STRATEGIC POSITIONING OF INVENTORY IN SUPPLY CHAIN MODELS

By

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Chapter 1

Introduction

A key feature of present day business is the idea that it is supply chains compete, not companies (Christopher, 1997), and the success or failure of supply chains is ultimately determined in the marketplace by the end consumer. So we are now entering the era of "network competition" where the prizes will go to those organizations which can better structure, co-ordinate and manage the relationships with their partners in a network committed to better, closer and more agile relationships with their final customers. The linchpin for competitive success is getting the right product, at the right price, at the right time to the consumer by responding rapidly, effectively and efficiently to changes in the marketplace. Managing inventory and achieving quick response to order in supply chain is a complex task due to the diversity of product and process characteristics, demand patterns and stocking profiles of stock keeping units as its various members. There is a drive to achieve world-class customer service levels coupled with minimum reasonable inventory (MRI) (Towill, 1996).

The quest for quick and efficient supply chains facilitated new paradigms like "leagility" (Naylor et.al, 1997. The new concept of leagility was developed by combining the two paradigms of leanness and agility, and could enable highly competitive supply chains capable of winning in a volatile and cost-conscious environment. One method of successful combination of the lean and agile paradigms is through the creation of a "de-coupling point" that uses strategic inventory (Christopher and Towill, 2001). The idea is to hold inventory in some generic or modular form and only complete the final assembly or configuration when the precise customer requirement is known. The decoupling point is the point at which strategic stock is often held as a buffer between fluctuating customer orders and/or product variety and smooth production output (Hoekstra and Rome, 1992). The principle is simple, if the economic production quantity of a downstream constituent is perfectly aligned and synchronized with the economic unit load of transportation consumption, there should be minimum finished goods and raw material inventory. But there has been no specific method explored until now for calculating the point of strategic inventory in supply chain models.

The issue of accurate positioning of inventory is not confined to supply chains itself. It also exists in assembly systems. This leads to exploring new concepts in production control system like the "Coupling Point Production Control System" (Mitsukuni et.al, 1997). A comparison of the coupling point production control system and de-coupling point principles shows that they are almost identical, except that they are implemented at different levels of a supply chain. This research shows how the two concepts of de-coupling point and coupling point can be blended successfully to develop an efficient inventory positioning strategy for supply chains. The theory and formulations used in the coupling point production control system are implemented in a broader perspective in the form of a supply chain strategy. The assumptions are that the demand lead time is constant and is determined based on customer characteristics and requirements, and supply lead time varies and is normally distributed. These formulations, along with the principle of de-coupling point solve the issue of where the point should be strategically located. Also positioning inventory strategically using the new principle eliminates inventories between the point and customer and also meets one of the key requirements, which is the quick response to orders.

Chapter 2

Literature review

2.1 Importance of efficient Inventory Management

Inventory control, inventory management and inventory positioning are the three levels of strategic inventory management pyramid as shown in **Figure 1**. Companies have to excel on all three levels of the strategic inventory management pyramid to achieve superior inventory performance.

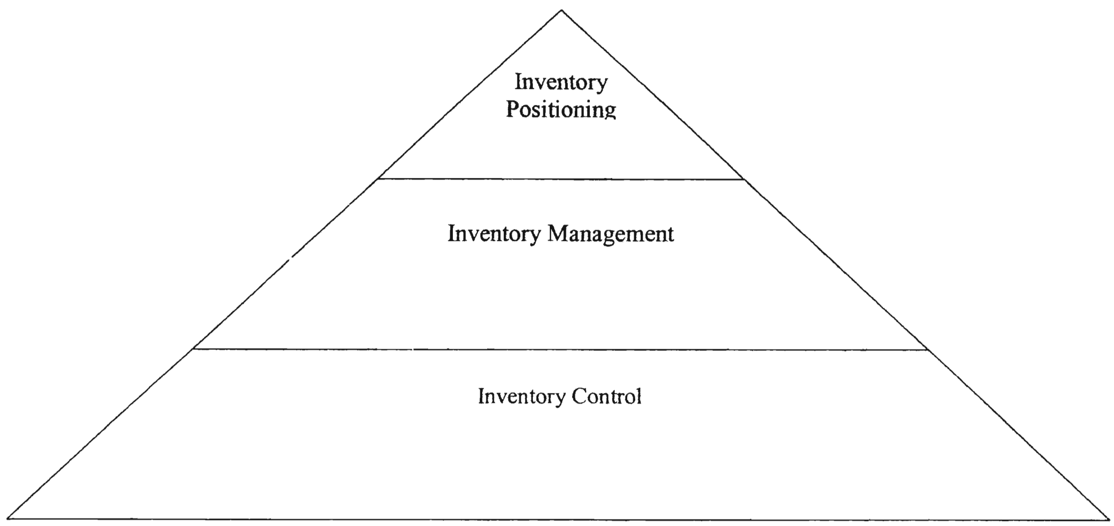

Figure 1. Strategic Inventory Management Pyramid (Copacino, 2000)

Inventories at all levels in a supply chain are driven by the alignment and synchronization of production quantity, unit load of transportation and consumption quantity. Efficient inventory management has become more difficult because customers require quicker response to their orders and the product life cycle has become shorter. Manufacturers have to keep larger inventory on stock to meet the variations and increase in demand. The ideal policy is to perfectly align and synchronize economic production quantity of a down stream constituent with the economic unit load of transportation consumption, resulting in minimum finished goods and raw material.

Development of an efficient inventory strategy is a very complex task due to organizational structures and individual business policies. Most organizations lack collaborative and analytic capabilities that let managers make the right decisions at the right time because of organizational barriers that hamper business units (manufacturing, sales, marketing, and distribution) from operating more closely and integrating their internal processes and information assets (Smith, 2000). The lack of collaborative decision making on a system level basis divest organizations from achieving one of the key objectives of supply chain management that is to be efficient and cost effective across the entire system (Simchi-Levi et al., 2000). Also, the consequence of such lack of collaborative decision making on a system level basis is conflicting objectives in a supply chain that are interlinked and influence the creation of more complex issues. These issues are sometime very difficult to resolve and result in diminution of supply chain efficiency. These conflicting objectives are well documented in supply chain literature and are as follows (Ingalls, 2000):

- Customers - Shorter order times, variety of products and low prices.
- Logistics - Quantity discounts, minimum inventory levels and quick replenishment.
- Manufacturer - Less change over, production efficiency and low demand variability.
- Supplier – Stable volume, mix requirements and flexible delivery times.

If the right decisions are not made on a system level, these conflicting objectives lead to complex trade offs. Well known tradeoffs in supply chain models are as follows (Ingalls, 2000):

- Lot size – Inventory trade off.
- Inventory – Transportation trade off.
- Lead time – Transportation Cost trade off.
- Product variety – Inventory trade off.
- Cost – Customer service trade off.

Organizations often fail in balancing this trade offs and the development of an efficient supply chain policy. Improved supply chain efficiency is achieved only when each element within the chain is operating as an independent subsystem with perfect coordination with other subsystems in the chain and contributing to improved efficiency of the entire chain (Chen, 1997). Each legitimate constituent within the supply chain must be able to create and add value to the product and when a downstream constituent produces the product, or does some value addition in the existing product for an upstream constituent to consume, costs are incurred along the supply chain from the point of production to the point of consumption. These costs are placed in five categories:

- Production cost
- Transportation cost
- Warehousing cost
- Inventory carrying cost.
- Internal material holding cost.

Out of all these costs, the cost related to inventory is very critical because the dynamics of the market (that is demand variance) have an impact on inventory levels and lead to increased safety stock requirements throughout the system if one wants to maintain a given service level. A reduction in service level will occur if appropriate levels of safety stocks are not kept. The results of such variations could be excessive inventory, poor product forecasts, insufficient or excessive capacities, poor customer service due to unavailable products or long backlogs, uncertain production planning (i.e., excessive revisions), and high costs for corrections, such as for expedited shipments and overtime. It is well documented as the "bullwhip effect" in the literature (L.Lee, et.al, 1997).

So, it is of utmost importance to balance inventory tradeoffs and have accurate inventory levels across the supply chain (Copacino, 1997). Also regardless of what type of inventory it is and whose capital is tied up in it; carrying inventory will ultimately add cost to the customers at the end of the supply chain. Management has realized the importance of positioning inventory strategically and strives to achieve quick response to orders and reducing inventories due to the following factors:

- Stock availability is a key dimension of customer service.
- Most companies have continued to emphasize the effective management of working capital, of which inventory investment is a key component.
- Companies focus on operational flexibility to respond to customer needs, for which low inventory levels are essential.

The need for effective management and scheduling of inventories led to development of production control systems that could support the managers to develop system wide efficient inventory policies and plan their production accordingly. Efforts are made to reduce the inventory levels and also to hold enough stock to achieve maximum customer satisfaction. The peak of the inventory management pyramid, inventory positioning is also critical as alignment of delivery quantity with economic production quantity affects several cost drivers in the supply chain (Chen, 1997).

2.2 Production Control Systems

As mentioned earlier, production control systems were designed to assist managers in effective planning of resources and to develop system wide policies. There are three production control systems that are widely used in the industry.

2.2.1 MRP

Materials requirement planning (MRP) is a computer based information system designed to handle ordering and scheduling of dependent-demand inventories (Stevenson, 1996). A production plan for a specified number of finished products is translated into requirements for component parts and raw materials by working backward, using lead time information to determine how much to order and when to order. As listed in **Figure 2**, an MRP system has three major components:

a) ***Master schedule*** – It states which items are to be produced, when they are needed and in what quantities. It also separates the planning horizon into series of time periods or time buckets, which are often expressed in weeks.

b) ***Bill of materials file*** – It contains a listing of all of the assemblies, sub-assemblies, parts and raw materials that are needed to produce one unit of a finished product.

c) ***Inventory records file*** – It is used to store information on the status of each item by time period. This includes gross requirements, scheduled receipts and expected amount on hand. It also includes other details for each item, such as supplier, lead-time, and lot size.

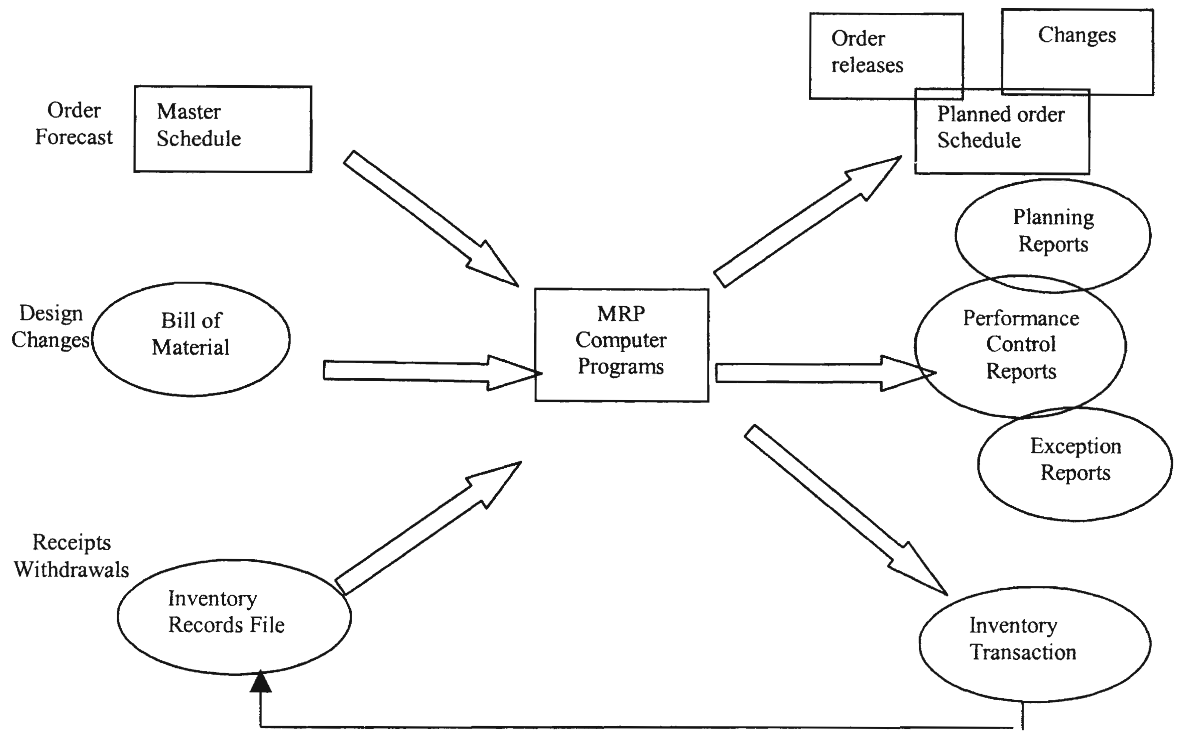

Figure 2. MRP System (Stevenson, 1996)

MRP offers a number of benefits for the typical manufacturing or assembly type of operation, including (Stevenson, 1996):

- Low levels of in-process inventories.
- The ability to keep track of material requirements.
- The ability to evaluate capacity requirements.
- A means of allocating production time.

In the 1980s MRP was expanded into MRPII, a much broader approach for planning and scheduling the resources of manufacturing firms. It is a second generation approach to planning which incorporates MRP but adds a broader scope to manufacturing resource planning because it links business planning, production planning, and the master production schedule.

2.2.2 Just-in-Time (JIT)

Just in Time refers to a production system in which both the movement of goods during the production and deliveries from the suppliers are carefully timed so that at each step of the process the next batch arrives for processing just as the preceding batch is completed (Stevenson, 1996). The foundation is made up of four building blocks – Product design, process design, personnel/organizational elements and manufacturing planning and control. The main benefits of JIT are as follows (Stevenson, 1996):

- Reduced levels of in-process inventories, purchased goods and finished goods.
- Reduced space requirements.
- Increase product quality and reduced scrap work and rework.
- Reduced manufacturing lead-times.
- Greater flexibility in manufacturing.
- Smoother production flow.

2.2.3 Kanban

Kanban is a "pull" system in which inventory falling below a critical number triggers more production. Managers assign a trigger number based on annual forecasts. When inventory reaches the critical number, the system signals the supplier to produce the next batch, using kanban tickets. By employing kanban tickets with its customers and later with suppliers, manufacturers eliminated the paperwork and time involved on a weekly and biweekly basis for quoting jobs and placing orders (Stevenson, 1996).

