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System Dynamics Modeling-based Study of Contingent Sourcing under Supply Disruptions

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Abstract

In this paper, using the methodology of system dynamics modeling, we separately build two models for a supply chain under two circumstances of supply disruptions, without backup supplier, and with a contingent supplier. The retailer's total profits are also compared under these two circumstances of supply disruptions to help the decision-makers better understanding the backup purchasing strategy. The supply chain studied only involves one retailer and two independent suppliers that are referred to as major supplier and backup supplier. The paper contributes to the literature by providing a better understanding of the impacts of supply disruptions on the system performance and by shedding insights into the value of a backup supply.

Keywords: System dynamics modeling, simulation modeling, supply disruption, backup purchasing strategy

1. Introduction

For any node company in a supply chain, it has to make appropriate purchasing and inventory strategies which can mitigate not only downstream demand uncertainty, but also upstream supply uncertainty as well as supply disruptions caused by various unexpected events. Supply disruption is defined as the sudden stop of supply; that is, when unexpected events occur, the main source becomes totally unavailable. Supply disruption is infrequent risk but has large impact on the whole supply chain [1], because it could cut off the cash flow and stop the operation of the entire supply chain. Thus it is necessary to model a supply chain with the consideration of these risks to support the decision-makers.

A lot of efforts have been made to examine supply chain risks and mitigating strategies, but little focused on studying the supply chain system under supply disruptions, with simultaneous demand uncertainty and recurrent supply uncertainty caused by lead time. In this paper, the supply chain studied only involves one retailer and two independent suppliers that are referred to as major supplier and backup supplier. The chain provides only one product; only the major supplier will experience disruptions, and the buyer uses the backup supplier (a contingent supplier). Using system dynamics modeling, we try to simulate such type of supply chain to examine the effects of supply disruptions and the impact of backup strategy. We compare different backup purchasing strategies for a retailer who has two suppliers of the

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same products: the cheaper one is the major supplier who is possibly prone to risking a disruption, 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.

The structure of this paper is as follows. A brief literature review is provided in Section 2. The model of supply chains under supply disruptions is introduced in Section 3. Simulation results and analysis are provided in Section 4. In Section 5, practical and managerial insights derived from the theoretical results are discussed.

2. Literature Review

The methods of system dynamics (SD) have been studied extensively for examining the behaviour of supply chains. We herein focus on several recent studies. Naim (2006) shows the impact of using the net present value on the assessment of the dynamic performance of e-commerce enabled supply chains [2]. The work of [3] models the operation of a supply chain network comprising of four echelons with a central medium-sized manufacturing company operating as a typical Make-to-Order (MTO) system. Georgiadis and Besiou (2008) examine the impact of ecological motivation and technological innovations on the long-term behaviour of a closed-loop supply chain with recycling activities [4].

Generally two problems have been addressed in recent literatures. One is about the impact of some factors or the effect of some strategies on the system performance. Another is about the decisions of implementing supply chain improvement strategies.

For the first problem, Potter and Lalwani (2008) aim to quantify the impact of demand amplification on transport performance [5]. Kim and Springer (2008) examine the volatility resulting from the cyclical oscillation of on-hand and on-order inventories and suggest strategies for avoiding or minimizing such volatility [6]; Campuzano et al. (2010) evaluate the behaviour of fuzzy estimations of demand instead of demand forecasts based on exponential smoothing in a two-stage, single-item, multi-period supply chain [7]. Springer and Kim (2010) use three distinct supply chain volatility metrics to compare the ability of two alternative pipeline inventory management policies to respond to a demand shock [8].

For the second, Saeed (2008) uses forecasting reliably to determine ordering policy in supply chains [9]. The work of [10] is recommended, which reviews on publications concerning simulation applications in manufacturing and business.

It is seen from the literature that most studies of supply chain risks using SD are focused on demand uncertainty or downstream risks. Thus far limited research efforts have been devoted to SD modelling of SC behaviours and backup strategies in the presence of supply disruption risks.

