Proceedings of the 2011 Winter Simulation Conference
S. Jain, R.R. Creasey, J. Himmelspach, K.P. White, and M. Fu, eds.

STUDYING THE IMPACT OF VARIOUS INVENTORY POLICIES ON A SUPPLY CHAIN WITH INTERMITTENT SUPPLY DISRUPTIONS

Avinash Samvedi
Vipul Jain

Department of Mechanical Engineering
Indian Institute of Technology Delhi
New Delhi – 110016, INDIA

ABSTRACT

The management of supply risks has become a highly critical component of supply chain management. Supply failures effect on the supply chain can be costly and lead to significant customer delivery delays. Inventory management is an important tool to mitigate the risks arising due to these failures. But there has always been a confusion on which inventory method will be best for such situations and what should be the values of the parameters. This study fulfills a part of this gap by studying the impact of changes in the parameter values of periodic inventory policy on supply disruption situations. The process is simulated using discrete event simulation with the inventory and backorder levels taken as the output parameters. The study shows that there is a definite connection between the costs experienced at a level in the chain and its distance from the disruption point.

1 INTRODUCTION

Supply chains are complex systems with material, financial and information flows through their nodes and branches. The mad rush to make the supply chains better, faster and cheaper is making the chain increasingly interdependent and risky. Although such supply chain design changes and supply chain management initiatives have great potential to make operations leaner and more efficient in a stable environment, they simultaneously increase the fragility and vulnerability of supply chains to disruptions (Craighead et al. 2007, Wagner and Bode 2006). This growing complexity of modern supply chains increases the risks of exposure to various types of major disruptions, which we define to be events that severely interrupt the normal course of business. Of all kinds of disruptions supply disruptions have been specifically considered in this study. A supplier may be unavailable to fill an order for a variety of reasons including equipment failures, damaged facilities, problems procuring necessary raw materials, or rationing its supply among its customers. For example in 2000, Sony was unable to deliver Playstation 2's for the holiday season due to parts shortages from its suppliers (Hendricks and Singhal 2005). To reduce vulnerability of the chain to such problems, they should be made more "resilient" (Sheffi and Rice 2005) and "robust" (Tang 2006) and inventory management is the key to do it.

Mathematical inventory control models date back to the early 20th century, where some of the earliest research concerned the development of the well-known economic order quantity (EOQ) model (Wilson 1934). However, research on stochastic inventory models was largely not undertaken until needed by the US war efforts in the 1940's, producing published results in the 1950's (Arrow et al. 1951). Scarf (1977) proves the optimality of a base stock policy and an (s, S) policy for periodic review inventory systems with stationary stochastic demand processes, constant deterministic order lead times and a total expected discounted cost evaluation criterion. The stochastic inventory control literature in which demand and lead time uncertainties are represented by probability distributions is quite extensive. However, these distribu-

978-1-4577-2109-0/11/$26.00 ©2011 IEEE

tions often lack attributes to represent rare or extreme events. Therefore, analytical models must be developed to explicitly model such events (Lewis 2005).

The remainder of the paper is organized as follows. Section 2 reviews the literature on inventory system management and supply chain disruptions. Section 3 describes the problem being considered here. Section 4 talks about the simulation model in detail. Section 5 analyses the results obtained from the simulation runs in detail. Section 6 concludes the paper.

2 LITERATURE REVIEW

Managing risk in the supply chain has never been as challenging as it is today. As more companies have outsourced production to overseas locations, supply chains have been extended, the number of nodes increased, and the complexity of the networks has moved exponentially. Whether real or imagined, we perceive greater exposure, increased likelihood and more severe consequences of already known risks whilst becoming aware of other risks previously unknown. Supply chain risks can come in a host of different kinds like natural disaster, terrorist attack, labor strike and accidents. These can all be the causes for supply chain disruption and delay (Christopher and Lee 2004, Norrman and Jansson 2004, Tang 2006). Any material, financial or information risk could create problems in a supply chain. Any such problems transpired within the supply chain will cause delay and even disruption. Disruption does not only halt the supply chain operations but without preparation and precaution, it takes time for the affected system to recover (Sheffi and Rice 2005, Hendricks and Singhal 2005). While there are many specific examples of supply chain disruptions, most can be classified by the following three categories: economic, demand, and supply. Supply risk involves the potential occurrence of events associated with inbound supply that can have significant detrimental effects on purchasing firms (Zsidisin et al. 2000).

