

Statistical Inventory Management in Two-Echelon, Multiple-Retailer Supply Chain Systems

H. T. Lee, Department of Business Administration, National Taipei University, Taiwan

Z. M. Liu, Department of Business Administration, Ming Chuan University, Taiwan

ABSTRACT

Members of supply chain carry inventory for different purposes. To effectively reduce the cost of inventory, information sharing mechanism is the key. The inventory can be managed in two ways in supply chain systems. The first one is the centralized inventory management system, in which, the information of inventory is highly exchanged among supply chain members. The other is the decentralized supply chain system. This paper aims at the decentralized inventory management systems with one supplier and multiple retailers. Only partial inventory information is shared and each member in the supply chain can select their own inventory replenishment policies. Simulation models have been built to simulate these scenarios with the demand variation and market share changes at the retailer side considered. In addition to the traditional replenishment method, e.g. lot size-reorder point (s, Q) model, and periodic review (R, S) model, the statistical inventory management techniques have been applied and compared. Based on lower inventory levels, higher fill-up rate, and higher turnover rate, practical suggestions for inventory management are given to both of the upstream and the lower stream of supply chain.

Keywords: supply chain management, decentralized inventory control, bullwhip effect

INTRODUCTION

The competition among enterprises becomes keener as economic globalization approaches. Industries try to re-compile the material, logistics, financial, and information flows along their supply chains to boost their market share while cutting down costs. The idea of re-compiling business flows and redefining the boundaries among companies is called supply chain management (SCM). Inventory control plays an important role in the demand-supply relationship. Carry inventories which cost up to 40% of their cost of goods sold a year, is one of the expenses that industries are anxious to reduce. On the other hand, inventory provides a good chance for customer satisfaction and smoothes the production planning processes, which are crucial to the entire supply chain. Besides the traditional inventory management problems e.g. when to order, and how much to order, researches report order swing due to downstream supply chain partners' fluctuation of sales. The swing is amplified as the order moves up to the supply chain. The phenomenon is called "bullwhip effect" (Lee and Billington, 1993). Bullwhip gives great impact to the cost and customer satisfaction in supply chain and it can never be totally eliminated. Lee *et al.* (1997) identify four major causes of the bullwhip effect as: (1) demand forecast updating, (2) order batching, (3) price fluctuation, and (4) rationing and shortage gaming. Many research aimed to reduce the impact of bullwhip effect. Demand can variation is one of the important factor that cause bullwhip effect. Metters (1997) shows that the demand seasonality brings about bullwhip effect and adds that reducing the demand variance-to-mean ratio can increase product profitability by 10 to 30%. Fransoo and Wouters (2000) measure the bullwhip effect on the basis of daily demand variability of convenience foods and prove that bullwhip effect can be reduced by eliminating the amplification in demand variability.

Information sharing is crucial while operating supply chain and it provides opportunities to further matching the upstream supply with downstream demand. Cachon and Fisher (2000) emphasis that solely exchanging the inventory related information is not enough; using information sharing to cut lead time and order size decreasing will gain operational advantages. Chen et al (2000) discuss the importance of information sharing by taking into account the demand forecast and order lead time in a two-stage supply chain system. Dejonckheere et al (2003) analyze four forecasting methods with order-up-to replenishment policies to avoid bullwhip effect in supply chain systems. Disney

and Towill (2003) develop an order policy to minimize bullwhip effect by controlling the inventory variance. Reyes (2005) presents an optimization model for a single period inventory problem in two-echelon supply chain.

The inventory control in supply chain is usually modeled as multi-echelon inventory decision problems. The echelons may consist two or more of the following characters, supplier(s), manufacturer(s), warehouse(s) and retailer(s). Three inventory control mechanisms, namely centralized, decentralized, and hybrid systems, with different degree of information sharing are usually used for making inventory related decisions. In a centralized system, the inventory replenishment decisions are made by a central decision maker. In a decentralized system, inventory replenishment decisions are made by local decision makers. The hybrid system is the mix of the previous two. Many researchers (Abdul-Jalbar *et al.*, 2003, Axsäter, 2001, 2003; Forsberg, 1996; Ganeshan, 1999; Ng *et al.*, 2001; Seo *et al.*, 2002, and Tee, 2002) are credited to derive the exact or optimal solutions mathematically on both systems under different assumptions. However, some of these models need to be adjusted in practical environments.

