model. The notations that are used throughout this paper are listed as follows:

Decision variables

X_i	production lot size of cycle i in the recovery schedule for stage 1 (units)
S_i	order lot size of cycle i in the recovery schedule for stage 2 (units)
n	number of cycles in the recovery window
z	number of optimal production lots in the recovery window

Other parameters and notation

A_1	setup cost for the first stage ($/setup)
A_2	ordering cost for the second stage ($/order)
D	demand rate for the system (units/year)
H_1, H_2	annual inventory cost for stages 1 and 2 ($/unit/year)
P	production rate (units/year)
Q_1	production lot size for stage 1 in the original schedule (units)
Q_2	ordering lot size for stage 2 in the original schedule (units)
Bq	back order quantity for stage 2
Lq	lost sales quantity for stage 2
T_d	disruption period
q	pre-disruption production quantity in a cycle
ρ	production up time for a normal cycle (Q/P)
u	production down time for a normal cycle
t_e	start of recovery time window
t_f	end of recovery time window
T	production cycle time for a normal cycle (Q/D)
B_1, B_2	unit back order cost per unit time for stages 1 and 2 ($/unit/time)
L_1, L_2	unit lost sales cost for stages 1 and 2 ($/unit)