Inventory management is an effective way of dealing with such disruption situations. A plethora of literature is available dealing with inventory during supply disruptions (Gupta 1996, Song and Zipkin 1996, Lewis 2005). Weiss and Rosenthal (1992) studies the classical EOQ model in which a supply or demand disruption will occur at a known future time and last for a random duration, and optimal order quantities are developed. The existence of an optimal (s, S) policy is proved in Parlar and Gerchak (1995) and Ozekici and Parlar (1999) respectively for finite and infinite horizon periodic review, discounted cost models in which the supplier's availability is modeled as a two-state discrete-time Markov chain (DTMC). Mohebbi investigates two continuous-review inventory systems with compound Poisson demand, with one having erlang distributed lead time (Mohebbi 2003) and the other having hyper exponentially distributed lead time (Mohebbi 2004). Chen and Li (2009) consider a continuous-review inventory system where a single supplier is subject to disruptions. They study the effect of customer segmentation on the system. Li and Chen (2010) investigate the impacts of supply disruptions and customer differentiation on a partial-backordering inventory system in the periodic-review setting of (r, S).

After scanning the literature, it was found that there is very less work done to analyze the impact of changes in the parameters of periodic inventory policy, such as maximum inventory level and review period, on the chain which is subjected to supply disruptions from the manufacturer end.

3 PROBLEM DESCRIPTION

This study considers a 4 level single-product supply chain that includes a retailer, a wholesaler, a distributor and a manufacturer. The system is depicted in the Figure 1. The demand stream is shown in blue colour and supply stream in purple colour. The demand from the customer end is generated at retailer. The retailer demands from wholesaler, who in turn demands from distributor and at last distributor demands from the manufacturer. The manufacturer places the order to its shop floor and thus the supply starts downstream. The supply chain is prone to disruptions and when a player fails all kinds of flows in the chain are disrupted which means all incoming and outgoing flows through that player are stopped. The demands from the downstream and supply from upstream are not collected. They wait for the player to go back to normal and then all pending demands and supplies are delivered to it together. The period in which a player is available for transactions is termed as ON period and when it is disrupted is termed as OFF period. ON periods reflect supply disruption frequency, while OFF periods represent supply disruption duration. Frequency and duration are two indices for the severity of supply disruptions. The longer the ON periods, the less frequent the disruptions and the slighter the disruptions. Contrarily, the longer the OFF periods, the longer the disruptions last and the more severe the disruptions (Chen and Wang 2010).

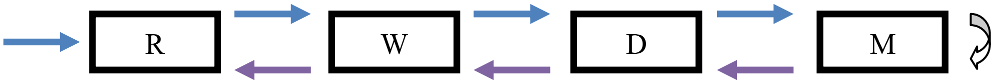
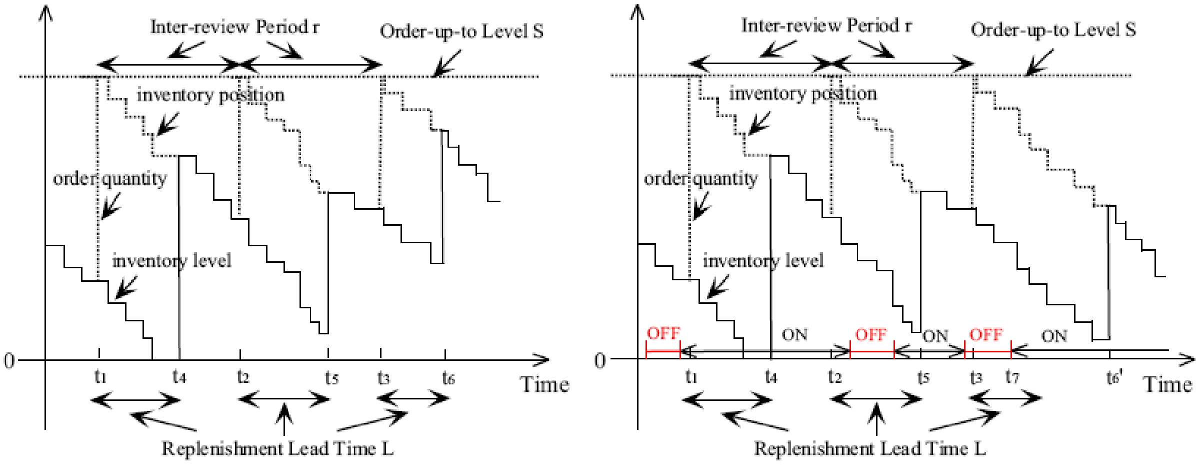


