VENDOR MANAGED INVENTORY:

A NEW APPROACH TO SUPPLY CHAIN MANAGEMENT

by

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Vendor Managed Inventory: A new approach to supply chain management

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ABSTRACT

The Global Supply Chain Forum (Stanford Global Supply Chain Forum Web Resource, http://www.stanford.edu/groups/scforum) defines supply chain management (SCM) as

"Supply chain management is the integration of key business processes from end user through original suppliers that provides products, services and information that add value for customer and other stakeholders"

The rapid development of the Internet has dramatically changed the traditional definitions of manufacturer, suppliers and customers. Newer approaches to supply chain management attempt to organize the supply chain as a network of cooperating intelligent agents, each performing one or more supply chain functions and each coordinating actions with one another. This research is aimed at creating a viable model of a single manufacturer-single supplier collaborative supply chain system using a Vendor Managed Inventory (VMI) system. The research further uses known inventory performance parameters to performance benchmark the VMI system with traditional push-pull systems, develop a collaborative forecasting spreadsheet solution and a best alternative ordering policy amongst EOQ, Monthly, JIT and VMI policies under known lead time and a variety of demand distribution functions.

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I dedicate this work to my family. My mother and father, Varsha and Sudhir Gandhi, my brother Dr. Umang Gandhi and his wife, Dr. Archana Gandhi and little Mahek. Their love and constant support helped me face the rigors of a Masters' degree in a new surrounding.

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CHAPTER 1. INTRODUCTION

1.1 GLOBALIZATION AND CHALLENGES

Market globalization has forced enterprises to rethink traditional supply chain approaches. With the development of the Internet, customers are no longer restricted to local buying. Companies must increasingly focus on gaining competitive advantage through effective management of their supply chains. The e-business revolution is affecting supply chain management dramatically and is changing how companies integrate business processes, both inside and outside the enterprise. These developments introduce new business and technical challenges and spotlight existing business processes and supporting enterprise systems that revolve around the supply chain. Newer approaches to supply chain management attempt to organize the supply chain as a network of cooperating intelligent agents, each performing one or more supply chain functions and each coordinating action with one another (Horvath, 2001).

The common characteristic among supply chain leaders in all the industry segments is the extent to which the various supply chain constituents engage in supply chain collaboration. Organizations need to break the traditional paradigm of looking at the supply chain as a set of inter-connected constituents (Sahay, 2003). There is an urgent need to employ systems thinking to supply chain management.

1.2 SUPPLY CHAIN CONSTITUENTS

Figure 1.1 illustrates the physical movement of products through a supply chain network for a manufactured product. The flow begins with several suppliers. They send raw materials/components to a factory. The factory either manufactures products or assembles them and sends the finished products to regional warehouses or to distribution centers. The warehouses and distribution centers support the customers.

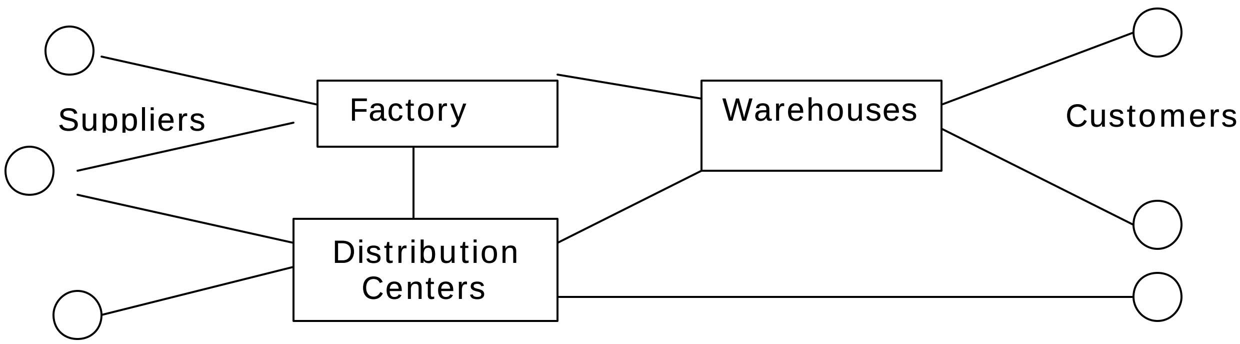

Figure 1.1 Flows within a supply chain

A typical supply chain is comprised of a manufacturer, one or more suppliers, distribution centers and retailer owned warehouses all serving the various downstream customers. Traditionally, the focus of companies has been on the flows within the organization or the flows over which the organization has direct control (Sahay, 2003). Supply chain management has done a very effective job of optimizing the individual supply chain constituents. However, successful supply chain management requires the recognition that the firm is simply one player in the long chain that starts with the suppliers and includes transporters, distributors and customers (Sahay, 2003). Organizations must interact cooperatively with their channel partners (e.g. suppliers, distribution centers, etc.) for the mutual benefit of the channel as well as the gain of each player. In order to adopt this systems perspective, organizations should not only consider the impact of any business decision on their own performance but also on the bottom line of their suppliers, distributors and transporters. Anderson and Lee (1999) call the new generation of supply chain strategy a "synchronized supply chain."

As organizations enter the era of network competition, the winners will be those organizations that can better structure, coordinate and manage the relationships with their partners in a network committed to better, faster and closer relationships with their final customers (Christopher, 1999). As organizations look beyond their own firms, it becomes important for them to involve their suppliers and customers in the various processes. Successful involvement yields major benefits: increased market share, inventory reductions, improved delivery service, improved quality and shorter product development cycles (Corbett et. al., 1999).

1.3 PROBLEM STATEMENT

Given the challenges posed by market globalization, there is a pressing need for newer approaches to supply chain management. Systems increasingly reflect supply chain costs from an integrated picture. Collaborative supply chain planning (CSCP) not only respects constraints, it reflects cost and profit objectives.

One of the important issues to be addressed in the development of a collaborative supply chain is the ordering and replenishment policy to be followed. An ordering policy that does not adhere to the principles of collaborative supply chain management can translate to sub-optimization in supply chains and, consequently, enormous losses for the organization (Sahay, 2002). One example of a CSCP system is Vendor Managed Inventory (VMI). Unlike a traditional business model which orders on the basis of an ordering amount decided by commonly known formulae like EOQ, in a VMI system, the supplier receives electronic data (usually through an Electronic Data Exchange or the Internet) that informs him about the manufacturer's sales and stock levels. The supplier is responsible for creating and managing the inventory replenishment schedule.

The research questions to be addressed in this thesis are:

Given the necessity for a collaborative supply chain environment in the current market scenario, what are the functional requirements for the development of a single-echelon system incorporating VMI principles under known lead-time and variable demand? How does a VMI ordering policy compare against standard ordering policies incorporating Economic Order Quantity, Monthly ordering and Just in time ordering on the basis of known inventory measures and under a variety of demand distribution functions? Additionally, can a spreadsheet analysis provide the best alternative among the four ordering policies mentioned?

1.4 RESEARCH OBJECTIVES

Horvath (2001) and Sahay (2002) identified the necessity for a collaborative supply chain environment as being essential to the success of any organization in the current paradigm of globalization. This research will require the development of an ordering policy for single manufacturer-single supplier supply chains with known lead-time and variable demand. Additionally, a collaborative supply chain model will be constructed that can serve as a building block for quantifying the inventory and service performance of supply chains in dynamic settings. The research question will be answered by constructing a database application system incorporating VMI logic. Using the results from the database system and a systems dynamics model, a best alternative ordering policy for a single manufacturer-single supplier system can be developed by a statistical analysis of four ordering policies – EOQ, Monthly, JIT and VMI-under three demand distribution functions – Uniform, Triangular and Poisson.

1.5 RESEARCH METHODOLOGY

The research method will be accomplished in three distinct phases. Each phase is incremental in nature and can generally be described by the primary steps that will occur in each – they are the modeling phase, the application system development phase, and the analysis phase.

The modeling phase consists of analyzing the supply chain constituents to create a conceptual design of a VMI network. With global competition imposing tremendous pressure on product and service providers to transform and improve their operations and practices, firms are reconsidering the design of traditional Supply Chain Networks (SCN) as a solution for effectively meeting customer requirements such as low costs, high product variety and short lead times (Crainic, 2000). The modeling phase will integrate the Axsater (2002) model, which will be used to investigate stock replenishment and shipment scheduling in VMI systems.

The application system design phase consists of the design and development of a database system incorporating VMI principles. The application system is limited to the design and implementation for a single manufacturer-single supplier-single distribution center system. Systems incorporating multi-echelon supply chain constituents will not be considered in this research. The application system for the MRP system will incorporate three ordering policies – EOQ, Monthly ordering policy and JIT ordering policy-under three demand distribution patterns – Uniform, Triangular and Poisson. The time period under review is one fiscal year, operating from January 1 to December 31. The system will incorporate C code that will write output results to a text file for analysis.

The analysis phase involves using the results of Kaplan and Norton (1996) and Beamon (2000) to generate a list of performance measures. These performance measures will be concentrated in the process metrics category with special emphasis on inventory management. Microsoft Excel will be used to generate performance curves based on inventory measures and creation of two-axis graphs for policy comparisons under the different demand distributions.

The research methodology can be represented in a flowchart representation as illustrated in Figure 1.2.

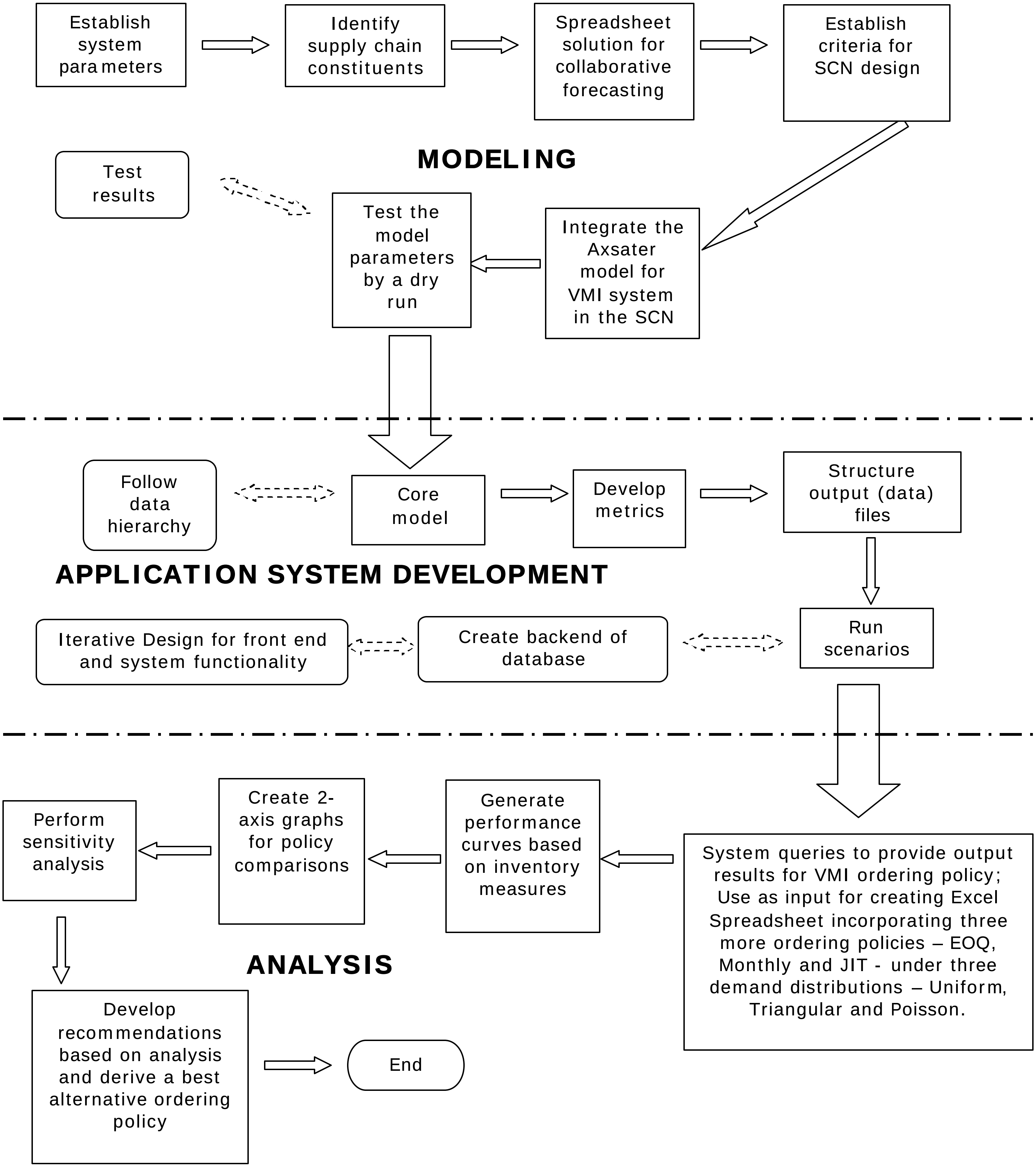

Figure 1.2 Research Methodology

CHAPTER 2. VENDOR MANAGED INVENTORY (VMI) SYSTEMS

2.1 INTRODUCTION

Hall (1998) defines VMI as a process where the supplier generates orders for the customers based on demand information sent by the customer.

One of the most challenging issues for fulfilling customer needs is to manage the order delivery process between the various supply chain constituents (Kaipia, 2002). One of the primary goals of effective supply chain management is to develop processes between all the supply chain members that minimize the wastage of time and enable fast and reliable reactions to demand changes. A traditional order delivery process is based on the principle that the manufacturer/retailer defines the amount and timing of deliveries of each item needed from the supplier. The supplier's task is to fulfill this as closely as possible. Exactly how this is done varies, depending on the industry and the company. Retailing organizations place purchase orders for every delivery, whereas manufacturing industries use economic order quantity purchases (Kaipia, 2002).

Fast transfer of information between organizations has, since the introduction of electronic data interchanges (EDI), been considered a key issue in improving the performance of supply chains. Just-in-time and agile practices like smaller lot sizes and frequent deliveries have been applied to permit the suppliers to react faster to changes in the customer's demand. However, there are several serious problems with the demand fulfillment solution using traditional approaches.

- The actual item level replenishment cycle is far slower than the order fulfillment cycle. A survey of manufacturers and retailers in United States

(Horvath, 2001) illustrates that frequently an order was placed when the product was already sold out or so late that the product would be out of stock before the delivery arrives.

- On the supplier side, there are high levels of inventory because of the short delivery time and high service level requirements. Typically, there exists accurate information neither about retail sales nor about out-of-stocks along the chain. This means that the real trade-off between providing a good logistics service level and cost level remains hidden from the supplier. Lee, et. al (1997) illustrated the development of the bullwhip effect in both manufacturing and retail scenarios using this fact.

2.2 VENDOR MANAGED INVENTORY PROGRAMS

Vendor Managed Inventory, VMI, is an alternative for the traditional order based replenishment practices. VMI is a fundamental change in the approach for solving the problem of supply chain coordination. Instead of putting more pressure on suppliers performance by requiring faster and more accurate deliveries, VMI gives the supplier both responsibility and authority to manage the entire replenishment process. The manufacturer/retailer provides the supplier access to inventory and demand information and sets the targets for availability. Thereafter, the supplier decides when and how much to deliver. The measure for the supplier's performance is availability and inventory turnover. This is a fundamental change that affects the operational mode both at the customer and at the supplier company. Waller (1999) investigated the impacts of VMI through simulation. The study shows how replacing purchase orders with inventory replenishments enable suppliers to improve service while reducing supply chain costs. The reason for this is that in VMI the inventory of the average product is reviewed more frequently than purchase orders were placed before. For the average item, the more frequent review in the VMI approach reduces the ordering delay in the information flow. Other VMI benefits (Cottrill, 1997, Nolan, 1998) are more long term in nature. The introduction of VMI gives the supplier more time to react - i.e. it levels demand and in this way brings benefits in reduced inventories and in effective production planning and control.

It is important to note that the more frequent inventory reviews in VMI do not require more frequent deliveries. It is exactly this requirement for frequent deliveries that has in many cases caused problems for suppliers when the customer has introduced the just-in-time (JIT) concept (Kaipia, 2001).

There are numerous case examples of successful VMI implementations (Cooke, 1998, Holmstrom, 1998). However, VMI has not become a standard way of managing replenishment processes in the supply chain. There seem to be some practical issues that slow down the implementation of VMI in many companies. The requirement of standard product identification and integrated information systems in the supply chain is one example. The two parties may also be unwilling to share information, and lack of trust often exists (Fraza, 1998). Purchasing, and not sourcing, is seen as a core competency of the company (Cooke, 1998). The lack of trust between the trading partners and the uncertainty about the potential benefits of VMI are difficult obstacles. For establishing trust a company should be able to demonstrate to the trading partner the benefits of shifting to VMI. Also, VMI is not a standard solution for all replenishment processes. The benefits of VMI vary in different supply chains and according to product demand.

2.3 VMI BENEFITS (Adapted from Hall, 1998)

The main benefits of VMI are given below.

1. **Lower customer Inventories** is the primary benefit of a VMI implementation program. Under VMI, the supplier is able to control the lead time component of the order point better than a

manufacture/supplier with a host of suppliers can ever hope to. Additionally, with frequent inventory review, the need for safety stocks on the supplier side is dramatically reduced.

