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System Dynamics Modeling of Backup Purchasing Strategies under Supply Disruption Risks

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Abstract

We model a supply chain using system dynamics involving one retailer and two independent suppliers that are referred to as major supplier and backup supplier, respectively. Furthermore, the chain provides only one product; only the major supplier will experience disruptions, and the buyer uses the backup supplier either as a contingent supplier or a standby supplier. Our paper extends the existing literature and contributes by providing a better understanding of the impacts of supply disruptions on the system performance and shedding deeper insights into the value of a backup supply. Three models are built under supply disruption risks: supply chain without backup supplier, that with a contingent supplier and the one with a stand-by supplier. The retailer's total profits are also compared to help the decision-makers choose the appropriate backup purchasing strategy.

Keywords: *System dynamics, Simulation modeling, Supply Disruption, Backup purchasing strategy*

1. Introduction

The best supply chains are not only responsive and cost-effective, but also agile and adaptable to ensure all the supply chain members' interests stay aligned. The objective of agility is to quickly respond to short-term changes in demand and supply and to smoothly handle external disruptions (Charles, 2010). Supply disruption is infrequent risk but has large impact on the whole supply chain (Hu *et al.*, 2013), because it could cut off the cash flow and stop the operation of the entire supply chain.

More attention have been paid to study supply chain risks and mitigating strategies, but little focused on supply chain system under supply disruptions, caused by lead time, with simultaneous demand uncertainty and recurrent supply uncertainty. In this paper, we try to

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simulate the supply chains using system dynamics modeling to examine the effects of supply disruptions and the impacts of backup strategies.

The methods of system dynamics (SD) have been used commonly for studying the behavior of supply chains. For example, Tang (2011), Choi etc. (2012), Mula *etc.* (2013), Georgiadis (2013). Generally, in recent stream of this literature, there are two problems addressed through “what-if” analysis: (1) considering the system performance, what is the impact of some certain factors or the effect of some certain strategies? For example, Kim and Springer (2008), Campuzano *et al.* (2010), as well as Springer and Kim (2010). And (2) the decisions to implement supply chain improvement strategies: Saeed (2008), Georgiadis and Athanasiou (2010), as well as Suryani *et al.* (2010) and Jahangirian *et al.* (2010).

The study of Wilson (2007) compares the effect of a transportation disruption on a traditional supply chain and a vendor managed inventory system (VMI), but it does not consider the mitigating strategies. Besides, the work of Hou *et al.* (2010) model the backup contract- a buy-back contract and a make-to-order contract respectively, in order to find the optimal order quantities from the backup supplier under supply disruption risks. In this paper, we compare different backup purchasing strategies for a retailer who has two suppliers of the same products: the cheaper one is the major supplier who is prone to a possibility of disruption risk, whereas the more reliable one is the backup supplier. The impacts of supply disruptions on the retailer’s inventory levels and customer satisfaction degree are examined first, and then the effects of two backup strategies are investigated with the backup supplier on the retailer’s total profits under different durations and magnitudes of supply disruptions.

2. Model Development

This research applies system dynamics simulation modeling to study the effects of two backup purchasing strategies on mitigating supply disruption risk for the retailer. Three simulation models were built - one of a supply chain under supply disruption risks without backup supply, one of a supply chain with a contingent supplier and another, with a stand-by supplier. In our model, the assumptions are:

The customer demand is represented by the demand at the retailer’s level determined by a normal distribution while the retailer’s orders are represented by the demand at the supplier’s.

The major supplier has no constraint on its production capacity, but it is vulnerable to stop production under supply disruption under which.

The lead times of the two suppliers are assumed to be the same and constant. The two suppliers have same and constant lead time.

Each of the retailer and the major supplier has an inventory order policy, so that the inventory in each period is replenished to a pre-set safety stock.

The suppliers order and receive raw materials from outside.

2.1. Supply Chain without Backup Supply

In this case, to examine the impact of supply disruptions on the system, we established two models of a supply chain, one without supply disruption risks and the other under supply disruptions but without backup supply. The results will be used as the basis of subsequent comparisons.

