

# Modeling the Propagation of Delay Risks in a Supply Chain

Rong Zhou ([tlizr@nus.edu.sg](mailto:tlizr@nus.edu.sg)), Mark Goh, Robert De Souza  
*The Logistics Institute – Asia Pacific, National University of Singapore*

## Abstract

We model the propagation of the supply delay risk in a supply chain to determine the delay occurring time and duration in the subsequent node. The analysis of several scenarios demonstrates that inventory levels, lead times, and risk duration are key factors determining the behavior of risk propagation.

**Key words:** risk propagation, supply risk, supply chain risk management

## Introduction

The recent decade has witnessed ever-increasing number of disasters. It is important for a company to scrutinize its supply chain to understand all potential risks and be prepared once risks occur. Generally, a company can systematically identify its most concerned risks through a risk framework. For example, Chopra and Sodhi (2004) categorized supply chain risks into well-accepted nine groups. Gaonkar and Viswanadham (2007) identified that uncertainty in the supply chain might manifest itself in three broad forms—deviation, disruption, and disaster. While those risk frameworks can facilitate spotting risks, the severity and scale of a particular risk should be evaluated in a wider view as risks can propagate across the supply chain through material, financial, or information links.

There are few papers working on supply chain risk propagation. Buldyrev et al. (2010) illustrated a risk propagation causing an severe electrical blackout in Italy in September 2003. The propagation was through an iterative process of a cascade of failures from a power network and an Internet network. The risk propagation demonstrates that the failure of one node in the network led to a wide-scale electrical blackout.

Gerard Weisbuch (2007) studied under which conditions local failures to produce or simply to deliver can result in avalanches of shortage and bankruptcies across the network. Fujiwara (2008) showed that a firm in a state of financial insolvency or bankruptcy can affect the firms on its upstream secondarily along the links. Huang *et al.* (2008), Hua *et al.* (2011), and Sun *et al.* (2012) have worked on bankruptcy propagation for its causes, mitigation and management.

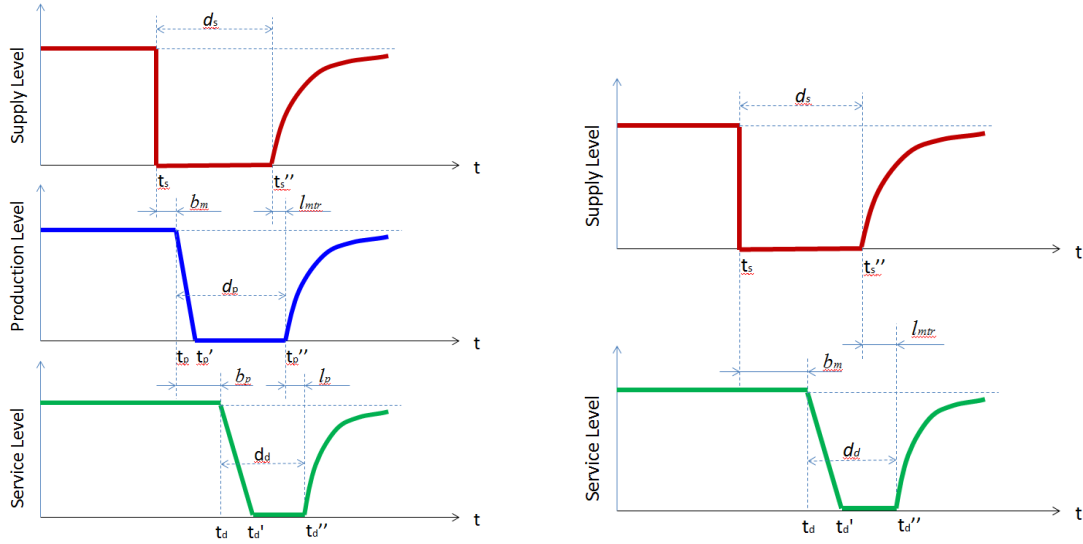
The literature review shows that most work on supply chain risk propagation has been focused on bankruptcy. Few efforts have been put on other types of supply chain risks. Among the supply chain risks identified in (Chopra and Sodhi, 2004), supply delay risk is one of most common risks faced by a company. Many other risk drivers like disruptions from natural disasters and supplier bankruptcy, or information system breakdown can trigger delay risks through information, financial, and material flows. It is important for the company to identify

how the supply delay risk can impact its operation and how the risk propagates across the supply chain.