2. **Better Forecasts** occur because of demand information sharing (Cooke, 1998). Better forecasts result from having a more stable demand distribution pattern. The demand is reflected in more frequent orders for the same parts and therefore lower variability of demand in business.
3. **Reduced costs** occur because of the reduction in the demand volatility downstream of the supply chain (Waller, 1999). VMI helps dampen the peaks and valleys of production, allowing smaller buffers of capacity and inventory. With VMI, greater channel coordination supports the supplier's need for smoother production without sacrificing the manufacturer/retailer's service and stock objectives (Lee, 1997). Transportation costs are reduced with VMI because the approach helps to increase the percentage of full truckload shipments and eliminate the higher cost LTL shipments (Lee, 1997).
4. **Improved Service.** From the manufacturer/retailer's perspective, service is usually assessed by measuring product availability. With VMI, coordination of replenishment orders and deliveries across multiple suppliers helps to improve service. Lee (1997) illustrated that the adverse effects of price markdowns and "product rollovers" can be drastically reduced by using channel coordination programs like VMI. Finally, coordinated logistics decisions ensure more predictable delivery schedules in VMI systems.

2.4 VMI PROCESS DESCRIPTION

The Voluntary InterIndustry Commerce Standards (VICS), an umbrella organization of industries across the United States, has defined some common technology standards for VMI programs (VICS Web Resource, www.vics.org).

There are two EDI transactions at the heart of any VMI process.

1. **Product Activity Report (852)**: The data contained in this document are sales and inventory information. The inventory data are typically segmented into various groups such as on-hand, committed, back ordered, etc. This transaction report is the backbone of the VMI program and is sent by the customer on a prearranged schedule, typically, on a daily basis.

The supplier reviews the information that has been sent by the manufacturer on the 852 to determine the necessity of an order. The following sequence of steps is recommended by the VICS standards.

- Verification of data to ensure accuracy. Most of this verification process is usually automated.
- On a scheduled basis, the software calculates a reorder point for each item based on the movement data and any overrides contributed by the manufacturer. The software compares the quantity available at the manufacturer with the reorder point for each item at each location. This determines the necessity of a new order. Order generation is possible only at the manufacturer site.
- Order quantities are calculated. Order quantities also take into account issues such as carton quantities and transaction costs.

2. **Purchase Order Acknowledgement (855)**: The second VMI transaction informs the customer what product to expect from the supplier. There are two transactions being used for this function. The

most frequently used is the "*Purchase Order Acknowledgement*", referred to as 855. This document contains the product numbers and quantities ordered by the supplier on the manufacturer's behalf. There is a feature in the VMI software to use the 856, "*Advance Ship Notice*", to alert the manufacturer about the order and shipment. 856 differ from the 855 in both the timing and content. The 856 is sent after the shipment has been made instead of at the time of the order. The 856 contains only the part numbers shipped as well as additional information such as carrier and waybill information. The use of either the 855 or 856 is dictated by the operational rules defined in the VMI software.

Figure 2.1 illustrates a typical VMI setup program.

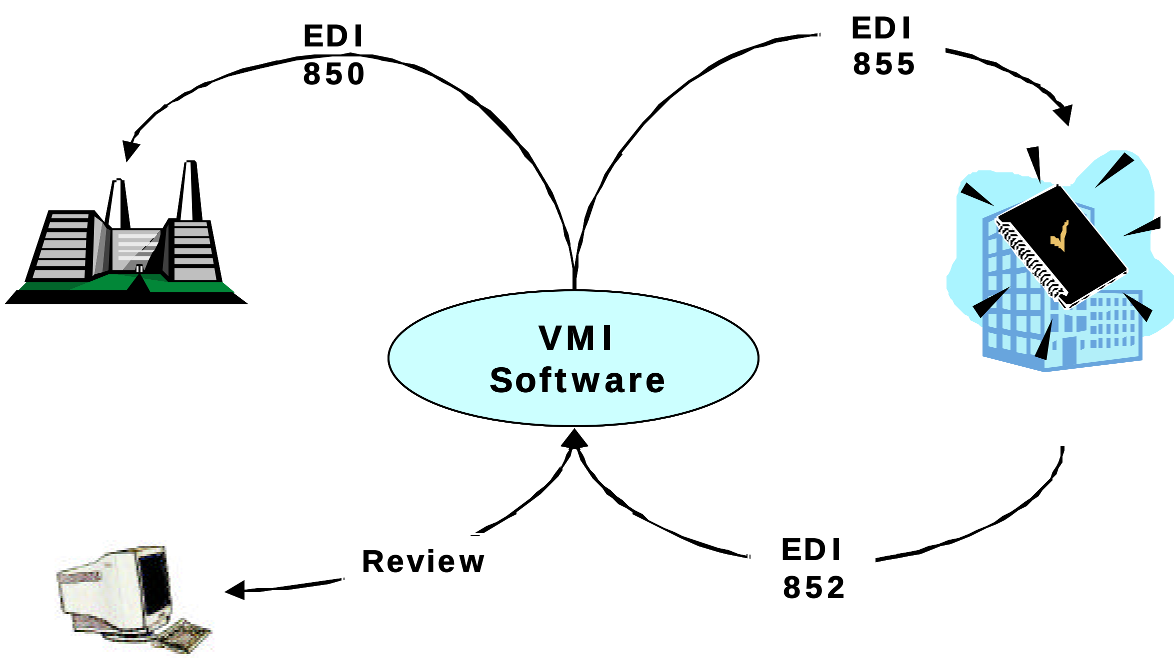

Figure 2.1 Typical VMI Setup Program

2.5 A SUPPLY CHAIN MODEL FOR VMI

The model studies vendor managed inventory issues using a supply chain model focused on inventory systems, purchase prices and purchase quantities. The model contains two supply chain constituents;

1. a manufacturer, also referred to as buyer in supply chain terminology, and,
2. a supplier (original equipment manufacturer or OEM in this case).

The manufacturer purchases the final product (or a major component of it) from the OEM supplier. The manufacturer appears to be the "leader" in this relationship, in that the manufacturer/buyer specifies order quantity according to its own cost characteristics, and determines purchase prices for the products provided by the supplier. However, the quantity the supplier is willing to provide is determined by the supplier itself for a given purchase price.

Several assumptions commonly used in inventory-channel coordination research (Kohli and Park, 1994; Weng, 1995) are made to facilitate the analysis of the consignment issue. Firstly, the inventory system of the manufacturer can be described by an economic order quantity (EOQ) policy based on deterministic demand and lead-times. The widely used EOQ policy is considered here due to its relative robustness in a variety of situations (Lowe and Schwarz, 1983).

Let y denote the demand per time period for the final product of the buyer. The profit function of the buyer can be given by,

$$\Pi_B = p_y y - wy - \left(\frac{s_B y}{Q_B} + \frac{h_B}{2} Q_B\right) \qquad \text{(i)}$$

(Source: Kohli and Park, 1994)

where,

p_y is the sales price of the final product,

w is the contract purchase price determined by the buyer,

h_B is the buyer's inventory carrying cost/unit,

s_B is the buyer's order setup cost/unit, and

Q_B is the buyer's order quantity and in this case is $(2s_B y/h_B)^{1/2}$.

Kohli and Park (1994) showed that the buyer's profit function is a function of the inventory holding and ordering costs, INV_B

$$\Pi_B = p_y y - wy - (2h_B s_B y)^{1/2} \quad \text{(ii)}$$

Since the supplier takes the order quantity from the buyer as given (Q_B=EOQ_B) and makes the necessary delivery, the supplier's profit function, after accounting for order setup, inventory holding and production and delivery costs is,

$$\Pi_S = wy - c_y - \left(\frac{h_B s_B y}{2}\right)^{1/2} \left(\frac{s_S}{s_B} + \frac{h_S}{h_B}\right) \quad \text{(iii)}$$

where

c_y is the production and distribution cost of the supplier,

h_S represents the supplier's carrying costs, and

s_S represent the supplier's order setup costs.

Weng (1995) and Joglekar (1998) showed that the supplier's lot size is treated as an integer multiple (m) of that of the buyer's.

$h_S = (m-1)h'_S$

$s_S = s_P + s'_S/m$

where,

h'_S is the supplier's actual inventory holding cost,

s_P is the supplier's fixed order processing cost per buyer's order, and

s'_S is the supplier's setup/ordering cost per buyer's order.

For any given purchase price w from the buyer, the supplier chooses a quantity y to maximize its profit and it can be obtained from the first order condition.

$$w = c'_y + \frac{1}{2}\left(\frac{h_B s_B}{2y}\right)^{1/2}\left(\frac{s_S}{s_B} + \frac{h_S}{h_B}\right) \quad \text{(iv)}$$

The buyer can maximize its profit by choosing the optimal quantity y^*, such that:

$$p'_{y^*}y^* + p'_{y^*} - c'_{y^*} - c''_{y^*}y^* - \frac{1}{4}(w^* - c'_{y^*}) - \frac{1}{2}(\frac{2h_B s_B}{y^*})^{1/2} = 0. \quad \text{(v)}$$

y^* exists when the second order condition is satisfied and can be solved numerically with relevant demand and cost function forms. In a traditional setting, the buyer, using knowledge of the supplier's cost and willingness to supply at a given purchase price can offer the supplier a price so as to get the optimal quantity the buyer desires.

In a VMI setting, the buyer no longer manages its inventory system and leaves it to the supplier to determine inventory levels, order quantities, lead times, etc. As a result, the supplier now has the combined inventory with order setup costs (s_S+s_B) and carrying costs (h_S+h_B). The supplier's profit function with VMI consignment becomes

$$\Pi\frac{c}{s} = w_c y - c_y - [2(s_S + s_B)(h_S + h_B)y]^{1/2} \quad \text{(vi)}$$

where w_c represents the new pricing method the buyer uses to induce the supplier to manage the buyer's inventory system. In VMI terminology, w_c represents the contract purchase price. The buyer's profit function is

$$\Pi\frac{c}{B} = p_y y - w_c y \quad \text{(vii)}$$

As the supplier maximizes its profit with the buyer's inventory added into the supplier's cost and profit functions, the relationship between the purchase price and the purchase quantity can be obtained from the first order condition of the supplier's profit function.

$$w_c = c'_y + \frac{1}{2}(\frac{2(h_B + h_S)(s_B + s_S)}{y_c})^{1/2} \quad \text{(viii)}$$

The optimal purchase quantity can be obtained from the first order condition of the buyer's profit function (vii) by incorporating (viii),

$$p'_{yc^*}y_c^* + p_{yc^*} - c'_{yc^*} - c''_{yc^*}y_c^* - \frac{1}{4}(w_{c^*} - c'_{yc^*}) = 0 \qquad \text{(ix)}$$

The extent of channel profit is the sum of (i) and (iii)

$$\Pi_B + \Pi_S = p_y y - c_y - (\frac{s_B y}{Q_B} + \frac{h_B}{2}Q_B) - (\frac{s_s y}{Q_s} + \frac{h_S}{2}Q_S)$$

The extent of channel profit is important because, as Schenck and McInerney (1998) note, to assess results in a VMI relationship with a retailer, it is important to consider the VMI impact on not only just retail, but the total supply chain as well.

VMI leads to immediate changes in both the buyer's and supplier's inventory management (Dong, 2000). For VMI to be considered and accepted by both the supply chain constituents, it has to be able to induce some observable benefits, especially in the reduction of inventory related costs. Although some other strategic or managerial considerations, such as strengthening competitive advantage or strengthening the buyer-supplier relationship, might play a role in the supplier's decision to adopt VMI, the bottom line is whether or not VMI could eventually save costs or generate revenues for the supplier.

Lemma. In the short term, VMI will reduce the total inventory related costs of the whole system (buyer-supplier integrated system).

Proof: Total inventory related costs (INV) of the system without VMI is given by summing the inventory ordering and holding costs of the buyer and supplier.

$$INV = (2s_B h_B y)^{1/2} + (\frac{s_B h_B y}{2})^{1/2}(\frac{s_S}{s_B} + \frac{h_S}{h_B})$$

Re-arranging the above equation yields,

$$INV = \frac{1}{2}(2s_B h_B y)^{1/2}[(1 + \frac{s_S}{s_B}) + (1 + \frac{h_S}{h_B})]$$

Total inventory related cost with VMI consignment (INV_c) is now borne by the supplier alone:

$$INV_c = (2s_B h_B y)^{1/2}[(1+\frac{s_S}{s_B})(1+\frac{h_S}{h_B})]^{1/2}$$

Thus,

$$INV - INV_c = \frac{1}{2}(2s_B h_B y)^{1/2}[(1+\frac{s_S}{s_B})^{1/2} - (1+\frac{h_S}{h_B})^{1/2}]^2$$

Comparing these inventory related costs, $INV \geq INV_c$. The equality holds when the ratio of setup costs and the ratio of the carrying costs are the same.

The reduction of combined inventory related costs through VMI, however, does not necessarily imply a cost reduction in the supplier's inventory system, although zero inventory costs can be realized on the buyer's side. Rather, since the supplier handles the combined inventory system, the supplier's inventory costs under VMI are likely to increase.

A significant mismatch between the buyer's and supplier's inventory systems creates the potential for substantial direct cost savings when introducing VMI. An example of such significant mismatch is $h_S=h_B$ while $s_S>7s_B$, i.e. the order setup cost at the supplier is 7 times or more of that at the buyer, indicating that the EOQ_S at the supplier is $7^{1/2}=2.546$ times or more of the EOQ_B at the buyer. Naturally this kind of scenario is where a VMI strategy is most powerful, as commonly observed in practice (Harrington, 1996). In this kind of situation with significant cost mismatch, the independent ordering practice of either the buyer or the supplier based on their individual goals tend to result in much higher total costs for the other party involved and far less optimal system performance. Therefore, taking over the buyer's inventory would allow the supplier to adjust order sizes based on the overall system conditions and possibly reduce the inventory related cost of the whole system dramatically.

2.6 STOCK REPLENISHMENT AND SHIPMENT SCHEDULING IN VENDOR MANAGED INVENTORY SYSTEMS

Centikaya and Lee (2000) presented a basic model for coordination of inventory and transportation decisions in VMI systems. The proposed VMI system incorporates the Centikaya-Lee model with some basic modifications. The reader is referred to their paper for a detailed description of the problem context and a discussion of related literature.

A periodic review inventory system with Poisson demand is considered. Shipments to customers can only be dispatched in connection with the reviews. At each review, the inventory position before a possible order is obtained as the inventory on hand minus the demand that has been backordered during the period. A (s, S) policy with s=-1 and S≥0 is applied for replenishing the inventory. Standard ordering and holding costs are considered.

$$C(S, T) = \frac{A_R}{(S+1)/l + T} + \frac{hS}{2} + \frac{A_D}{T} + \frac{wlT}{2}$$

Source: Centikaya and Lee (2000)

where

C Total costs per time unit
T Review period T
A_R Fixed cost of replenishing inventory
l Demand Intensity
H Holding cost per unit and time unit
A_D Fixed cost of dispatching
W Customer waiting cost per unit and time unit

Axsater (2002) optimized the model put forth by Centikaya and Lee and calculated the unconstrained optimal solution for the demand quantity S and review period T.

$$S = \sqrt{\frac{2A_R l}{h}} - \sqrt{\frac{2A_D l}{w-h}} - 1$$

$$T = \sqrt{\frac{2A_D}{l\,(w - h)}}$$

Source: Axsater (2002)

2.7 VENDOR MANAGED INVENTORY – SOFTWARE DEMONSTRATION

The VMI application software has been designed in Microsoft Access and Visual Basic. The main reasons for using an Access-VB system are,

- ease of use in using Microsoft Access as a back-end,
- compatibility of visual basic code across a variety of operating platforms,
- capability in Microsoft Access to easily web-enable the application system,
- ability to harness the power of SQL server language for coding queries, and
- prior experience of the author in handling Microsoft Access as a database development platform.

The other choices for the application software were an Oracle-ASP system (rejected because of security issues arising out of use of Microsoft Internet Information exchange server) and an Access-Cold Fusion system (rejected because of non-availability of a Cold Fusion server).

Using the PDSA (Plan-Do-Study-Act) methodology, a process flowchart was first created before actually designing the software application.

The PDSA methodology involves the use of a systems thinking approach to any problem. The development of the VMI application system consisted of the following steps,

- Creating a flowchart to document the process steps (PLAN)
- Design and documentation of the relationships in the system (DO)
- Implementation of the VMI application system (STUDY).
- Testing of the VMI application system (ACT)

2.7.1 Flow-charting process

Figures 2.2 through 2.4 are a graphical representation of the VMI process. Smart Draw 6.0 was used to create the process flowcharts in three steps. Figure 2.2 is the basic system, Figure 2.3 handles exception handling in the system and Figure 2.4 is a graphical representation of the system reports being generated at the end of the review period.