Figure 1 shows the relationship between orders placed and goods shipped for the retailer and one supplier (major supplier) using causal loop diagrams, which has been depicted in previous work (Huang, 2001).

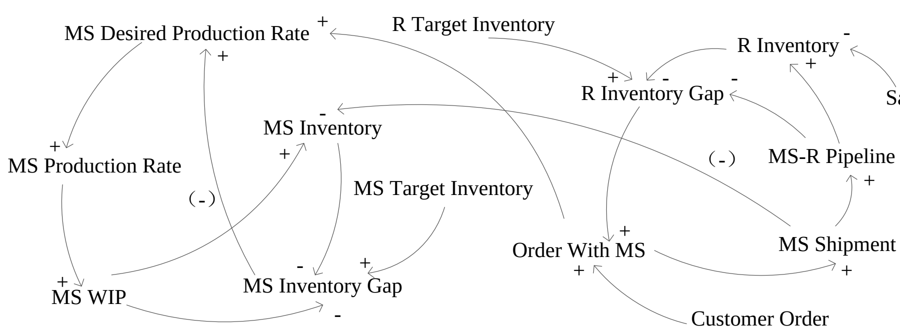

Figure 1. Causal Loop Diagram of Retailer and Major Supplier

According to the relationships, Figure 2 represents the logic of rate and level diagrams for the retailer and the major supplier.

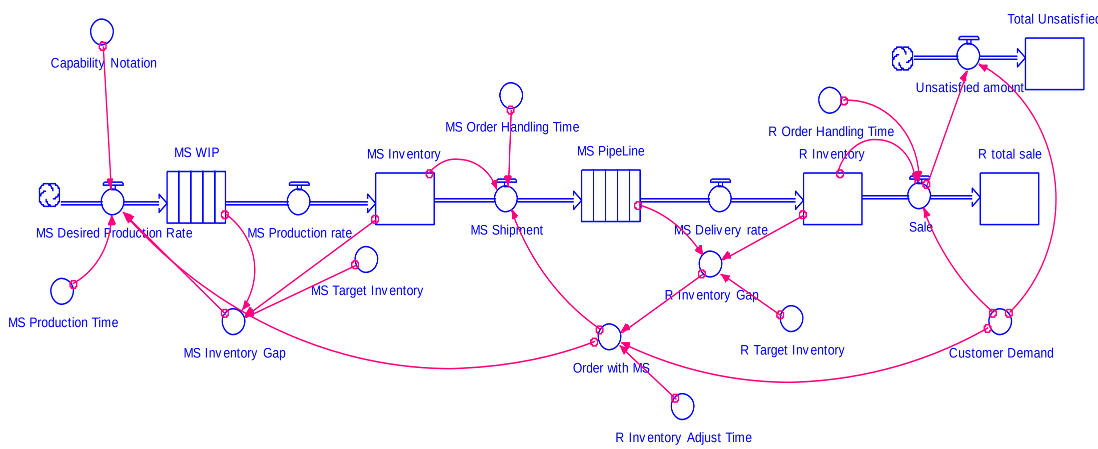

Figure 2. System Dynamics Model for the Retailer and the Major Supplier

2.2. Two Backup Strategies for Dealing with Supply Disruption Risks

We build two models of a supply chain under supply disruption risks, one with a contingent supplier and the other with a stand-by supplier. To examine the effects of the two backup strategies, the retailer’s inventory levels, unsatisfied demand as well as the retailer’s total profits are compared with those without backup supply.

Suppose the buyer has a backup supplier of the same product- more reliable but more expensive. The buyer can choose the backup supplier as a contingent supplier, that is, only when supply disruption from the major supplier occurs, the backup supplier is used. Therefore, the contingent supplier doesn't need to hold any inventory for the retailer. And when the retailer places orders, the contingent supply starts its production accordingly and delivers the products.

The other backup strategy is: the buyer can reserve some products at the backup supplier whether there is a supply disruption or not, the premium of which is e \$/unit paid by the retailer. When the major supplier is stuck down, the retailer directly buys these products at regular price c_m, as the major supplier's. If the order is higher than the stand-by quantity, the buyer will pay the backup supplier a higher price c_b for the excess quantities. For the standby supplier, he can also sell the surplus products to a secondary market, which is not the major concern of this paper.