Although widely used, the MRP and JIT systems fall short in several areas (Gupta, 1997). MRP does not adjust the schedule if the manufacturing load exceeds capacity. To avoid uncertainty, MRP allocates fixed lead times to work orders and in reality lead times are not fixed. To make matters worse, they increase lead times and force manufacturers to increase safety stocks (Watanbe et al., 1991). JIT systems also result in increased transportation cost and congestion due to frequent deliveries (Stevenson, 1996). In JIT, lot size reduction can lead to inventory levels that last for only two or three hours of usage. In that case, even a traffic jam causing delayed deliveries can lead to stock-outs (Natrajan & Goyal, 1993). In MRP system inventories are necessary at the position of final products (Lagodimos & Andeson, 1993). In the JIT system and Kanban, inventories are positioned at each process. JIT is successful in shortening production lead times and decreasing sub assembly inventories, but with the globalization of manufacturing, suppliers are often located at great distance from the final product line, making transportation time an important factor. In case of any transportation delays, manufacturers are confronted with out of stock situations due to unavailability of raw material on time. MRPII is often confronted with out-of-stock or over stock situations due to faulty forecasts. For products with constant value addition, as they move upstream across the chain, positioning inventories at the final stages as in MRP system is costly because the value of a finished product is more as compared to the in-transit inventory. So the issue of accurate positioning of inventories lead to a new concept in production control systems called the "Coupling Point Production Control System" (Mitsukuni et.al, 1997). In the proposed production control system, the authors have concentrated inventories at the position where supply lead-time and demand lead-time are equal and the inventory and production plans are made at this position. It was proposed to solve drawbacks of MRP and JIT systems.

2.3 Coupling Point Production Control System

2.3.1 Theory and Principle of Coupling Point

The coupling point production system (CPPS) was developed at Institute of Advanced Business System – Hitachi ltd. and Department of Information Systems – Osaka University. The core concept of the CPPS is that inventories are positioned at the point where supply lead-time and demand lead-time are equal and inventory and production plans are made at this point.

Coupling Point (CLPi*) can be defined as follows----"the stock position where the supply lead time and the demand lead time are equal".

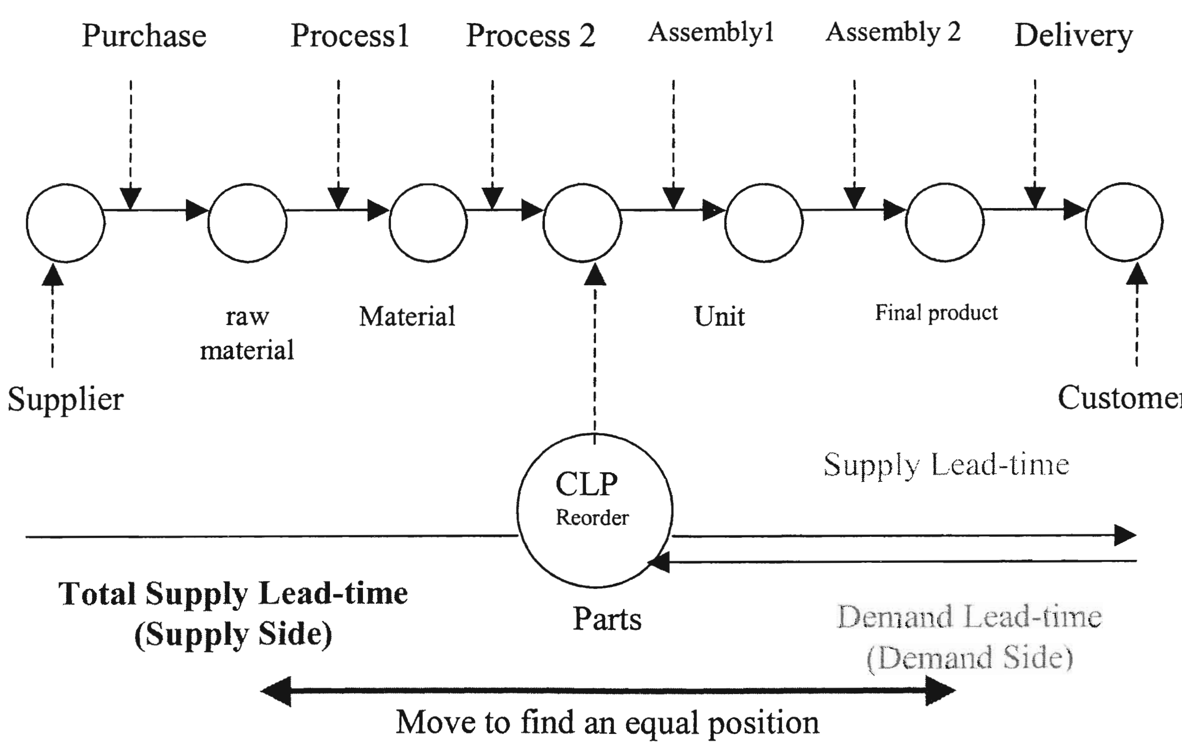

Figure 3. Coupling point production system (Mitsukuni et.al, 1997)

Figure 3 shows an example of CPPS in an assembly system. Each arrow shows a sub-process (processing, assembly etc.). There are various nodes in the system and each node could be an inventory stock position. These nodes could be various inventory positions in the same manufacturing site or inventory positions at multiple manufacturing sites. Products flow on the sub-processes from the supply side to demand side, and varieties of final products increase as they go to the demand side. Any node in this chain can be a coupling point. A coupling point is determined by two kinds of lead-time, the 'supply lead-time' and the 'demand lead-time'. Supply lead-time is defined as the time it takes to send products from a certain position in the process to a customer. It is the sum of all times like processing, assembling, delivery, etc for all sub-processes. Demand lead-time is defined as the time it takes for customers to receive products from ordering. Using these lead times, the coupling point is defined as the stock position where the supply lead-time and demand lead-time are equal. As demand lead-time and supply lead-time are changed, as the coupling point is moved towards supply or demand side, depending on the situation. Inventory and production plans are made at the new coupling point. This makes the need for inventories unnecessary on the demand side of the coupling point and also makes quick response to orders possible.

2.3.2 Calculating Coupling Point:

The coupling point, ***CLPi**** is given as

$$i^* = \left\{ \max_{1 \le i \le n} i \,\middle|\, \sum_{j=1}^{i} P(j) \le Ld \right\}$$

Where $\sum_{j=1}^{i} P(j)$ denotes the processing time of a sub-process i, where $i = 1, 2, \ldots, n$ increasing from demand side to supply side. *Ld* is the demand lead-time.

Two examples are shown in **Table 1** for an assembly process. Case 1 has sub-process times longer on the supply side and Case 2 has sub-process times longer on the demand side.

Table 1
Sub-Process processing times

Sub-Process	Case 1	Case 2
Delivery	1	1
Assembly 2	2	6
Assembly 1	2	4
Process 2	4	2
Process 1	6	2
Purchase	5	5

Table 2 shows supply lead times for both cases.

Table 2
Supply Lead Time

Sub-Process	Case 1	Case 2
Delivery	1	1
Assembly 2	3	7
Assembly 1	5	11
Process 2	9	13
Process 1	15	15
Purchase	20	20

For Case 1 if the demand lead time, *Ld*, is 8 days, then according to the definition of a coupling point, the coupling point is situated at process 2. Similarly, for Case 2 if the demand lead time, *Ld,* is 15 days, then coupling point is situated at process 1.

The main principle of CPPS is to reduce inventories on the demand side. The total inventory is reduced because the varieties of final products and value added of inventories are greater on the demand side.

2.3.3 Inventory Calculations at Coupling Point:

To achieve quick response to orders, the inventory at the coupling point must be adequately controlled, that is, necessary and minimum products must be stocked at coupling point. Authors (Mitsukuni et.al, 1997) have made certain assumptions for computing inventory at the coupling point.

a) The authors have assumed that the replenishment system of coupling point to be a lot-size reorder-level system, that is, when the inventory level falls below certain level, an order is placed and the order quantity is equal to difference between present inventory level and final inventory level.

b) Annual demand in units/year is normally distributed with mean of Qd and standard deviation of σ.

c) Supply lead times are not constant. The variance of supply lead times is equal to the mean.

So the necessary stock of inventory is given by:

$$I = Qd \times Ls + K\sqrt{Ls}\sigma$$

Where

Qd = mean value of annual demand in units/year.

Ls = supply lead-time in days.

σ = standard deviation of annual demand.

Now if process consists of n stage sub-processes, in which inventories are stocked exclusively at the stock position of coupling point, the necessary stock of inventories is given by:

$$I(i^*) = Qd \times \sum_{i=i^*+1}^{n} P(i) + K \times \sqrt{\sum_{i=i^*+1}^{n} P(i)} \times \sigma$$

Where
Qd = mean value of annual demand in units/year.
σ = Standard deviation of annual demand.
Ls = Supply lead-time in days.
K = coefficient of safety stock determined by the service level required.

2.3.4 Mechanism of Coupling Point Movement:

In a production system, one cannot assume constant process times, due to various constraints like capacity constraints, break downs etc. It would not be unusual to see an increase in process times on the demand or supply side. One case is when the time of each sub-process becomes longer on the demand side. In this case, moving the coupling point to the demand side is effective in reducing inventory as shown in **Figure 4**. When the coupling point changes towards demand side, an inventory shortage occurs because of the lead-time difference between the coupling points. To avoid this shortage, extra production is required at the processes between the previous and the new coupling point and then the coupling point is moved after supplying extra products to the new point.

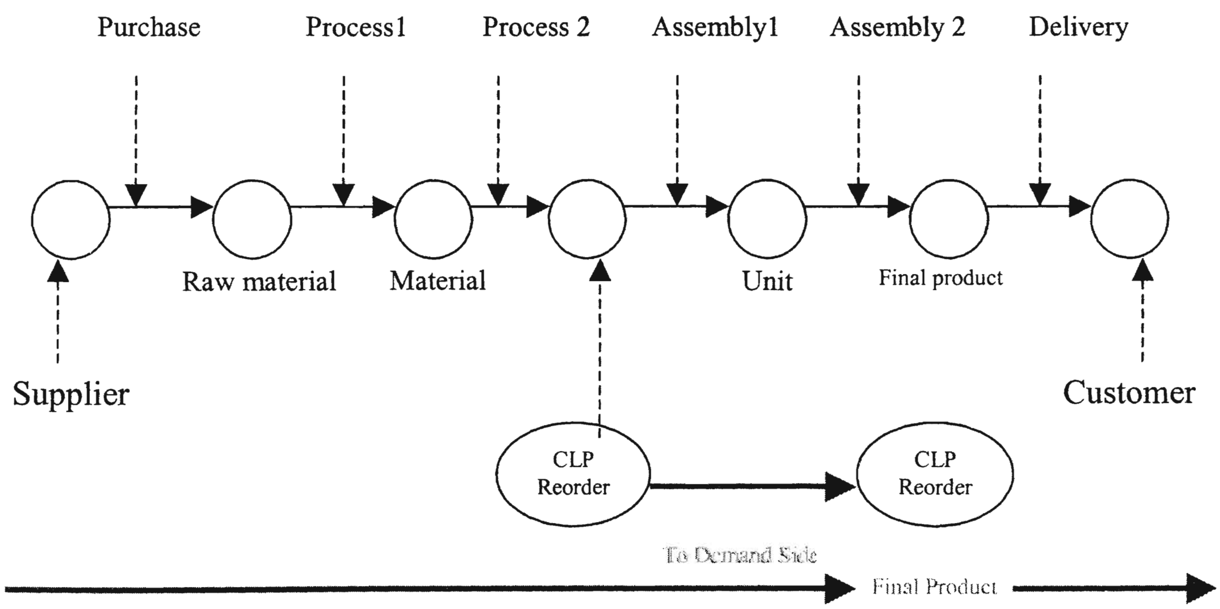

Figure 4. Movement of Coupling Point to Demand Side (Mitsukuni et.al, 1997)

The second case is when the time for each sub-process becomes longer on supply side as shown in **Figure 5**. In this case, moving the coupling point to the supply side is effective in reducing inventory. When the coupling point changes towards supply side, excess inventory occurs because of the lead-time difference between the coupling points. To avoid excess inventory, first, production is not made between the previous and the new coupling point until the inventory just for the lead-time becomes zero. Second, the coupling point is moved after the entire inventory becomes zero at existing coupling point.

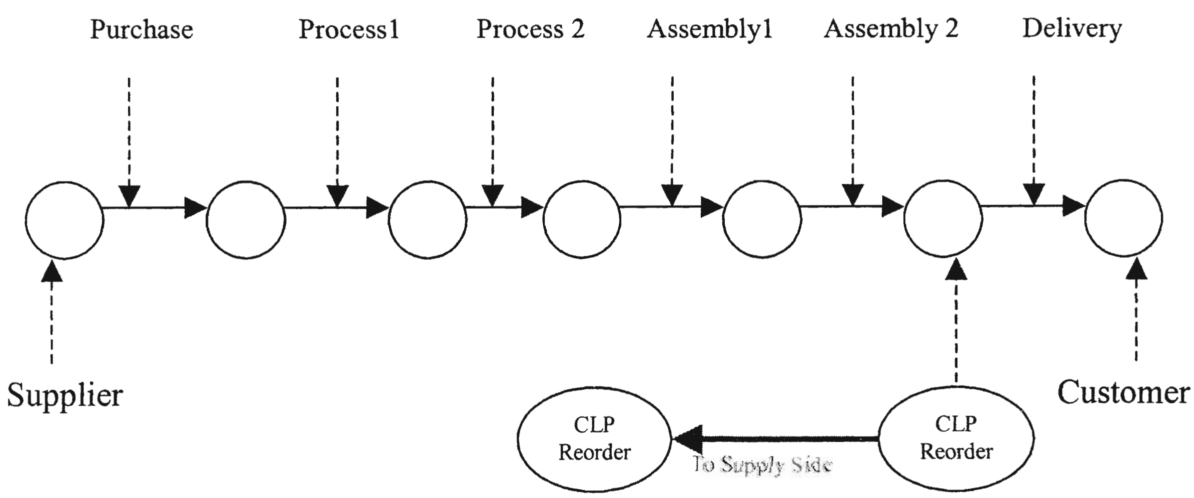

Figure 5. Movement of Coupling Point to Supply Side (Mitsukuni et.al, 1997)

2.3.5 Functions of Coupling Point Production Control System

Coupling point control system has 5 main functions that enable it to function as a system and are as shown in **Figure 6.**

a) Coupling Point Planning Function

This function determines the position of the coupling points by referring to the demand lead time and the supply lead time of each product. It also calculates movement of coupling points and the lead-time difference between the new and existing points.

b) Sales Planning Function

This function calculates demand lead-time of each product. It also forecasts demand quantity for fixed interval in order to fix the inventory level at the coupling point for that period.

c) Inventory Planning Function

This function makes planning of inventory supplement at the coupling point of each product. It counts the in-and-out quantity of products. It also makes planning for inventory supplement to avoid shortage.

d) Scheduling Control Function

This function schedules jobs on the production or delivery side by considering efficiencies when production advice or delivery advice is directed. Production advice is directed to the process on the demand side of coupling point in the sequence of delivery. Supplement advice is directed to the process on the supply side of the coupling point for inventory supply. It calculates the supply lead-time and updates the master data of each product.

e) Purchase Order Planning Function

This function calculates the requirements of parts, materials and raw materials by referring to the bill of materials. It also plans the purchasing activities to be in time for the inventory supplement and the production. It calculates the supply lead-time and updates the master data in each product.