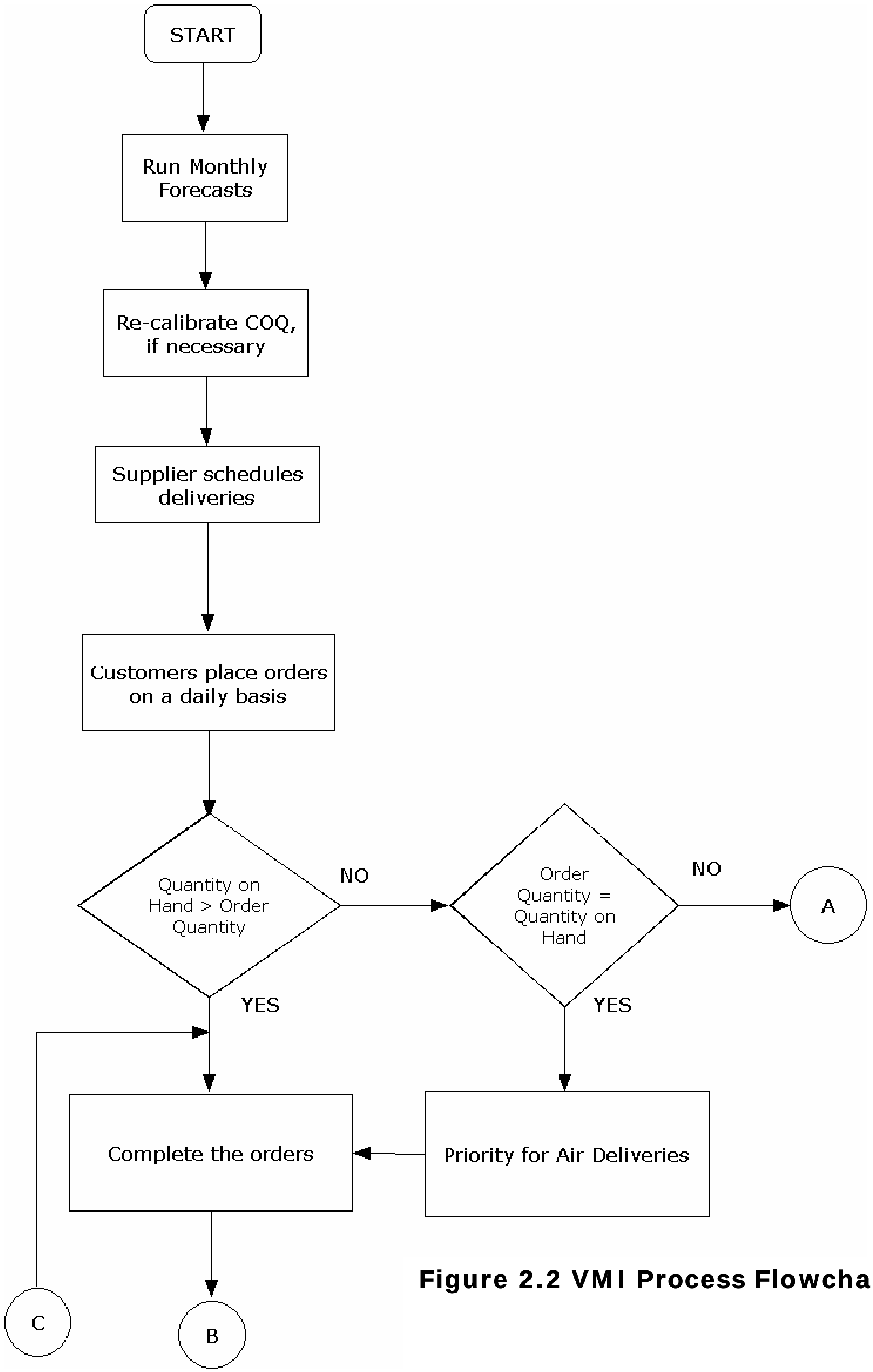

Figure 2.2 VMI Process Flowchart - 1

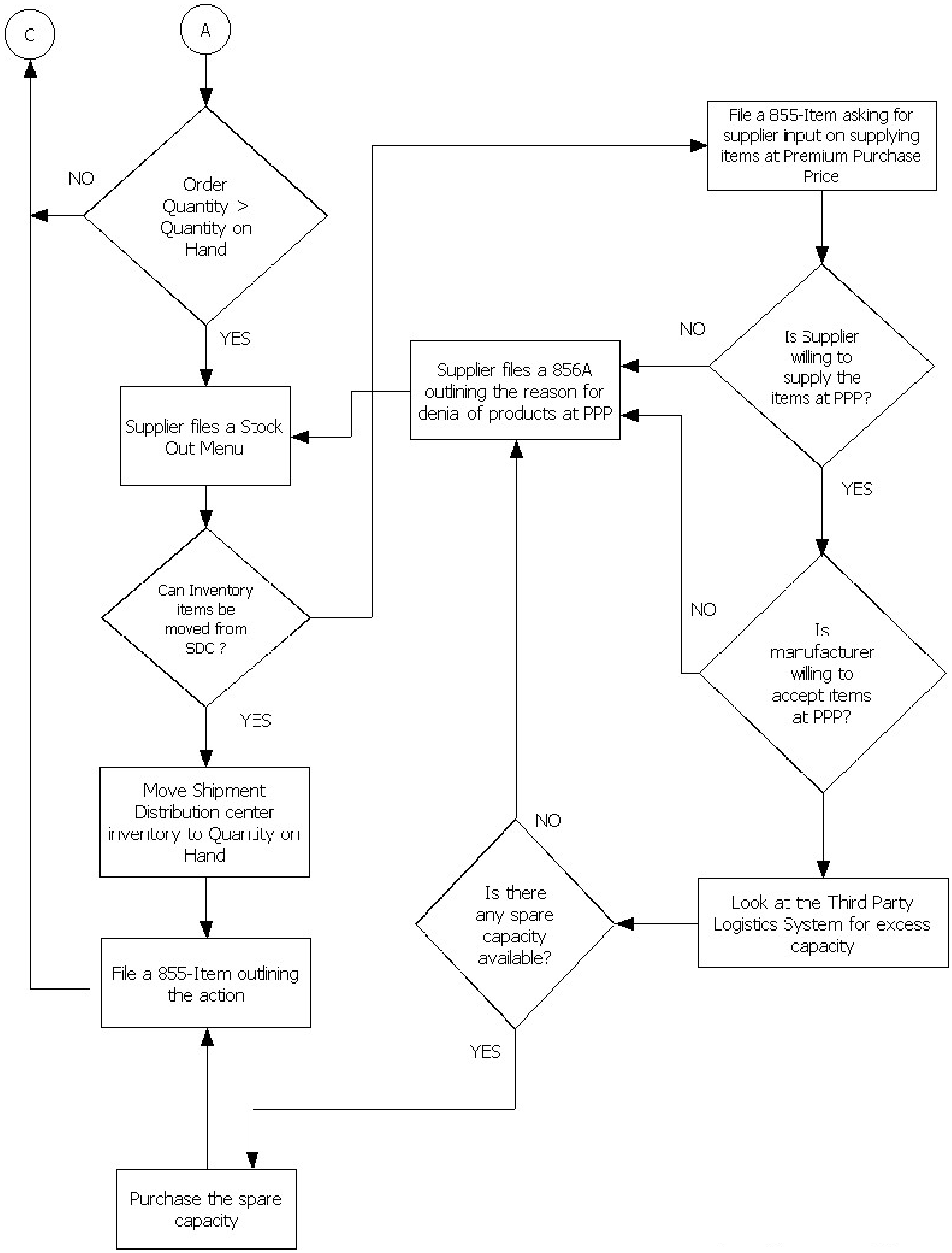

Figure 2.3 VMI Process Flowchart – 2

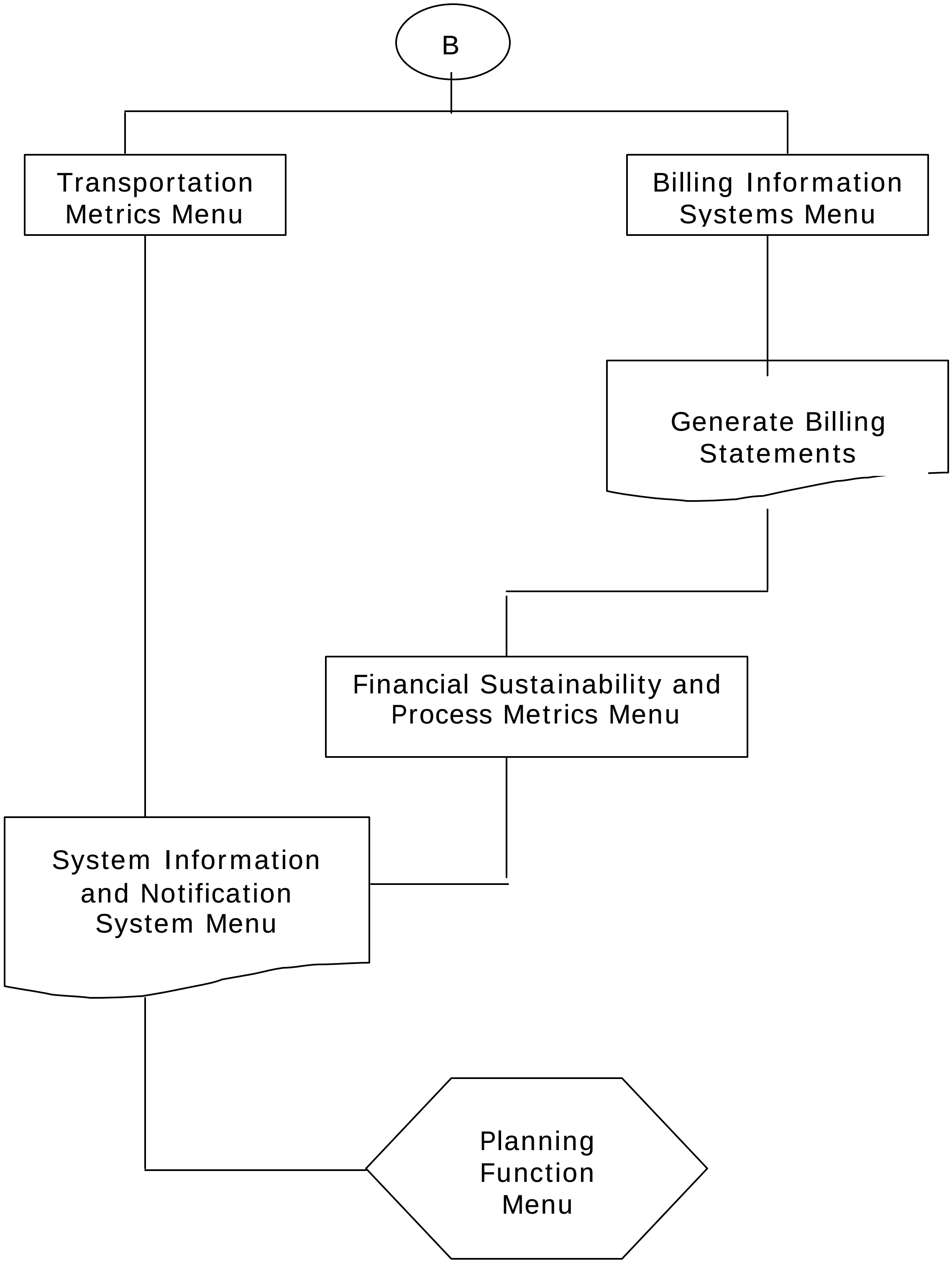

Figure 2.4 VMI Process Flowchart – 3

The above flowchart can be explained in a 6 step fashion as follows,

Step 1. Run a monthly forecast, 8 days before the start of the review period.

Assumption 1. The lead time for production and delivery of the items is 8 days

Assumption 2. The review period is the first of every month.

Re-calculate the contract order quantity as

COQ = *f*(Forecasted Demand, % of supplier capacity committed)

Step 2. If item information like the COQ or any pricing information has to be changed, these changes are incorporated using the ITEM EDIT MENU. The supplier stocks inventory equal to the COQ level at the beginning of the review period.

Step 3. Customers use the web-based order placement menu to place their order. Step 3 is a continuous process, i.e the system continuously accepts orders from the customers.

Step 4. Orders incorporating air deliveries are given priority over ground deliveries.

Step 5.

Step 5.a If Order Quantity (Order placed by customer) < Quantity on Hand, then orders are completed with first priority given to orders having air delivery as shipping mode,

Step 5. b If Order Quantity = Quantity on Hand, orders with air delivery are given higher priority,

Step 5.c If Order Quantity > Quantity on Hand,

- Supplier reports stock-outs using the Stock Out Menu.
- The manufacturer checks the Shipment Distribution Center level and can move items from the Shipment Distribution Center (SDC) to the Inventory Warehouse. A 855-Item Recommendation is filed after this action to alert the supplier about the updated inventory levels.

- In the case of non-availability of items in the SDC, the manufacturer can purchase additional items from the supplier at a premium purchase price.
- In the case of non-availability at the supplier end, the system backlogs all orders and waits for the next replenishment cycle.

Step 6. An end of period review updates the billing information system and incorporates current data in the planning system.

2.7.2 Table Relationships

The results of the flowcharting process were used to create the Access backend. Relationship database fundamentals were followed in the design and creation of the Microsoft Access database. Figure 2.5 illustrates the relationships between the key tables and field values.