Watts *et al.* (1994) and Pfohl *et al.* (1999) use statistical process control (SPC) technique for inventory management. Pfohl *et al.* (1999) develop a set of replenishing rule to dynamically adjust the amount of replenishment and inventory levels. The SPC inventory system performs well with different classes of products (A, B, and C products) accordingly. Lee and Wu (2006) develop a statistical process inventory control (SPIC) system inspired by Watts *et al.* (1994) and Pfohl *et al.* (1999) in a one-supplier-one-retail decentralized supply chain and demonstrate the superiority of SPIC over the traditional lot size-reorder point order-quantity (s, Q), and periodic review order-up-to (R, S) replenishment systems.

This study further extends Lee and Wu's study into a single supplier multi-retailer environment with market share variations at the retailer side. The inventory replenish policies considered are (s, Q) and (R, S) systems. The performance metrics used are inventory levels, fill-up rate, and turnover rate. The SPIC method developed by Lee and Wu (2006) is applied as well and the results will be compared with the results from traditional (s, Q) and (R, S) replenishment policies. At last, replenishment suggestions based on the objective of cutting the inventory expenses throughout the entire supply chain are given.

SUPPLY CHAIN MODELLING AND SIMULATION

The studied model assumes that a single product with a constant unit price is stocked in a two-echelon supply chain system. The system contains one supplier and multiple retailers. Both sides of the supply chain members can select their own replenishment policies. The market share of the retailers varies and the customer demand surges. The replenishment policy is first-come-first-serve (FIFO). Once multiple orders appear in the same day and the order amount exceeds the inventory level of supplier, the retailers will receive partial stock up. The order will be fulfilled when the supplier has enough stocks. Other assumptions are listed as follows.

- The time needed for order replenishment is short (i.e. one day) compared to the time between two orders.
- All excessive demand between the retailer and supplier is backordered. The order will be fulfilled as soon as the inventory is available.
- The excessive demand between retailers and customers is considered as loss of sales.
- The producer has unlimited capacities.

The business logic is illustrated in Figure 1. A MS Excel VBA program is developed to assist of model building and simulation.

Illustrative Example

The studied system contains one supplier and two retailers. The demand rate is 48,000 units per year, and the demand can be represented as Poisson distribution. The standard deviations of the supplier and vender are 45 and 38 units per day respectively. The holding costs for supplier and vender are 600 and 300 and the setup costs for supplier and vender are 3,000 and 5,000. The service level of the supplier and vender are set to 95% and 99% respectively. The market share of the two retailers varies from 50%-50% to 90%-10%. Retailers suffer from demand surge, and the

variation of demand is from 40% to 80% of their sale. Six models are built and tested for different scenarios. The models and the replenishment systems used are listed as follows.

- Model 1: Both the upstream and downstream companies use (R, S) system.
- Model 2: The upstream uses (R, S) and downstream companies use (s, Q) system.
- Model 3: The upstream uses (R, S) and downstream companies use (R, S) and (s, Q) systems.
- Model 4: The upstream uses (s, Q) and d downstream companies use (R, S) system.
- Model 5: Both the upstream and downstream companies use (s, Q) system.
- Model 6: The upstream uses (s, Q) and downstream companies use (R, S) and (s, Q) systems.