Figure 1: A 4-level single product supply chain

The periodic review inventory policy (r, S) has been adopted at each tier of the chain, where *r* is an inter-review period and *S* is an order-up-to level. This policy means that, every a period of time *r*, the player reviews its inventory position and orders an appropriate quantity of products from the upstream supplier such that inventory position is increased to the order-up-to level *S*. Figure 2(a) shows a standard (*r*, *S*) inventory policy that does not consider supply disruptions and Figure 2(b) shows the one which considers them. Time points *t*1, *t*2 and *t*3 are inventory review points when inventory position is reviewed and an order of appropriate quantity is placed to the supplier. *t*4, *t*5 and *t*6 are time points when the ordered products are received by the retailer. Time periods *t*4−*t*1, *t*5−*t*2 and *t*6−*t*3 are three realizations of stochastic replenishment lead time *L* (Chen and Wang 2010). In Figure 2(a), the solid line represents net inventory level, which is defined as on-hand inventory minus backorders (Hadley and Whitin 1963). When inventory level is positive, the retailer incurs holding cost that is proportional to holding duration and the quantity of held products. The dotted line in the figure represents inventory position, which by definition is equal to the corresponding net inventory level plus the quantity of products in the currently outstanding orders (Hadley and Whitin 1963). Outstanding orders stand for the orders that have been placed to the supplier but have not yet been received by the retailer.



(a)

(b)

Figure 2: (a) A standard (r,S) inventory policy (b) An (r,S) inventory policy with supply disruptions (Chen and Wang 2010)

4 SIMULATION SETUP

A simulation model has been developed to study the impact of failures at a level on other levels in a chain and also the impact of various inventory policies during disruptions. This is a discrete event simulation with four events i.e. demand, supply, disruption and inventory review. The simulation starts from an initial pre-defined state with demands and supplies between levels scheduled. The simulation kicks off with first demand from the customer end. During the demand process the player checks if there are any backlogged orders. These orders combined with the current demand are treated as the cumulative demand. The player then checks the availability in the inventory and supplies to the downstream level as much as possible i.e. if inventory is available to fulfill the cumulative demand then it is done. If less inventory is available then all the available inventory is supplied and the balance is put in backlogged orders. If this was the retailer then next demand from the customer end is scheduled and else the supply is scheduled to the downstream level. Supply event is simpler and requires just the updating of the inventory levels. The disruption event is called for a particular player. That player is flagged as disrupted and any further demand or supplies events will only update the demand in waiting and supply in waiting respectively. Only after the disruption flag is removed from the player, these demand and supplies in waiting will be considered for the updating of inventory levels. The next disruption is scheduled and also the end of the current disruption is scheduled. At the end of the disruption a inventory review is also scheduled. Inventory review event is called after a fixed review period for all players in the chain and during this event the inventory levels are checked if they are lower than the maximum inventory level defined. If the levels are lower they are updated to the level S.

The supply lead time has been taken as 2 working days and order processing time as 1 working day. Maximum inventory level has been defined as a constant multiple of product of lead time and average demand. The value of this constant is made to vary between 1 & 9 and the review period takes any value between 1 and 9 days. The demand varies between 4 and 8 units. The inventory holding cost is Rs 1 per unit per day and backlogging cost is Rs. 2 per unit per day. The disruption frequency is between 50 and 200 days and the duration is between 7 and 14 days. The simulation is run for 5 replications for each scenario. All variables follow a uniform distribution in this study.