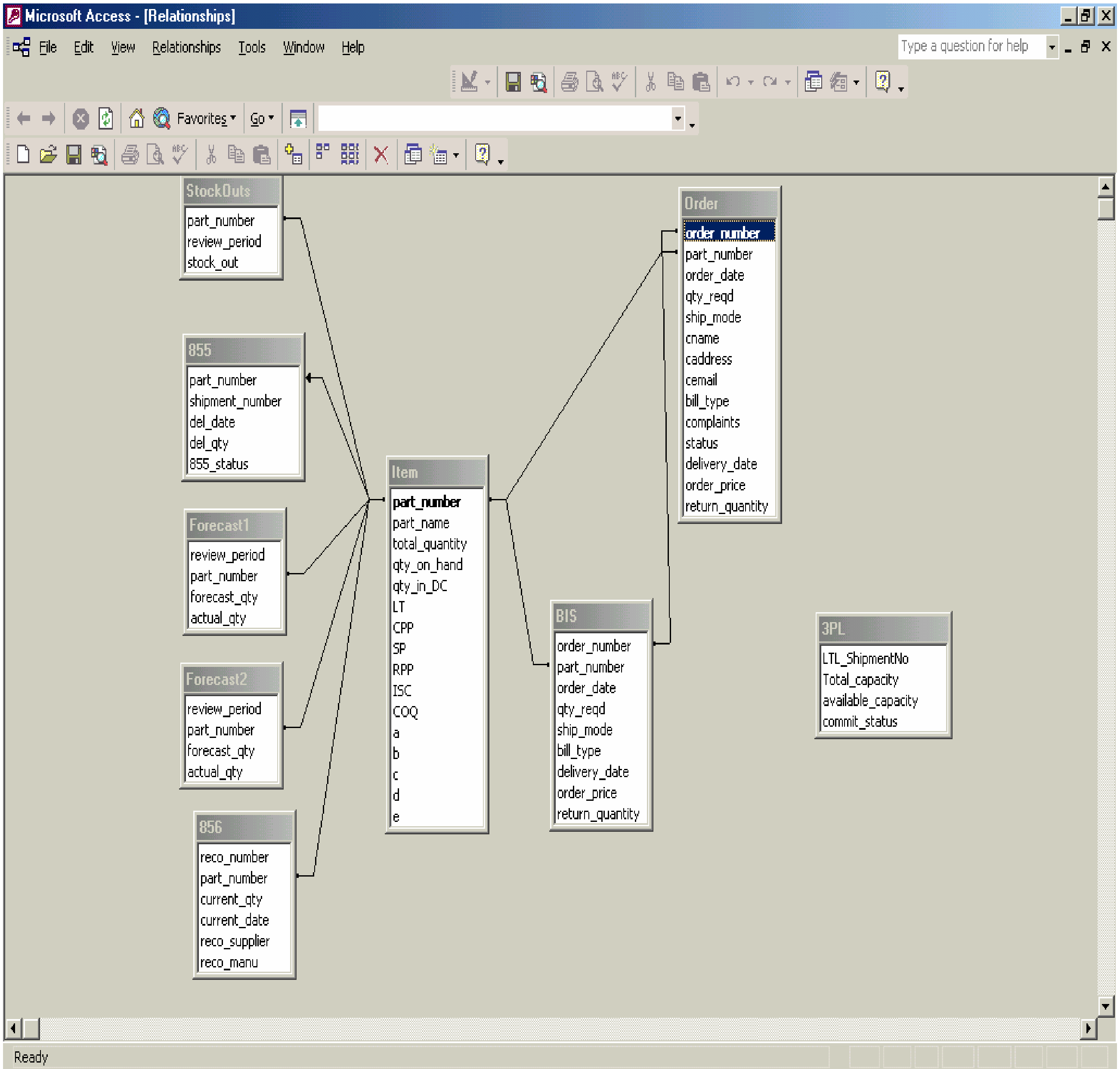

Figure 2.5 Relationship structure in the application system

2.7.3 APPLICATION SYSTEM SNAP-SHOTS

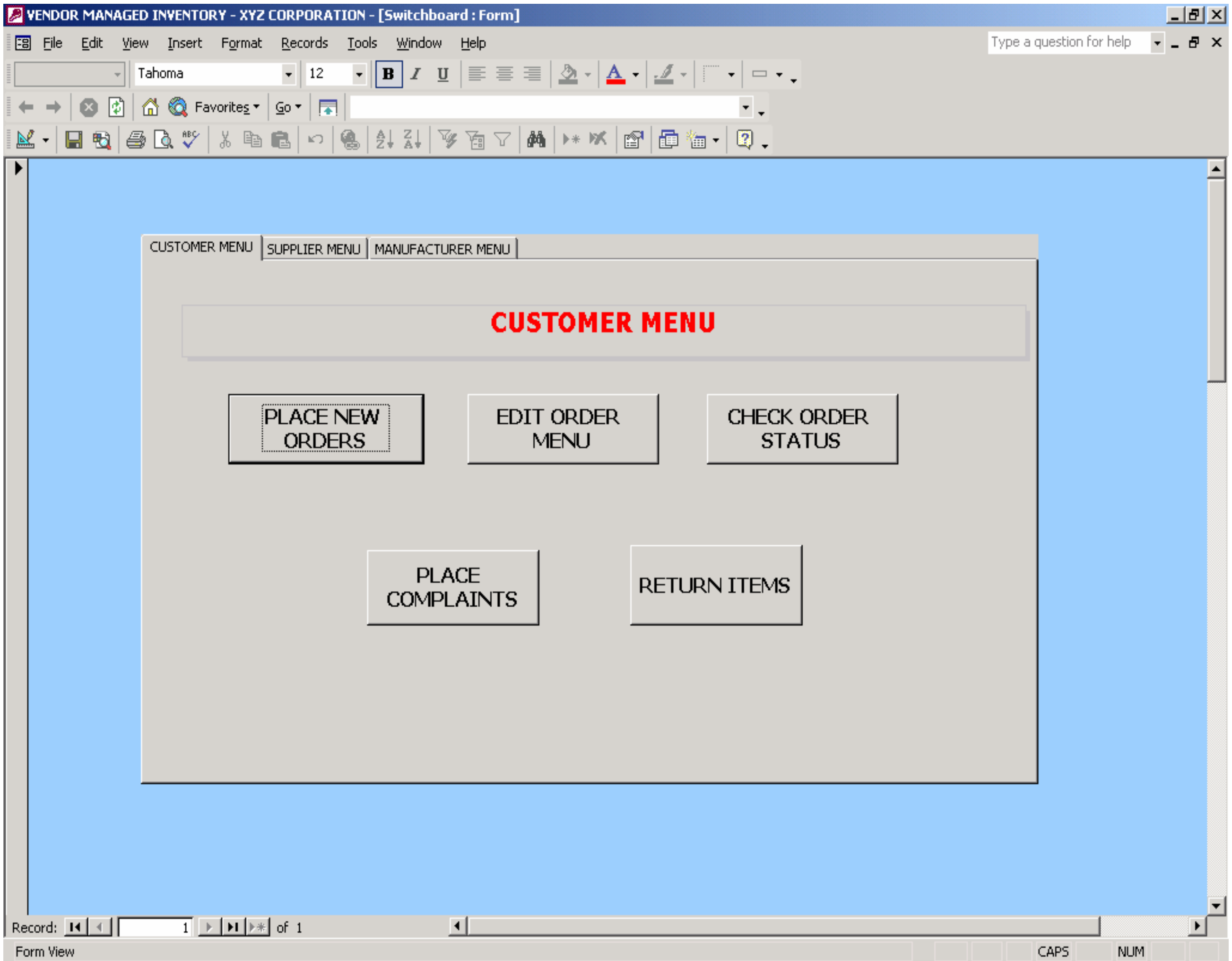

Figure 2.6 Customer Menu Login Page

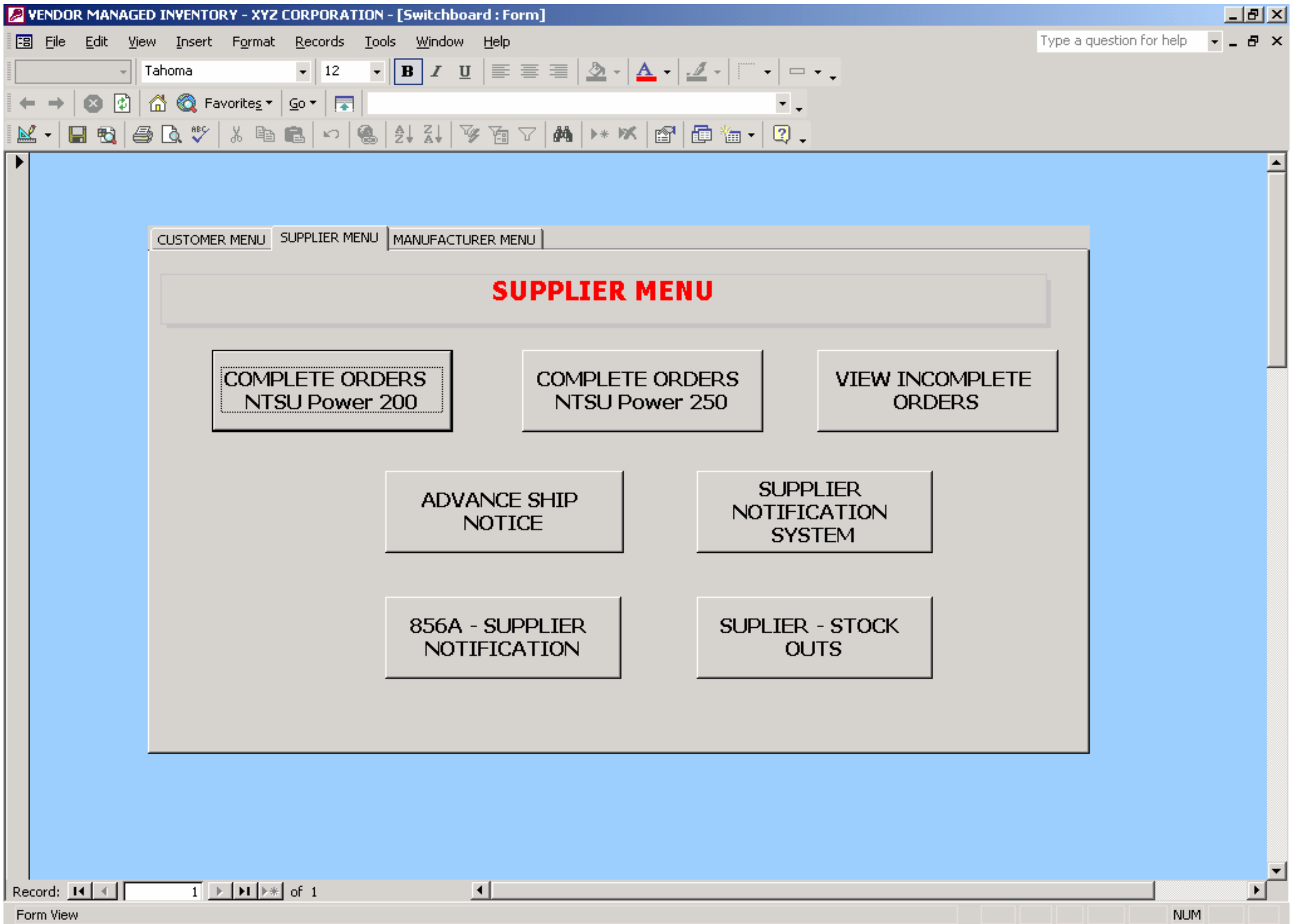

Figure 2.7 Supplier Menu Login Page

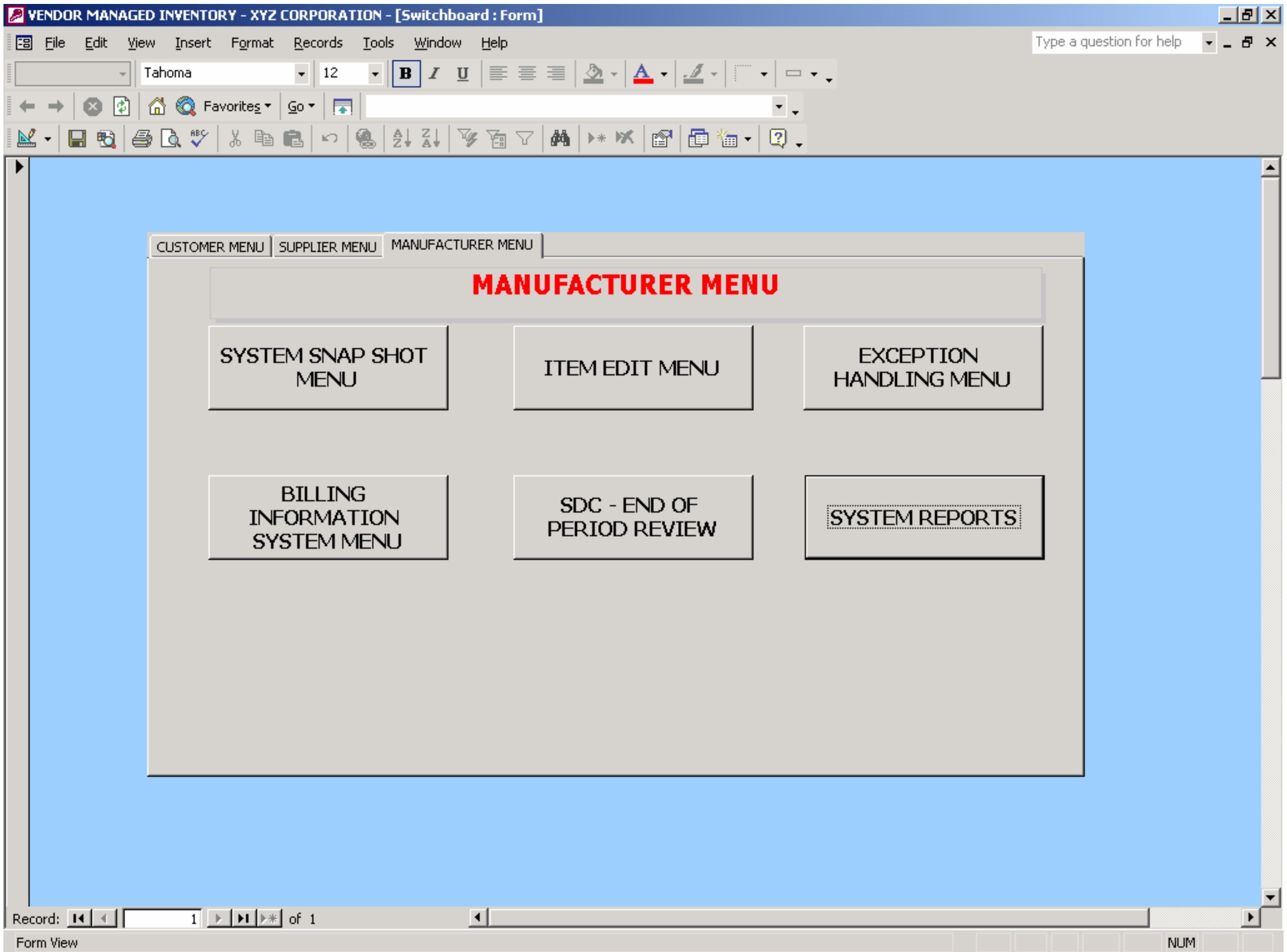

Figure 2.8 Manufacturer Menu Login Page

CHAPTER 3. POLICY COMPARISONS

This section presents an analysis of the four ordering policies (previously introduced in Chapter 1) so that the best alternative ordering policy can be identified. The product under consideration is a Dell 19” color monitor. All cost data are from Goyal (2002).

3.1 ORDERING POLICIES

3.1.1 Order at Economic Order Quantity (EOQ) – The EOQ is calculated as follows,

$$\text{EOQ} = \sqrt{\frac{2 * D * CPP}{ISC}}$$

where,

D is the annual demand,

CPP is the contract purchase price (assumed to be $400), and

ISC is the inventory stocking cost (assumed to be $25).

Both the CPP and the ISC were derived from literature on Dell’s costing and pricing structure (Goyal, 2002). These prices change within a fiscal year due to demand fluctuations and product availability. However, the system assumes constant CPP and ISC for one fiscal year.

The EOQ is calculated using the annual demand (from the previous year’s demand data), the contract purchase price, and the inventory stocking price. The manufacturer observes incoming demand and fulfills the demand. If there are insufficient items in the inventory, a stock out is filed and items are ordered from the supplier at EOQ levels. The order lead time is eight days, so for the next eight days, items are backordered until the supplier completes the delivery. The cycle continues until the end of the fiscal year.

3.1.2 Monthly Policy – This policy involves deliveries at the first of every month. The previous year's cumulative demand is divided into twelve equal monthly demands and this serves as the delivery amount every month.

3.1.3 Just In Time Policy – JIT involves shipment of inventory units in such a manner that at the start of every week there is a fixed amount of inventory available with the manufacturer. This amount is calculated by using the previous year's demand data and dividing it equally over 52 weeks. A JIT policy is different from a monthly ordering policy because a JIT policy requires a fixed amount to be available at the start of every work week. A monthly policy involves a fixed ordering amount at the start of every month, whereas JIT involves variable ordering amounts to satisfy a fixed beginning inventory requirement.

3.1.4 Vendor Managed Inventory (VMI) – VMI involves the use of COQ (Contract Order Quantity) as the ordering basis. The VMI ordering policy uses the same inventory calculations as the EOQ policy, but the difference is that in VMI the supplier can observe incoming demand, correlate it with the previous year's demand, and replenish inventory without system stock outs.

3.2 BASIC DEMAND DATA

The total number of monthly orders is generated by Minitab 13 using an appropriate random number generator corresponding to the demand distribution selected. Two datasets corresponding to each demand distribution were generated. The reasons for using two demand datasets for each demand distribution function are two-fold. First, two datasets for each demand distribution provides more data for analysis and, second, they provide an estimate of system performance under different demand. The total order quantity is derived from the monthly orders by summing the monthly order quantities for the twelve months. The distribution functions for the daily demand have been generated in Minitab 13 for the uniform distribution (generated with a lower bound of 30 and an upper bound of 40 for demand dataset 1 and a lower bound of 35 and an upper bound of 55 for demand dataset 2), triangular distribution (generated using a triangular generator with a minimum value of 25, a likeliest value of 30 and a most likely value of 35 for demand dataset 1 and 35,45 and 55 for demand dataset 2) and Poisson demand distribution functions (generated using a Poisson generator with a rate of 0.2 a low cutoff of 25 and a high cutoff of 35 for demand dataset 1 and 0.2,35,55 for demand dataset 2). The terms most likely, low cutoff and high cutoff refer to spreadsheet functions used for demand data generation. The choice of these three demand distributions is based on a survey of manufacturing firms by Zimmerman (1998) who found out that most manufacturing firms faced demand that followed one of these three demand distributions. The **planning horizon** for the system is one fiscal year. Demand was generated for each day. In each demand distribution dataset, there is a requirement that there should be a demand of at least one unit every day. Daily demand was then aggregated across one year to have a net **annual demand**. The annual demand data are listed in table 3.1.

Table 3.1 Demand Data

DEMAND DISTRIBUTION	DATASET 1	DATASET 1 MEAN	DATASET 2	DATASET 2 MEAN
UNIFORM	9261	26	14704	41
TRIANGULAR	7700	22	13056	36
POISSON	9100	25	12577	35

Goyal (2002) sets the safety stock at 30 units. The current analysis also assumes a safety stock of 30 units of inventory. A re-order is provided to the supplier any time the inventory level drops below 30 for all the policies. The fiscal year is assumed to start with an initial value of 200 units of inventory.

3.2.1 Uniform Distribution

Figure 3.1 portrays the monthly orders for the uniform distribution in demand datasets 1 and 2.

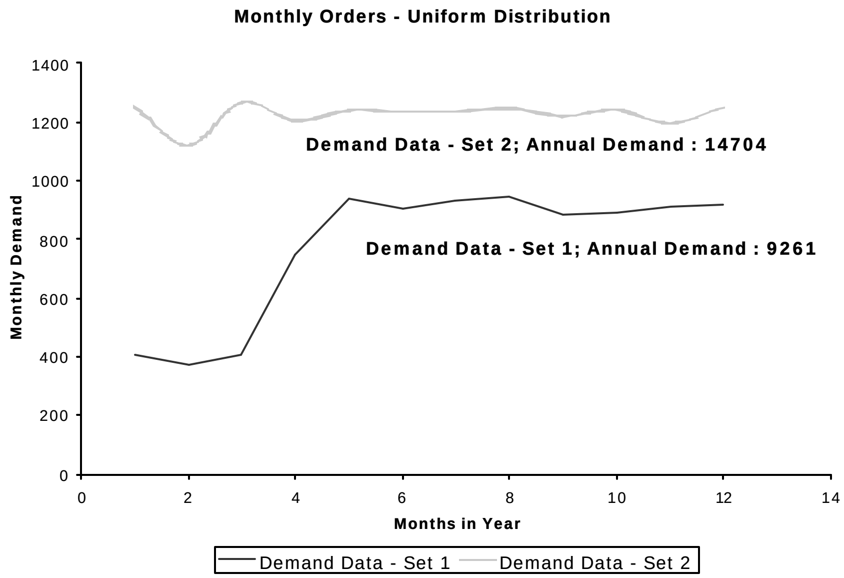

Figure 3.1 Monthly Demand– Uniform Distribution

3.2.2 Triangular Distribution

Figure 3.2 portrays the monthly orders for triangular distribution in demand datasets 1 and 2.

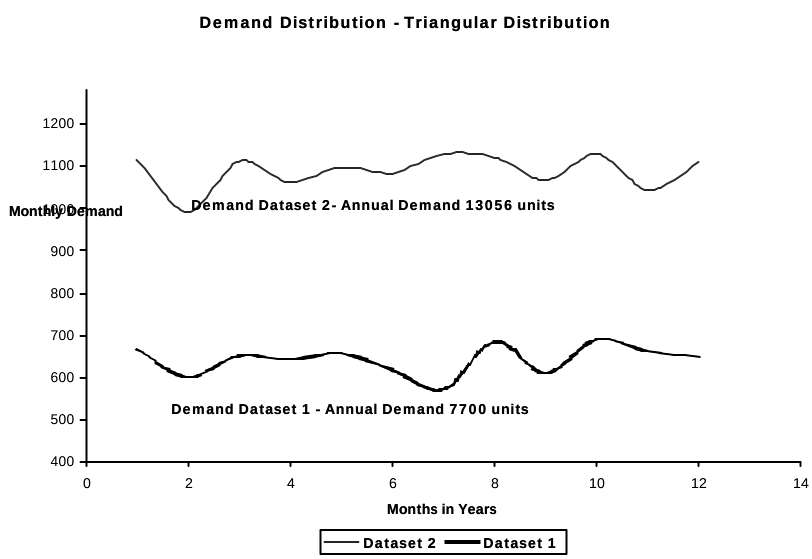

Figure 3.2 Monthly Demand – Triangular Distribution

3.2.3 Poisson Distribution

Figure 3.3 portrays the monthly orders for the Poisson distribution in demand datasets 1 and 2.

