2014

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Original Publication Citation

Verma, A. K. (2014). *Enhancing agility of supply chains using stochastic, discrete event and physical simulation models.* Paper presented at the 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014), Guwahati, Assam, India.

Enhancing Agility of Supply Chains using Stochastic, Discrete Event and Physical Simulation Models

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Abstract

Managing supply chains in today's distributed manufacturing environment has become more complex. To remain competitive in today's global marketplace, organizations must streamline their supply chains. The practice of coordinating the design, procurement, flow of goods, services, information and finances, from raw material flows to parts supplier to manufacturer to distributor to retailer and finally to consumer requires synchronized planning and execution. Efficient and effective supply chain management assists an organization in getting the right goods and services to the place needed at the right time, in the proper quantity and at acceptable cost. Managing this process involves developing and overseeing relationships with suppliers and customers, controlling inventory, and forecasting demand, all requiring constant feedback from every link in the chain. First, a survey of existing stochastic models is presented. Base Stock Model and Q (r) models are applied to three tier single-product supply chains to calculate order quantities and reorder point at various locations within the supply chain. A computer based discrete event simulation model is created to study the three tier supply chain and to validate the results from the stochastic models. Results indicate that agility of supply chains can be enhanced by using the stochastic models to calculate order quantities and reorder points. In addition to reducing the total cost of inventory, probability of backorder and customer dissatisfaction is minimized. Results are further validated with physical simulations. Both computer based simulation and physical simulation demonstrate the improvement in the agility of the supply chain with reduced cost for inventory.

Keywords: Stochastic inventory models, base stock model, discrete event simulation and physical simulation.

1 Introduction

Results obtained from base stock model are validated with physical and discrete event simulation values for three-tier supply chain where the demand follows a Poisson distribution.

We have considered the virtual company with a three-tier supply chain. We applied Base Stock Inventory Model at primary supplier, secondary supplier and at warehouse. We calculated the fill rate, probability that the order has arrived before demand for each case and calculated reorder point at Primary Supplier, Secondary Supplier and Warehouse for five replenishment lead time (12,8,6,4 and 2 months) using mathematical model.

Physical and Discrete Event Simulations were run to validate the optimum inventory levels and reorder point at warehouse, primary supplier and secondary supplier. Positive validation was obtained by both the methods.

2 Background

Inventory management throughout the supply chain is critical when the demand is not deterministic. Demand variability increases as one move up the supply chain away from customer and any small changes in customer demand can result in large variation in orders upstream. This phenomenon is known as Bullwhip effect. Thus, it is necessary to study inventory models for uncertain demand. Wilson (1934) (Wallace & Mark, n.d; Zheng 1992) has done major work on statistical modeling of production and inventory control. Wilson breaks the inventory control problem into two distinct parts: 1. Determining the order quantity, which is the amount of inventory that will be produced with each replenishment. 2. Determining the reorder point or the inventory level at which replenishment will be triggered. P Zipkin (Zipkin, 1992) emphasized on backorder policies in multistage supply chain where base stock inventory model is used.

A survey was conducted to identify the key issues related to supply chain facing the ship building industries under a project of NSRP. The key issues are:

long lead time, inventory cost, scheduling problem, irregular performance, challenge in synchronizing flow with suppliers, vendors furnishing information late. Wincel P.J. (2004) introduces lean methodology as the key factor in its supply chain strategies. Issues related to streamlining supply chain are discussed by Copacino, William C. and Cooper (Copacino et. al, 1995; Cooper et. al, 1999). Inventory issues in supply chain are explored further by Handfield, Robert B., Nichols, Ayers and James (Handfield et. al, 1999, Ayers & James, 2004)

This paper deals with supply chain issues related to stochastic demand. Various inventory models such as (Q, r) model, News Vendor model and Base stock model, are available to address issues related to stochastic demand. We decided to apply Base Stock Model to supply chain (Figure-1) and find out the reorder point at each stage.

Physical and Discrete Event simulations were then designed to verify the validity of the results obtained by mathematical model.

3. The Base Stock Model

The Base stock Model uses a continuous time frame and makes the following assumptions:

1. Demands occur one at a time.
2. Any demand not filled from stock is backordered.
3. Replenishment lead times are fixed and known.
4. Replenishments are ordered one at a time.
5. Products can be analyzed individually.