In the following sections, a model is established to represent the impact of a supply delay risk to its immediate subsequent node. Then simulation scenarios are set up to demonstrate this impact as well as the effects of the supply delay propagation to members in a simple supply chain.

### The model

A model in *Figure 1* shows the relationship between supply, production (for manufacturer), and order fulfillment within a company.



(a). For a manufacturer/supplier

(b). For a distribution center/retailer

Figure 1. Relationship between supply, production and order fulfillment

$$t_d = t_s + b_m + b_p \quad (1)$$

$$d_d = d_s - b_m - b_p + l_{mtr} + l_p \quad (2)$$

or

$$t_d = t_s + b_p \quad (3)$$

$$d_d = d_s - b_m + l_{mtr} \quad (4)$$

Notations are as follows.

$t_d$ : the starting time of the order fulfillment disruption

$t_s$ : the starting time of the supply disruption

$b_m$ : the lagged period of disruption in production provided by buffers like raw material inventory and materials on the way

$b_p$ : the lagged period of disruption in product delivery provided by buffers from production

$d_d$ : the duration of the order fulfillment/delivery disruption

$d_s$ : the duration of the supply disruption

$l_{mtr}$ : the transportation lead time from the supplier to the plant/tier 1 supplier

$l_p$ : the production lead time

From equations (1) to (4), we can conclude that the starting time of the order fulfillment disruption ( $t_d$ ) is related to the starting time of the supply disruption, supply in transportation, inventory level of raw material, and production level. Similarly, The duration of the order fulfillment disruption ( $d_d$ ) is related to the duration of the supply disruption, raw material inventory, supply in transportation, production level, the transportation lead time, and the production lead time.  $t_d$  is always larger than  $t_s$ ; but the duration of disruption in the subsequent node ( $d_d$ ) can be less or larger than the original disruption duration ( $d_s$ ).

### Case studies

Two scenarios are designed to demonstrate 1) the effects of the supply delay disruption to its immediate subsequent node and 2) the propagation of the disruption along a simple supply chain and its effects to the nodes. Discrete event simulation models are built to observe the above behaviors.

- Impacts of disruption to the immediate subsequent node

Supply chain is comprised of one supplier, one retailer, and one customer. Random orders come to the retailer according to the uniform distribution where the quantity of any order is between 4 and 12. Orders come in at every simulation time unit. Initially, the service level at the retailer is 1 at the state steady time for all three sets of values of control policy  $rS$ . No back order exists and the order cycle time is zero. The  $rS$  policy refers to a safety inventory policy where the inventory level is regularly checked at the certain time interval ( $r$ ) to maintain a target inventory level ( $S$ ). Three combinations of  $r$  and  $S$  are used in the simulation (Table 1). The transportation times from the retailer to customers and from the supplier to the retailer are 0 and 1, respectively.

Table 1 Values of inventory control policy  $rS$

|        | $r$ | $S$ |
|--------|-----|-----|
| Case 1 | 1   | 12  |
| Case 2 | 2   | 24  |
| Case 3 | 3   | 35  |

Assuming the disruption occurs at the supplier side at the time of the 51<sup>st</sup> order sent by the retailer to the supplier. The duration of the disruption is 20 time units. The simulation lasts for 500 time units and the results are given as follows.

The 51<sup>st</sup> order sent by the retailer to the supplier occurs at time 50, 99, or 148, respectively regarding different cases. It is observed that the supply disruption impacts the recovery of the inventory level, the back order, the order cycle time, and the service level different in three cases. Figure 2 refers to the inventory levels of the retailer for three scenarios. The time taking to recover to the original levels of inventory is different, e.g. Case 1 takes longest time while Case 3 takes shortest time to recover. The disruption in supply causes more back orders to Case 1 than the other two cases. Case 1 actual keeps back orders for the rest of simulation time while cases 2 and 3 only have back orders for a short period of time (Figure 3). The severity of the disruption to order cycle times (Figure 4) are also greatest to case 1 and then to case 2 and 3. Finally, for the service levels, Case 1 decreases to 73% while cases 2 and 3 can recover to above 90% before the end of simulation (Figure 5).