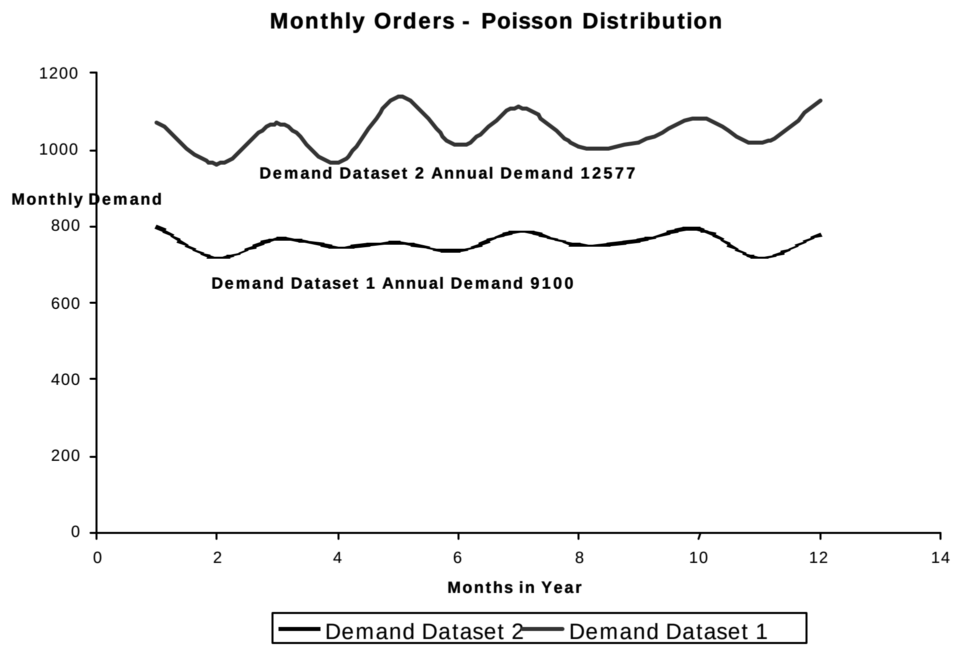

Figure 3.3 Monthly Demand – Poisson Distribution

3.3 SYSTEM PARAMETERS

3.3.1 Independent Variables

The independent variables are **Monthly Orders** and the **ordering policy** under consideration. Each of these variables is generated using a function not dependent on any system.

3.3.2 System Constants

They are the shipping costs and re-order point because do not vary.

- **Shipment Costs**: Shipment costs are assumed to be $25000/shipment for a Less than Trailer Load (LTL) shipment and $5000 for a Full Trailer Load (FTL) shipment. Shipment costs are also referred to as **Transportation Costs**. Schneider National, Incorporated, North

America's premier transportation company, calculates LTL shipment to be four to six times more expensive than a FTL load of the same product (Schneider Web Resource). J.D Edwards has conducted a survey of nearly 900 manufacturing firms and found a similar relationship (Cottrill, 2003). Although exact rates for the shipment vary from product to product and also within the industry segment under consideration, for ease of use, this research assumes $5000/shipment for a FTL load and a factor of 5, i.e. $25000/shipment for a LTL shipment as the per unit cost for calculations.

- **Reorder Point**: The reorder point corresponds to the safety stock limit of the system which is set at 30 units of inventory.

3.3.3 Dependent Variables

The dependent variables are inventory availability, shipment quantities, the total number of shipments, fulfillment rate, total costs, inventory turns, the inventory days of supply and the service efficiency level. These are calculated using functions set up in Microsoft Excel and they change based on the ordering policy and demand distribution variables. For the system under consideration, dependent variables can also be termed *"first-derivative"* i.e. they are obtained by manipulating the independent variables. Some of the dependent variables are obtained by a manipulation of the independent variables and other dependent variables.

- **Inventory Availability**: Inventory availability is a function of the ordering policy under consideration and the demand.
- **Shipment Quantities**: The shipment quantities are also a function of the ordering policy under consideration. EOQ policies follow the EOQ formula for ordering, a monthly policy looks at demand data for the previous month to place one consolidated order at the beginning of the month, and JIT orders in such a way that a fixed amount of inventory is available at

the beginning of each week. The shipment quantities can also be referred to as the total quantity shipped.

- **Total Number of shipments**: The total number of shipments is the sum of the number of the times the supplier has to ship the order quantities. The **average number of units shipped** is the ratio of the total shipped quantity to the total number of shipments.
- **Fulfillment Rate**: The fulfillment rate (Total quantity shipped/Annual Demand) is a process metric representing the efficiency of both the ordering policy under consideration and the ability of the supplier to fulfill performance targets.
- **Total Costs** (Inventory carrying costs plus backlog costs plus transportation costs): The total costs are a summation of the **inventory carrying costs** (assumed to be $15/unit), **backlog costs** ($25/unit back-ordered) and transportation costs. The costs listed for the inventory carrying costs and the backlog costs are from Goyal (2002). Goyal (1995) has indicated that the backlog costs are usually 1.5 to 2 times higher than inventory carrying costs in a manufacturing supply chain.
- **Inventory Turns**: Inventory Turns is defined as the number of times inventory cycles or turns over per year. It is expressed as a ratio of the annual demand to the average daily inventory carried in the year under consideration.
- **Inventory Days of Supply**: The inventory days of supply is the number of days of available inventory that a company has in reserve to fulfill customer demand. It is the ratio of (Average Inventory * Number of days in the planning horizon) to the annual demand in the planning horizon.
- **Service Efficiency Level**: Service efficiency level is a function of system stock outs. It is a supplier performance measure. It can be derived as follows.

Service Efficiency Level = (1 – (number of system stockouts/365))*100

Table 3.2 is a template that will be used for a system summary to provide a snapshot of the system behavior. Table 3.2 lists system parameters that are system performance measures in that they represent process metrics as set out in the Kaplan and Norton balanced scorecard (Kaplan and Norton, 1996). Each of these system parameters is calculated using a combination of either independent and dependent variables or dependent variables by themselves.

Table 3.2 System Summary

System Parameter	**EOQ**	**Monthly**	**JIT**	**VMI**
Total Number of Shipments				
Fulfillment Rate (Units shipped/Total Order Qty)				
Average number of units/shipment				
Total Costs				
Inventory Carrying Costs				
Backlog Costs				
Transportation Costs				
Inventory Turns				
Inventory days of supply				
Service Efficiency Level				

3.4 EXPERIMENTAL ANALYSIS

This section describes the steps executed to determine the variables that have the largest impact on system performance.

Step 1. Generate two demand datasets corresponding to the demand distribution function under consideration using Minitab. Setup a Microsoft Excel workbook for data analysis. Aggregate the data on a monthly and annual basis for data analysis.

Step 2. Calculate the inventory availability for each ordering policy. The starting inventory level for all four ordering policies is 200 units.

Step 2 a. Calculate the EOQ amount using last year's demand and the cost data from section 3.1. Table 3.3 illustrates the inventory availability calculations for the EOQ policy

Table 3.3 Inventory Availability Calculation

A	B	C	D	E
Number	**DAY OF THE YEAR**	**DEMAND**	**INVENTORY**	**COST**
			200	
1	1-Jan	38	162	4050
2	2-Jan	39	123	3075
3	3-Jan	34	89	2225
4	4-Jan	33	56	1400
5	5-Jan	39	17	425

Column D is calculated as follows,

$D_i = D_{i-1} - C_i$

$D_{i+1} = D_i - C_{i+1}$, and so on. (i represents the day of the year)

If the inventory is greater than zero, the supply chain system incurs an inventory carrying cost and if the value is below zero a backlog cost is incurred. Since the re-order point is 30, the system re-orders at the EOQ amount and it takes eight days for the supplier to deliver the order. During this period, if the system is out of inventory, it backlogs all old orders. Once the supplier has delivered the EOQ ordering quantity, the inventory is replenished and calculations for inventory availability are repeated again.

Step 2 b. Since all the dependent variables are derived from column D, it is essential to set up a verification mechanism to check the validity of the spreadsheet model. A flow balance equation has been set up to check for data validity.

At any given day in the planning horizon,

Incoming Inventory + Backorders – Demand = Outgoing Inventory + Outgoing Backorders

Additionally, at any given point of time, MIN(Inventory, Backorder) = 0

The flow balance equation has been set up in the spreadsheet model to check data validity at each day.

Step 2 c. The difference in the monthly ordering policy is that instead of ordering at EOQ amounts, the manufacturer places twelve equal orders depending on last year's demand data. These 12 deliveries are made at the beginning of each month. The rest of the calculations remain the same. The calculations for inventory availability for the JIT and the VMI ordering policy are done as outlined in sections 3.1.3 and 3.1.4 respectively. Appendixes A through C illustrate the experimental analysis for demand dataset 2.

Step 3. Use the spreadsheet to calculate the system variables. Tables 3.4 through 3.9 provide a system summary.

Step 3 a. The cost matrix can be constructed for each ordering policy within each demand distribution function using the costs per unit from section 3.3.2. If the inventory is greater than zero, inventory carrying costs are incurred, whereas backlog costs are incurred whenever the system faces stock outs.

Step 3 b. Daily inventory is assumed to be zero in the case of stock outs. The daily inventory can then be averaged across the year to obtain an average daily inventory. Inventory Turns and the Inventory Days of supply can be calculated for each ordering policy using the method outlined in section 3.3.3. The number of times a stock out occurs is the basis of calculation for the service efficiency level for each ordering policy within each demand distribution.

Step 4. Generate comparative results based on the system summary shown in Table 3.2

3.5 EXPERIMENTAL RESULTS

Table 3.2 and steps 1 through 3 were used to populate the system summary for each demand distribution.

3.5.1 Uniform Distribution

Table 3.4 provides a system snapshot of an order distribution following an uniform demand distribution with demand dataset 1.

Table 3.4 System Summary - Uniform Distribution Dataset 1

System Parameter	EOQ	Monthly	JIT	VMI
Total Number of Shipments	21	12	52	26
Fulfillment Rate (Units shipped/Annual Demand)	97.97%	100.04%	113.55%	100.78%
Average number of units/shipment	686	1226	322	570
Total Costs	2337140	7322150	2791650	2518340
Inventory Carrying Costs	1812140	7262150	1491650	2388340
Backlog costs	3925	0	25	550
Transportation Costs	525000	60000	1300000	130000
Inventory Turns	86	19	90	57
Inventory days of supply	4	35	8	19
Service Efficiency Level	57%	100%	99.72%	93.97%

Table 3.5 lists the system summary for demand dataset 2.

Table 3.5 System Summary – Uniform Distribution Dataset 2

System Parameter	EOQ	Monthly	JIT	VMI
Total Number of Shipments	35	12	52	14
Fulfillment Rate (Units shipped/Annual Demand)	95.99%	112.3%	102.99%	100.42%
Average number of units/shipment	254	867	184	665
Total Costs	3850380	10755650	2431875	3268275
Inventory Carrying Costs	167225	10695650	1131350	2980100
Backlog costs	2808155	0	525	194760
Transportation Costs	875000	60000	1300000	70000
Inventory Turns	45.96	7.9	74.72	28.47
Inventory days of supply	7.95	46.19	4.88	12.83
Service Efficiency Level	20.27%	100%	89.04%	95.34%

3.5.2 Triangular Distribution

Table 3.6 provides a system snapshot of an order distribution following a triangular demand distribution with demand dataset 1 and Table 3.7 provides the same for a triangular demand distribution dataset 2.

Table 3.6 System Summary – Triangular Distribution Dataset 1

System Parameter	EOQ	Monthly	JIT	VMI
Total Number of shipments	33	12	52	12
Total Order Quantity	7700	7700	7700	7700
Fulfillment Rate (Units shipped/Annual Demand)	96.43%	104.68%	152.05%	87.7%
Average number of units/shipment	225	672	179	563
Total Costs	1719920	3221075	2582950	3095945
Inventory carrying costs	94225	3143925	1282950	2846875
Backlog Costs	800695	17150	0	4480
Transportation Costs	825000	60000	1300000	60000
Inventory Turns	148	23	55	23
Inventory Days of Supply	3	17	7	9
Service Efficiency Level	27.4	96.71	100	97.81

Table 3.7 System Summary-Triangular Distribution Dataset 2

System Parameter	EOQ	Monthly	JIT	VMI
Total Number of Shipments	20	12	26	24
Fulfillment Rate (Units shipped/Annual Demand)	99.11	100.18	125	101
Average number of units/shipment	647	1090	636	505
Total Costs	2227855	6723975	2270150	2376655
Inventory Carrying Costs	1727855	6663975	1620150	2256655
Backlog costs	3475	0	0	0
Transportation Costs	500000	60000	650000	120000
Inventory Turns	77	18	74	53
Inventory days of supply	8	21	5	7
System Stock Outs	140	0	0	0
Service Efficiency Level	62	100	100	100

3.5.3 Poisson Distribution

Table 3.8 provides a system snapshot of an order distribution following a Poisson demand distribution with demand dataset 1 and Table 3.9 provides the same snapshot for an order distribution following a Poisson demand distribution with demand dataset 2.

Table 3.8 System Summary – Poisson Distribution Dataset 1

System Parameter	EOQ	Monthly	JIT	VMI
Total Number of shipments	36	12	52	12
Fulfillment Rate (Units shipped/Annual Demand)	96.92%	96.92%	128.72%	97.06%
Average Number of units/shipment	245	735	226	737
Total Costs	1865010	3669815	2437525	3532765
Inventory Carrying Costs	86475	3593050	1137525	3284650
Backlog costs	878535	16765	0	315
Inventory Turns	153.46	23.18	73	25.3
Inventory Days of Supply	3	16	6	15
Service Efficiency Level	26.30%	96.72%	100%	99.45%

Table 3.9 System Summary - Poisson Distribution Dataset 2

System Parameter	EOQ	Monthly	JIT	VMI
Total Number of Shipments	20	12	52	26
Fulfillment Rate (Units shipped/Annual Demand)	101	99.66	113.6	99.22
Average number of units/shipment	635	1045	275	480
Total Costs	2326255	6570825	2577350	1907155
Inventory Carrying Costs	1826255	6510825	1277350	1777155
Backlog costs	3275	0	50	1325
Transportation Costs	500000	60000	1300000	130000
Inventory Turns	69	18	90	66
Inventory days of supply	6	21	4	6
Service Efficiency Level (%)	64.11	100	99.45	85.48

3.6 COMPARATIVE RESULTS

3.6.1 EOQ based policies

The key assumptions behind an EOQ policy are that there is a fixed, known set up cost, constant demand and infinite capacity (Julia M, 2003). The current research assumes varying demand, and in practical scenarios suppliers are highly reluctant to provide cost information (Cachon, 1997). Cachon (2001) also showed that the EOQ policy does not function appropriately in systems with longer lead times and in particular when the lead time involves cross shipping from and to distribution centers. Although the current research does not involve cross shipping, most organizations resort to a hub and spoke system for inventory management making EOQ based policies obsolete. Suri (2002) showed that bt sizes appropriate for quick response bear little relation to the values calculated by EOQ theory, which fails to consider many costs of large lots and ignores the value of responsiveness. Suri (2002) also showed that the use of the EOQ policy is valid only if the variability in demand is low. In systems where the coefficient of variation (ratio of variance in demand to the average demand) is less than 0.2, EOQ policies can be used, otherwise some other heuristics have to be used. Table 3.10 is lists the variance in demand, the average demand, and the coefficient of variation across the three demand distribution functions for the three ordering policies

Table 3.10 Coefficient of variation comparison

	UNIFORM		TRIANGULAR		POISSON	
Annual demand	9261	14704	7700	13056	9100	12577
Average demand	26	41	22	36	25	35
Variance in demand	100.5	8.2	63.1	17.3	24.7	33.6
Coefficient of variation	**3.86**	**0.2**	**2.86**	**0.48**	**0.98**	**0.96**

As table 3.10 illustrates, in each case the coefficient of variation is greater than 0.2, thus making it necessary to discard the EOQ policy for this current research.

3.6.2 Total Costs Comparison across the three demand distribution functions

The total costs for each demand distribution function in both the runs can be evaluated. These data are then grouped by the demand distribution under consideration. Figures 3.4 through 3.6 illustrate the total cost comparisons.