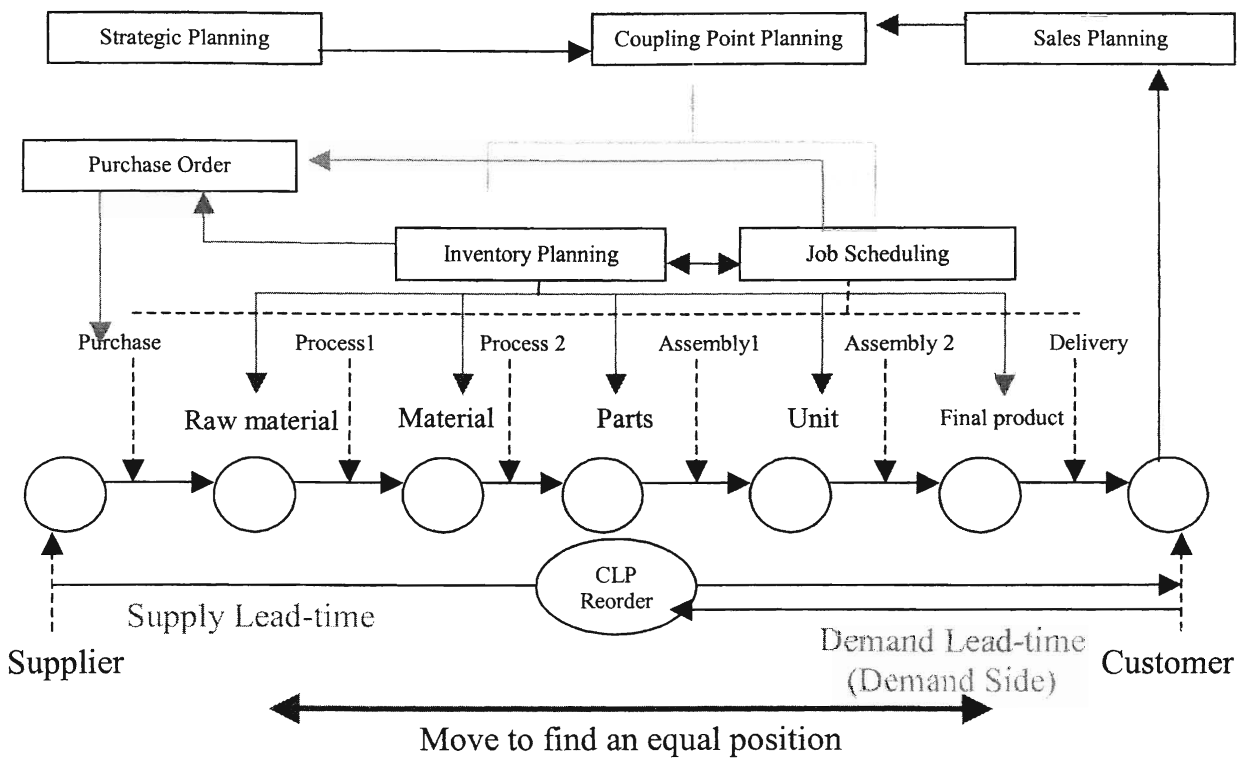

Figure 6. Functions of Coupling Point Production Control System (Mitsukuni et.al, 1997)

2.3.6 Optimal Ordering Method

The Coupling Point Production Control System was proposed to solve problems such as over stock and out-of-stock situations in traditional MRP and JIT systems due to faulty forecasts. In the coupling point production control system, multiple products are placed on the same coupling point. The total quantity of re-order at the coupling point changes as the quantity of re-order at the coupling point is determined by the replenishment planning of each product. Hence due to multiple products, the warehouse space becomes smaller and the replenishment reorder increases. The current model often resulted in stock out or over stock positions as the manufacturers often over reacted to the unpredictable conditions. So the authors (Mitsukuni et.al, 1998) came up with an **optimal ordering method** for this system that limits the extent of capacity and prevents out-of-stock situation.

According to the optimal ordering method, prediction of the out-of-stock situation is estimated by the actual stock of inventory based on certain service ratios and the coefficient of safety stock. The products with higher probability of an out of stock situation are replenished between extents of limited re-order. **Figure 7** shows the concept of the optimal ordering method.

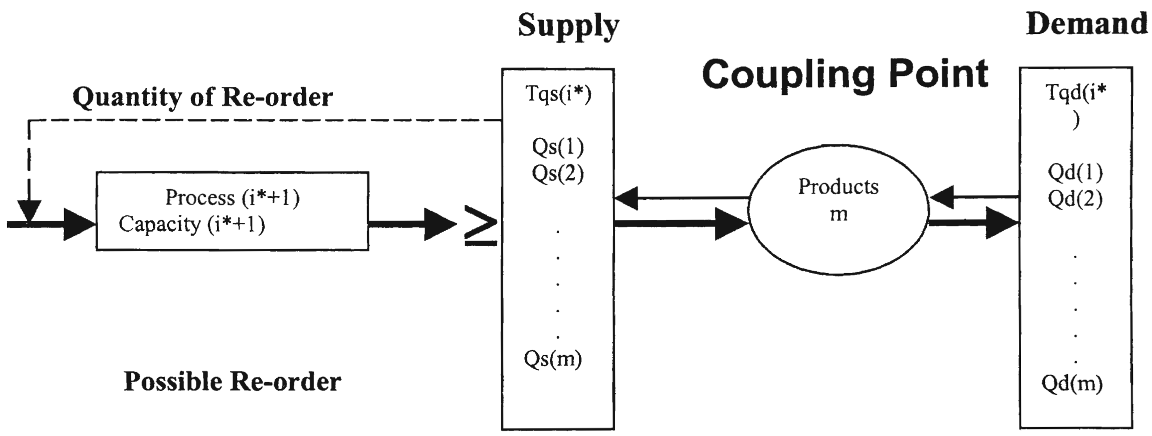

Figure 7. Optimal ordering method (Mitsukuni et.al, 1998)

Notations and definitions:

For number of different products ***m***, where $m = 1, 2, \ldots, M$.

I(m) = Necessary stock of inventory

S(m) = Safety stock

Qd(m) = Demand quantity per unit

Qs(m)= Quantity of reorder per time

T(i*) = Total inventory level.

Tqs(i*) = Total re-order quantity.

Ts(i*) = Total safety stock inventory level. $Ts(i^*) = Tqs(i^*) - Td(i^*)$

Td(i*) = Total demand quantity. $Td(i^*) = \sum_{j=1}^{m} Qd(j) \times Lclp(j)$

2.3.7 Algorithm for optimal ordering method:

The algorithm for Optimal Ordering Method is shown in **Figure 8**. The capacity of sub-process before the coupling point is ***C(i*+1)***, and the extent of re-order ***Es(i*)*** is established with this limit capacity condition.

a) The prediction of out-of-stock ***Ps(m)*** is estimated by the ratio, which is calculated by the safety stock ***S(m)***, actual stock of inventory ***A(m)*** and the coupling point lead-time ***Lclp***.

Safety stock is calculated as $S(m) = A(m) - Qd(m) \times Lclp(m)$

Prediction of out-of-stock $Ps(m) = \dfrac{S(m)}{Qd(m) \times Lclp(m)}$

b) The prediction of out-of-stock is arranged in ascending values and the sequence number ***x***. Where, $x(1 \le x \le m) = SQRT : Ps(m), ascending$

The above formula sorts products in ascending order based on the prediction of out-of-stock.

c) The quantity of re-order is determined by $Qs(m) \ge Qd(m)$, the extent of limited re-order determined by $Es(i^*) \le C(i^*+1)$, where *C(i*+1)* is the capacity limit and supply lead time determined by

$$Ls(i^*) = \frac{Qs(i^*)}{C(i^*+1)} \times P(i^*) + Tc$$

Where *Tc is the time for change over or tool change time.*

d) The quantity of re-order is summarized and ***x*** has also counted from 1 to ***m*** until they reach the extent of limited re-order ***Es(m)***, and the counted final sequence number is ***x****. where $x^* = \{ \max_{1 \le x \le m} x \,|\, \sum_{j=1}^{x} Qs(j) \le Es(i^*) \}$

e) Next the quantities of re-order ***Qs(m)***, ***m = 1,…,x**** are replenished. The sequence number ***x*** is called priority of re-order.

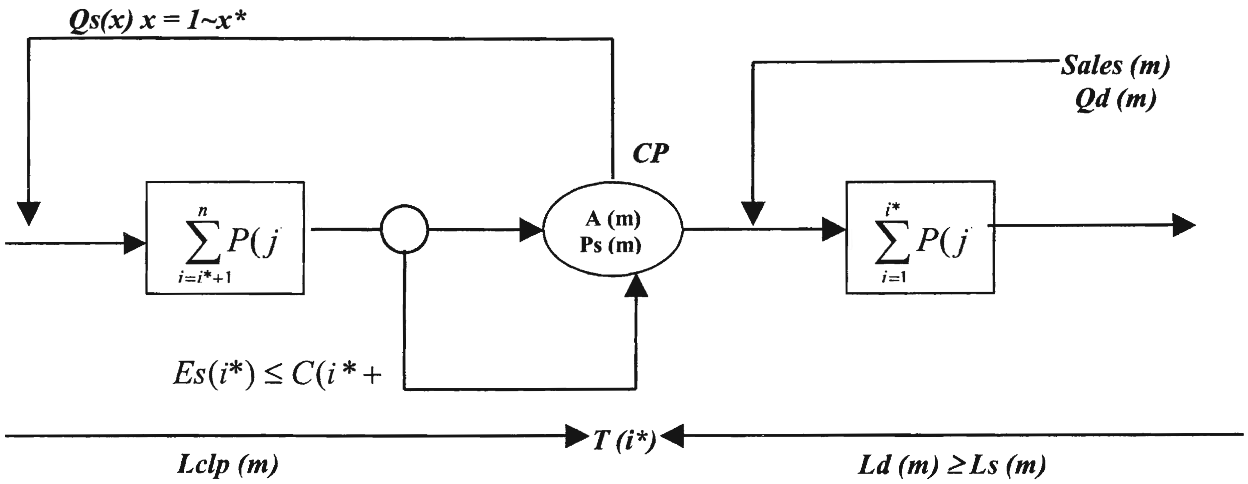

Figure 8. Algorithm for optimal ordering method (Mitsukuni et.al, 1998)

When the results of the total stock of inventory and the ratio of out-of-stock are smaller than the inventory stock position at the coupling point, the authors (Mitsukuni et.al, 1998) believe that optimal ordering method is effective in preventing out-of-stock situations and limiting re-order quantities.

2.3.8 Evaluation of optimal ordering method:

For evaluating the optimal ordering method, authors (Mitsukuni et.al, 1999) conducted simulation runs using the concept of optimal ordering method.

Initial Simulation Data:

The extent of limited re-orders ***Es(i*)*** is 50. The service level of each product is 95%. The period for simulation days is 150 days. The initial simulation data is as shown in **Table 3** and the results of the simulation run are as shown in **Table 4.**

Table 3
Initial Simulation Data

M	*Lclp*	*Qd*	*σ*	*Int*	*I(i*)*	*Qs*	*Sales*
HU1	4	10.27	6.00	1	64	16	Random
HU2	6	10.18	5.84	1	89	16	Random
HU3	8	9.95	6.15	1	113	16	Random
HU4	7	9.87	6.00	1	100	16	Random
HU5	5	8.87	5.94	1	70	16	Random

Table 4
Simulation results

M	*A(m)*	*I(i*)*	*A(m)/ I(i*)*	*Out of Stock*	
				Count	*%*
HU1	34.2	64	0.53	7	4.7
HU2	48.5	89	0.55	5	3.3
HU3	63.2	113	0.56	7	4.7
HU4	51.0	100	0.51	1	0.7
HU5	39.0	70	0.56	2	1.3
Total	235.9	436	0.54	22	2.9

From the **Table 4**, the necessary stock of inventory is 436 units. As the total quantity of the actual stock is 235.9, the actual stock of inventory is decreased by 54%. The total level of out-of-stock decreased to 2.9%. The out-of-stock level of each product decreases and it also shows that the re-order is replenished by a fixed quantity although the inventory depends on demand. The dynamics of this production system makes it possible to respond to dynamic market conditions and also reduces the risk of holding inventories. The authors (Mitsukuni et.al, 1997) have mentioned that this production system is not for replacing MRP or JIT but instead it can supplement them.

2.3.9 Issues and drawbacks

a. The authors have not included bill of materials in inventory planning at the coupling point or even at positions downstream.

b. The variance in the demand is not included in inventory calculations at the coupling point.

c. The supply lead time varies but the distribution for supply lead time is not mentioned in the literature.

d. In the formulations for inventory calculations at the coupling point, the authors have not explained certain terms like standard deviation and service level criteria elaborately. The calculation of safety stock does not include variance in demand.

e. In the movement of the coupling point, the authors have not mentioned any definite criteria to explain how often the coupling points should be moved to the demand side or to the supply side.

f. While assigning a sequence number to prediction of stock out in the optimal ordering method, the authors have included the square root of prediction of out of stock. The authors have not mention of why it is used. The sequence number x can be assigned to the prediction of out of stock and not its square root. In case of negative safety stock, the square root value will be undefined.

g. In the evaluation of optimal ordering method, the authors have not mentioned the assumptions for the inventory coming into coupling point and the outline of the basic simulation logic. There is no information provided on the simulation model used.

h. In the optimal ordering method, there is no definition provided for extent of limited reorder, although the term has been used in the literature.

i. The authors have used the coupling point lead time for calculating safety stock in the optimal ordering method, but it has not been defined earlier.

j. Although the necessary stock of inventory is defined earlier, it is not used in the optimal ordering method calculations.