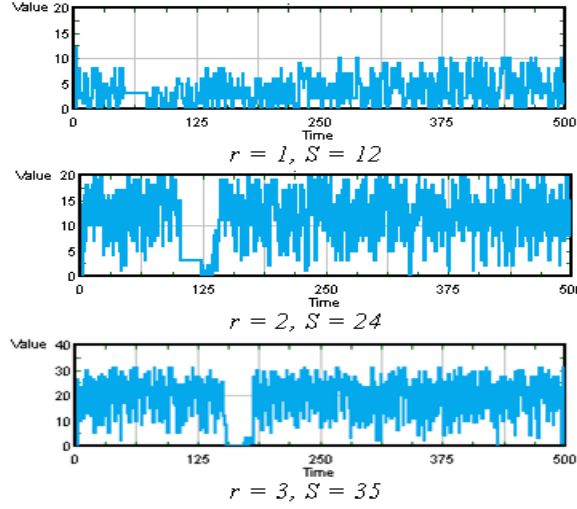


Figure 2 Inventory level

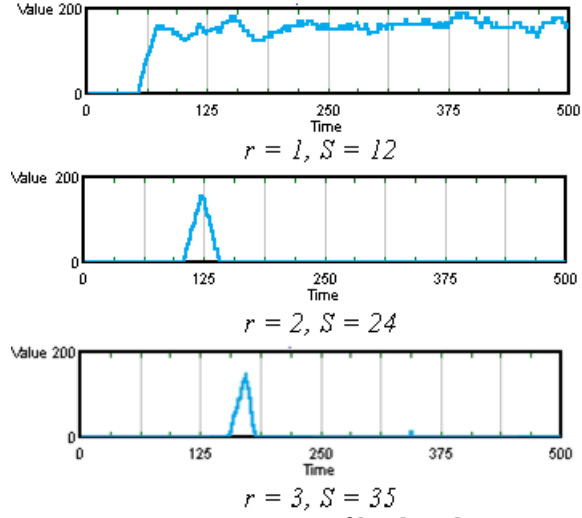


Figure 3 Sum of back orders

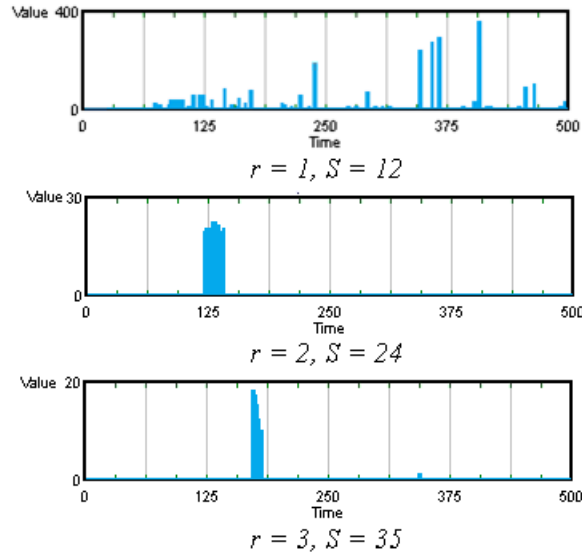


Figure 4 Order cycle time

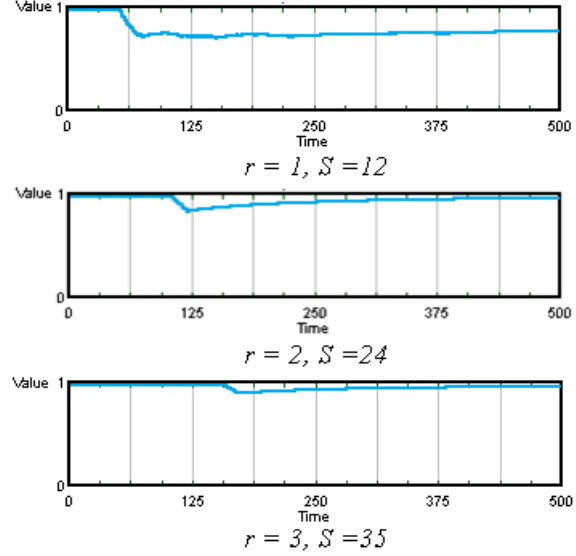


Figure 5 Service level

The simulation shows that different inventory levels targeted in three cases lead to different performance change upon the occurrence of supply delay risk. Cases with high inventory levels perform better but with higher costs.

- Impacts of risk propagation to the nodes in a supply chain

In this scenario, a supply chain comprised of 4 entities is built. There are one supplier, one manufacturer, one retailer, and one customer. Random orders come to the retailer according to the uniform distribution where the quantity of any order is between 4 and 12. Orders come in at every simulation time unit. Initially, both service levels at the retailer and the manufacturer are 1 at the state steady time assuming rS control policy is adopted at the both sites. The detailed values of  $r$  and  $S$  are given in Table 2 and the transportation times between different entities are given in Table 3. Finally, the production time in the manufacturer is 1 time unit.