We make use of the following notations:

l = Replenishment lead time (in years)

x = Demand during replenishment lead time (in units), a random variable

G (x) = P (X<=x), cumulative distribution function of demand during replenishment lead-time; we will allow G to be continuous or discrete.

θ = E [X] = mean demand (in units) during lead time l

r = reorder point which represents the inventory level that triggers a replenishment order

R = r + 1 base stock level

S = r - θ, safety stock level

Base stock model is equivalent to the Japanese Kanban System (with kanban size of one) since, order quantity is one

The primary insights from the model:

1. Reorder points control the probability of stockouts by establishing safety stock.
2. To achieve a given fill rate, the required base stock level (and hence safety stock) will be an increasing function of both mean and standard deviation of the demand during replenishment lead time.
3. Base stock levels in multistage production systems are very similar to kanban.

We have assumed Poisson distribution for demand and found out reorder point, order quantity and the safety stock in supply chain.

3.1 Application runs of Base Stock Model to Three-Tier Supply chain

Replenishment lead time = 12 months

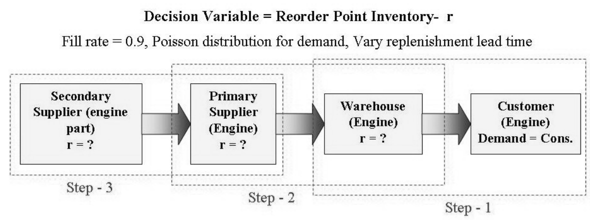

Figure 1. Supply chain considered for Base Stock model

At Warehouse

Demand during 12 months is 10 units /year

Average Demand = 10 units per year

3.2 Results from Base Stock Model

Table 1 summarizes all the results for base stock model and frequency of order. Order cost is assumed to be $ 25 per order. The total cost is calculated by using

$$TC = c\left(\frac{Q}{2} + r - \theta\right) + \text{Order cost.} \qquad (1)$$

3.3 Total cost VS. Replenishment Lead-time

The total inventory cost is plotted against replenishment lead time in Figure 2.

Table 1. Summary of results of costs (Base Stock Model)

Replenishment Lead Time (months)	Warehouse ($)	Primary Supplier ($)	Secondary Supplier ($)
12	925	1175	1450
8	741.25	925	1175
6	775	925	1225
4	725.5	975	1350
2	316.25	450	650

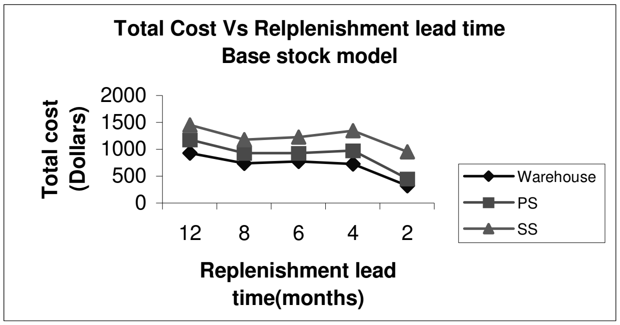

Figure 2. Total cost vs. replenishment lead- time (Base Stock Model)

3.4 Reorder point vs. Replenishment Lead time

The reorder point decreases with replenishment lead- time. Reorder point is plotted against replenishment lead time in Figure 3.

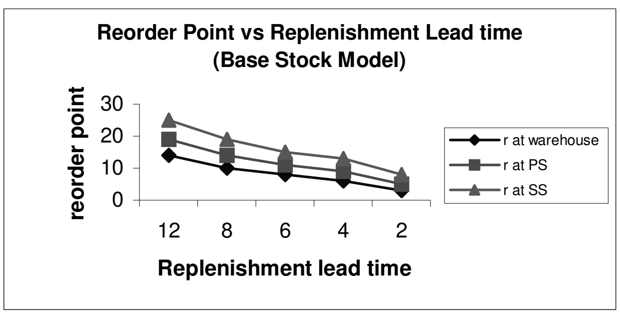

Figure 3. Reorder point vs. replenishment lead-time (Base Stock Model)

3.5 Summary

The graph in Figure 3 shows the decreasing trend in reorder point from warehouse to secondary supplier for the same lead time. The total inventory cost decreases with replenishment lead-time for Base Stock Model. We can conclude from Figure 2 that there is decreasing trend in costs of warehouse, primary supplier and secondary supplier for the same replenishment lead-time.

