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Research Article

An Approach to Real Multi-tier Inventory Strategy and Optimization

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Abstract: Multi-tier goods inventory strategy and optimization in large enterprises are hard nuts to crack. Thus goods distribution network often either carry excess total inventory, or lower customer service level due to improper goods safety stock in the network. Two typical approaches for managing multi-tier inventory and their pitfalls are examined in this study. Based on the review, real multi-tier inventory strategy and optimization tools are presented with a simulation result to reflect the impact of multi-tier strategy on the network inventory optimization. The result shows that uncertainties in supplier delivery lead-time and/or demand variations will be the two most important factors with non-linear impact.

Keywords: Lead time, multi-tier inventory, service level, safety stock, uncertainties

INTRODUCTION

China distribution and manufacturing enterprises have experienced high speed increase in the past 20 years, but their inventory levels increased even higher than their business, which bring significant risk for their business when the economy goes down. They have to face great challenge in the inventory issues.

Managing inventory can be a daunting task for an enterprise with thousands of products that are located in hundreds of locations. The challenge is even greater when the locations are situated in different tiers of the enterprise's distribution network. In such multi-tier networks, new product shipments are first stored at those central facilities then to the stores locations. This is a common distribution model for many retail chains as well as for large distributors and manufacturers. For example, a national retailer of automotive aftermarket parts and equipment manages more than 25,000 Stock-Keeping Units (SKUs) that are spread out across 15 DCs and more than 900 stores. And a global manufacturer/distributor of furniture fittings carries inventory in European DCs located near its factories before shipping the finished goods to 15 stores worldwide which serve end customers.

It is well established and relatively easy to managing single-point inventory, since there are many strategies of replenishment and tools to estimate the appropriate safety stock level (Krajewski and Ritzman, 2002). But managing multi-tier inventory is hard to achieve true network inventory optimization, because normal replenishment strategies are applied to only one tier without regard to its impact on the other tiers. A network view of inventory usage up and down the demand chain is absent when you are only dealing with a single location. These pitfalls can create substantial negative consequences, including the following (Simchi-Levi *et al*., 2000):

- The network carries excess inventory in the form of redundant safety stock.
- End customer service failures occur even while adequate inventory exists in the network.
- Store locations experience undesirable stockout, while service between tiers is more than acceptable.
- External suppliers deliver unreliable performance, because they have received unsatisfactory demand projections.

This study will examine several approaches for solving the thorny problem of managing inventory in a multi-tier network and will present a method for setting a proper tier-strategy according to customer service requirement, external suppliers' shipping lead time and its variations (arrival may be delayed). When two-tier strategy is determined, managing internal DC to store lead time and reducing uncertainties in the product transfer are most two critical factors, in order to minimize the total safety inventory in multi-tier network while meeting all of your customer service goals.

MANAGING INVENTORY IN MULTI-TIER NETWORKS

The complexities of managing inventory increase significantly for a multi-tier distribution network with multiple storage locations (e.g., a network comprising a central warehouse and downstream customer-facing locations-stores).

Table 1: Inventory drivers for SKU's at store level

Drivers	Sym	Description
Demand	D	Rate of product flow out of the DC; usually express the amount of goods demand in day or week or month.
Demand variation	v	Fluctuation of the product outflow from period to period, also expressed in standard deviation
Lead time	L	Expected time delay between ordering and having new product available to fulfill demand
Lead time variation	s	Fluctuation of the lead time from order to order, especially those late-arrived orders, also expressed in standard deviation
Service level	SL	Store's service commitment to end customers
Service level factor	k	Used in safety stock calculation which depend upon the "Service Level"
Replenish-ment Frequency	R	Frequency or time intervals with which the DC checks its inventory position to see if a new order is needed
Order supply strategy	n/a	The store's supply objective, which depends on the economic trade-offs among carrying inventory, handling, transportation and purchase cost
Inventory level	n/a	The store's available stock, taking into account the on-hand inventory, on-order quantities, back orders and committed stock

All locations are under the internal control of a single enterprise. Instead of simply replenishing the warehouse that sit between your supplier and your end customers, as in the single tier situation, you also need to contend with the problems of replenishing another distribution point between your supplier and your DCs. The objective of multie-tier inventory management is to deliver the desired end customer service levels at minimum network inventory, with the inventory divided among the various locations.