2.4 Traditional Supply Chains

2.4.1 Structure of Supply Chains

Supply chain management is defined (Simchi-Levi et al., 2000) as – The process of planning, implementing and controlling the efficient, cost effective flow and storage of raw materials, in-process inventory, finished goods, and related information from point of origin to point of consumption for the purpose of conforming to customer requirements. This chain that links suppliers and a buyer begins with the production of raw material by a supplier and ends with consumption of raw material by the buyer (Chen, 1997). There may be several constituencies in the supply chain depending on the industry. A simple traditional supply chain is as shown in **Figure 9**

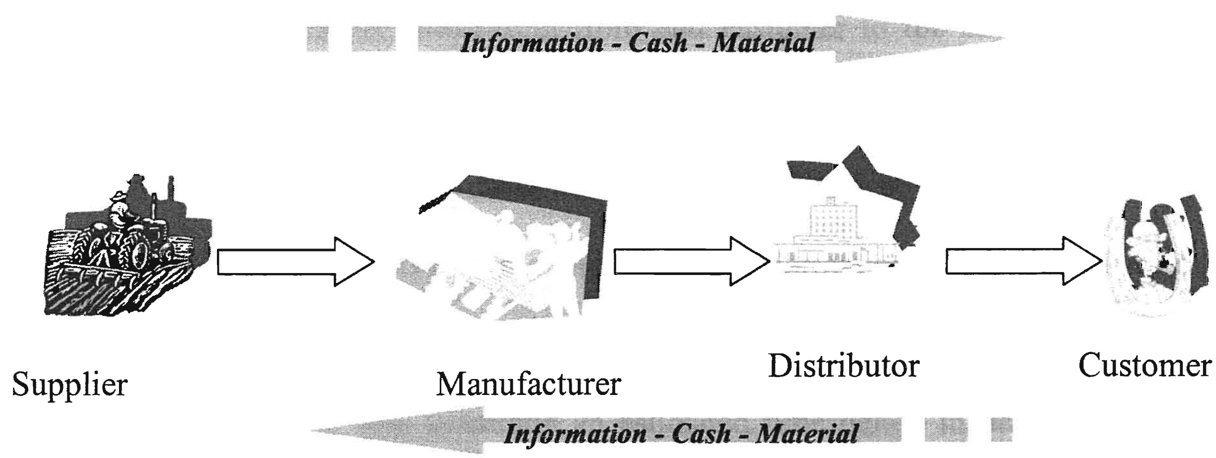

Figure 9. Traditional supply chain model (Simchi-Levi et al., 2000)

The traditional model has a supplier, a manufacturer, a distributor and end customer. It is very important to understand how material flows downstream from the base supplier to the customer and how information flows upstream from the end customer to the supplier. When customer places an order, it is processed and shipped directly from the distributor. The distributor keeps a log of all orders shipped and this information is used to forecast future demand. When the inventory level at the distributor is less than or equal to the reorder point, the distributor orders products from the manufacturer. The manufacturer processes this order and ships products to the distributor from its warehouse or immediately after production is complete. The manufacturer keeps a log of products shipped to the distributor and this information is used to forecast future demand at the manufacturer level. The final products manufactured at the manufacturer level need raw material which is ordered from supplier when the inventory level is less than or equal to the reorder point level. The quantity depends on the bill of material relationship. Whenever an order is placed, the supplier keeps a log of it and uses the information to forecast future demand. The supplier also ships raw material to manufacturer from the available stock at the warehouse or directly on completion of production.

When the flow of information from end customer to the supplier is analyzed, planning at the distributor level is based on end customer orders, while planning at the manufacturer and the supplier level is based on demand at the distributor and the manufacturer level respectively. In short, demand information is transferred from one inventory echelon to other. The various lead times used in the decision rules, which drive echelon replenishment, also constitute an estimated time delay. In practice actual lead times can be either longer or shorter than these estimates. Traditional supply chains tend to be extended with multiple levels of inventory between the point of production and the final market place. Having multiple levels of inventory increases risk and is costly. The most important point in traditional supply chains is they tend to be forecast driven rather than demand driven. Conventional logistics systems that are based on this paradigm seek to identify the optimal quantities at each inventory echelon and its spatial location. Many complex formulae and algorithms exist to support multi echelon inventory systems. But the impact of demand distortion on forecast driven supply chains is well documented and supply chain partners are being forced to take a look at how their supply chain is structured. It is very important to understand the structure of supply chains before any initiatives for improvement are under taken.

2.4.2 Classification of Supply Chain Models

Based on their structure, supply chain models can be classified into four classes (Ingalls, R., 2001),

a) The retail supply chain model

The retail supply chain model has characteristics that are unique to that business. They include key assumptions about the customer, their buying patterns, and buying preferences. It is tied to seasonal demand patterns and inventory levels can be large, especially to meet seasonal demands. Products are pre-configured, product variety is large and the lead-time varies. Demand plans are made well in advance and manufacturing is in high volumes to cut down cost.

b) The build-to-inventory supply chain model

The build-to-inventory supply chain model is a business that builds its products to an inventory and then sells out the inventory. It attempts to balance customer satisfaction in an unpredictable market with manufacturing and logistics efficiency. It is tied to random demand patterns and the key goal is to maintain planned inventory positions. Products are pre-configured, product variety is large and lead-time is less. Demand plans are made well in advance in order to position material.

c) The build-to-order supply chain model

The build-to-order supply chain is a business that builds a standard product only after an order is received and ships it directly to the customer. The main characteristic is customer choice and elimination of finished goods inventory. Products are made up of a mix of pre-configured products, product variety is large and lead-time is less. Inventory is maintained as raw material at the manufacturer and the goal is to maintain planned inventory levels. Demand plans are developed well in advance in order to position material and equipment and production is not planned unless an order exists. Distribution networks and production schedules are structured to be highly flexible.

d) The engineer –to-order supply chain model

The engineer-to-order supply chain is a business that builds specialized products only after an order is received and ships it directly to the customer. The main characteristic is customization of the end product according to customer specification. It is almost similar to build-to-order supply chain with the only difference being that products are custom built based on customer requirements. Lead-time is long as customers wait to get products designed according to their needs. Demand plans are made well in advance in order to position material and equipment, but production is not planned unless an order exists. Distribution networks and production schedules are structured to be highly flexible.

These four types of supply chain models are basic structures of the current industry. Hence it is of key importance to comprehend these models and also their demand patterns, inventory policies, production schedules, and distribution networks.

2.5 Supply Chain Migration

In late 1990's the focus of supply chains shifted from being market driven to customer driven. **Table 5** shows a brief comparison of this drift. Hill (1993) had earlier developed the concept of "order qualifiers" and "order winners" to determine which manufacturing strategy has to be adopted. Hill's principle is applied to existing and very popular paradigms in the industry lean thinking and agile manufacturing.

Table 5
Market qualifiers and Market winners (Mason et.al, 2000)

	Market Qualifiers	Market Winners
Agile	Quality Cost Lead Time	Service level
Lean	Quality Lead Time Service Level	Cost

Market qualifiers for lean thinking are quality, lead time and service level and the market winner is cost. The focus of the lean approach has essentially been on the elimination of waste or *muda.* The upsurge of interest in lean manufacturing can be traced to the Toyota Production System with its focus on the reduction and elimination of waste (Ohno, 1988). A useful definition of the lean paradigm is as follows: *Leanness* means developing a value stream to eliminate all waste including time, and to enable a level schedule (Naylor *et al.* 1999). Lean supply chains focused on minimum total cost and elimination of waste.

On the other hand, market qualifiers for agile manufacturing are quality, cost, and lead time and the market winner is service level. Agility is a business-wide capability that embraces organizational structures, information systems, logistics processes and in particular, mindsets. A key characteristic of an agile organization is flexibility. In that respect, the origins of agility as a business concept lie partially in flexible manufacturing systems. Initially it was thought that the route to manufacturing flexibility was through automation to enable rapid changeovers (i.e. reduced set-up times) and thus enable a greater responsiveness to changes in product mix or volume. Later this idea of manufacturing flexibility was extended into the wider business context (Nagel and Dove, 1991) and the concept of agility from an organizational perspective was born. A useful definition of the agile paradigm is as follows: *Agility* means using market knowledge and a virtual corporation to exploit profitable opportunities in a volatile marketplace (Naylor *et al.* 1999). Agile supply chains focused on service levels and quick response to orders.

Based on the principle of market qualifiers and market winners, the winning criterion in late 1990's was availability. In 2000, it is implied that supply chains have to take into account demand variance and respond effectively and quickly to it. The concept of supply chains being totally forecast driven is becoming obsolete and is migrating towards being demand driven. Boeing pursued a lean manufacturing strategy without taking into account the variability of demand in aerospace industry. Boeing has been able to cope up with a doubling of production but this still falls short of the market demand (Anon, 1997). A valuable lesson is the implementation of one manufacturing paradigm across the chain is also no longer valid. Supply chains are expected to respond rapidly, effectively and efficiently to changes in the marketplace and also achieve world-class customer service levels coupled with minimum reasonable inventory (Towill, et.al, 2000). To achieve this objective, the paradigm that is pursued at any point in the chain should depend upon the requirements and nature of customer. Management should be aware of their core supply chain competencies and then implement a strategy based on these core competencies, and customer requirements.

2.6 Hybrid Suppy Chain Models

Examples like Boeing have proved that implementation of one paradigm across the entire chain is also not beneficial in the present dynamic environment. In the case of the lean manufacturing environment, demand should be smooth; leading to a level schedule. Agile businesses also can strive to maximize their profit in volatile markets but it will result in higher stock levels to meet market volatility. This started the quest for development of hybrid paradigms by combining multiple paradigms and strategies that could enable achieving multiple objectives and gear the supply chain towards a demand driven environment. Later it was shown that lean and agile paradigms could be combined to enable highly competitive supply chains capable of winning in a volatile and cost-conscious environment as shown in **Figure 10**.

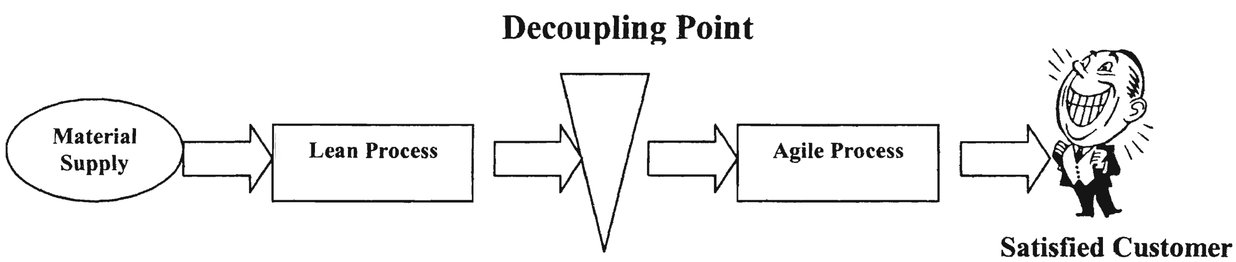

Figure 10. Hybrid supply chains (Mason et.al, 2000)

The principle in this strategy is to separate that part of the supply chain geared towards directly satisfying customer orders from the part of the supply chain based on planning (Hoekstra and Romme, 1992). This point till which real demand penetrates upstream in a supply chain may be termed as the de-coupling point and is the echelon at which market "pull" meets upstream "push" as shown in **Figure 11**.

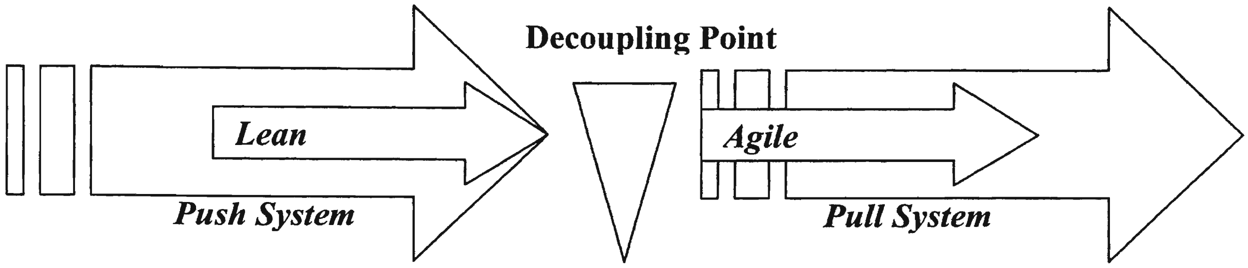

Figure 11. Decoupling point (Towill, 2001)

Previously this idea has been termed as the order penetration point. The flow of product up to the point is forecast driven, and from the point to the customer is demand driven. The point also dictates the form in which inventory is held. The supply chain should carry inventory in a more generic form that would include standard semi finished products awaiting final assembly or localization. Since the inventory is held at a generic level there will be fewer stock keeping units and hence less total inventory. Since the inventory is generic, it is more flexible because the same component modules or platforms can be converted into a variety of end products. This concept is well known in supply chain literature as "postponement" or "delayed differentiation". Leagile systems achieved the goal of minimum cost and high service level as shown in **Figure 14.** However the issue is where the point should be located so to differentiate between push and pull paradigms.

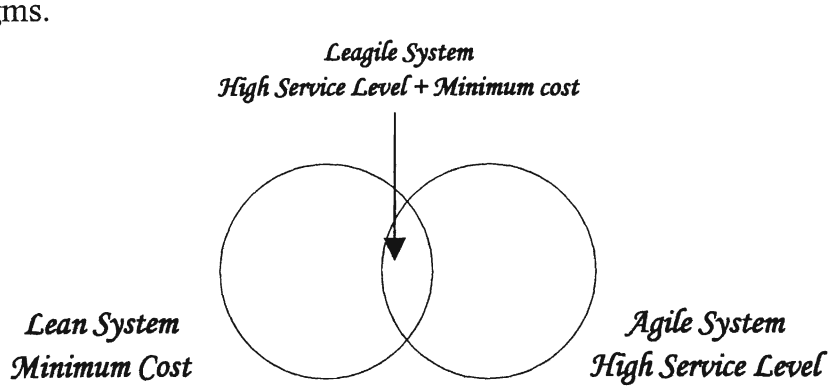

Figure 12. Leagile system

2.7 Information decoupling point

EDI and the internet have enabled partners in the supply chain to act upon the same data, i.e the real demand, rather than be dependent on distorted forecast that emerges when orders are transmitted from one step to another in an extended chain. A parallel concept to the "material" de-coupling point described above is that of the "information" de-coupling point (Mason-Jones and Towill, 1999). This point does not have to be the same point at which postponement is applied in theory. Customer data can be shared throughout the supply chain without all of the operations being postponed. This represents the furthest point upstream to which information on ``real" demand flows, i.e. information which has not been distorted by inventory policies such as re-order points and re-order quantities. The ability to base replenishment decisions on real demand clearly contributes to supply chain agility. The information coupling point ideally should lie as far downstream the supply chain and as close to the final marketplace as possible. Mason-Jones and Towill (1997) have demonstrated through simulation the beneficial impact that information feedback can have on reducing upstream amplification and distortion of demand. By managing these two decoupling points a powerful opportunity for agile response can be created. At the same time the notorious ``bullwhip" or Forrester effect (Forrester, 1961) can be reduced. The combined effect of shared information in supply chain and delayed configuration through postponement can significantly improve responsiveness (Billington and Amaral, 1999). Furthermore a separate study has shown that the effect of optimal delayed configuration is actually even greater than the impact created by shared information (Gavireni and Tayur, 1997).