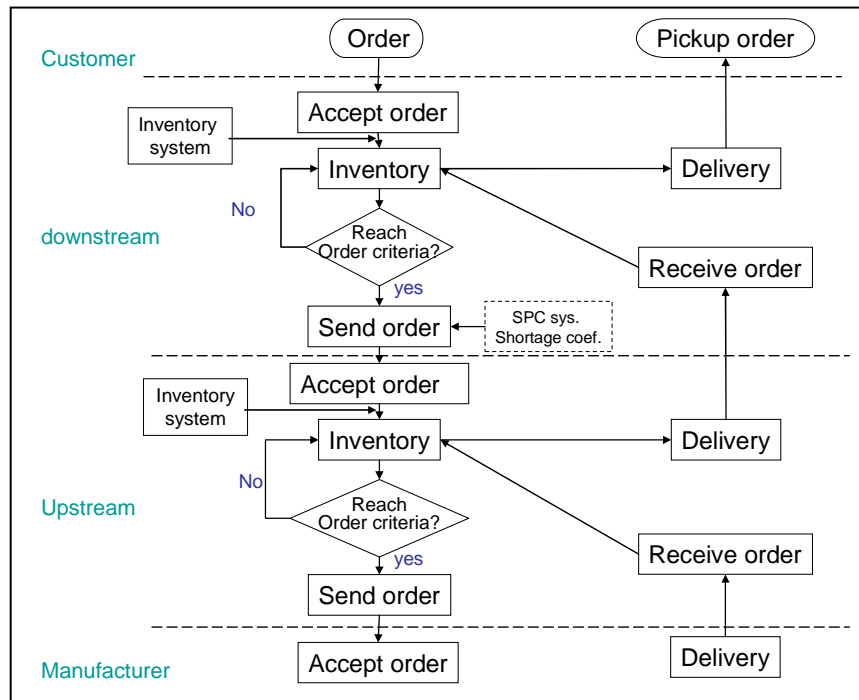


Figure 1: Business logic of the studied problem

RESULTS

Part of the results is listed in this section. Table 1 to Table 3 list some performance indexes for inventory for different market share combinations. The performance indexes considered are: average number of backorder, average turnover rate, and average inventory level, and the market share combinations used in this study are 50-50%, 70-30%, and 90-10%.

Table 1: Comparison between the inventory systems with 50%-50% market share

	Traditional inventory system						SPC inventory system					
	Average number of backorder		Average turnover rate		Average inventory level		Number of backorder		Average turnover rate		Average inventory level	
	Up stream	Down stream	Up stream	Down stream	Up stream	Down stream	Up stream	Down stream	Up stream	Down stream	Up stream	Down stream
Model 1	24	2.5	57.11	39.08	840.54	592.43	21	1.5	63.8	33.6	752.39	726.43
Model 2	31	9	83.62	55.14	574.04	418.73	26	8	85.36	52.24	445.65	502.49
Model 3	31	7	75.01	48.38	642.06	476.61	20	2.5	61.02	46.39	769.54	499.99

Model 4	23	2.5	64.34	39.26	558.91	588.63	21	2	72.82	41.32	603.91	525.89
Model 5	27	3.5	95.57	48.84	493.21	469.53	25	2	67.57	45.08	694.88	508.4
Model 6	20	6.5	97.14	50.78	438.88	457.34	18	3	99.83	50.11	472.16	469.95

Table 2: Comparison between the inventory systems with 70%-30% market share

	Traditional inventory system						SPC inventory system					
	Average number of backorder		Average turnover rate		Average inventory level		Number of backorder		Average turnover rate		Average inventory level	
	Up stream	Down stream	Up stream	Down stream	Up stream	Down stream	Up stream	Down stream	Up stream	Down stream	Up stream	Down stream
Model 1	9	2	52.35	36.99	916.76	596.1	11	1.5	54.34	31.17	883.33	741.74
Model 2	45	7.5	57.31	48.16	837.50	460.08	28	9.5	79.27	39.90	592.32	592.85
Model 3	22	3.5	64	43.01	748.84	514.64	20	3.5	73.39	45.04	639.79	490.74
Model 4	9	2	56.47	42.47	478.69	576.44	11	1.5	48.47	38.09	843.87	533.72
Model 5	35	6.5	94.31	47.14	499.78	467.75	27	5	74.48	47.09	630.45	485.62
Model 6	45	5.5	90.52	41.98	509.56	523.18	36	3.5	88.17	39.96	534.62	547.24