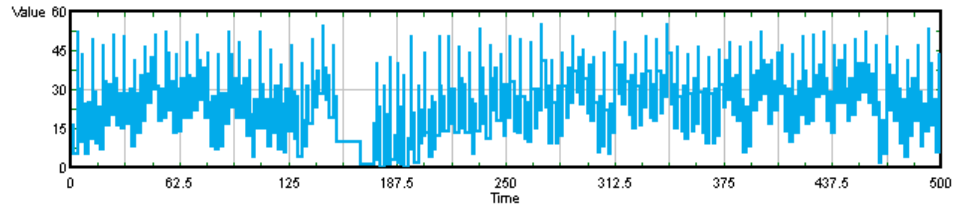
Table 2 Parameters of the inventory control policy

| Retailer        | Manufacturer    |
|-----------------|-----------------|
| $r = 2; S = 23$ | $r = 3; S = 63$ |

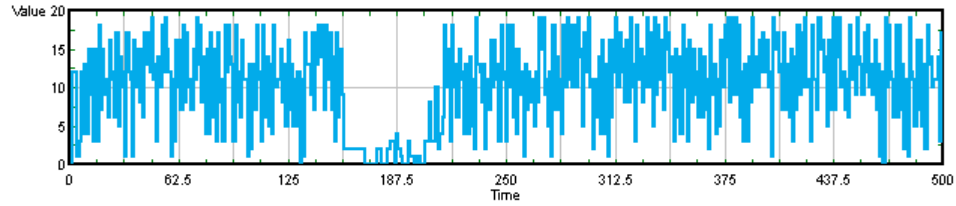
Table 3 Transportation times

| Retailer to Customer | Manufacturer to Retailer | Supplier to Manufacturer |
|----------------------|--------------------------|--------------------------|
| 0                    | 1                        | 2                        |

Similarly, assuming the disruption occurs at the supplier side at the time of the 51<sup>st</sup> order sent by the manufacturer to the supplier. The duration of the disruption is 20 time unit. The simulation lasts for 500 time unit and the results are given as follows.