Chapter 3

Research

3.1 Introduction

The principle of de-coupling points gives a strategy to separate that part of the supply chain geared towards directly satisfying customer orders from the part of the supply chain based on planning. Its implementation in the various supply chain models also gives a clear picture of how to adapt this theory based on the structure of the supply chain. But the past literature does not give a definite method to calculate the point of strategic inventory. This issue of how to calculate the point of strategic inventory leads to the "Coupling Point Production Control System" (Mitsukuni et.al, 1997). The core concept of the production system is to strategically position inventory where supply lead-time and demand lead-time are equal and inventory and production plans are to be made at this point. Comparison of coupling point production control system and de-coupling point principles shows that they are almost identical and just that they are implemented at different levels of a supply chain.

De-coupling point is a new supply chain strategy, while coupling point is a production control system based on certain assumptions applicable to assembly systems in series and where production cycle time is not a significant part of the total supply lead time. The core concept is similar to that of a de-coupling point and this concept when implemented in a supply chain model gives an accurate point at which market "pull" meets upstream "push". The theory and formulations used in the coupling point production control system are implemented in a broader perspective in the form of a supply chain strategy. These formulations, along with the principle of a de-coupling point solve the issue of where the point should be exactly located. Also positioning inventory strategically using the coupling point principle eliminates inventories between the point and customer and also meets the key requirement, which is the quick response to orders. The determination of an accurate point is relative to both the demand lead time and supply lead time. The other key principle is demand lead time is constant while supply lead time varies. Demand lead time is determined based on customer requirements, so the point to position inventory strategically also depends on customer requirements.

This research shows how the two concepts of de-coupling point and coupling point can be blended successfully to develop a very efficient strategy that could position inventory strategically in a supply chain.

3.2 Theory

In order to explore implementation of the coupling point principle for strategically positioning inventory in supply chain model, a traditional single product linear supply chain model is shown in **Figure 13** that consists of a supplier, manufacturer, distributor and end customer. Material flows from the supplier to the end customer and there is continuous value addition to the product as it moves downstream. Information flows upstream from the end customer to supplier. As per the definitions of the coupling point system, nodes represent possible inventory stock position and arrows represent processes that perform value addition to the product. There are two possible inventory stock positions nodes at the supplier level and they are represented by node 1 and node 2. There are two possible inventory stock positions nodes at the manufacturer level and they are represented by node 3 and node 4. There is one possible inventory stock position at the distributor level and it is represented by node 5 and the end customer level has no inventories.

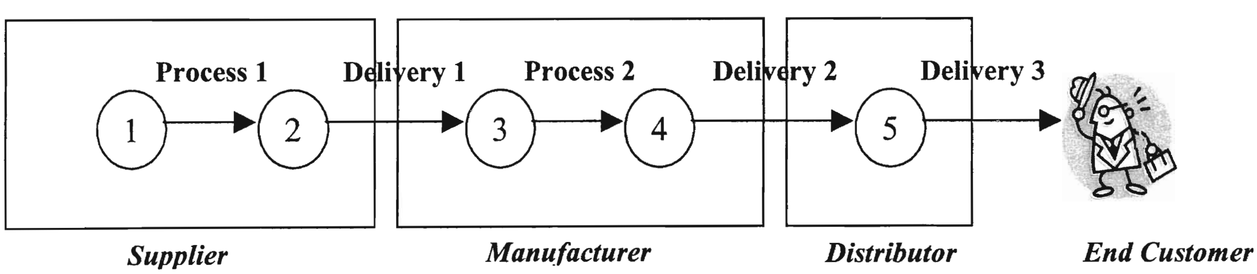

Figure 13. Traditional single product linear supply chain model

There are 5 processes in the system and their individual process times are as shown in **Table 6.**

Table 6
Individual Process Times

Processes	Process Time in days	Summation of Process Times
Delivery 3	2	2
Delivery 2	3	5
Process 2	2	7
Delivery 1	3	10
Process 1	6	16

The notations used in the model and their definitions are as follows:

1. ***Ls*** = Average supply lead time. It is the average value of total time required to send products from a certain position in the supply chain to the end customer. It is the sum of all sub process times like processing, assemble, delivery etc. The supply lead time is in days.
2. ***Lstd*** = Standard deviation of supply lead time.
3. ***Ld*** = Demand lead time. It is the acceptable delivery time for the customer. Demand lead time is in days.
4. ***D*** = Average Annual demand. Units of finished product required per year.
5. ***Dstd*** = Standard deviation of annual demand.
6. ***xavg*** = Average demand over average supply lead time in units.
7. ***Iavg*** = Average inventory for a time period.
8. ***ss*** = safety stock. It is defined as the average level of the net stock just before the replenishment arrives.
9. ***Q*** = Economic Order Quantity also known as EOQ.
10. ***k*** = safety stock factor based on customer satisfaction level.
11. ***A*** = the fixed cost incurred with each replenishment, in dollars.
12. ***i*** = inventory carrying cost. The cost of having one dollar of the item tied up in inventory for a unit time interval (year).
13. ***C*** = unit variable cost of the item.
14. ***cv*** = coefficient of variation.
15. ***BOM*** = Bill of material. It is defined as quantity of raw material required per unit of finished product.

16. ***WFC*** = Warehouse fixed cost. Fixed cost incurred with storing product in warehouse for a unit time interval (year).

17. ***WVC*** = Warehouse variable cost. Variable cost per unit associated with storing products in warehouse.

18. ***Whse Cost*** = Total warehouse cost = ***WFC*** + (***D*** * ***WVC***)

19. ***MC/unit*** = Material cost per unit = (***i*** + ***C***) / ***Q***

20. ***Order cost*** = Cost occurred at every instance of placing an order = ***A*** + ***C*** *(***Q***/***D***).

21. ***Inv Cost*** = Total cost of holding inventory = ***i*** * ***Iavg***.

Assumptions

1. Supply lead time is considered towards the customer side and is time required to send products from a certain position in the supply chain to the customer in days.
2. Demand lead time is from the customer to the supplier in days.
3. Costs tangible to inventory stock position are only considered.
4. Suppliers from the coupling point to the customer are assumed to have infinite capacity.
5. Variance in demand is incorporated in the safety stock calculations at the coupling point.
6. Variance in supply lead time due to any possible reason like break downs or change over is incorporated in the coefficient of variation.
7. Supply lead time is normally distributed with a mean of *Ls* and standard deviation of *Lstd.*
8. The bill of material is with respect to end customer demand and not that of the immediate customer.

According to the principle of a coupling point, inventory is positioned where demand lead time and supply lead time are equal, that is $Ls \leq Ld$. But supply lead time is the summation of all process times including processing, assemble, delivery etc. from a point in supply chain to the end customer. So supply lead time is $Ls = \sum_{j=1}^{i} P(j)$. It is the sum of the times of all sub-processes *i*, where i = 1,2,...n increasing from demand side to supply side. For the above model, demand lead time is assumed to be 10 days. So the individual process times are summed starting from the end customer until the sum equals the demand lead time. Inventory is strategically positioned at that point. Based on process times mentioned in **Table 6** the coupling point will positioned at end of process 1 and beginning of delivery 1 as shown in **Figure 14**.

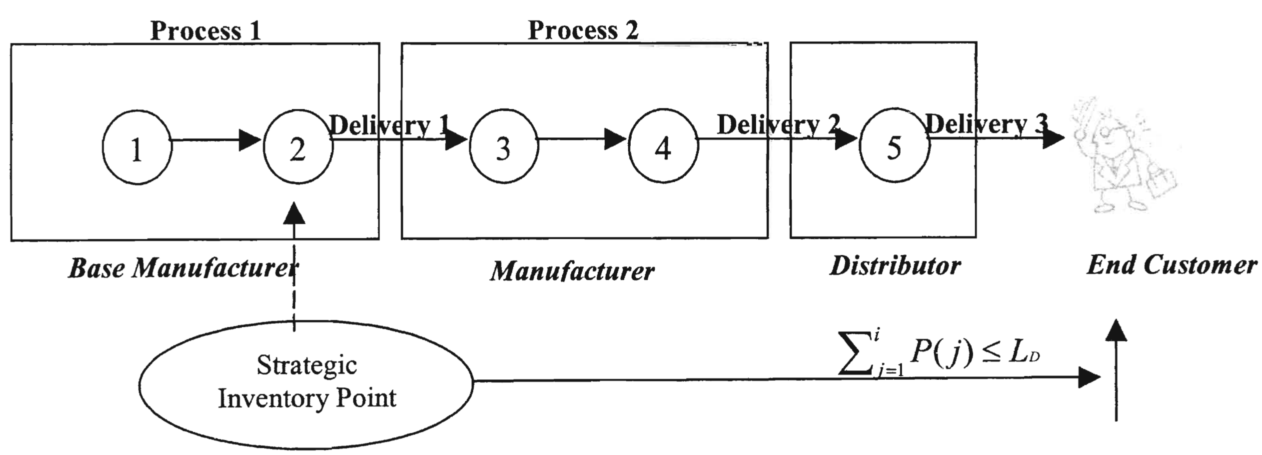

Figure 14. Strategic inventory point by coupling point principle

Another important point in the coupling point principle is that the demand lead time is constant and the supply lead time varies. Let us assume that supply lead time follows a normal distribution with mean of *Ls* where $Ls = \sum_{j=1}^{i} P(j)$ and standard deviation of *Lstd*. Based on this criteria, if inventory is positioned where $Ls \leq Ld$, then the probability of Ls actually being less than or equal to Ld is only 50%. This is the left side of the probability density curve shown in **Figure 15**.

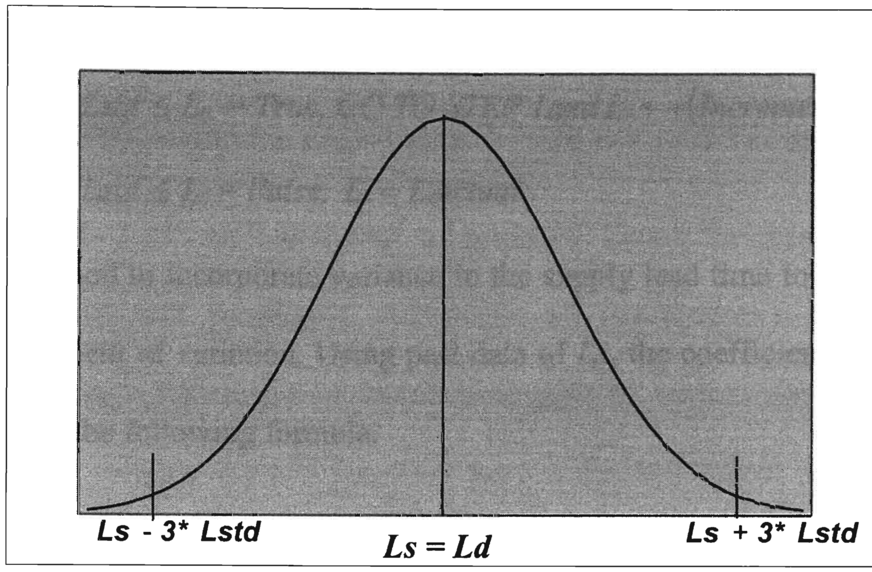

Figure 15. Distribution of *Ls*

At the right side of the curve supply lead time is greater than the demand lead time. If that occurs, customers don't receive products on time and result in unsatisfied customers or even lost sales to competitors. This is a critical factor that is not considered in the formulations of coupling point and has to be incorporated in the calculations. So the new criteria that consider this factor is:

$Ls + k * Lstd \leq Ld$

where

$Lstd$ = standard deviation of Ls

k = safety factor based on customer service levels

A further, issue is that average value of supply lead time and standard deviation of supply lead time are relative to each other. So, at least one value has to be known to find another. An iterative method can be used to find supply lead time by initializing it by assigning $Ls = 1$ and incrementing it by a unit value till it reaches a maximum value where $L_S + k * Lstd \leq L_D$.

Iterative method

Step 1: Initialize Ls. $L_S = 1$ and assign value of L_D and k

Step 2: Calculate standard deviation of assigned Ls. $(Lstd)$.

Step 3: $If L_S + k * Lstd \le L_D = True,\ GO\ TO\ STEP\ 1 and\ L_S + +(Incrementing\ Ls)$

Step 4: $If L_S + k * Lstd \le L_D = False,\ L_S = L_S actual$

Another method to incorporate variance in the supply lead time to the customer is by using the coefficient of variation. Using past data of *Ls*, the coefficient of variation ***cv*** is calculated using the following formula.

$$cv = \frac{Lstd}{Ls}$$

$\therefore$ Solving for $Lstd$: $Lstd = \mathrm{cv} * Ls$

since we must find Ls such that $Ls + k * Lstd \le Ld$, then

$$\therefore Ls \le \frac{Ld}{1 + k * cv}$$

Assuming that co efficient of variation is 0.2 and $k = 1.64$ from unit normal distribution table (*Appendix A*), with $Ld = 10$, Ls from the above formula is as follows:

$$\therefore Ls \le \frac{10}{1 + 1.64 * (0.2)} = 7.52 days$$

Ls is the total time required to send a product to the customer from a particular point in supply chain, and is defined as $\sum_{j=1}^{i} P(j) = Ls$

So based on the new strategy, individual process times are summed starting from the end customer side to the supplier side and where it does not exceed the supply lead time (*Ls*) that is calculated using above criterion. Inventory is strategically positioned at that point.

So based on process times mentioned in **Table 6** the $\sum_{j=1}^{i} P(j) = Ls \leq 7.52$ lies at Delivery 1, which is between node 2 and node 3. But inventory cannot be positioned at a process where Ls = 7.52, so it will positioned at the closest possible inventory stock position (node). This position is node 3 with $\sum_{j=1}^{i} P(j) = Ls = 7$ at the end of delivery 1 and the beginning of process 2 as shown in **Figure 16**. This is the point that differentiates between push and pull paradigms. All points on the upstream side towards base manufacturer have a replenishment based push type of system and all points on the downstream side towards the end customer have a demand driven pull type of system with no inventories between the point and the end customer.