This paper differs from the existing studies in that first we examine the effects of supply disruption on the performance of supply chain, which is defined as the sudden stop of supply, that is, the main source becomes totally unavailable, caused by unexpected events. We also extend the model to the situation that the major supplier still has limited available supply or production capability.

3. Modeling

Two simulation models were built. One of a supply chain under supply disruption risks without backup supply, and one of a supply chain with a contingent supplier. The assumptions in our model include:

- The demand at the retailer's level is determined by a normal distribution that represents customer demand while that at the suppliers are the retailer's orders.
- There is no constraint on the major supplier's production capacity, but he is prone to a probability of supply disruption under which the major supplier cannot manufacture any product, while the backup supplier is always reliable.

- The lead time of the supply is assumed to be constant.
- Each of the retailer and the major supplier's inventory has an order policy such that in each period, the stock is replenished to a pre-set safety stock.
- The supplier orders and receives raw materials from an external source.

We use three indices to describe the performance of each system: unsatisfied demand of the customer, the retailer's inventory level and the retailer's total profit.

3.1. Supply chain without backup supply

In this situation, to examine the effects of supply disruptions on the system, we build 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 a basis for subsequent comparisons.

Fig. 1 illustrates the relationship between orders placed and goods shipped for the retailer and one supplier (major supplier) using causal loop diagrams.

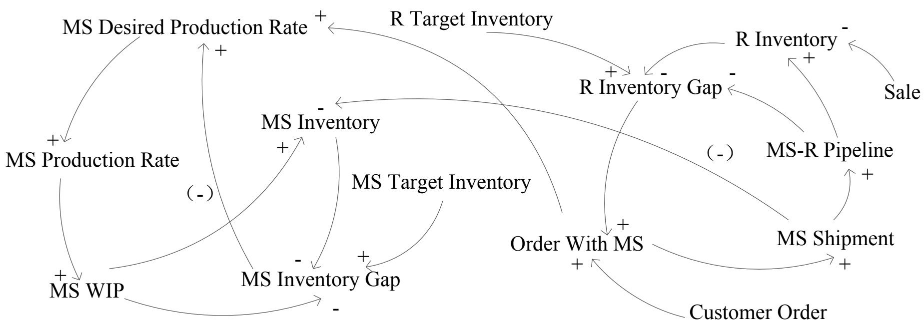

Fig. 1. Causal loop diagram of retailer and major supplier

For the retailer, as Fig.1 indicates, the customer demand and the inventory gap both influence the order as well as the shipment from the major supplier in the same direction (+). And as the major supplier's shipment increases, the retailer's inventory level increases which in turn decreases its inventory gap. Therefore, the retailer's inventory has a negative effect on the supplier's shipment. As the loop is negative it will always try to reduce the inventory gap to zero. In the same way, the major supplier's inventory level also has a negative effect on its production rate.

The notations and equations for the retailer and the major supplier are shown in Table 1.

In Table 1, "R" stands for retailer and "MS" for major supplier.

Mention that we use Capability_Notation=0 to denote the case of supply disruption and under normal situations, Capability_Notation=1. By unsatisfied amount, we mean the amount of demand that cannot be satisfied, for which the retailer would be punished for cu \$/unit.

Table 1. Parameter settings and assumptions for supply chain without backup supply

Variable	Equation
p	Unit sale price at the market, 30$/unit
wm	Major supplier's unit wholesale price, 6$/unit
cu	Unit penalty cost for unsatisfied demand, 12$/unit
hb	Unit inventory holding cost at the retailer, 2$/unit/day
Customer_Demand	Normal(100, 2)
Capability_Notation	The notation for the major supplier's production state, (0 or 1)
Production time	6
Delivery time	4
R Initial Inventory	600 units
R Target Inventory	600 units
Sale	MIN(R_Inventory/R_Order_Handling_Time, Retail_Backlog_Orders)
R Inventory Gap	MAX(R_Target_Inventory_S-MS_PipeLine-R_Inventory,0)
Order with MS	If R_Inventory_Gap=0 then 0 else Retail_Backlog_Orders +R_Inventory_Gap/R_Inventory_Adjust_Time
MS Shipment	MIN(MS_Backlog_Orders, MS_Inventory/MS_Order_Handling_Time)
MS Initial Inventory	700
MS Target Inventory	700 units
MS Inventory Gap	MAX(MS_Target_Inventory_S-MS_WIP-MS_Inventory,0)
MS Desired Production Rate	(if MS_Inventory_Gap=0 then 0 else Order_with_MS+MS_Inventory_Gap/MS_Production_Time)*Capability_Notation
R Profit per cycle	p*Sale-wm*MS_Delivery_Rate-cu*Unsatisfied_amount -hb*R_Inventory
Unsatisfied_amount	MAX(Customer_Demand-Sale,0)