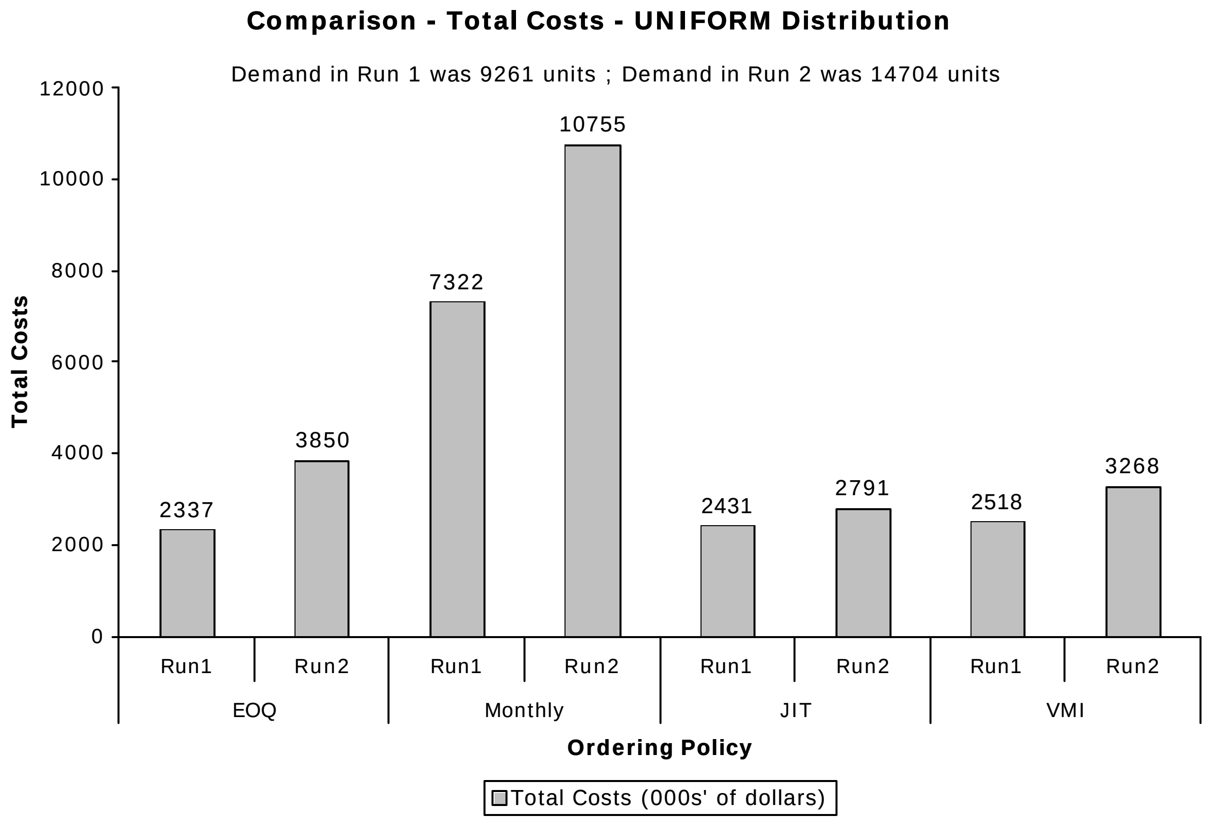

Figure 3.4 Total Costs Comparison – Four Ordering Policies for Uniform Distribution

The aggregate demand indicates a 58.77% increase from Run 1 to Run 2. All the four ordering policies show an increase in total costs with an increase in demand, with the EOQ ordering policy exhibiting the maximum increase of 64.75%, followed by the Monthly ordering policy (46.8%), VMI (29.7%) and finally the JIT policy (14.8%). In all the four ordering policies, there is a direct correlation between larger ordering quantities and economies of scale. The monthly ordering policy has a very high inventory carrying cost component because of the high average inventory carried per day to fulfill demand and avoid stock outs. EOQ generally has the lowest costs, however the high level of stock outs indicates that in industry segments where there are high costs associated with backorders (e.g. consumer electronics), an EOQ ordering policy is not a desirable alternative. Looking at just total costs in isolation and dscounting the EOQ ordering policy (because of section 3.6.1), the JIT policy is the best among the three with respect to costs, followed by the VMI policy.

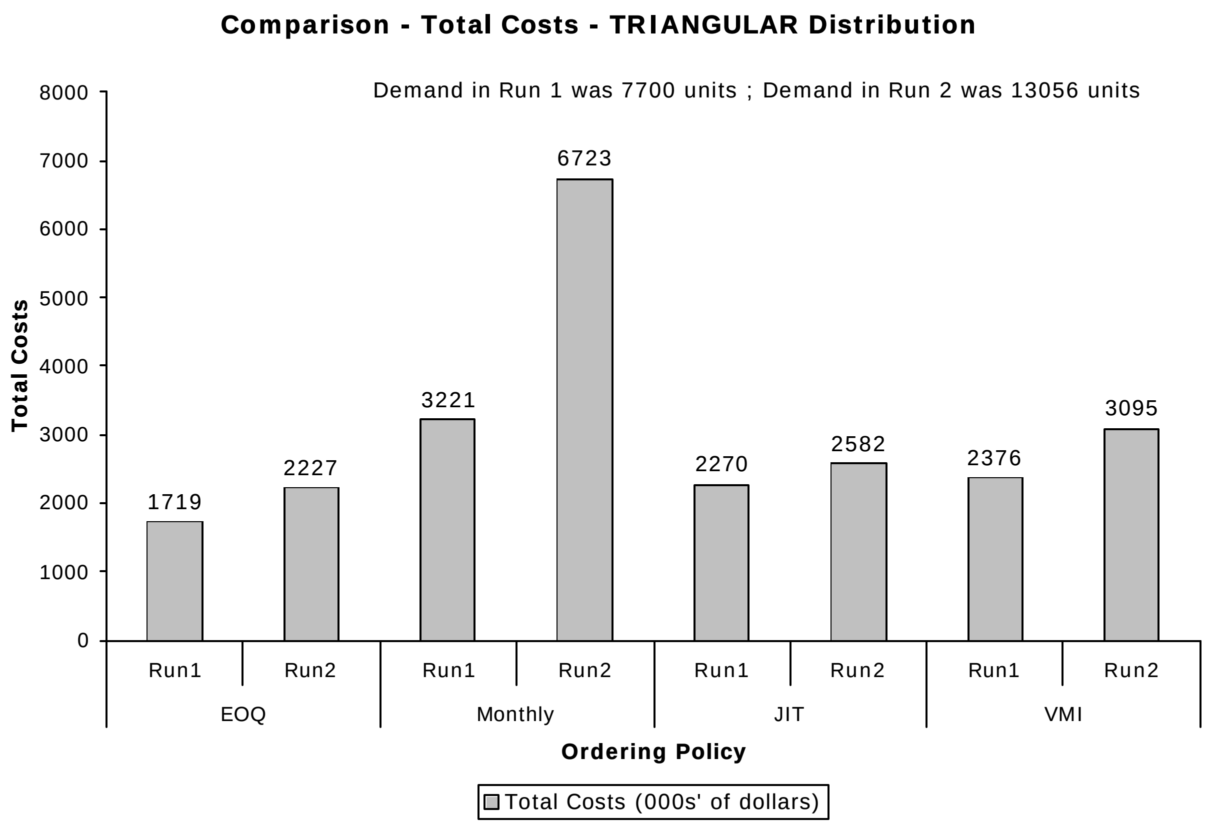

Figure 3.5 Total Costs Comparison – Four Ordering Policies for Triangular Distribution

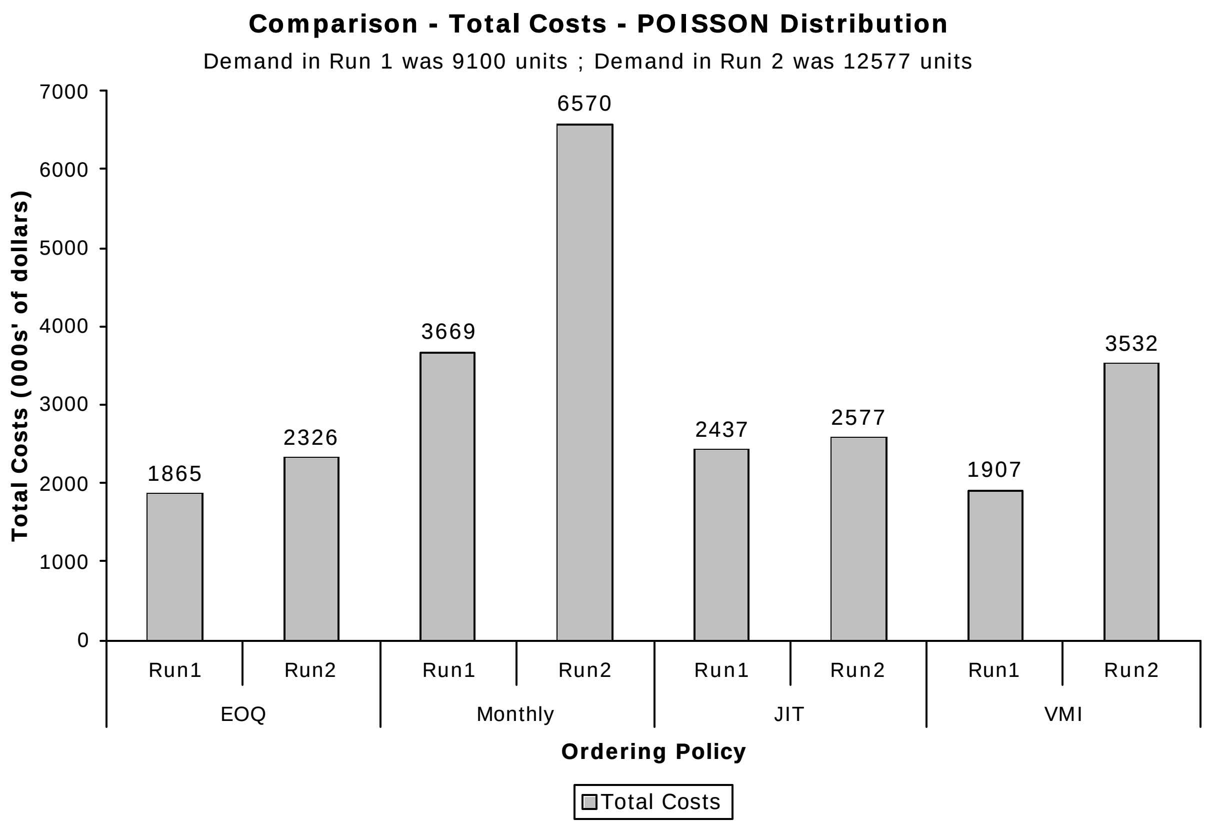

Figure 3.6 Total Costs Comparison – Four Ordering Polices for Poisson Distribution

3.6.3 Average Daily Inventory Comparison across the three demand distribution functions

Figures 3.7 through 3.9 illustrate the average daily inventory carried when compared across the three demand distribution functions for the four ordering policies. EOQ based ordering policies have the lowest average inventory, however, this is due to the large number of days items are back ordered (115 days of the fiscal year, on average). Monthly ordering policies avoid backorders in the system by having large inventories at the start of the month.

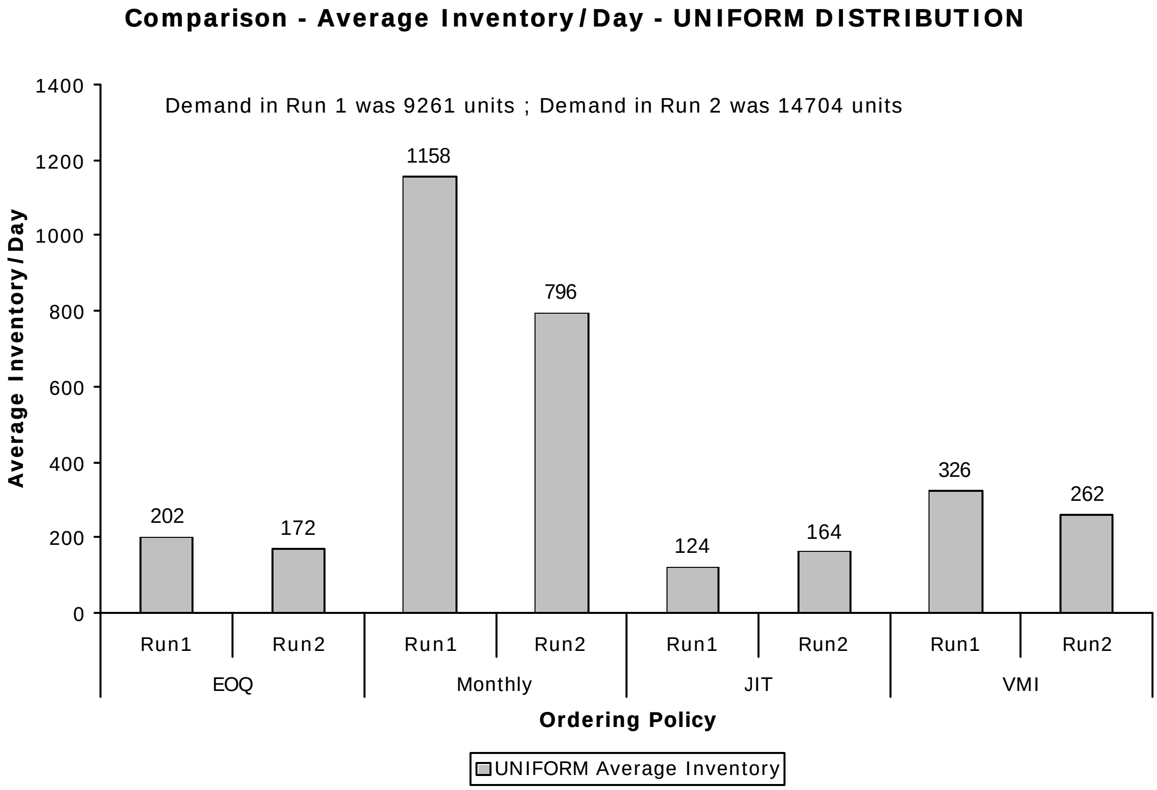

Figure 3.7 Average Daily Inventory – Uniform Distribution

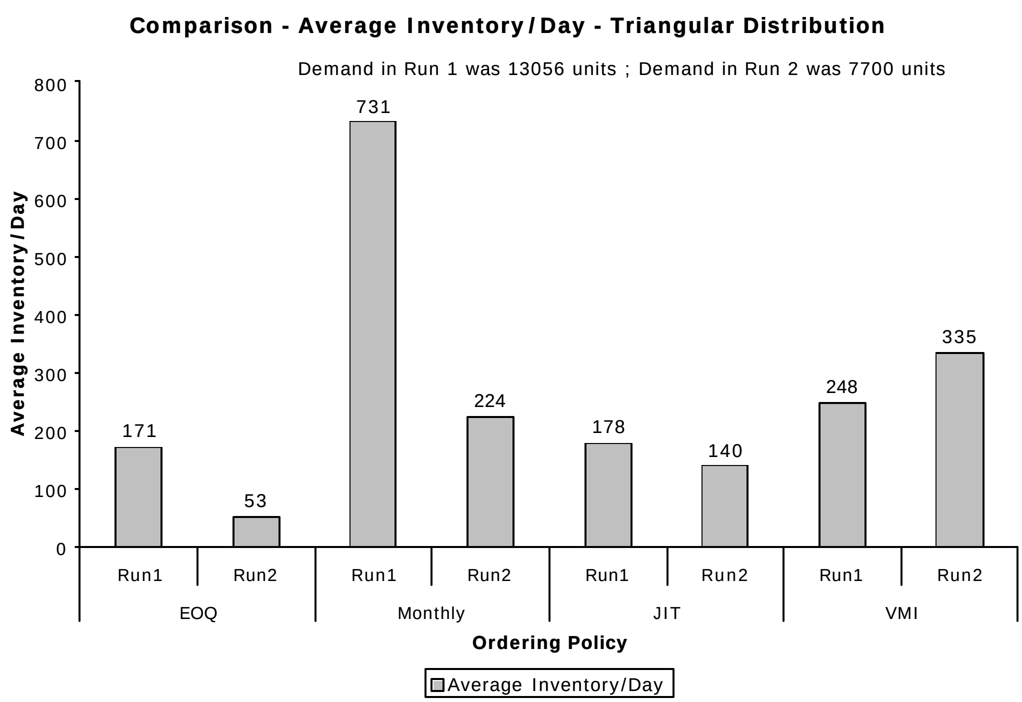

Figure 3.8 Average Daily Inventory – Triangular Distribution

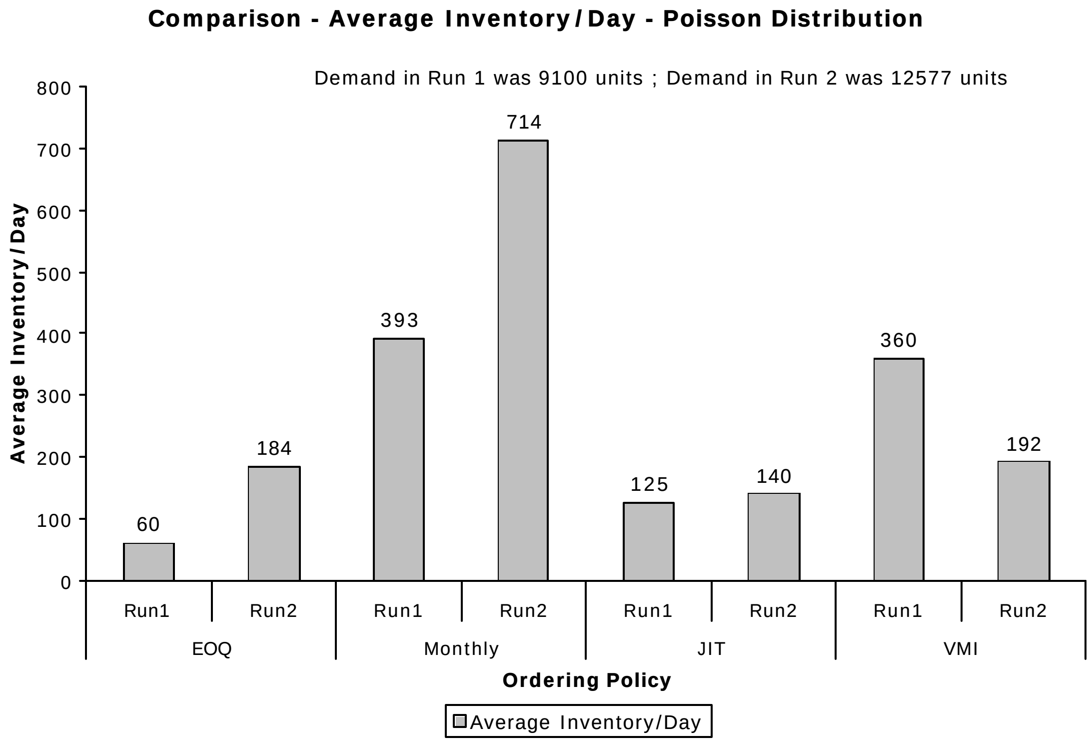

Figure 3.9 Average Daily Inventory – Poisson Distribution

3.6.4 Inventory Turns Comparison across the three demand distribution functions

Figures 3.10 through 3.12 represent the comparison of inventory turns across demand distribution functions. The number of times an inventory turns over in a year is an important performance metric in certain industry segments, like consumer electronics. The number of inventory turns is a performance metric that can be benchmarked against industry competitors.