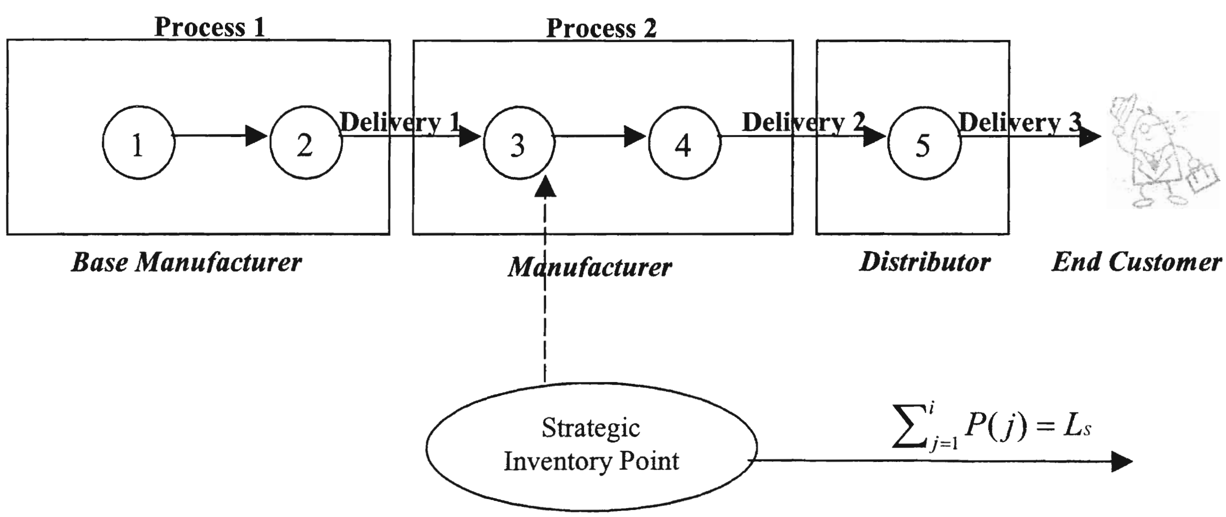

Figure 16. Strategic inventory point by the new principle

After determining the point to strategically position inventories, inventory planning is done at the strategic point using the end customer demand and the chosen type of replenishment system. One key point is there are no inventories between the strategic point and the end customer. Variance in demand is incorporated in the safety stock at the strategic point and is calculated by the following formula,

$$ss = k\sqrt{P(i^*+1) * Dstd^2 + D^2 * P(i^*+1)std^2}$$

where *P(i*+1)* is the average sub process time before the strategic point and *P(i*+1)std* is the standard deviation. There are two inventory systems (s,Q) and (s,S), that are the most common and widely used inventory systems in the industry. A brief overview of the two inventory systems and the formulations used to calculate economic order quantity, safety stock and reorder point are as follows:

Order-Point, Order Quantity (s,Q) System

In this system a fixed quantity Q is ordered whenever the inventory position drops to the reorder points or lower. The inventory position and not the end stock are used to trigger an order. The inventory position, because it includes the on-order stock, takes proper account of the material requested but not yet received from the supplier. This system is referred as a two bin system as one physical form of implementation is to have two bins of storage of an item. As long as units remain in the first bin, demand is satisfied from it. The amount in the second bin corresponds to order point. Hence when the second bin is opened, a replenishment is triggered. When the replenishment arrives, the second bin is refilled and the remainder is put into the first bin. The calculations for (s,Q) inventory system are as follows:

1. The economic order quantity is calculated by formula

$$Q = \sqrt{\frac{2 * A * D * BOM}{i * C}}$$

2. Safety stock is calculated by formula

$$ss = k\sqrt{P(i^* + 1) * Dstd^2 + D^2 * P(i^* + 1)std^2}$$

3. Average demand over lead time *Ls* (*xbar*) is calculated by formula

$$xavg = D * Ls$$

4. Reorder point is calculated by formula

$$s = xavg + ss$$

Order Point, Order-up-to-level (s,S) System

In this system a variable replenishment quantity is used to raise the inventory position to the order-up-to-level **S** whenever inventory position drops to the order points or lower. It also includes on-order stock and takes proper account of the material requested but not yet received from the supplier. This system is referred as min-max system because the inventory position, except for a possible momentary drop below the reorder point is always between minimum value of **s** and maximum value of **S**. The calculations for **(s,S)** inventory system are as follows:

1. The economic order quantity is calculated by formula

$$Q = \sqrt{\frac{2 * A * D * BOM}{i * C}}$$

2. Safety stock is calculated by formula

$$ss = k\sqrt{P(i*+1)*Dstd^2 + D^2 * P(i*+1)std^2}$$

3. Average demand over lead time *Ls* (*xbar*) is calculated by formula

$$xavg = D * Ls$$

4. Reorder point is calculated by formula

$$s = xavg + ss$$

5. Order up to stock position is calculated by formula

$$S = \max\{Q, D * L\} + k\sqrt{P(i*+1)*Dstd^2 + D^2 * P(i*+1)std^2}$$

$$Iavg = s + 0.5(S - s)$$

3.3 Example of single product linear supply chain

Consider a single product linear supply chain consisting of 6 nodes and 5 processes as shown in **Figure 21**. The 6th node is the end customer. The customer satisfaction level is assumed to be 95% and the safety factor k is calculated from a unit normal distribution table (*Appendix A*).

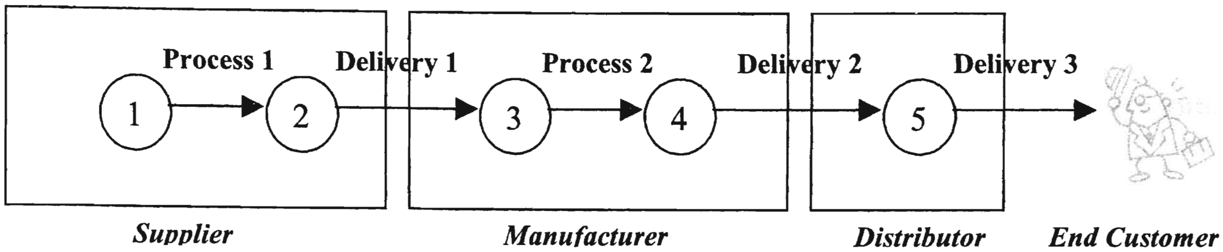

Figure 17. Single product linear supply chain

The individual process times and their summation are as shown in **Table 7**:

Table 7
Individual Process Times

Processes	Time in days	Summation of Process Times
Delivery 3	1	1
Delivery 2	2	3
Process 2	4	7
Delivery 1	3	10
Process 1	4	14

Demand lead time Ld is assumed to be 10 days and Ls is calculated as follows:

$$Ls = \frac{Ld}{1 + k * cv}$$

$$\therefore Ls = \frac{10}{1 + 1.64 * (0.2)} = 7.52 days .$$

Based on the supply lead time, node 3 becomes the strategic inventory point and delivery 1 becomes the sub process before the strategic point.

Data

The annual demand is in units/year D, the fixed cost incurred with each replenishment in dollars A, the inventory carrying cost i, and unit variable cost of the item C are assumed and are as shown in **Table 8.** Also BOM, the bill of material with respect to end customer demand is assumed to be 1 for all products.

Table 8
Data for example model

NODES	A	I	C	BOM	Davg in units/yr	Dstd
1	1	0.5	2		1000	500
2	1	1	5	1	1000	500
3	1	2	7	1	1000	500
4	1	10	10	1	1000	500
5	1	10	15	1	1000	500
6				1	1000	500

The model with new inventory positioning strategy is compared to the traditional supply chain model. To map the differences between the two models, some cost factors had to be included. This way, the reduction in total supply chain cost can be calculated. In the experimental model, cost factors tangible to the inventory stock position are only considered as other cost factors like processing cost will be same regardless of where the inventory is positioned. Economic reorder quantity, safety stock, average inventory and reorder point are calculated depending on the inventory system used. The details of inventory calculations for (s,Q) inventory system are as listed in **Table 9.**

Table 9
(s,Q) Inventory system.

P(i)	Sum P(i)	Q	s	safety	xbar	k	Ld	Ibar
4	14.0000	44.72	21.04	10.08	10.96	95.00%	10	43.396308
3	10.0000	20.00	16.95	8.73	8.22			26.945877
4	7.0000	11.95	21.04	10.08	10.96			27.011771
2	3.0000	4.47	12.60	7.13	5.48			14.84084
1	1.0000	3.65	7.78	5.04	2.74			9.6038298

The details of inventory calculations for (s,S) inventory system are as listed in **Table 10.**

Table 10
(s,S) Inventory system

P(i)	Sum P(i)	Q	S	S	ss	xbar	k	Ld	Iavg
4	14	44.72	21.04	31.11	10.08	10.96	95.00%	10	26.07399
3	10	20.00	16.95	25.67	8.73	8.22			21.309226
4	7	11.95	21.04	31.11	10.08	10.96			26.07399
2	3	4.47	12.60	19.73	7.13	5.48			16.167432
1	1	3.65	7.78	7.78	5.04	2.74			7.7780879

While calculating total cost for both traditional and new model, other all parameters were kept same. The difference between these two models is where inventory is positioned. The individual and total cost for the traditional model and the new model with (s,Q) inventory system and 95% customer satisfaction is as follows:

Table 11
Traditional model with (s,Q)

Links	WFC	WVC	MC/Unit	MtlCost	InvCost	Whse Cost	Order Cost	TotalCost
5-6	1000	1	6.846532	6846.532	657.52928	2000	1.0547723	9511.9625
4-5	1000	1	4.472136	4472.136	663.70253	2000	1.0447214	7141.3553
3-4	1000	1	0.752994	752.99402	40.679404	2000	1.083666	2795.5101
2-3	1000	1	0.3	300	8.0837631	2000	1.1	2309.4838
1-2	1000	1	0.0559017	55.901699	1.2129637	2000	1.0894427	2058.26
								23816.572

Table 12
New model with (s,Q)

Links	WFC	WVC	MC/Unit	MtlCost	InvCost	Whse Cost	Order Cost	TotalCost
5-6	1000	1	0	0	0	0	0	0
4-5	1000	1	0	0	0	0	0	0
3-4	1000	1	0.752994	752.99402	55.221969	2000	1.083666	2810.0527
2-3	1000	1	0.3	300	8.0837631	2000	1.1	2309.4838
1-2	1000	1	0.0559017	55.901699	1.2129637	2000	1.0894427	2058.26
								7177.7964

As there are is no inventory between the strategic point and the end customer, the total cost of the new model is less compared to the traditional supply chain model. The reduction in total cost for this model by strategically positioning inventory at node 3 is **$16638.**

The individual and total cost for the traditional model and the new model with (s,S) inventory system and 95% customer satisfaction is as follows:

Table 13
Traditional model with (s,S)

Links	WFC	WVC	MC/Unit	MtlCost	InvCost	Whse Cost	Order Cost	TotalCost
5-6	1000	1	25	25000	1944.522	2000	1.015	28970.537
4-5	1000	1	6.6666667	6666.6667	1077.8288	2000	1.03	9752.1921
3-4	1000	1	1.2857143	1285.7143	67.047402	2000	1.049	3355.0964
2-3	1000	1	0.6	600	12.785536	2000	1.05	2614.4355
1-2	1000	1	0.1785714	178.57143	2.3280348	2000	1.028	2182.106
								46874.367

Table 14
New model with (s,S)

Links	WFC	WVC	MC/Unit	MtlCost	InvCost	Whse Cost	Order Cost	TotalCost
5-6	1000	1	0	0	0	0	0	0
4-5	1000	1	0	0	0	0	0	0
3-4	1000	1	0.752994	752.99402	61.745241	2000	1.049	2816.5413
2-3	1000	1	0.3	300	8.0837631	2000	1.05	2309.4338
1-2	1000	1	0.0559017	55.901699	1.2129637	2000	1.028	2058.1986
								7184.1736

The reduction in total cost for this model by strategically positioning inventory at node 3 is **$39690**

3.4 Application of the concept to different classes of supply chains.

The strategic inventory point is relative to both demand lead time ***Ld*** and supply lead time ***Ls***. Demand lead time is assigned based on customer requirements and customer requirements are not same for all supply chain structures. So a "one-size-fit-all" strategy is no longer valid. Management has to take a look at how their supply chains are structured and also the requirements of the customer. Assigning demand lead time is very subjective and any error in the process will result in positioning inventories at a totally wrong location. In the literature, supply chains are classified into different classes and have already been discussed before. Based on customer requirements and their structure, these four different classes of supply chains will have different demand lead times ***Ld***. Implementation of the new strategy for these four classes of supply chains will provide a guideline to management on how to create a new strategy for their supply chains.

3.4.1 The build-to-order supply chain

As discussed earlier, in the build-to-order supply chain a standard product is built only after an order is received and is shipped directly to the customer. As the main characteristic of this class of supply chain is customer choice, product variety is large and customer has a choice to customize the final product from available options. Hence the final product consists of a mix of pre-configured and configured products made from the same raw material. If inventory is positioned as finished product at distributor level, there is a risk of inventory becoming obsolete if the final product doesn't match the customer requirements. To avoid this risk, elimination of finished goods inventory is necessary. So inventory is pushed to manufacturer level eliminating finished goods inventory as shown in **Figure 17.** The supply lead time ***Ls*** now increases as inventory is pushed to manufacturer level. But customers are ready to wait to get products of their choice, usually 8-10 business days. So the inventory is strategically positioned in modular form, i.e. in form of components, as products are made from the same raw material. Components are then assembled to finished product according to customer specification and shipped directly to the customer within the acceptable demand lead time.

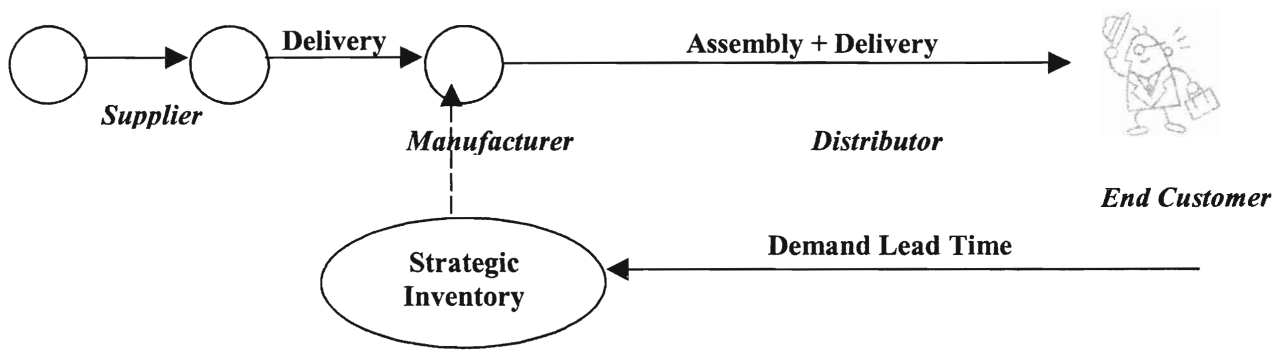

Figure 18. Strategic inventory point in the build-to-order supply chain

3.4.2 The engineer-to-order supply chain

As discussed earlier, in the engineer-to-order supply chain specialized products are built only after an order is received and shipped directly to the customer. It is almost similar to build-to-order supply chain only difference, products are not pre-configured and are custom built according to customer specifications. The main characteristic is customization of the end product according to customer specification. As end product is completely customized based on customer specifications, there is a risk of inventory becoming obsolete at manufacturer level and distributor level. To avoid this risk, the inventory is pushed further to the supplier level and is strategically positioned in form of raw material as shown in **Figure 18**. The supply lead-time ***Ls*** is further increased, but normally customers are ready to wait to get products designed according to their needs.

Due to high level of customization, production is not planned unless an order exists. It gives an option for customers to choose raw materials for end product instead of building product from available components. The final product is then built or assembled from chosen or available raw material and shipped directly to the customer within the acceptable demand lead time ***Ld***.