Base stock model emphasizes on order quantity of 1. Base stock model can be used where demand is stochastic. Base stock model proves to be better for small lead-time.

4 Physical Simulation of Base Stock Model

Primary goal of conducting the physical simulation is to validate the results obtained from the mathematical models. Simulation was run to confirm that optimum inventory levels i.e. reorder point at warehouse, primary supplier and secondary supplier are realistic values. Physical simulations are being used very effectively as a teaching tool for Lean training.

This physical simulation models a three-tier single-product supply chain. ABC Company uses a certain type of engine for their product. Final assembly department of the company withdraws these engines from the warehouse as needed. The Warehouse receives engines from Primary Supplier. Primary Supplier receives the engine parts like cylinders from Secondary Supplier. We will make the assumption that only one cylinder is needed per engine. We are interested in inventory levels at Warehouse, Primary Supplier and Secondary Supplier. Excessive inventory results in increased holding costs while inadequate inventory results in backorders. Thus it is necessary to keep the optimum level of inventory at Warehouse, Primary Supplier and Secondary Supplier.

Customer, Warehouse, Primary Supplier and Secondary Supplier are 4 departments in the simulation. The movement of the parts is as shown in the Figure below. The Secondary Supplier provides cylinders to Primary Supplier. The Primary Supplier assembles the cylinders in the Engine Block and sends the Engine to the Warehouse. Engines are pulled from warehouse based upon a demand that follows Poisson distribution.

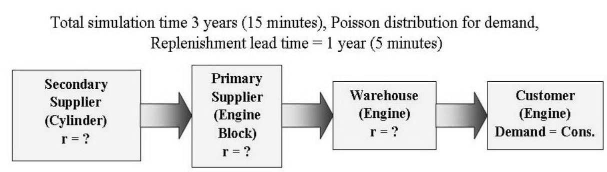

Figure 4. Layout of Supply Chain for Physical Simulation

a. Simulation Activity Time Frame

The total duration of simulation for each phase is 15 minutes (3 years). Customer sends the Order Requirement Form to the Warehouse at the start of simulation. Inventory at Warehouse goes below reorder point when the customer demands parts from Warehouse (at 1st min). Warehouse then sends Order Requirement Form to Primary Supplier. This triggers production activity at Primary Supplier, which has a replenishment lead time of one year. Replenishment lead time at Secondary Supplier is also one year. Warehouse has initial inventory (equal to reorder point). Demand at Customer is satisfied with this initial inventory.

In second year Primary Supplier sends the parts to Warehouse as per the schedule provided by Warehouse. Demand at Warehouse also follows Poisson distribution. When inventory level at Primary Supplier goes below reorder point (at 6th min), it sends Order Requirement Form to Secondary Supplier. This initiates production at Secondary Supplier.

In third year, Secondary Supplier starts sending parts to Primary Supplier (11th min). Primary supplier sends engine to Warehouse as per the schedule received in second year. Warehouse fulfills the Customer demand as per the Order Requirement Form provided by Customer in third year.

b. Simulation Phases

During phase-I, amount of initial inventory is same as reorder point calculated but lower than the quantities predicted by the mathematical model. The level of inventory is 10 at Warehouse, 14 at Primary Supplier and 19 at Secondary Supplier. Customer demand is 10 units per year. These values are intentionally kept lower than the ideal values of inventory predicted by mathematical model.

Any demand not filled from stock is backordered. The number of backorders during this phase is noted in the form provided at each department. Simulation activity takes place and data is collected. Base Stock model assumes replenishment quantity of one unit. Hence there is Single Piece Flow in supply chain.

Inventory at the end of simulation at Warehouse, Primary Supplier and Secondary Supplier is documented. The ideal values calculated by mathematical model are Warehouse=14, Primary Supplier=19. Secondary Supplier=25. Total number of backorders is documented and results are shown in spreadsheet.