Single tier inventory review: Let us review the single-tier inventory problem, in which the distribution network is Supplier->Store->Customers. Table 1 describes the inventory drivers for a SKU that is located at store. In this situation, the lead times are between the store and its external supplier. The enterprise's order supply strategies depend on its internal cost factors, such as handling and carrying inventory and the external supplier's ordering constraints. The replenishment quantities depend on a combination of internal and external factors.

In single tier inventory management, safety stock calculation will use the following formula as it has been widely applied the textbook or used in the industry (Shapiro, 2001):

$$SS = k \cdot \sqrt{v^2 \cdot L + D^2 \cdot s^2}$$

Complexities in multi-tier network inventory: Now consider the same product in a multi-tier network that includes an DC between the suppliers and the stores. The same inventory drivers described in the Table 1 apply for the SKU at the DC. However, some significant issues emerge (Young and O'Burne, 2001):

- What is the proper measure of demand to the DC and how should this demand be forecasted?
- How do you measure the demand variation into the DC?
- How do the orders from the DC to the supplier affect the order supply strategy?
- How do you factor the individual store inventory levels into the DC replenishment decisions?
- How do the inventory drivers at the DC, such as the replenishment review frequency and the service level goal, affect inventory and service levels at the store level?
- For a limited supply situation at the DC, how should you allocate product down to the stores?

Because the store also stocks inventory, the replenishment decision at each store also must address some new questions because of its relationship with an internal supplier:

- How will the ordering constraints imposed by DC (internal supplier) influence the store's order supply strategy?
- To achieve the targeted service level commitment with its end customers, should the store use the same service level goal when the DC is available as a backup source for end customers?
- Do the external supplier lead time and lead time variation still play a role in the store's replenishment strategy?

Figure 1 illustrates how the inventory drivers are linked in the two tiers. The node labeled "store" stands for all the stores that stock the same product. The approaches for setting these control variables in the single-tier case are well known, but how should you set the control variables in the multi-tier case? Today, one of following two approaches is typically used in the enterprises:

- Sequential Approach-apply the single-tier approaches to each tier in the network.
- Use Distribution Requirements Planning (DRP) approach.

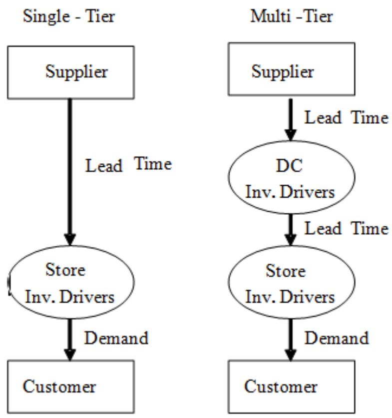

Fig. 1: Inventory drivers

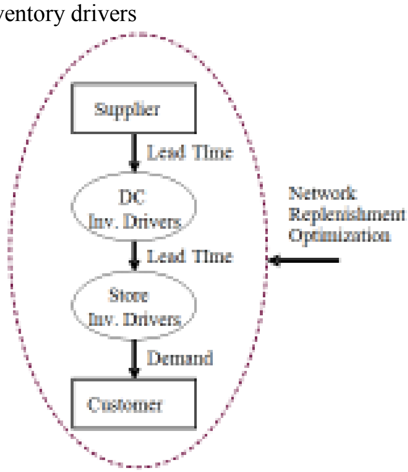

Fig. 2: Real multi-tier approach

REAL MULTIPLE-TIER-STRATEGIES AND OPTIMIZING TOOLS

When an enterprise wants to use a real multi-tier approach in managing inventory, the primary objective is to minimize the total inventory in all tiers and locations (the DC and all the stores) while meeting service commitments to end customers, as shown in Fig. 2. Even though inventory is the main focus, transportation (transferring from DC to stores) and warehouse operations expenses also are kept in line, because their cost factors are part of the optimization. The tool for multiple-tiers optimization have multiple parameters set manually to calculate total inventory, especially safety stock level as percentage of demand level, which is the most important factor to consider warehouse and transfer costs globally. The characteristics of the optimizing tools include:

- A set of spreadsheets using Microsoft EXCEL with macro code.
- Using real sales history data or random data generator.
- Set multiple parameters according to drivers in two-tier inventory, such as overall service level, lead times to supplier and to DC, demand and variations at each stores, lead time variation from suppliers, etc.
- Parameters set manually or automatically through macro code
- Calculate total inventory level, especially safety stock.

By pooling the demands from many stores into DC level, the demand variation at DC will be significant reduced. This principle has been considered into the tools to help enterprise when optimizing multi-tier network.

$$v_{pooled} = \sqrt{\sum_i v_i^2}$$

With a real multi-tier approach, demand forecasting and inventory replenishment decisions are made at the enterprise level in a single optimization exercise rather than in a sequence of sub-exercises for each tier location. Specifically, to apply the real multi-tier approach successfully, enterprises must set proper tier strategy for every SKU category. The following critical principals have to be considered.

- **Determine tier strategy according to SKU's supply and demand characteristics:** Not all SKU's need to be tiered, enterprise must make right decision on the tier strategy. Typically considerations include supply and demand characteristics-much longer lead time to supplier than to DC, or significant lead-time or demand variations exist. In section IV of this study, a simulation results will be presented to show the inventory saving percentage in different supply and demand situation (Brown *et al*., 2005).
- **Avoid multiple independent forecast updates in each tier:** The primary customer demand signal and other information at the DCs drive the forecasts in all tiers.
- **Account for all lead times and lead time variations:** In each tier, the replenishment decisions account for lead times and lead time variations of all upstream suppliers, not just the immediate suppliers. Enterprise must know that any internal uncertainties will increase the safety stocks in the network.
- **Monitor and manage the bullwhip effect:** The enterprise measures the demand distortion and determines the root causes for possible corrective actions.
- **Enable visibility up and down the demand chain:** Each tier takes advantage of visibility into the other tier's inventory levels-on hand, on order, committed and back ordered. At the stores, this negates any

need for shortage gaming. At the DC, visibility into store inventories improves projections of demand requirements (Kinaxis, 2008).

- **Synchronize order strategies:** Synchronizing the ordering cycles at the stores with DC operations reduces lead times and lead time variation between the DC and stores.

SIMULATION ON TIER STRATEGIES' IMPACT ON INVENTORY REDUCTION

Characteristics of supply or demand have significant impact on the strategies using tiered inventory-DC level for polling the safety stock and store level for economic cycle stock. By using the