Besides, mention that the major supplier shares its production capacity information with the retailer; when the supply disruption occurs, the retailer orders as much as the major supplier can provide until it recovers production, that is, the minimum of the major supplier's inventory and the needed amount of the retailer. Figure 3 shows the logic of rate and level diagrams for backup supplier.

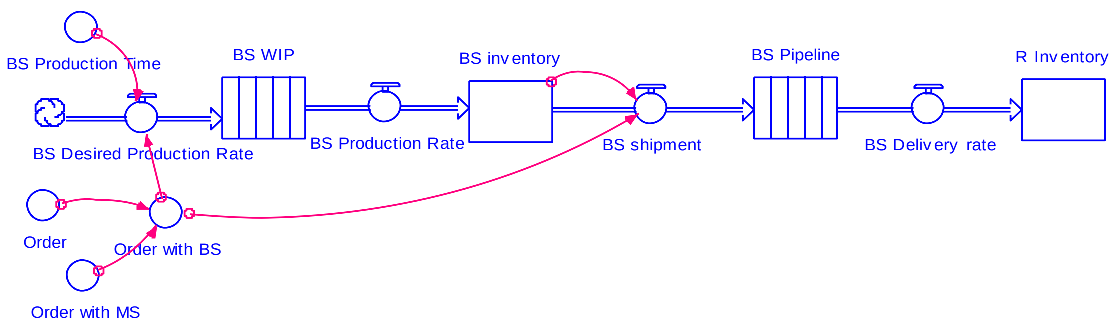

Figure 3.1. System Dynamics Model for the Contingent Supplier

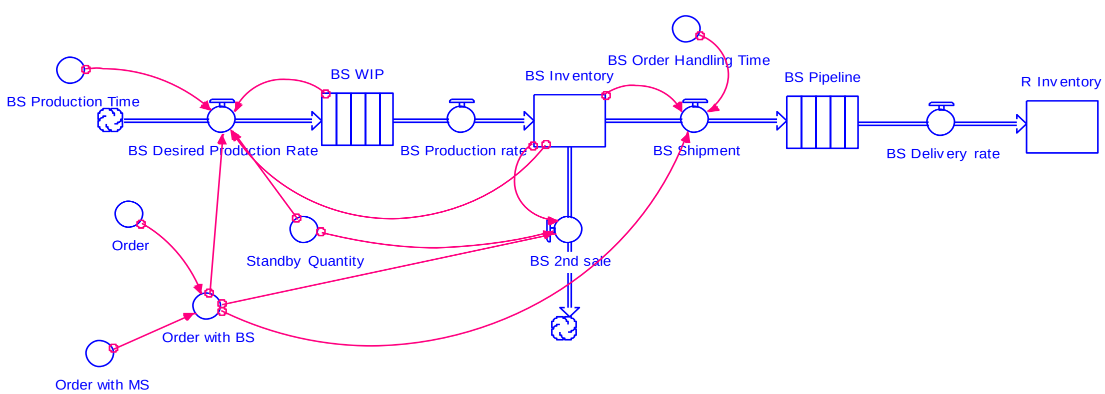

Figure 3.2. System Dynamics Model for the Stand-by Supplier

3. Simulation Results and Analysis

3.1. Supply Chain without Backup Supply

In previous work (Huang, 2001), we examined the retailer's total profits and the total unsatisfied amount under conditions without disruption and with disruption respectively. The basic idea can be described briefly as follows. By setting Capability_Notation with constant 1 during the whole period, the results when no disruption happens are shown in Figure 4, with the retailer's total profits of $427,172 over the whole period and the total unsatisfied amount as 127 units.