3.2. Contingent sourcing for dealing with supply disruption risks

We build a model of a supply chain under supply disruption risks with a contingent supplier. To examine the effects of the backup strategy, 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.

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. Fig. 2 shows the logic of rate and level diagrams for backup supplier.

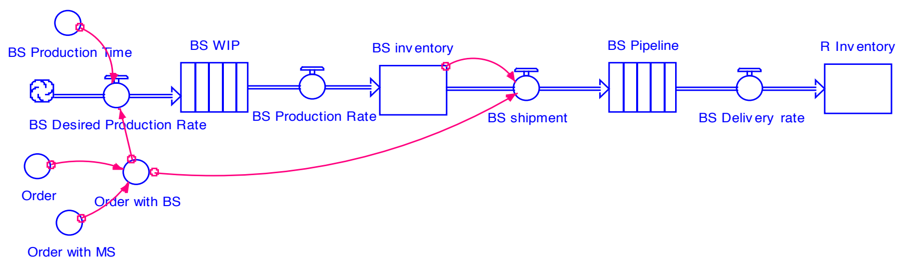

Fig. 2. System dynamics model for the contingent supplier

The notations for supply chain with a backup supplier are listed in Table 2, where "BS" stands for backup supplier. Equations for managing and controlling inventory of the retailer and the major supplier are the same as shown in Table 1.

Table 2. Parameter settings and assumptions for supply chain with a backup supply

Variable	Equation
e	Unit premium for the stand-by products in Strategy 2, 0.5$/unit (<hb)
Q	Stand-by quantity
Order	If R_Inventory_Gap=0 then 0 else Retail_Backlog_Orders+R_Inventory_Gap/R_Inventory_Adjust_Time
Order with MS	if Capability_Notation=0 then MIN(Order,MS_Inventory) else Order
Order with BS	Order-Order_with_MS
BS Desired Production Rate	Order_with_BS
R Profit per cycle	p*Sale-wm*MS_Delivery_Rate-cu*Unsatisfied_amount-wb*BS_Delivery_Rate-hb*R_Inventory

4. Simulation results and analysis.

4.1. Supply chain without backup supply

By setting Capability_Notation to be constant 1 across the whole period, we can get the results when no disruption happens, as in Fig. 3, with the retailer's total profits over the whole period as 427,172$ and the total unsatisfied amount as 127 units.

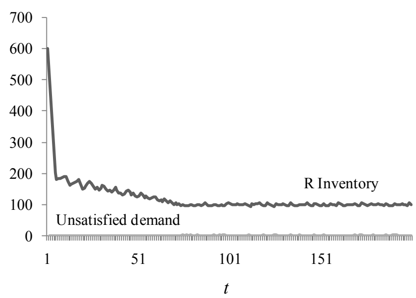

Fig. 3. Performance graph of supply chain without supply disruptions

By setting Capability_Notation to be 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), we could see the system's performance in Fig. 4. Note that to ensure the two disruptions are independent and compare their impacts, we ensure the time interval between them is long enough.

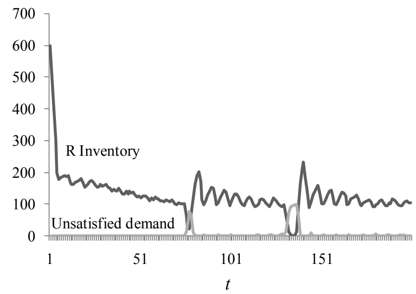

Fig. 4. Performance graph of supply chain under supply disruptions

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 days 129-138.