The initial inventory level at each of the player is set at 4 units. Further a demand of 4 units is scheduled for the first day on each players and a supply of 4 units for the next 2 days on each player. A inventory review is scheduled to take place during the first working day and a disruption is scheduled for the manufacturer after a randomly generated time. Later we will warm up the simulation model to remove the influences these initial settings may bring about. The warm up time is kept as 100 days in a total run duration of 1000 days. The impact on the system by changing the review period and the maximum inventory level is studied first.

5 RESULTS AND ANALYSIS

This section illustrates the results obtained from the simulation runs. Figure 3 shows the impact of increase in frequency of disruptions on the cost of different tiers in the chain. It is noticed that the costs increases at first and then stabilizes and does not change with increasing frequency. This can be attributed to the fact that as the disruptions increase the backlogging costs increase too and inventory costs come down (as there is less in stock due to disrupted supply). But the increase in backlogging costs is more than the decrease from inventory costs and hence the increase in overall costs. As the frequency of disruptions is further increased, both of these costs stabilize because of the overlap of the effect of disruptions of one cycle on the other. Also the difference in costs of various players in the chain increases with increasing frequency. The difference in the costs is almost negligible at a low frequency but increase to a sizeable amount and then stabilizes.

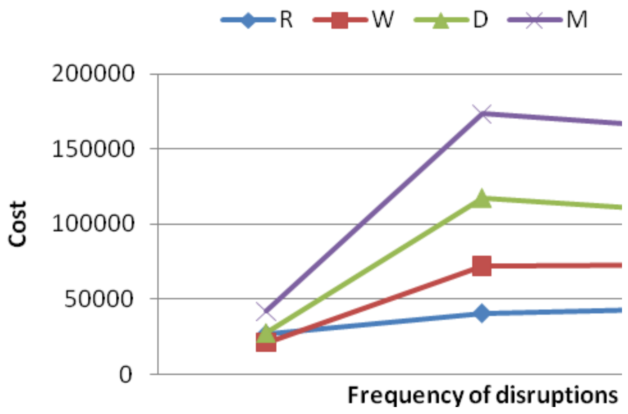


Figure 3: Impact of change in frequency of disruptions on the cost

Figure 4 illustrates the change in cost with the changes in review period and maximum inventory level. The four series in the figure represents different maximum inventory levels increasing from one to four. It can be noticed that the overall cost increases as the inventory level increases and also it decreases as the review period increases. This can be deduced from the fact that having more inventory will definitely cost more and with increasing review period there will be less inventory replenishments and thus the inventory costs will come down. A resurgence in the cost is also seen as we go increasing the review period. This increase is more pronounced when maximum inventory levels is less. With less maximum inventory levels the chances of backlogging will be more and this explains the late increase due to backlogging costs.

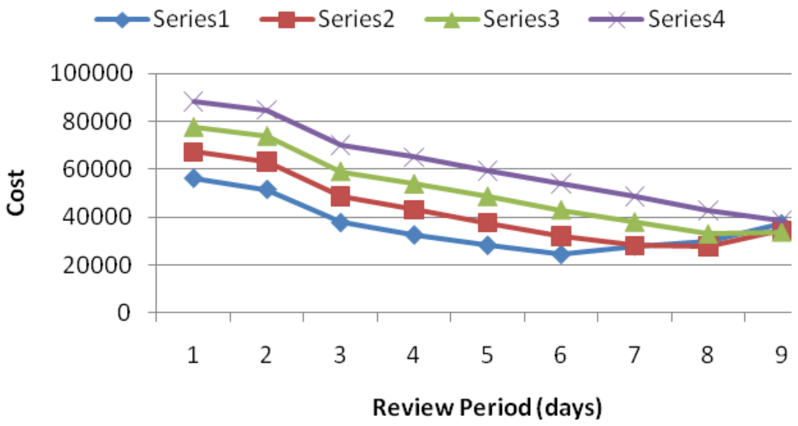


Figure 4: Impact of changes in review period and maximum inventory level on cost

Figure 5 & 6 illustrates the impact of changes in review period on the cost of different players in a chain which is prone to supply disruptions from the manufacturers end. Here again it is noticed that when the frequency is increased the difference in costs between players increases.