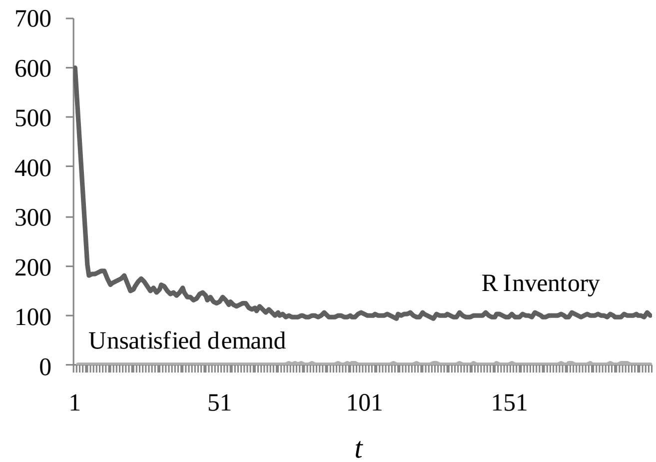

Figure 4. Performance of Supply Chain without Supply Disruptions

By setting Capability_Notation as 0 after the 60th day, and the 1st disruption last for 3 days (65-67) while the 2nd one last for 7 days (120-126), the system's performance is shown in Figure 5. Note that to compare impacts of the two independent disruptions, we ensure the time interval between them is long enough.

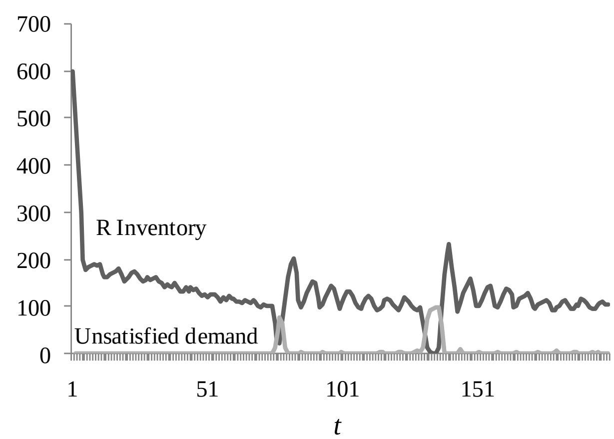

Figure 5. Performance Graph of Supply Chain under Supply Disruptions

The 1st disruption causes clearly fluctuation in both retailer's inventory during days 75-105 and unsatisfied demand during days 75-80. While the 2nd disruption causes a fluctuation on the retailer's inventory level during days 129-164 and on unsatisfied amount during days129-138.

4.2. Strategy 1- Supply Chain with Contingent Supply

Under the same disruptions with the above simulation, Figure 6 shows the performance of a supply chain with contingent supply.

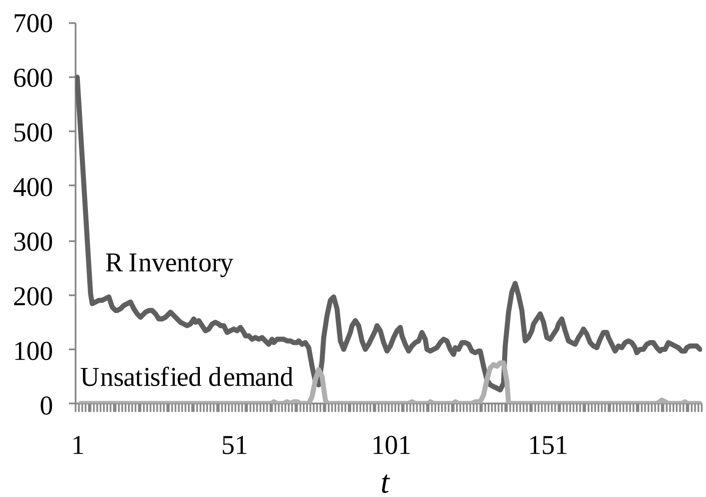

Figure 6. Performance Graph of Supply Chain with Contingent Supply

Compared with Figure 5, Table 1 lists the differences of disruption impacts between the supply chain with and without a contingent supplier.

Table 1. Comparison of the Outputs between Supply Chain with and without a Contingent Supplier (Day: 1st disruption: 65-67, 2nd disruption: 120-126)

Output	Without backup supply		With a contingent supplier	
Retailer's lowest inventory	1st	20	1st	41
	2nd	1	2nd	26
Retailer's highest inventory	1st	203	1st	196
	2nd	233	2nd	223
Retailer's inventory fluctuation duration	1st	30	1st	24
	2nd	35	2nd	35
Total unsatisfied amount	922		686	

4.3. Strategy 2- Supply Chain with Stand-by Supply

Under the same disruptions with 4.1, Figure 7 shows the performance of a supply chain with stand-by supply.