During phase-II, the inventory levels are kept at the optimum values predicted by the mathematical model. The inventory levels are same as reorder points in this phase also. With optimum levels of inventory, no backorders were documented in this phase confirming the results predicted by mathematical models.

During phase-III, the inventory levels are kept intentionally higher than the optimum levels and the reorder points are as shown in the figure below. No backorders were observed in this phase due to high inventory levels but inventory costs were high due to large inventory level.

4.1 Distribution of Demand

We ensure that the demand at Warehouse, Primary Supplier and Secondary Supplier follows Poisson distribution as in the case of mathematical models. This is done by using Stat-Fit software to calculate demand quantities for Customer, Primary Supplier and Secondary Supplier. The values obtained are shown in Table 2.

Table 2. Order Quantity vs. Replenishment Lead Time

Demand at Customer	Demand at Primary Supplier	Demand at Secondary Supplier
2	3	4
3	4	5
2	3	4
2	2	3
1	2	3
10	**14**	**19**

4.2 Performance Metrics

The assumptions about backorder cost and inventory holding costs match with the mathematical models. It is assumed that each backorder costs $100 and unit inventory holding cost is $20. The order cost is assumed to be $25 per order. In Base Stock model, the order quantity is one therefore; total numbers of orders are same as order quantity. Following spreadsheet is used to collect the data:

Table 3. Performance Metrics

Performance Criteria	Phase I	Phase II	Phase III
Total number of orders	24	33	44
Order cost	$600.00	$825.00	$1,100.00
Excess Inventory	6	24	41
Total number of backorders	10	0	0
Cost of each backorder ($)	$100.00	$100.00	$100.00
Total cost of backorder	$1,000.00	$0.00	$0.00
Cost of inventory cost	$10.00	$10.00	$10.00
Excess Inventory cost	$60.00	$240.00	$410.00
TOTAL COST	$1,660.00	$1,065.00	$1,510.00

4.3 Summary

Excess inventory and number of backorders is documented at the end of each phase. The inventory holding cost and backorder cost are calculated in each phase. Ten backorders were observed during phase-I because of inadequate inventory at Warehouse. Therefore, total backorder cost is $1000 in phase-I. During phase-III, excess inventory exists and cost associated with this inventory is $410.

Phase-II includes the optimum level of inventory as predicted by mathematical models. In this case, backorder cost is zero and excess inventory cost is higher than phase-I but lower compared with phase-III. Total cost of inventory is the lowest in Phase-II as predicted by the mathematical models. The physical simulation used Lego blocks for engine blocks, cylinders and assembled engines during the simulation.

5 Discrete Event Simulation

Primary goal of the computer based simulation is to demonstrate that Base Stock Model can effectively predict the level of inventory at reorder point. Another goal is to compare the results obtained here with those of mathematical model and physical simulation model. Discrete event simulation is a pedagogical tool that uses computer models to study a production system with the goal of optimizing its performance. ProModel simulation software is used for analyzing and assessing the flow of parts through a two tier supply chain system. The model uses four locations to indicate the key players in the supply chain namely Customer, Ware House, primary Supplier and Secondary Supplier. The layout of the model is shown in Figure 5.