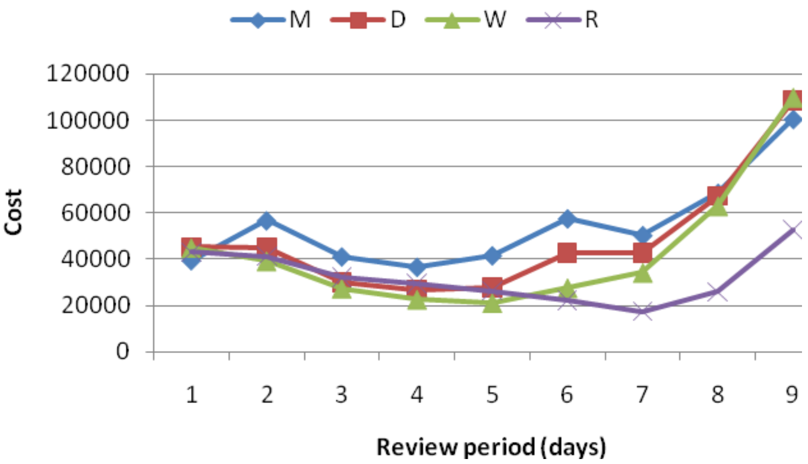


Figure 5: Impact of changes in review period on cost when disruption frequency is low

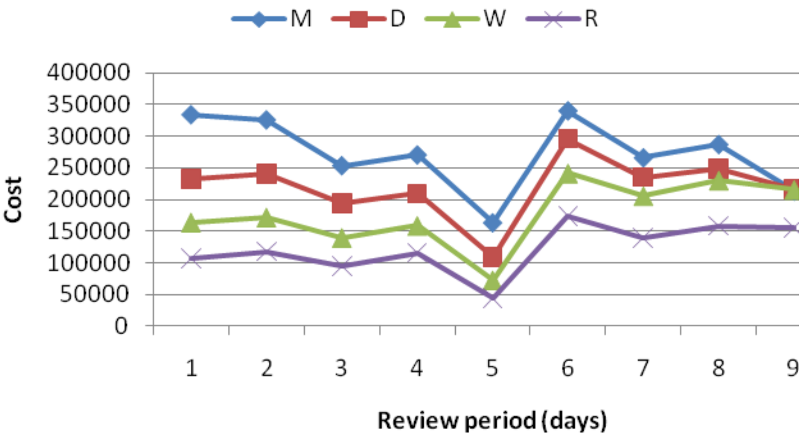


Figure 6: Impact of changes in review period on cost when disruption frequency is high

One thing to notice from Figures 5 & 6 is that the overall average cost goes up as we move from less frequent disruption towards more frequent disruptions. This can be attributed to the fact that the disruptions seriously affects the levels of inventory as well as backlogging in the chain. Another point to notice is that the retailer costs are generally the minimum of all and the manufacturer costs are the maximum of all. This can be attributed to the bullwhip effect or to the fact that the manufacturer tier is disrupted and the retailer is the farthest tier from the disruption point. The costs are lower as we move farther away from the manufacturer. It is actually hard to tell which factor is more pronounced for this effect. But when we see Figure 7, where in all the players are open for disruption and randomly a player is chosen for disruption during the simulation run time, we see that the manufacturers have the minimum average cost. This lends us the support to say that the cost lowers as we move farther away from the disruption point and it is not due to the bullwhip effect.