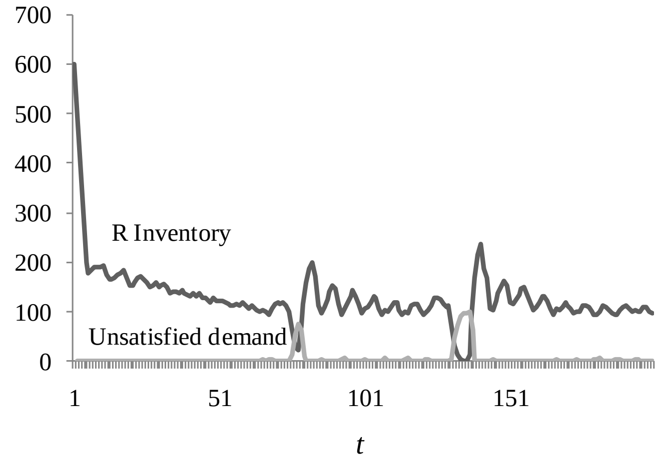

Figure 7. Performance Graph of Supply Chain with Stand-by Supply

Compared with the performance with a contingent supplier, the total unsatisfied amount is increased to 833, but also smaller than that without backup supplier (922).

Next we will examine how the retailer's profits can be improved by using a backup supplier under different durations of disruptions. Intuitively, the disruption probability, or proportion, plays an important role: because of the large premium cost, the larger the disruption probability is, the better the Strategy 2 is compared to Strategy 1, although it always means larger customer satisfaction. Through the model to perform "what if" analyses regarding the results under different disruption proportions, Figure 8 confirms this thought.

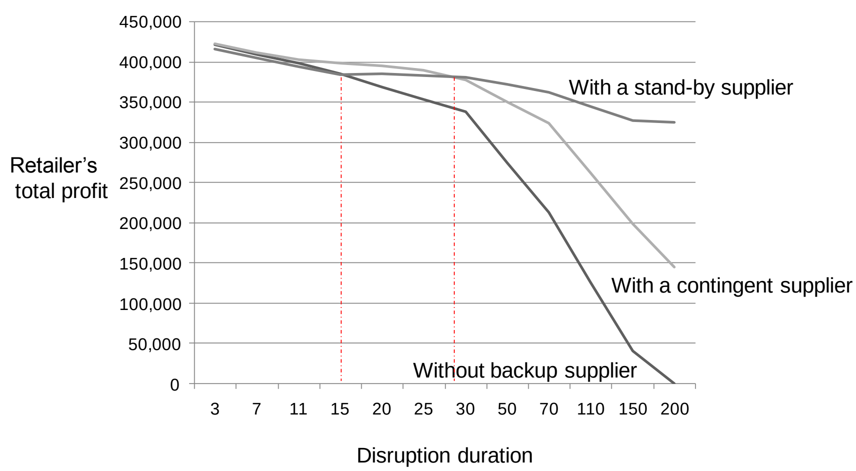

Figure 8. Retailer's Total Profit under Different Sourcing Strategies vs. Disruption Duration (Q = 50, e = 0.5)

In conclusion, the use of a backup supplier can reduce the unsatisfied amount and weaken the impact of the disruption duration on the retailer's profit. When the disruption duration or duration is small, the retailer had better use a contingent supplier; while if the disruption frequently occurs, the use of a standby supplier takes more advantages.

5. Conclusion

It contributes to the literature in the following aspects. Based on system dynamics modeling, this paper examines the impact of supply disruptions and the effects of two backup purchasing strategies with standby supply and contingent supply. Contributions of this paper are in the following aspects.

We investigate the impacts of supply disruption on the customer's unsatisfied amount and the retailer's inventory level. Three purchasing strategies are examined: no backup supply, with a contingent supplier and with a stand-by supplier; and profits are compared to help the retailer choose the optimal strategy under different disruption risks. Whereas very few research papers have examined the problem of choosing backup strategies under different supply disruptions.

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