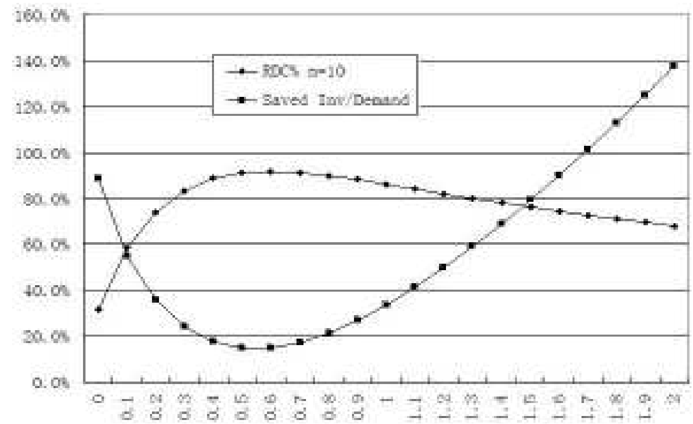

Fig. 3: Base scenario simulation result

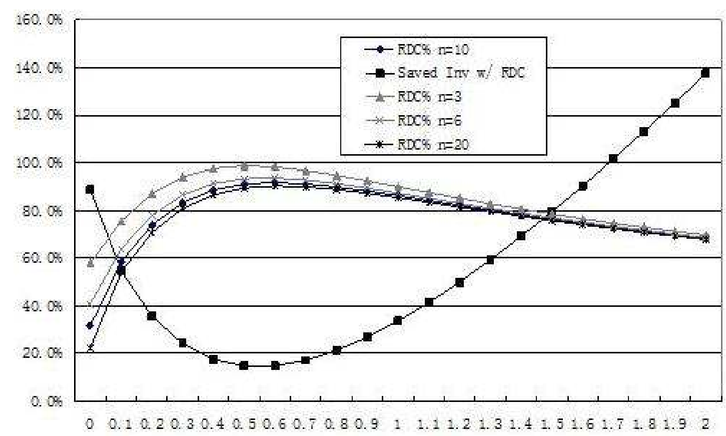

Fig. 4a: SS% -DC over stores

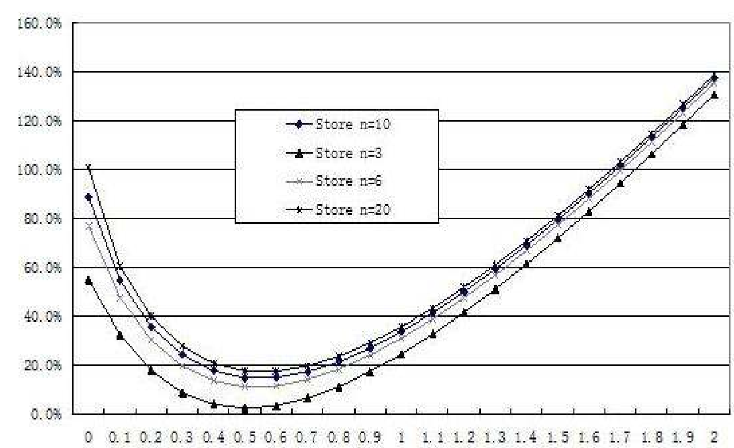

Fig. 4b: SS reduction as demand %

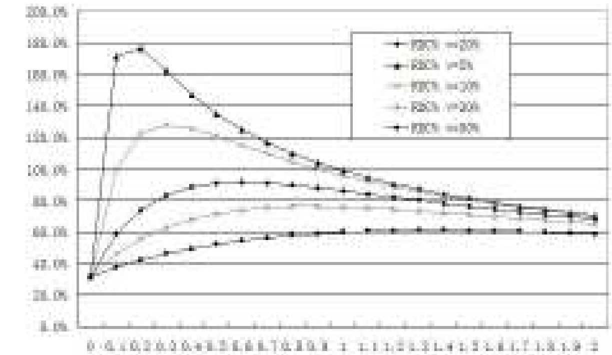

Fig. 5a: SS%-DC over stores

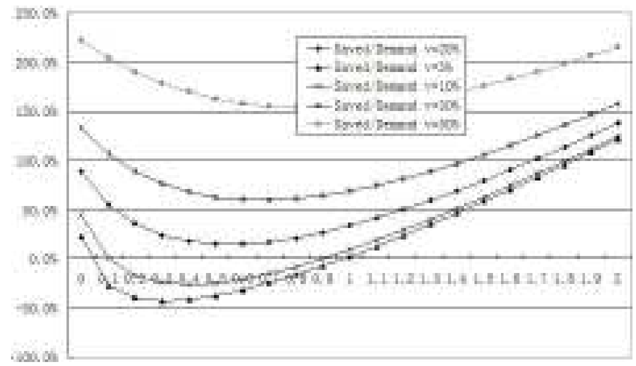

Fig. 5b: SS reduction as demand %

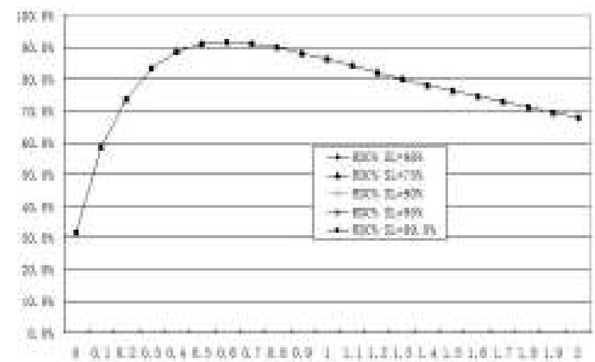

Fig. 6a: SS%-DC over stores

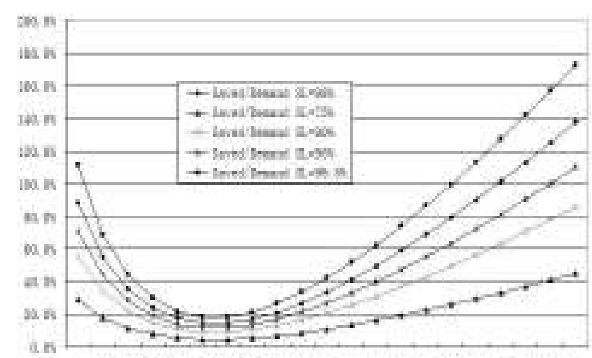

Fig. 6b: SS reduction as demand %

inventory optimization tools, a simulation research is performed under different scenarios. Simulation results showed that supply lead-time and variations will be the most factors in determining the tier strategy for SKU's.

We will see the graphics to show network inventory reduction percentage (%) as the supply lead time variations changing from 0 (guaranteed delivering) to 2 days (means 20% uncertainty in supply). Then the curves on the graphics will be distorted for different scenarios which reflecting changes in number of stores, demand uncertainties and service level commitment.

The inventory reduction percentage will presents in two ways-one is total safety stock inventory at DC (pooling) over which at stores without using DC. Another is inventory reduction as percentage of demand level, which is much concerned in retail and distribution enterprises.

Base scenario: As shown in Fig. 3. One DC for ten stores (n = 10). Overall service level set at 98% (SL = 98%), Lead time to supplier in days (Lu = 10).

Simulated scenario A: Store numbers at n = 3, 6, 10 and 20. Simulation results are shown in Fig. 4a and b.

Simulated scenario B: Demand variations at v = 5, 10, 20, 30 and 50%, respectively. Simulation results are shown in Fig. 5a and b.

Simulated scenario C: Service levels at SL = 75, 90, 95, 98 and 99.5%, respectively. Simulation results are shown in Fig. 6a and b.

CONCLUSION