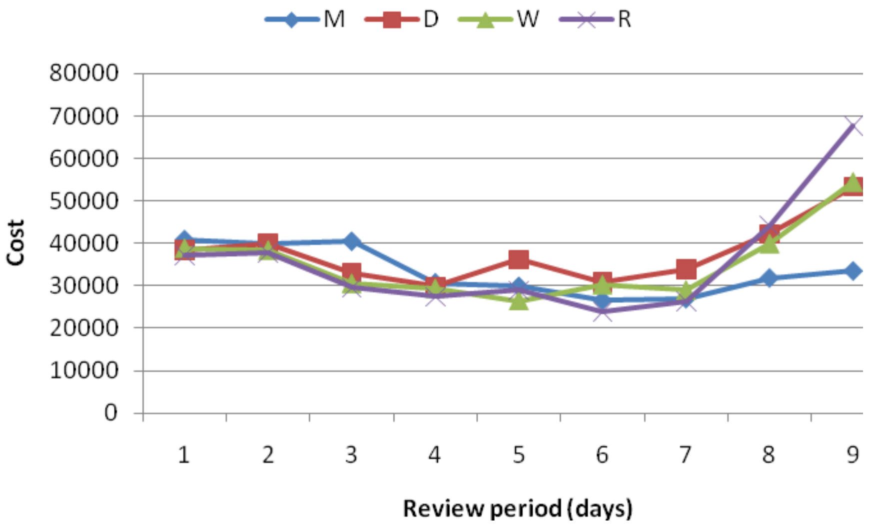


Figure 7: Impact of changes in review period on cost when any tier can be randomly disrupted

From the results shown above we can say that the effect of disruption at a level in the chain is more pronounced on the levels closer to the disruption point and lowers as we move farther from it. This is clearly shown in all the figures and also Figure 7 proves it beyond doubt as when we do not mark a specific player for disruption and allow any player to be disrupted the difference in costs of the players is almost removed.

6 CONCLUSIONS

Understanding comprehensively what risk is, where risk exists, and how to mitigate risk definitely exhibits an additional research challenge in supply chain management. Also as the risk situation continually changes in this rapidly changing world, our present risk handling activities may easily become obsolete. However, with an increasing awareness of risk management issues, both from industrial and academic aspects, we believe that developing risk management models should improve a supply chain competence in the new business environment and definitely it is a promising and important research area in operations management. As a matter of fact, a better understanding of one's risks, a sound mitigation designed with this improved knowledge, and the development and placement of risk financing mechanisms and insurance covers all contribute to a reduction of the residual uncertainties. Even though risk cannot, and may be should not, be completely eliminated, all the tools that lead to some mitigation constitute a source of sound practice for risk management.

The simulation study of a 4 tier single product supply chain, subjected to disruptions with varying frequency and duration has been done here. All the players in the chain follow the periodic review model here and the impact of various parameter values such as review period and maximum inventory level when the supply chain is subjected to supply disruptions from the manufacturer is analyzed. The results show that there is a huge effect of changes in values of these parameters. The cost of the players in the chain increases with increasing maximum inventory level and decreases with increasing review period. Future work can be conducted on a more complex supply chain as this is a relatively simple supply chain model and far from reality where multiple branches span out from each tier. Order splitting between suppliers will have to be incorporated in such chains and a comparative analysis on various order splitting strategies during disruption situations will be useful. Also different kind of forecasting strategies can be compared. Different players in the chain can be made to use different inventory policies etc.

REFERENCES

Arrow, A. K., T. E., Harris and T. Marschak. 1951. “Optimal Inventory Policy.” *Econometrica* 19:250–272.

Chen, Y. and S. Wang. 2010. “Investigating The Impacts Of Dynamic Pricing And Price-Sensitive Demand On An Inventory System In The Presence Of Supply Disruptions.” In *Proceedings of the 2010 Winter Simulation Conference*, ed. B. Johansson, S. Jain, J. Montoya-Torres, J. Hugan, and E. Yucesan, 1809 – 1819. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Chen, Y., and X. Li. 2009. “The Effect Of Customer Segmentation On An Inventory System In The Presence Of Supply Disruptions.” In *Proceedings of the 2009 Winter Simulation Conference*, ed. M. D. Rossetti, R. R. Hill, B. Johansson, A. Dunkin, and R. G. Ingalls, 1610–1621. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Christopher, M., Lee, H., 2004. “Mitigating Supply Chain Risk Through Improved Confidence.” *International Journal of Physical Distribution and Logistics Management* 34 (5): 388–396.

Craighead, C.W., J. Blackhurst, M.J. Rungtusanatham and R.B. Handfield. 2007. “The Severity Of Supply Chain Disruptions: Design Characteristics And Mitigation Capabilities.” *Decision Sciences* 38(1): 131-156.

Gupta, D. 1996. “The (Q, R) Inventory System With An Unreliable Supplier.” *INFOR* 34 (2): 59–76.

Hadley, G., and T. M. Whitin. 1963. *Analysis of inventory systems*. Prentice-Hall, Inc., Englewood Cliffs, N.J.