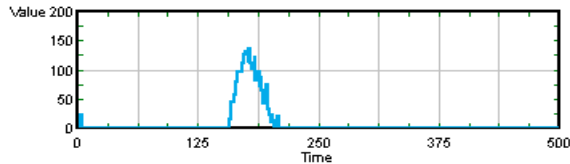


(1) Manufacturer

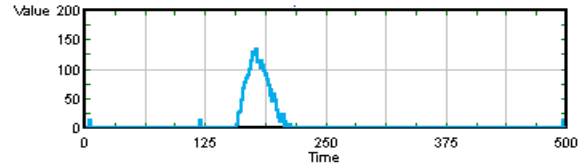


(2) Retailer

Figure 6 Inventory levels

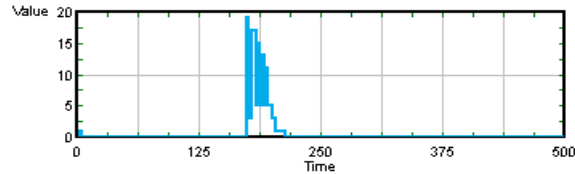


(1) Manufacturer

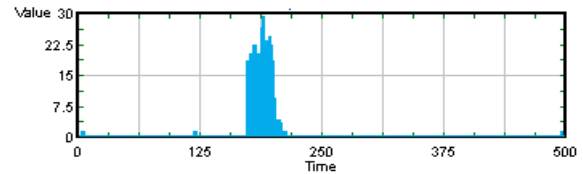


(2) Retailer

Figure 7 Sum of the back orders



(1) Manufacturer



(2) Retailer

Figure 8 Order cycle times

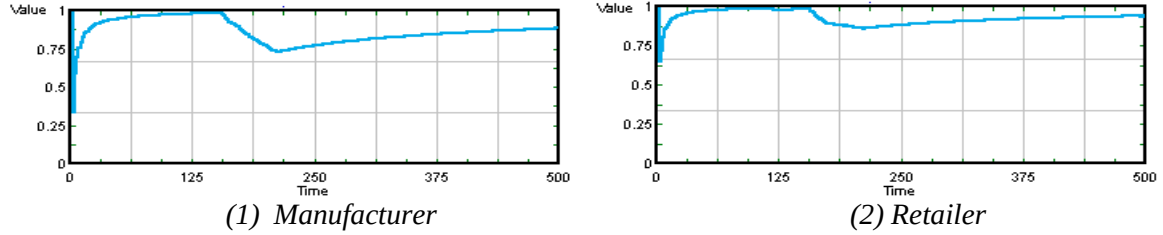


Figure 9 Service levels

The 51<sup>st</sup> order sent by the manufacture to the supplier occurs at time 148. From time 148 till time 168, the supplier fails to supply materials to the manufacturer. From time 151, the inventory level of the manufacturer drops. It starts to receive delayed goods from the supplier at time 171, and recover its inventory to the normal level at about time 176. At the same time, the inventory level of the retailer drops from time 157. It starts to receive delayed goods from the manufacturer at time 172 and recover to normal level at around time 215 (*Figure 6*).

From *Figure 7*, the manufacturer starts to build up back orders at time 157 and goes back to pre-disruption level at time 209 while the retailer starts to build up back orders at time 158 and removes those back orders at time 214. From *Figure 8*, the delay times of back orders are illustrated. For the manufacturer, the longest delay time is 19 time units while the longest delay time is 29 time units for the retailer.

Those changes can be reflected at the changes of service levels for both the manufacturer and the retailer. At time 155, the service level of the manufacturer starts to drop and bounces back from time 213; similarly, the service level of the retailer starts to drop at 157 and bounces back from time 213 (*Figure 9*).

Summarily, the disruption occurred at the supplier has greater impacts to the subsequent supply chain members in terms of inventory level and delay in order fulfillment. *Figure 10* illustrates this observation clearly. The disruption at the supplier occurring at time 148 with the duration of 20 time units triggers the disruptions at the manufacturer and the retailer at times 151 and 157, respectively. The duration of disruption is also extended to 25 and 58 time units, respectively.

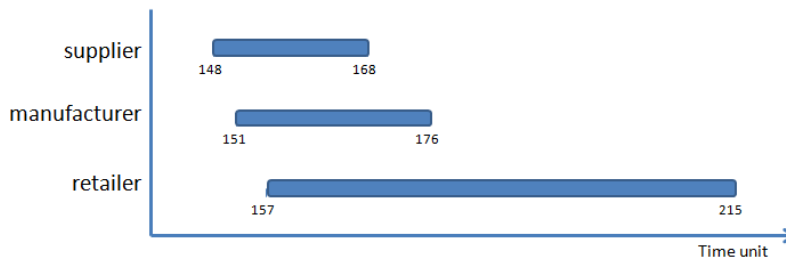


Figure 10 Propagation of disruption from the supplier, the manufacturer to the retailer

## Conclusion

The current work models the disruption of the supply delay risk to the members of the supply chain. The simulation results show that maintaining proper inventory level can help reduce the impacts from disruption. Furthermore, escalating of disruption is also observed when the supply delay risk propagates along the supply chain. The simulation model can be used to explore other types of risks that may propagate.

## References

- Buldyrev, S. V., R. Parshani, G. Paul, H. E. Stanley and S. Havlin (2010). "Catastrophic cascade of failures in interdependent networks." Nature **464**(7291): 1025-1028.
- Chopra, S. and M. S. Sodhi (2004). "Managing risk to avoid supply-chain breakdown." Mit Sloan Management Review **46**(1): 53-62.
- FUJIWARA, Y. (2008). "CHAIN OF FIRMS' BANKRUPTCY: A MACROSCOPIC STUDY OF LINK EFFECT IN A PRODUCTION NETWORK." Advances in Complex Systems **11**(5): 703–717.
- Gaonkar, R. S. and N. Viswanadham (2007). "Analytical Framework for the Management of risk in supply chain." IEEE Transactions on Automation Science and Engineering **4**(2): 265 - 273.
- Gerard Weisbuch, S. B. (2007). "production networks and failure avalanches." J. Econ. Behav. Organ. **64**: 448–469.
- Hua, Z., Y. Sun and X. Xu (2011). "Operational causes of bankruptcy propagation in supply chain." Decision Support Systems **51**(3): 671-681.
- Huang, C. D., R. S. Behara and Q. Hu (2008). "Managing Risk Propagation in Extended Enterprise Networks." IT Professional Magazine **10**(4): 14-19.
- Sun, Y., X. Xu and Z. Hua (2012). "Mitigating bankruptcy propagation through contractual incentive schemes." Decision Support Systems.