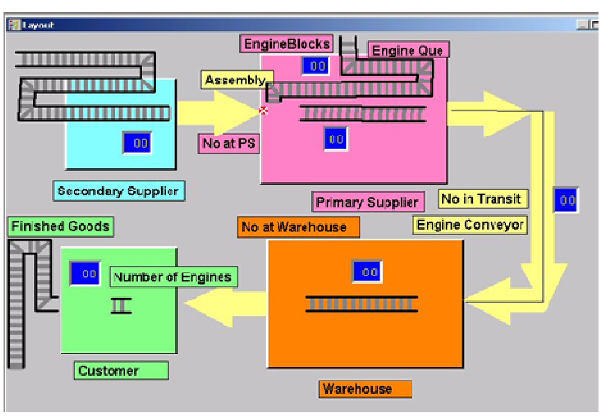

Figure 5. Layout of the Supply Chain in ProModel

The model uses real time counters and global variables to define and display the number of parts as they go through the supply chain. The conveyors are designed long enough to display all parts as they are waiting to be processed. A specified number of cylinders arrive at the secondary supplier with a Poisson distribution. Engine blocks arrive at the primary supplier with another Poisson distribution. One cylinder is assembled with the engine block at the assembly station. Engine block icon is initially grey in color. After assembly of cylinder, the color of the engine block changes to blue indicating an assembled engine. The assembled engine proceeds to the warehouse via engine conveyor and then on to customer. The replenishment lead time is simulated by the travel delay between these stations. For example, if the replenishment lead time is 2 months, transportation between these stations takes 2 months.

5.1 Summary

The simulation was run with the values of r predicted by the base stock model. For example, the base stock model predicted that to obtain a fill rate of 90%, following inventory levels must be maintained; warehouse-3, primary supplier-5 and secondary supplier-8 for a customer demand of 10 units/yr and replenishment lead time of 2 months. The part counter in this case indicates that 10 engines were delivered to the customer without any backorder. These results are summarized in Table 4.

Table 4. Results from Discrete Event Simulation

Case	Inventory at PS	Inventory at WH	Lead Time (days)	Engines to Customers	Number of Backorders
1	0	0	60	7	3
2	5	3	60	10	0

6 Conclusions

Base Stock Model is effective when the demand is not deterministic and service factor assumed in mathematical model is 0.9, which is quite acceptable. Base stock model assumes replenishment order quantity as 1 and the total inventory cost decreases with replenishment lead time. Base stock model is beneficial for supply chains having short replenishment lead time.

Physical simulation and Discrete Event Simulations are used to validate the results from the Base Stock Model. Both Physical Simulations and Discrete Event Simulations are designed to include all the assumptions made by mathematical model. Hence all three models are comparable. Demand follows Poisson distribution in both the simulations. For physical simulation, the backorder cost and inventory holding cost are calculated in each phase of simulation and summarized in Table 4. We can refer that the total inventory cost is optimum in phase II, in which reorder point is same as that calculated by mathematical model. In phase I, total inventory cost is more than that of phase II because of backorders. In phase III, excess inventory increased the total cost. Thus the values obtained from mathematical model produce optimal inventory cost. Results from the computer simulation model validate the results predicted by base stock model.

Results from both the Physical and Discrete Event simulations indicate that these methods can be used to successfully model stochastic systems like organizational supply chains.

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Biography

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Dr. Alok K. Verma is Ray Ferrari Professor and, Chair of the Engineering Technology Department at Old Dominion University. Dr. Verma received his B.S. in Aeronautical Engineering from IIT Kanpur, MS in Engineering Mechanics and PhD in Mechanical Engineering from ODU. Prof. Verma is a licensed professional engineer in the state of Virginia, a certified manufacturing engineer and has certifications in Lean Manufacturing and Six Sigma. He has organized several international conferences as General Chair, including ICAM-2006 and ICAM-1999 and also serves as associate editor for three International Journals. He serves as the chief editor of the International Journal of Agile Manufacturing. Dr. Verma's scholarly publications include more than 87 journal articles and papers in conference proceedings and over 50 technical reports. He is actively involved in applied research, and has served as a PI or Co-PI on several funded competitive grants exceeding $4.0 million. Dr. Verma has developed and delivered training program in Lean Enterprise & Design for Manufacturing for Northrop Grumman Newport News, STIHL and several other companies in U.S. He has developed simulation based training programs for shipbuilding and repair industry under a grant from the National Shipbuilding Research Program (NSRP). He is well known internationally and has been invited to deliver keynote addresses and invited papers at more than 12 national and international conferences on Lean/Agile manufacturing. Dr. Verma has received the Regional Alumni Award for Excellence for contribution to Lean Manufacturing research, the International Education Award at ODU and Ben Sparks Medal by the American Society of mechanical Engineers (ASME). He is active in ASME, American Society for Engineering Education (ASEE), Society of Manufacturing Engineers (SME), Institute of Industrial Engineers (IIE) and the Society of Naval Architects and Marine Engineers (SNAME). Dr. Verma continues to serve the Hampton Roads community in various leadership positions.