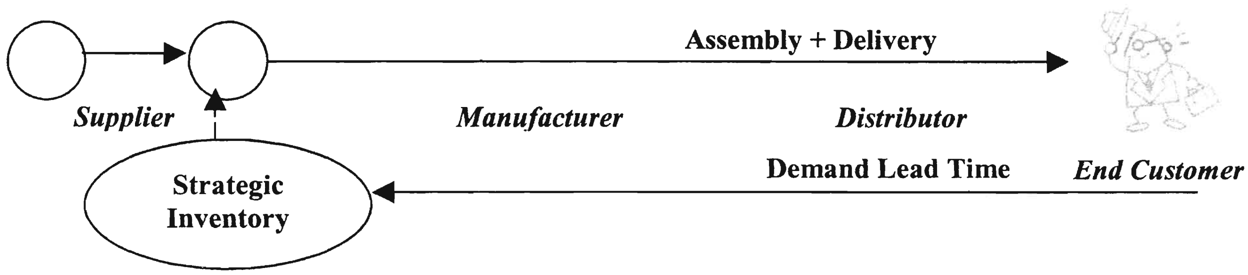

Figure 19. Strategic inventory point in the engineer-to-order supply chain

3.4.3 The build-to-inventory supply chain

As discussed earlier, in the build-to-inventory supply chain model, products are built to an inventory and then the inventory is sold out. Important factor in this class of supply chain is customer satisfaction is balanced in an unpredictable market with manufacturing and logistics efficiency. Build to inventory supply chains are tied to random demand patterns and key goal is to maintain planned inventory positions. The demand lead-time ***Ld*** is small compared to build to order and engineer to order supply chain, as products are sold from the available stock. As demand patterns are random and demand lead time ***Ld*** is small it is risky to hold inventory as raw material at supplier level or as components at manufacturer level. To avoid this risk and assuming that manufacturing and logistics part of the supply chain are highly efficient, inventory is strategically positioned as finished product at manufacturer level or at distributor level as shown in **Figure 19**. Products are pre-configured so there is no risk of finished goods inventory becoming obsolete at manufacturer level or supplier level.

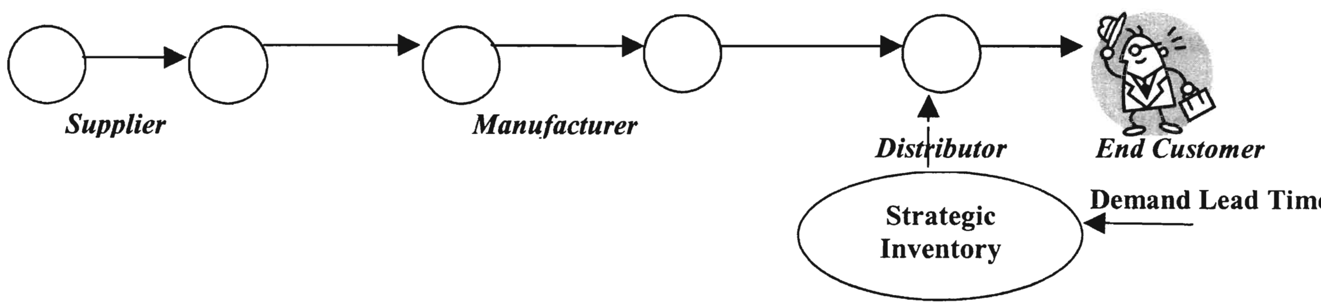

Figure 20. Strategic inventory point in the build-to-inventory supply chain

3.4.4 The retail supply chain

As discussed earlier, the retail supply chain model has characteristics that include key assumptions about the customer, their buying patterns, and buying preferences. It is also tied to seasonal demand patterns and inventory levels can be large, especially to meet seasonal demands. Product variety is large as customers prefer choice and the demand lead-time ***Ld*** is almost zero as products are sold off the shelf at retail locations. As demand patterns are seasonal and demand lead time ***Ld*** is less, it is risky to hold inventory as raw material at supplier level or as components at manufacturer level. Inventory is strategically positioned either at retailer location or at distribution center depending on space available at retailer location as shown in **Figure 20**.

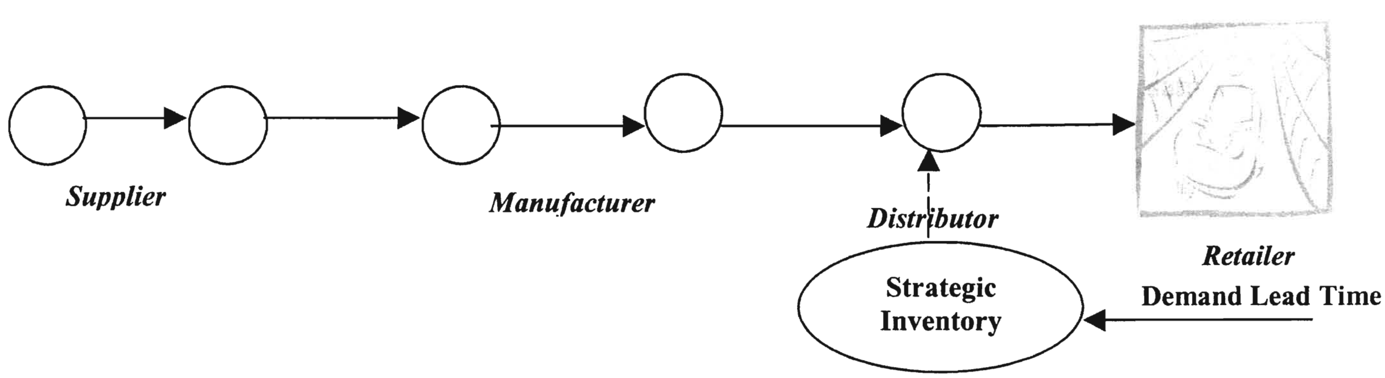

Figure 21. Strategic inventory point in the retail supply chain

3.5 Multiple products with same demand lead times and infinite capacity

Implementation of the principle into above four different classes of supply chains provides a guideline to management on how to implement the new strategy for their supply chains. Another issue is supply chains handling multiple end products and positioning inventories strategically for these multiple end products. The point where inventories are positioned strategically in the supply chain depends on the demand lead time and customer requirements. To explain the concept more effectively, consider a linear multi product computer hardware supply chain as shown in **Figure 22**.

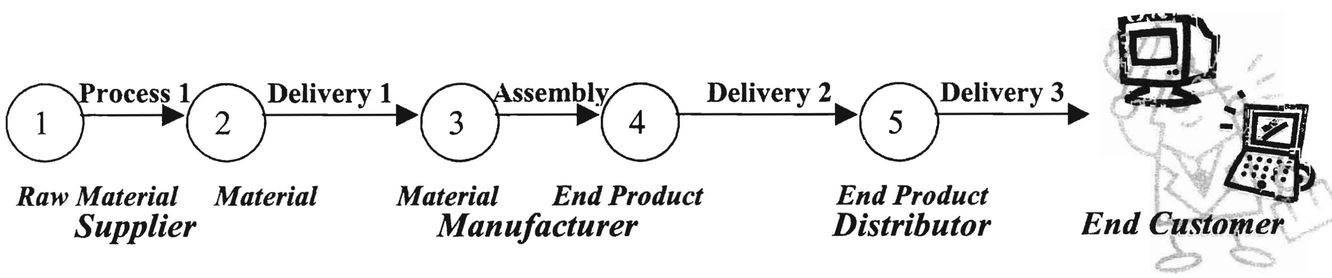

Figure 22. Multi product linear supply chain

For this supply chain there are two types of end products, desktops and notebooks. Further classification of these two product lines can be made based on type of processors used. Although there is a surging demand for processors above 1 gigahertz, there is still demand for processors below 1 gigahertz as they are cheap. According to this classification there are four end products, desktops above 1 gigahertz, desktops below 1 gigahertz, notebooks above 1 gigahertz and notebooks below 1 gigahertz. All of these end products have the same demand lead time as the customer segment is the same. In this case inventory is positioned at the strategic point in a generic form like chassis with power kit, motherboard and modem, and then based on specifications of customer order the final product is assembled. Although the demand lead time for these products is same, the demand for all these four products is not same. So when reordering raw material from the supplier, prediction of the out-of-stock situation is estimated by the actual stock of inventory based on service ratio and the coefficient of safety stock. Then the products are sorted in ascending order based on probability of out-of-stock situation. Products with higher probability of out-of-stock situation are replenished first.

Notations for number of different products ***m***, where ***m = 1, 2…M***.

a) ***D(m)***= Demand quantity per unit in units/year.

b) ***P(i*+1)*** = Process time of the sub-process before the strategic point.

c) ***ss(m)*** = Safety stock in units

d) ***Q (m)*** = Quantity of reorder per time in units.

e) ***Ts(i*)*** = Total quantity of safety stock in units = $\sum_{m=1}^{M} ss(m)$

f) ***Td(i*)***= Total demand quantity in units = $\sum_{m=1}^{M} D(m) \times Ls$

g) ***Tqs(i*)***= Total quantity of re-order in units = $\sum_{m=1}^{M} Q(m)$

h) ***Ps(m)*** = Prediction of out-of-stock.

i) ***A(m)*** = Actual stock of inventory in units at re-order time.

Method:

The method is an adaptation of the optimal ordering method with an assumption that the capacity of sub process ***C(i*+1)*** before the strategic point is infinite.

a) The prediction of out-of-stock ***Ps(m)*** is estimated by the ratio, which is calculated by the safety stock ***ss(m)***, and the average demand over supply lead-time ***Ls***.

Safety stock is calculated as $ss(m) = k\sqrt{P(i*+1) * D(m)std^2 + D(m)^2 * P(i*+1)^2}$

Prediction of out-of-stock $Ps(m) = \dfrac{ss(m)}{D(m) \times Ls}$

b) The prediction of out-of-stock is arranged in ascending values and the sequence number x is assigned. $x(1 \le x \le m) = Ps(m), ascending$

c) Total demand quantity in units ***Td(i*)*** is calculated by $\sum_{m=1}^{m} D(m) \times Ls$

d) Total quantity of safety stock in units ***Ts(i*)*** is calculated by $\sum_{m=1}^{m} ss(m)$

e) Total quantity of re-order in units ***Tqs(i*)*** is calculated by $\sum_{m=1}^{m} Q(m)$

f) Next the quantities of re-order ***Q (x)***, where ***x = 1, 2 …M*** are replenished based on the sequence number ***x,*** which is also called as priority of re-order.

Positioning multiple product inventories at one point in case of equal demand lead time and finite capacity of sub process before strategic point is as shown in **Figure 23**.

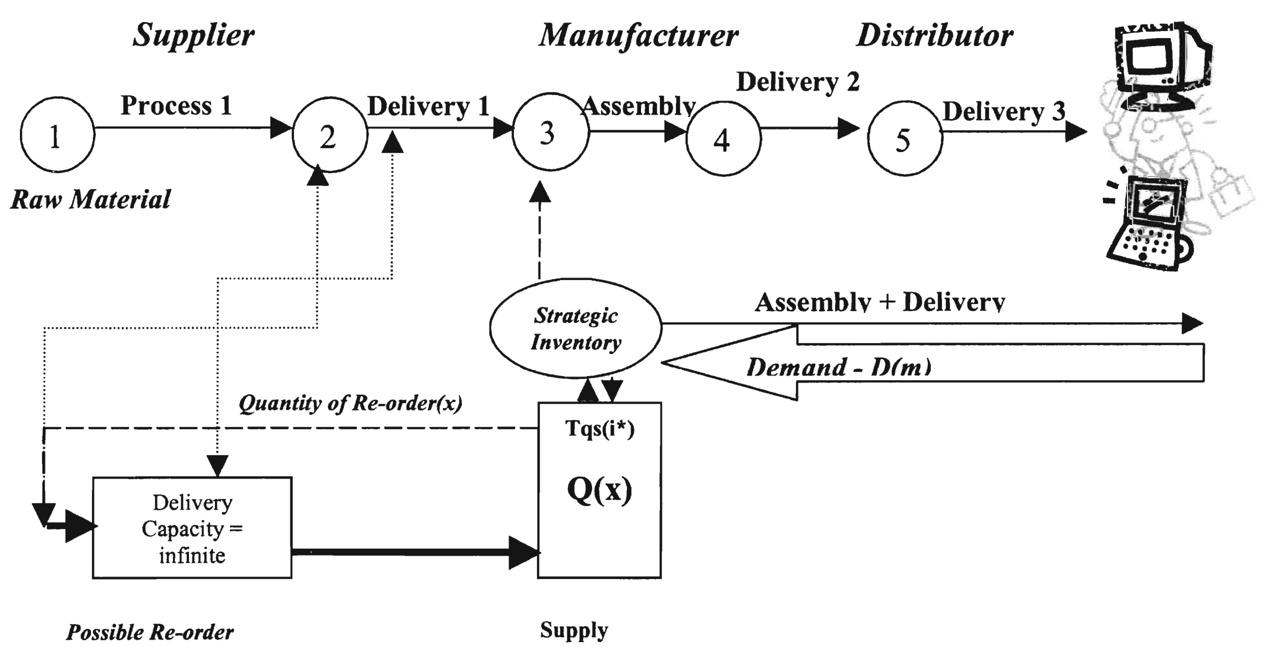

Figure 23. Multiple products with same demand lead times and infinite capacity

Example

Consider a multi product linear supply chain as shown in **Figure 22.** There are 4 end products for the supply chain - desktops above 1 gigahertz, desktops below 1 gigahertz, notebooks above 1 gigahertz and notebooks below 1 gigahertz. For simplicity, these four end products are assigned product numbers from 1 to 4. Their respective annual demand is in units/year *D(m)*, the fixed cost incurred with each replenishment, in dollars *A(m)*, the inventory carrying cost *i(m)*, and unit variable cost of the item *C(m)* is as shown in **Table 15**

Table 15
Product details

Product	product no.	A(m)	i(m)	C(m)	D(m)	D(m)std	BOM
Desktop>1Ghz	1	1	0.5	2	1000	500	1
Desktops<1 Ghz	2	1	1	5	2000	500	1
Notebooks>1 Ghz	3	1	2	7	500	500	1
Notebooks< 1Ghz	4	1	10	10	2800	500	1

Process times for each sub processes are assumed and are as shown in **Table 16**.

Table 16
Individual process times

Processes	Time in days	Summation of Process Times
Delivery 3	2	2
Delivery 2	3	5
Process 2	2	7
Delivery 1	3	10
Process 1	6	16

Assumptions:

Customer satisfaction level is assumed to be 95% and the safety factor is calculated from the unit normal distribution table (*Appendix A*). The bill of materials with respect to end customer demand is assumed to be 1 for all products. Demand lead time *Ld* is assumed to be 10 days and *Ls* is calculated as follows:

$$Ls = \frac{Ld}{1 + k * cv}$$

$$\therefore Ls = \frac{10}{1 + 1.64 * (0.2)} = 7.52 days .$$

Based on this supply lead time node 3 becomes the strategic inventory point and delivery 1 becomes the sub process before the strategic point.