4.2. Strategy 1- Supply chain with contingent supply

Under the same disruptions with the above simulation, Fig. 5 shows the performance of a supply chain with contingent supply.

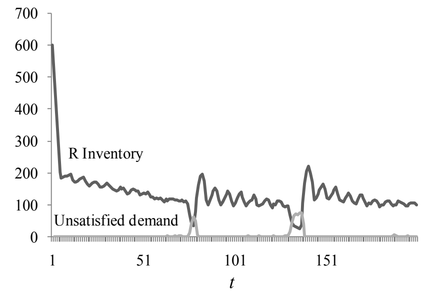

Fig. 5. Performance graph of supply chain with contingent supply

Compared with Fig. 4 and Fig. 5, Table 3 lists the differences of disruption impacts between the supply chain with and without a contingent supplier.

Under the same disruptions with the above simulation, we can obtain the performance of a supply chain with contingent supply. Table 3 lists the differences of disruption impacts between the supply chain with and without a contingent supplier.

Table 3. Comparison of the outputs between supply chain with and without a contingent supplier (Day: first disruption: 65-67, second 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	

5. Conclusions

This paper relies on system dynamics modelling to examine the impact of supply disruptions and the effects of contingent supply. We investigate the impacts of supply disruption on the retailer's inventory level and the customer's unsatisfied amount. We examine two purchasing strategies: no backup supply, and with a contingent supplier. And compare the retailer's profits to help the retailer choose the optimal strategy under different disruption risks. There are 3 conclusions. First of all, compared with the disruption time, there is clearly a delay of inventory fluctuation for the retailer, and the duration of retailer's fluctuation is much larger than the duration of supply disruption. Secondly, there is a sudden increase of the retailer's inventory level after supply disruptions. Thirdly, the longer the supply disruption is, the heavier the fluctuation is.

This research can be extended by relaxing the assumptions made in this paper; for example, the buyer only has one backup supplier. In addition, it will be interesting to consider the lead time of the two suppliers - what if the delivery time of the main and the backup suppliers is different? It may be also worthwhile to derive theoretical results confirming some of the implications suggested by the numerical examples in this paper.

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References

[1] Ellisa SC, Henryb RM, Shockley J. Buyer perceptions of supply disruption risk: A behavioural view and empirical assessment. *Journal of Operations Management* 2010; **28**:34-46.

[2] Naim MM. The impact of the net present value on the assessment of the dynamic performance of e-commerce enabled supply chains. *International Journal of Production Economics* 2006; **104**:382-393.

[3] Özbayrak M, Papadopoulou TC, Akgun M. Systems dynamics modelling of a manufacturing supply chain system. *Simulation Modelling Practice and Theory* 2007; **15**:1338-1355.

[4] Georgiadis P, Besiou M. Sustainability in electrical and electronic equipment closed-loop supply chains: A System Dynamics approach. *Journal of Cleaner Production* 2008; **16**:1665-1678.

[5] Potter A, Lalwani C. Investigating the impact of demand amplification on freight transport. *Transportation Research Part E: Logistics and Transportation Review* 2008; **44**:835-846.

[6] Kim I, Springer M. Measuring endogenous supply chain volatility: Beyond the bullwhip effect. *European Journal of Operational Research* 2008; **189**:172-193.

[7] Campuzano F, Mula J, Peidro D. Fuzzy estimations and system dynamics for improving supply chains. *Fuzzy Sets and Systems* 2010; **161**:1530-1542.

[8] Springer M, Kim I. Managing the order pipeline to reduce supply chain volatility. *European Journal of Operational Research* 2010; **203**:380-392.

[9] Saeed K. Trend forecasting for stability in supply chains. *Journal of Business Research* 2008; **61**:1113-1124.

[10] Jahangirian M, Eldabi T, Naseer A, Stergioulas LK, Young T. Simulation in manufacturing and business: A review. *European Journal of Operational Research* 2010; **203**:1-13.