Uncertainties in supply and/or demand are two most critical drivers for applying multiple-tier as safety stock pooling strategy. A multi-tier distribution network presents many opportunities for inventory optimization that the enterprise must pursue to offset potential increases in transportation, warehouse and occupancy costs. The key to achieving those savings is to use a real multi-tier strategy to manage inventory. It is not a simple task to pursue such a strategy because of the multiplicities of inventory drivers and the complexities in modeling the interactions of the drivers between tiers. Nevertheless, the benefits are worth the effort. Taking the right approach can yield rewards on both sides of the inventory equation-better customer service with less inventory. Using a multi-tier approach is the ultimate win-win strategy for inventory management.

Further research under planning will focus on real data collection from retail and distribution enterprises. Based on the daily goods import and export in their DCs and RDCs, we will make detailed analysis using statistical tools, like SPSS or MiniTAB, to find the characteristics (mean and standard deviation) in the goods streaming. With these statistics characters, in combining with the tools provided in this study , we could give these enterprises proper suggestion in setting their inventory levels in every RDCs, as well as solutions for running the inventory replenishment, in order to archive higher stock turnover rate while keeping competitive customer service levels.

ACKNOWLEDGMENT

The study is based on author's research project on inventory optimization for distribution and retail network. Key initiatives include discovering critical issues in multi-tier inventory optimization using traditional approaches, like DRP or serial single-tier inventory cascade method. A set of simulation and optimization tools introduced in this study with some simulation results have great values for large scale distribution enterprises. Academic value is also obvious since multi-tier inventory has been constantly focused area in management science.

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