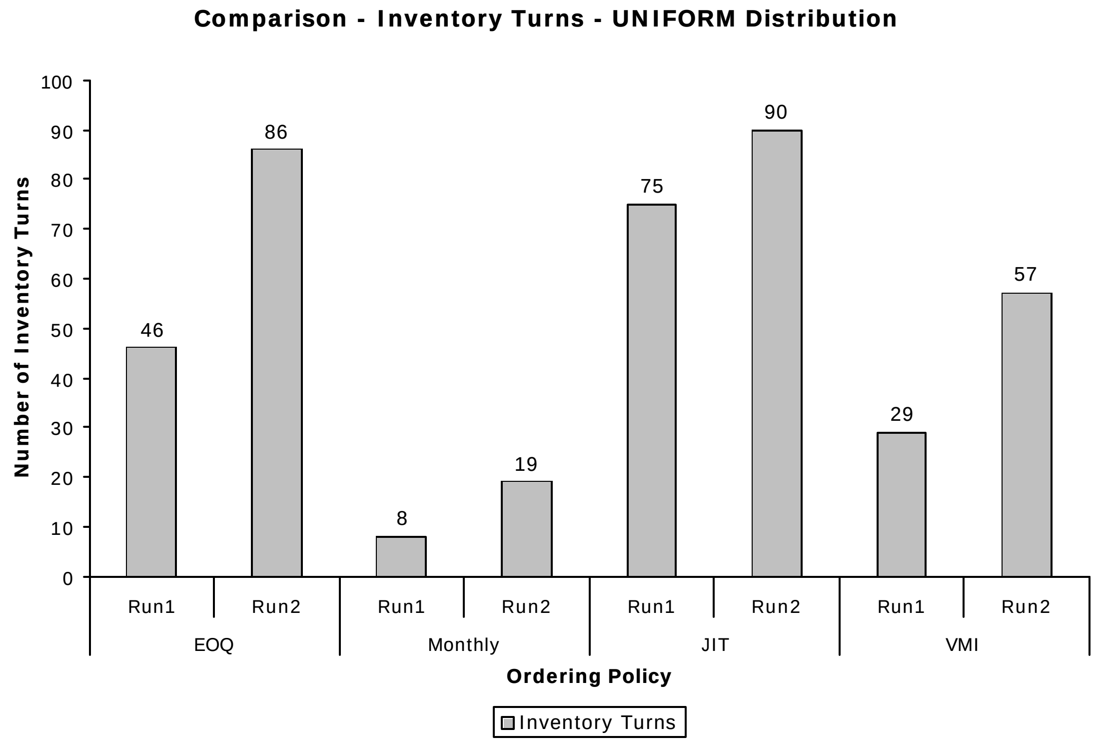

Figure 3.10 Inventory Turns Comparison – Uniform Distribution

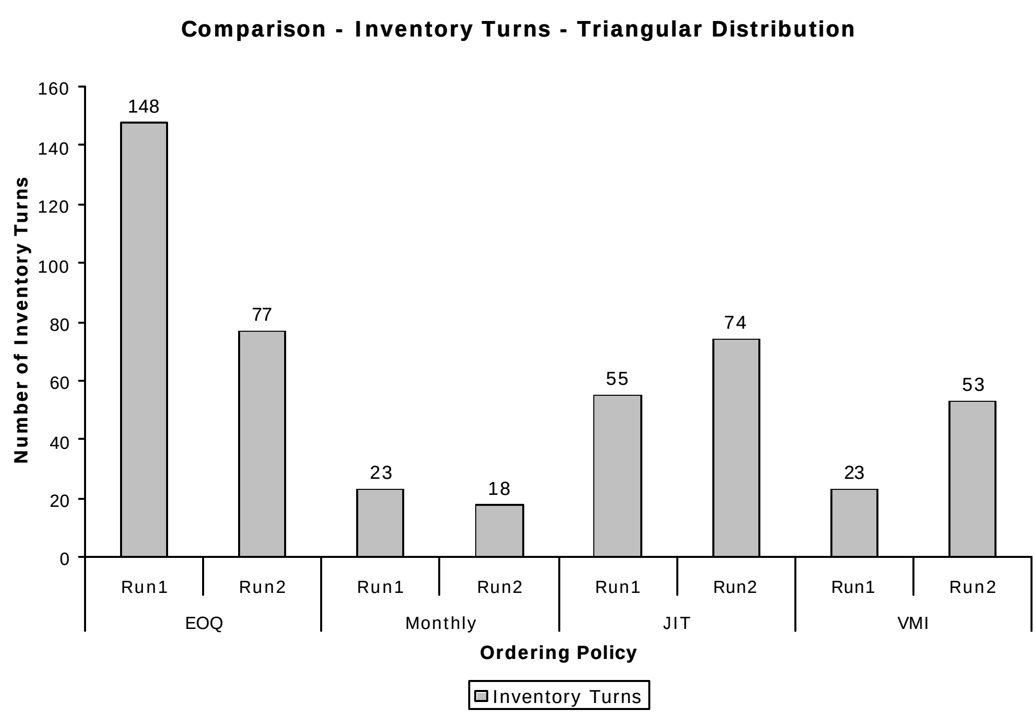

Figure 3.11 Inventory Turns Comparison – Triangular Distribution

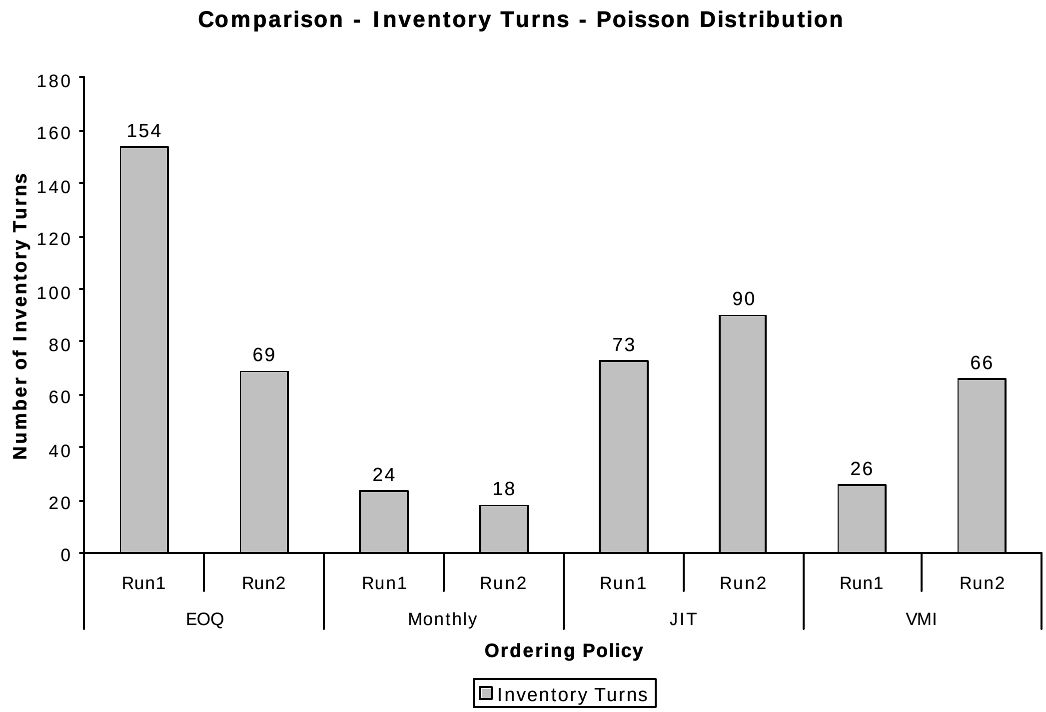

Figure 3.12 Inventory Turns Comparison – Poisson Distribution

3.6.5 Fulfillment Rate Comparison across the three demand distribution functions

Figures 3.13 through 3.15 represent the comparison of fulfillment rate across demand distribution functions. The fulfillment rate is an important customer satisfaction metric. The fulfillment rate in many cases here is above 100, indicating that the units being shipped are more than the annual demand. According to Sahay (2003), this is a common occurrence in most supply chain systems because of the inherent fear against loss of customer value arising from stock outs. Most supply chain systems tradeoff stock outs with a higher than required average daily inventory, which necessitates more units being shipped. This consequently results in a fulfillment rate higher than 100%.

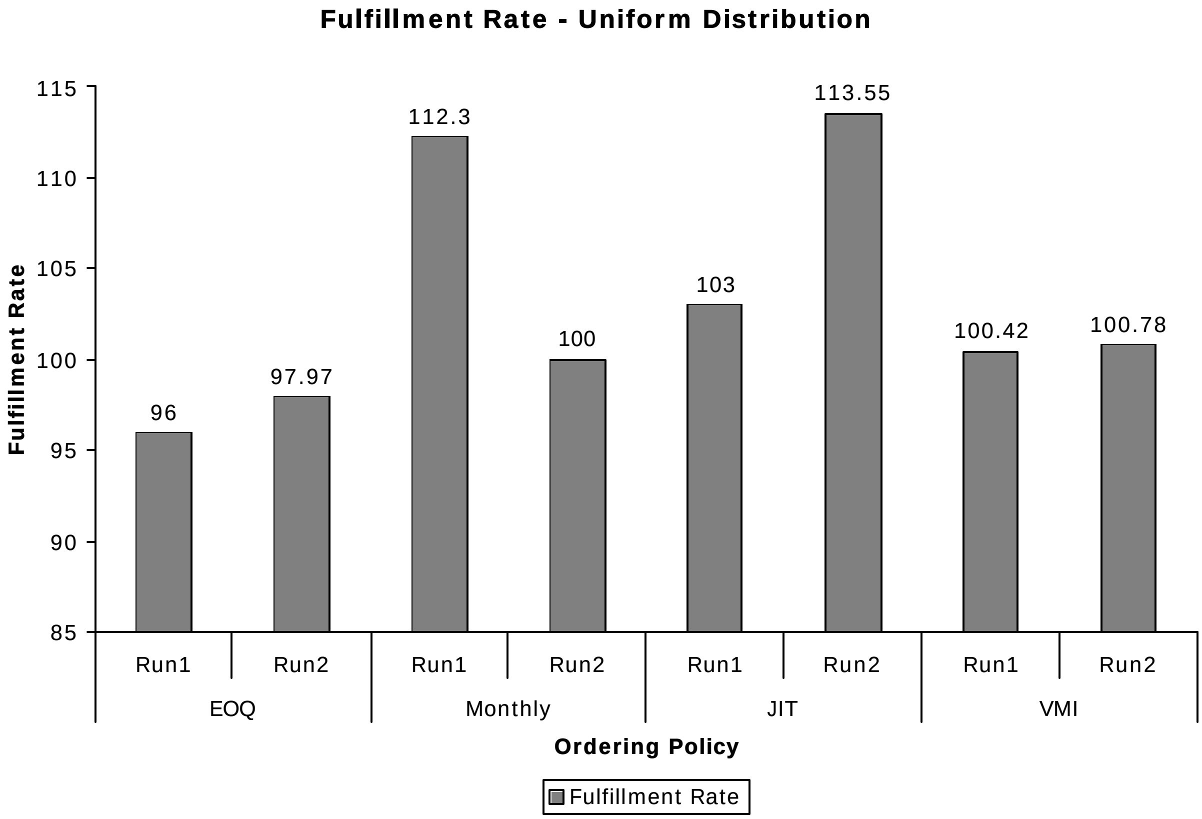

Figure 3.13 Fulfillment Rate Comparison – Uniform Distribution

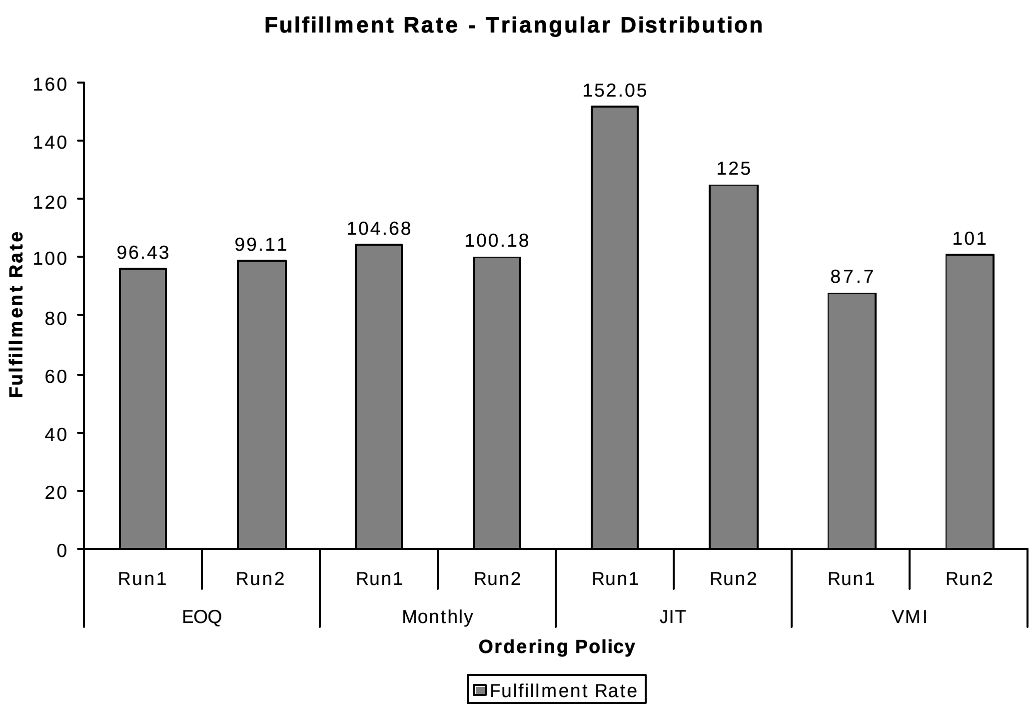

Figure 3.14 Fulfillment Rate Comparison – Triangular Distribution

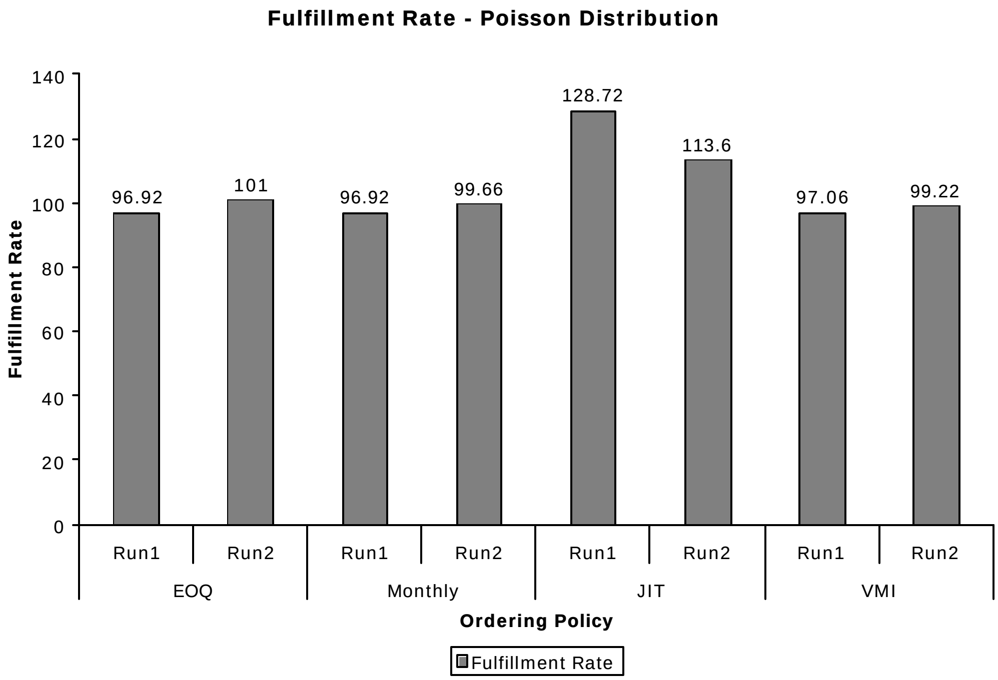

Figure 3.15 Fulfillment Rate Comparison – Poisson Distribution

3.6.6 Service Efficiency Level Comparison across the three demand distribution functions

Figures 3.16 through 3.18 illustrate the service efficiency levels for the four ordering policies. Since the monthly ordering policy involves large daily inventories, there are almost no stock outs in a monthly ordering system. Looking at the service efficiency levels in isolation, the monthly ordering policy is the best. Table 3.11 provides a comparison of the average inventory carried and the service efficiency level. D1 and D2 refer to demand datasets 1 and 2, respectively. Figures 3.19 through 3.21 represent a comparative idea of the average inventory carried and the corresponding service efficiency across the demand distribution functions. Table 3.11 illustrates the fact that monthly ordering policies provide high service efficiency levels at the cost of high daily average inventories.