Table 3: Comparison between the inventory systems with 90%-10% market share

	Traditional inventory system						SPC inventory system					
	Average number of backorder		Average turnover rate		Average inventory level		Number of backorder		Average turnover rate		Average inventory level	
	Up stream	Down stream	Up stream	Down stream	Up stream	Down stream	Up stream	Down stream	Up stream	Down stream	Up stream	Down stream
Model 1	22	6	52.81	31.39	908.85	579.92	17	5.5	54.3	24.32	645	803.59
Model 2	31	11	55.17	43.65	870.04	429.69	28	10.5	66.34	45.14	707.79	384.35
Model 3	29	9.5	58	34.74	829.6	445.55	34	7.5	64.49	36.55	728.08	504.25
Model 4	41	3.5	95.66	32.76	492.77	551.81	37	3	97.78	30.15	675.43	487
Model 5	42	3.5	97.26	42.97	484.66	436.03	35	3.5	75.59	29.19	621.16	655.75
Model 6	33	4	92.75	33.15	508.03	539.33	28	3.5	91.6	30.71	514.6	621.37

CONCLUSION MARK AND FEUTURE WORK

The SPC controlled inventory systems have overall advantages over the traditional methods in the category of backorder. However, it suffers from higher inventory levels. While the number of backorder is important, the (R, S) replenishment system is recommended whether the traditional or SPC inventory control method is used. Table 4 to Table 7 summarize the recommendations under different circumstances.

Table 4: Recommendations of replenishment combination with equal market share

			Upstream supplier			
			Inventory turnover rate		Number of backorder	
			(s ,Q)	(R, S)	(s ,Q)	(R, S)
Downstream vendor	Tradition	(R, S)& (R ,S)				recommend
		(s ,Q)& (s ,Q)				
		(R ,S)& (s ,Q)	recommend			
	SPC	(R, S)& (R ,S)				recommend
		(s ,Q)& (s ,Q)				
		(R ,S)& (s ,Q)	recommend			

Table 5: Recommendations of replenishment combination with unequal market share

			Upstream supplier			
			Inventory turnover rate		Number of backorder	
			(s ,Q)	(R, S)	(s ,Q)	(R, S)
Downstream vendor	Tradition	(R, S)& (R ,S)				recommend
		(s ,Q)& (s ,Q)	recommend			
		(R ,S)& (s ,Q)				
	SPC	(R, S)& (R ,S)	recommend			recommend
		(s ,Q)& (s ,Q)				
		(R ,S)& (s ,Q)				

Table 6: Recommendations of replenishment combination with mild demand variation

			Upstream supplier			
			Inventory turnover rate		Number of backorder	
			(s ,Q)	(R, S)	(s ,Q)	(R, S)
Downstream vendor	Tradition	(R, S)& (R ,S)				recommend
		(s ,Q)& (s ,Q)	recommend			
		(R ,S)& (s ,Q)				
	SPC	(R, S)& (R ,S)				recommend
		(s ,Q)& (s ,Q)				
		(R ,S)& (s ,Q)	recommend			

Table 7: Recommendations of replenishment combination with large demand variation

			Upstream supplier			
			Inventory turnover rate		Number of backorder	
			(s ,Q)	(R, S)	(s ,Q)	(R, S)
Downstream vendor	Tradition	(R, S)& (R ,S)				
		(s ,Q)& (s ,Q)			recommend	
		(R ,S)& (s ,Q)	recommend			
	SPC	(R, S)& (R ,S)				
		(s ,Q)& (s ,Q)			recommend	
		(R ,S)& (s ,Q)	recommend			

It is difficult to quantify the bullwhip effect. In this paper, we focused on bullwhip effect based on inventory variations within a simple two echelon supply chain framework. Suggestions are offered for different objectives of the pull supply chain members. The SPC inventory control technique is found to be useful while backorder is important.

It is of our great interest to introduce the lost of sales costs in this frame work, extend the supply chain to a multi-echelon one, theoretically validate the results, and choose different replenishment policies in future studies.

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