Hendricks, K.B. and V.R. Singhal. 2005. “An Empirical Analysis Of The Effect Of Supply Chain Disruptions On Long-Run Stock Price Performance And Equity Risk Of The Firm.” *Production and Operations Management* 14 (1): 35–52.

Lewis, B. 2005. “Inventory Control With Risk Of Major Supply Chain Disruptions.” Ph. D. thesis, Georgia Institute of Technology.

Li, X., and Y. Chen. 2010. “Impacts of supply disruptions and customer differentiation on a partial-backordering inventory system.” *Simulation Modelling Practice and Theory* 18:547–557.

Mohebbi, E. 2003. “Supply Interruptions In A Lost-Sales Inventory System With Random Lead Time.” *Computers & Operations Research* 30:411–426.

Mohebbi, E. 2004. “A Replenishment Model For The Supply-Uncertainty Problem.” *International Journal of Production Economics* 87:25–37.

Norrman, A. and U. Jansson. 2004. “Ericsson’s Proactive Supply Chain Risk Management Approach After A Serious Sub-Supplier Accident.” *International Journal of Physical Distribution and Logistics Management* 34/5: 434–456.

Ozekici, S. and M. Parlar. 1999. “Inventory Models With Unreliable Suppliers In A Random Environment.” *Annals of Operations Research* 91:123–136.

Parlar, M., Y. W. and Y. Gerchak. 1995. “A Periodic Review Inventory Model With Markovian Supply Availability.” *International Journal of Production Economics* 42:131–136.

Scarf, H., “The Optimality Of (*S; S*) Policies In The Dynamic Inventory Problem,” in *Mathematical Methods in the Social Sciences* (Arrow, K., Karlin, S., and Suppes, P., eds.), pp. 196–202, Stanford, CA: Stanford University Press, 1977.

Sheffi, Y. and J.B. Rice. 2005. “A Supply Chain View Of The Resilient Enterprise.” *MIT Sloan Management Review* 47 (1):41–48.

Song, J., and P. Zipkin. 1996. “Inventory Control With Information About Supply Conditions.” *Management Science* 42 (10): 1409–1419.

Tang, C.S. 2006. “Perspectives In Supply Chain Risk Management.” *International Journal of Production Economics* 103: 451–488.

Wagner, S.M. and C. Bode. 2006. “An Empirical Investigation Into Supply Chain Vulnerability.” *Journal of Purchasing and Supply Management* 12(6):301-312.

Weiss, H. and C. Rosenthal. 1992. “Optimal Ordering Policies When Anticipating A Disruption In Supply Or Demand,” *European Journal of Operational Research* 59:370–382.

Wilson, R. 1934. “A Scientific Routine For Stock Control.” *Harvard Business Review* 13:116–128.

Zsidisin, G.A., A. Panelli and R. Upton. 2000. “Purchasing Organization Involvement In Risk Assessments, Contingency Plans, And Risk Management: An Exploratory Study.” *Supply Chain Management* 5(4):187.

AUTHOR BIOGRAPHIES

AVINASH SAMVEDI is a research scholar at the Department of Mechanical Engineering, Indian Institute of Technology Delhi, New Delhi, INDIA. His research interest include Supply Chain Risk Management, Multi Criteria decision analysis, Simulation Modeling and Analysis, Inventory Control. His email address is avinash.samvedi@gmail.com.

VIPUL JAIN is an Assistant Professor in the department of Mechanical Engineering at IIT Delhi. Prior to joining IIT Delhi, he was working as a researcher at INRIA (The French National Institute for Research in Computer Science and Control). At INRIA, in addition to the fundamental research, he is also involved in the European project I*PROMS (Innovative Production Machines and Systems). He holds a Ph.D. in Supply Chain Management from IIT Delhi in 2006. His primary research interests are Supply chain management and mechanism design in supply chain settings. He is the editorial board member for seven international journals, including International Journal of Industrial Engineering, International Journal of Intelligent Enterprise, International Journal of Management Development, International Journal of Information Systems and Supply Chain Management, International Journal of Agile and Extreme Software Development, Information Management an official publication of Information Resources Management Association and International Journal of Modeling in Operations Management. His email address is vjain@mech.iitd.ac.in.