Calculations:

Economic reorder quantity *Q(m)* for each product is calculated by using the following formula:

$$Q(m) = \sqrt{\frac{2 * A(m) * D(m) * BOM}{i(m) * C(m)}}$$

Safety stock for each product is calculated by using the following formula:

$$ss(m) = k\sqrt{P(i^* + 1) * D(m)std^2 + D(m)^2 * P(i^* + 1)^2}$$

Prediction of out of stock *Ps(m)*is calculated using the following formula:

$$Ps(m) = \frac{ss(m)}{D(m) \times Ls}$$

Results:

The results of these calculations with the given data are as shown in **Table 17**.

Table 17
Results of multiple products method.

product no	Q(m)	P(i*+1)	ss(m)	Ps(m)	Unsorted(m)	Sorted(x)	k	Ls
1	44.72136	3	5136	0.73	1	2	95%	7
2	28.28427	3	9971	0.71	2	3		
3	8.451543	3	2849	0.81	3	1		
4	7.483315	3	13890	0.70	4	4		

Along with economic reorder quantity and safety stock, there are two more columns, the unsorted reorder list and the sorted reorder list. The sorted reorder list is sorted in ascending order based on the priority of reorder explained earlier. Based on this list, the product with higher priority, that is product no. 3 will be replenished first, then product no. 1 and so on. This method doesn't change the reorder quantity or the reorder point. It simply sorts the products in ascending order based on the prediction of going out of stock first. So fast moving items are replenished first and then the slow moving items are replenished.

3.7 Multiple products with same demand lead times and finite capacity

In this case the sub process before the strategic point has a finite capacity. So the total reorder quantity has to be less than or equal to the total capacity of the sub process. The method used is adaptation of the optimal ordering method.

a) The prediction of out-of-stock ***Ps(m)*** is estimated by the ratio, which is calculated by the safety stock ***ss(m)***, actual stock of inventory ***A(m)*** and the supply lead-time ***Ls***.

b) Safety stock is calculated as $ss(m) = k\sqrt{P(i^*+1) * D(m)std^2 + D(m)^2 * P(i^*+1)std^2}$

   i. Prediction of out-of-stock $Ps(m) = \dfrac{A(m) - ss(m)}{D(m) \times Ls}$

c) The prediction of out-of-stock is arranged in ascending values and the sequence number ***x*** is assigned. $x(1 \le x \le m) = Ps(m), ascending$

d) Total demand quantity in units ***Td(i*)*** is calculated by $\sum_{m=1}^{M} D(m) \times Ls$

e) Total quantity of safety stock in units ***Ts(i*)*** is calculated by $\sum_{m=1}^{M} ss(m)$

f) Total quantity of re-order in units ***Tqs(i*)*** is calculated by $\sum_{m=1}^{M} Q(m)$

g) Next the quantities of re-order ***Q(x)***, ***x = 1, 2 ...M*** are replenished based on the sequence number ***x,*** which is also called as priority of re-order such that the total quantity of re-order in units ***Tqs(i*)*** $\le$ ***C(i*+1)***.

Consider example from chapter 4 used to explain multiple products with equal demand lead time at one point and infinite capacity of sub process before strategic point. Assume that capacity of sub process before strategic point ***C(i*+1) = 85 units.*** The reorder quantities for each product and priority of reorder are as shown in **Table 17**. The total quantity of reorder ***Tqs(i*)***, which is sum of individual reorder quantities ***Q(m)***, is *89 units*. As ***Tqs(i*)> C(i*+1)***, all products cannot be replenished completely. So, products with high priority are replenished completely and then products with low priority depending on available capacity. According to the example, products 3, 1 and 2 will be replenished completely and only ***3 units*** of product 4 will be ordered. During the next reorder, product 4 will have higher priority and will be replenished completely. Positioning multiple product inventories at one point in case of equal demand lead time and finite capacity of sub process before strategic point is as shown in **Figure 25**.

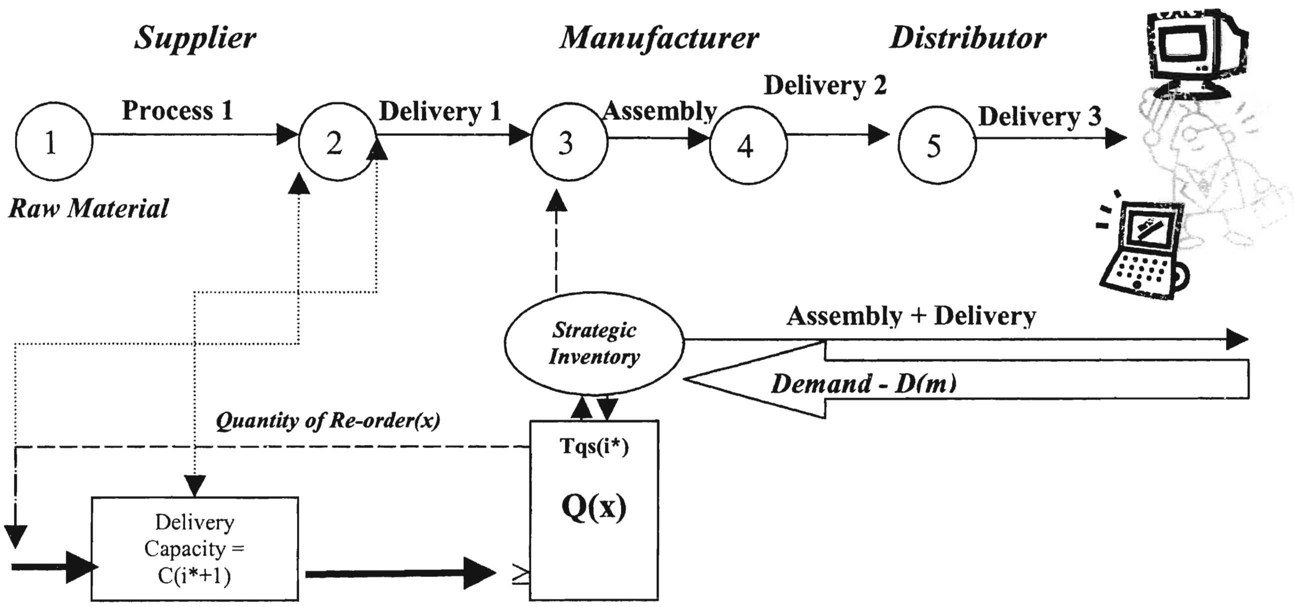

Figure 25. Multiple products with different demand lead times and finite capacity

Chapter 4

Conclusion

The objective of conducting this research was to review principles of the existing model of coupling point production control system and incorporate them for strategically positioning inventory in supply chain models. The principle and structure of the coupling point model is similar to that of the de-coupling point model. The only difference is that they are implemented at different levels in the supply chain. Both principles have similar advantages that are very unique with respect to positioning of inventories. This research shows how the two concepts can be blended to develop a very efficient strategy that could position inventory strategically in a supply chain. Comparison of the new strategy with the traditional model shows that there is definitely reduction in total cost of the supply chain without changing its existing structure and by positioning strategically.

The new principle minimizes finished goods and raw material inventory by strategic positioning inventory in supply chain models enabling them to respond rapidly, effectively and efficiently to changes in the marketplace. But it assumes that management is aware of their core business competencies and constraints in their supply chain models. It also assumes that management has mapped their customer requirements and preferences effectively. Failure to do so will result in degradation of existing supply chain efficiency. Information technology has enabled channel partners to have good visibility of the system and also to act upon the same data. Good visibility of the system also gives channel partners competitive advantage of reacting rapidly and effectively. So, simply positioning inventory strategically in a supply chain is not going to result in increased supply chain efficiency. Along with it, customer requirements have to be mapped efficiently and all channel partners should have good visibility of the system as shown in **Figure 26**. All these factors combined can make supply chains responsive, effective and efficient focusing on high service levels and minimum total cost.

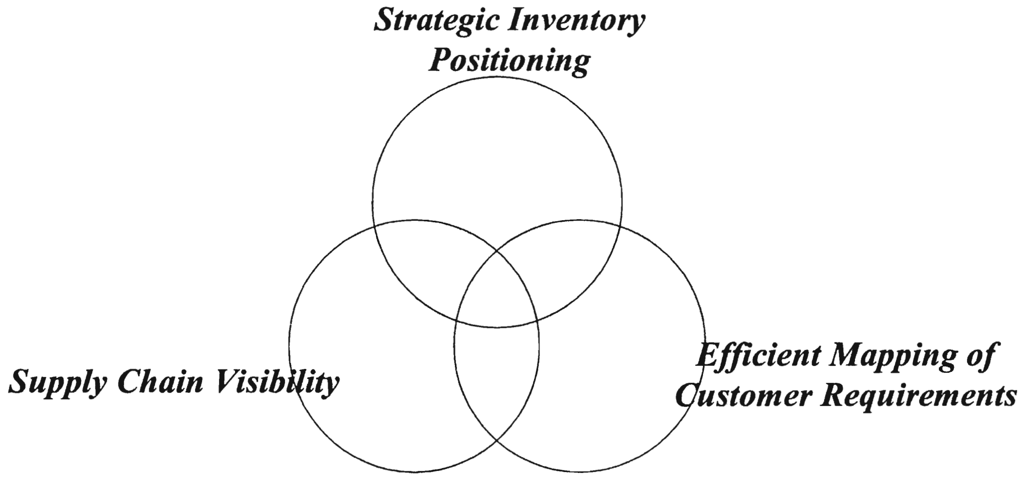

Figure 26. Efficient strategy

Competitive advantage is achieved when an organization links the activities in its value chain more cheaply or more expertly than do its competitors - Michael Porter

Chapter 5

Future Research

Although all supply chain models considered in this research are linear, modern supply chains need not be linear. They are more in the form of complex networks rather than simple linear models. To be more precise, a supply chain is a part of multiple supply chains coexisting as a network just as in the case of computer hardware supply chain mentioned earlier. The computer hardware supply chain requires raw material like hard disks, motherboards, processors etc. These products are raw materials of the hardware supply chain but are end products of some other supply chain. The complex network of these supply chains is as shown in **Figure 27.**

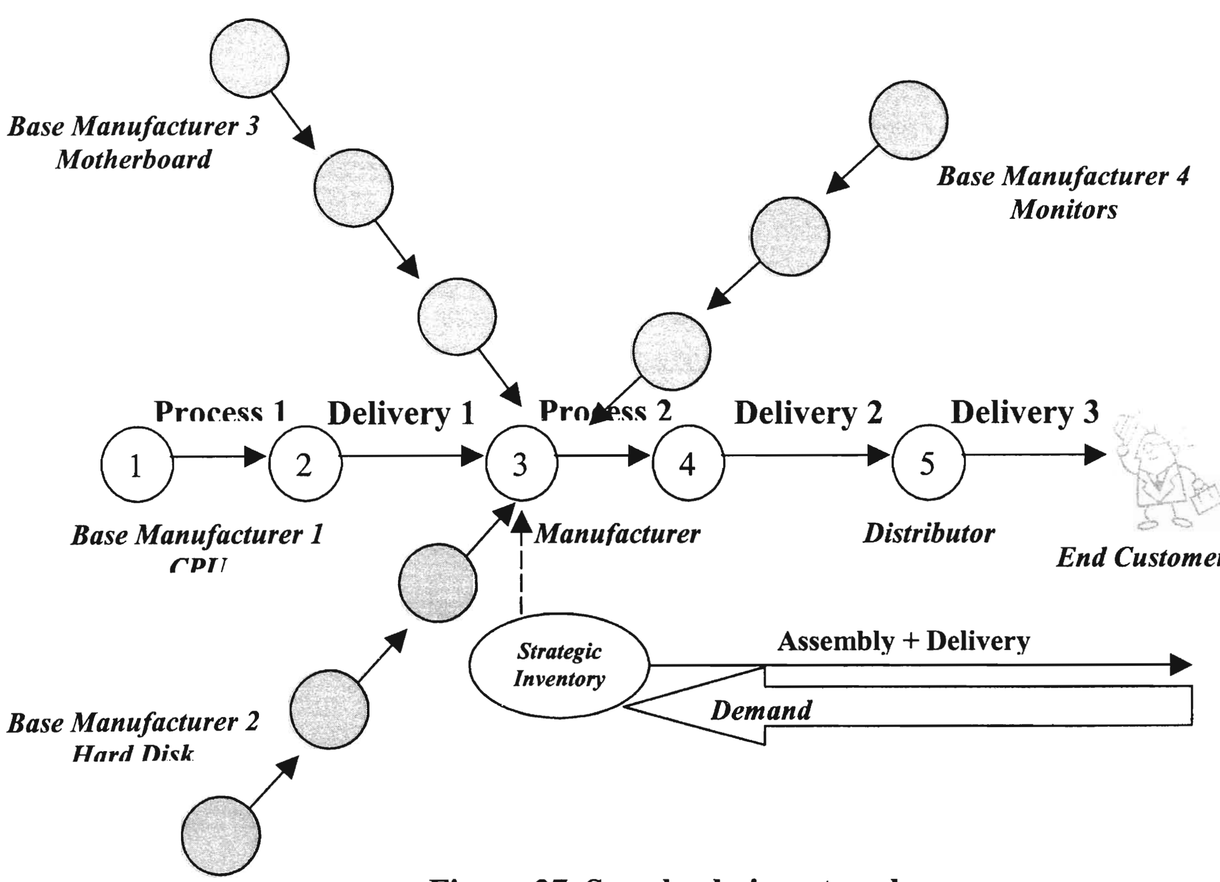

Figure 27. Supply chain networks

How inventory is positioned strategically in the hardware supply chain affects the way material flow is planned for these individual supply chains. For these raw material supply chains, the quantity of raw material (end customer demand * BOM) required at the strategic inventory point in hardware supply chain becomes the end product demand and the demand lead time is calculated based on total number of replenishments per year. So the principle of coupling point is also implemented in raw material supply chains and inventories are planned accordingly. Another approach for this issue is as designed by Dr. Ricki Ingalls at department of Industrial Engineering and Management, Oklahoma State University. His approach is using network optimization techniques to find optimal inventory stock positions based on objective function of minimized total supply chain cost.

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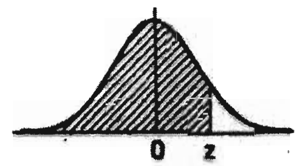
APPENDIX

APPENDIX A

UNIT NORMAL DISTRIBUTION TABLE



Area under the standard normal curve from $-\infty$ to z.

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767

Area under the standard normal curve from $-\infty$ to z (*cont.*).

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998

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