Table 3.11 Comparative analysis – Service Efficiency and average inventory carried

	EOQ		MONTHLY		JIT		VMI	
	Average Inventory	SEL	Average Inventory	SEL	Average Inventory	SEL	Average Inventory	SEL
UNIFORM DISTRIBUTION								
D1	202	21	1158	100	124	89	326	96
D2	172	57	796	100	164	99	262	94
TRIANGULAR DISTRIBUTION								
D1	171	274	731	96	178	100	248	97
D2	53	62	224	100	140	100	335	100
POISSON DISTRIBUTION								
D1	60	27	393	96	125	100	360	99
D2	184	64	714	100	140	99	192	86

(D1 and D2 refer to Demand datasets 1 and 2 respectively)

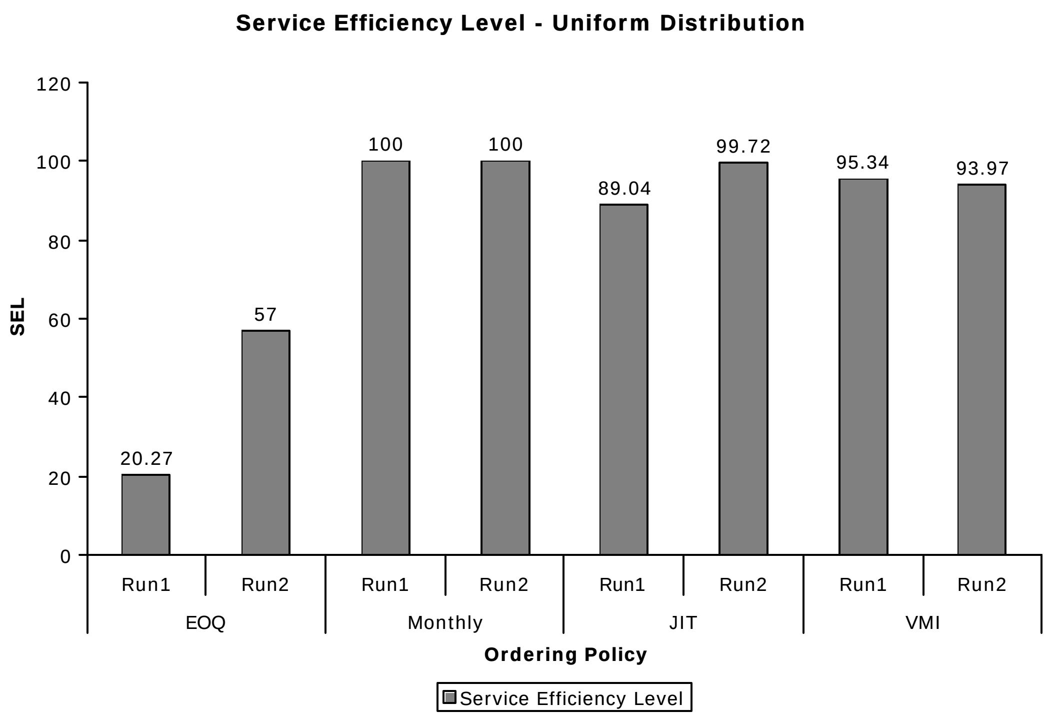

Figure 3.16 Service Efficiency Level Comparison – Uniform Distribution

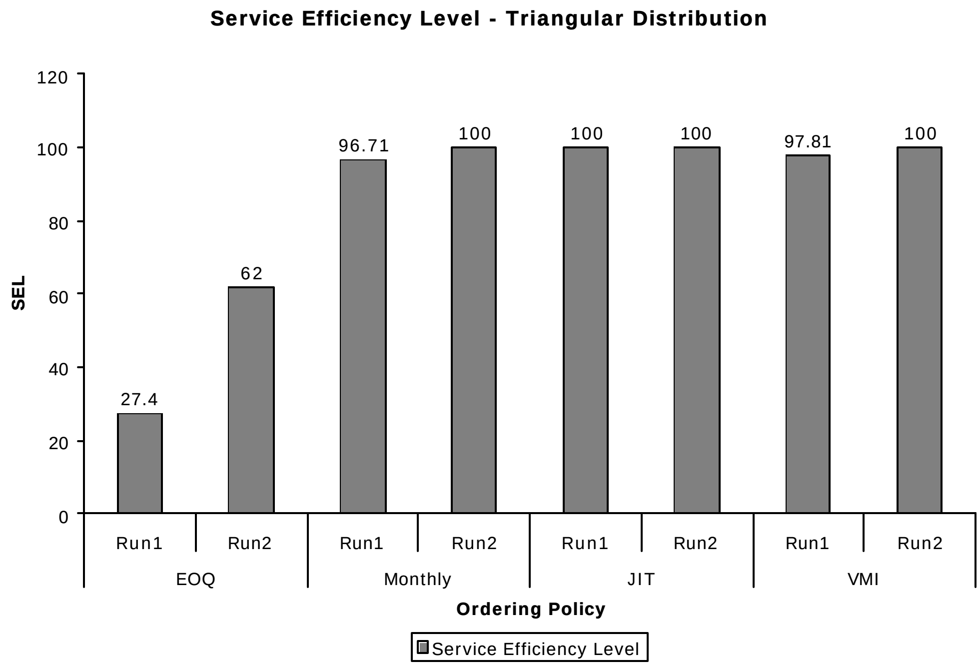

Figure 3.17 Service Efficiency Level Comparison – Triangular Distribution

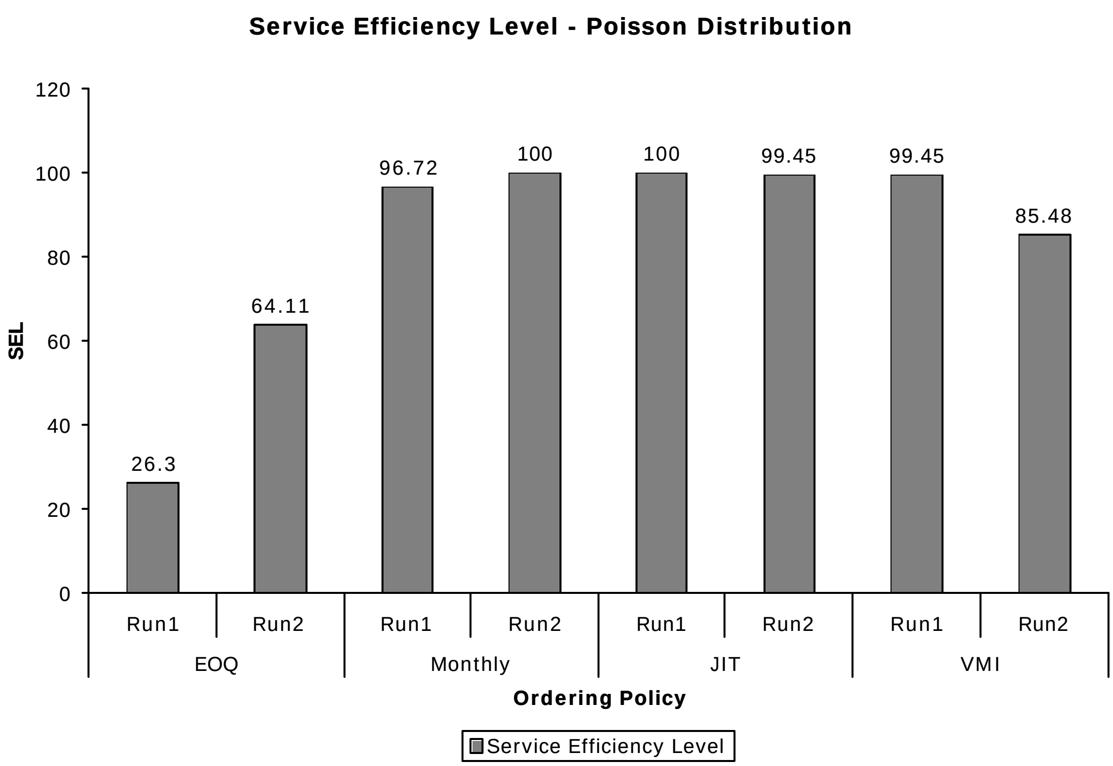

Figure 3.18 Service Efficiency Level Comparison – Poisson Distribution

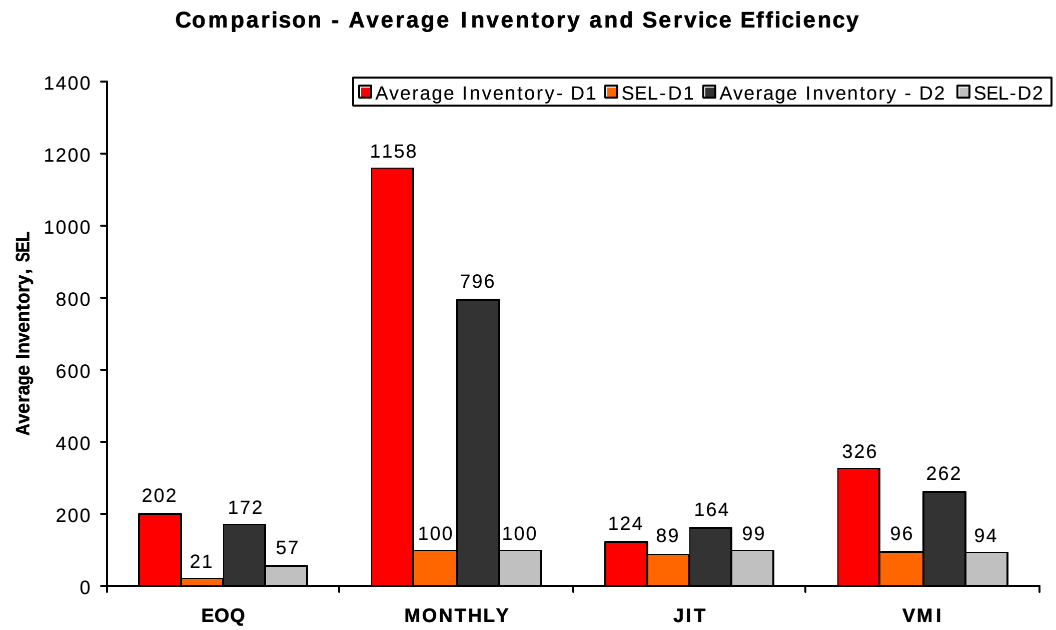

Figure 3.19 Comparison of Average Inventory and Service Efficiency Level – Uniform Distribution

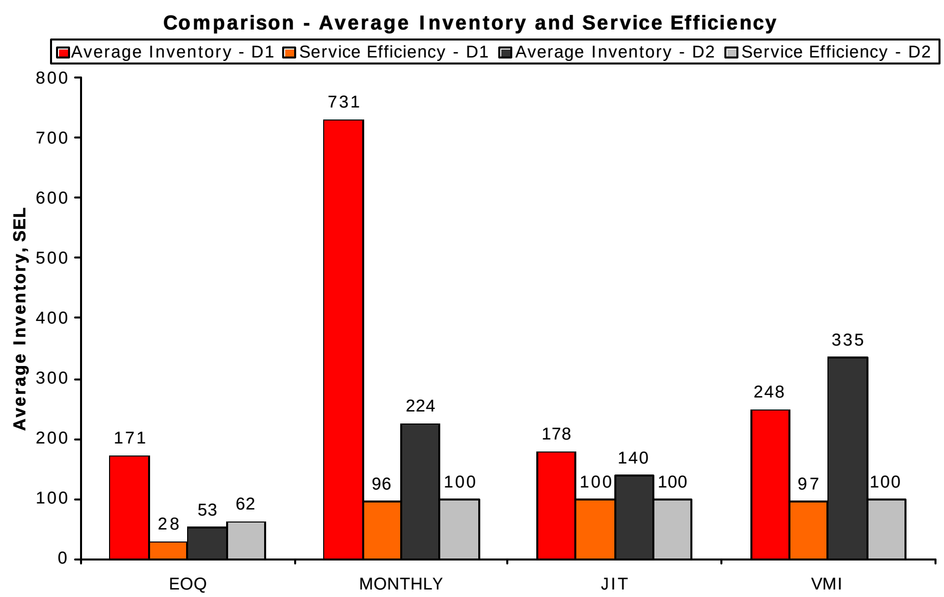

Figure 3.20 Comparison of Average Inventory and Service Efficiency Level – Triangular Distribution

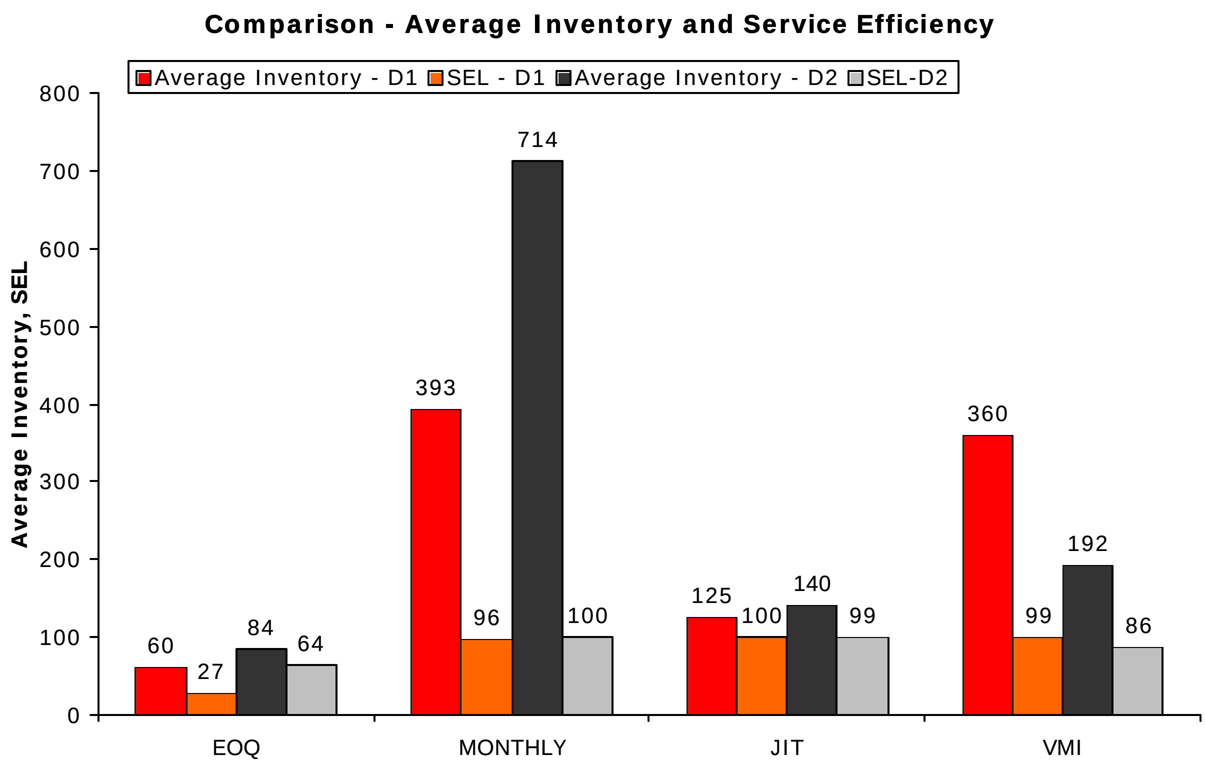

Figure 3.21 Comparison of Average Inventory and Service Efficiency Level – Triangular Distribution

3.7 DEVELOPMENT OF A BEST ALTERNATIVE ORDERING POLICY

Sections 3.4 and 3.5 reveal that among the four policies, the JIT and the VMI policies are the best. For the **current datasets**, monthly ordering policies are discounted because of the high inventory carrying costs and the large amount of daily inventory carried. Sahay (2002) and Goyal (2002) have shown that large inventories, particularly in industry segments like consumer electronics can lead to failure of the organization. EOQ based ordering polices are reactive in nature and exhibit a large number of stock outs. Both JIT and VMI ordering policies have the least cost and the best performance characteristics with respect to inventory replenishment decisions.

3.7.1 Single Supplier Strategy

O'Neal (1987) pointed out that the implementation of a JIT ordering policy results in a shift to fewer suppliers, with a majority of organizations following JIT using single-point sourcing. In the current globalization paradigm, single-point sourcing might be cost-attractive, however, Lewis (2000) conducted a survey of over 900 organizations, spread over a variety of fields like service, manufacturing and retail, and concluded that moving toward single supplier strategies does not leverage cost and performance effectiveness opportunities. Although it is generally believed that single supplier sourcing promotes greater commitment, in reality single supplier sourcing leads to sub-optimization of supply chains by price discounting, bulk volume discounts and monopolistic strategies (Sahay, 2002). Many organizations, like Dell and HP, have realized that it is best to move to strategic partnership relationships (like VMI entails) rather than stick to a JIT-preferred single supplier strategy.

3.7.2 Change in Shipment Policies

The increase in delivery frequencies in a JIT system typically results in smaller quantities per shipment, often causing a shift from FTL to LTL shipments. Additionally, it requires faster and more precise deliveries putting more pressure on the carrier firm (Ramasesh, 1993).

Figure 3.22 illustrates that a JIT ordering policy exhibits large variation in both supplier quantities and number of deliveries. Since the ordering policy requires the inventory levels to be replenished at a level of 200 units of inventory with weekly deliveries, a JIT ordering policy experiences large variation in the number of units/shipment in the case of a change in demand (Figure 3.20). Although no literature exists on the effect of large scale variations in supplier deliveries on supply chain performance, Sahay (2002) conducted a comprehensive survey which indicates that suppliers tend to opt out of a JIT arrangement in the long run. Coupled with a single sourcing strategy prevalent in most JIT supply chains, this development could spell doom for the supply chain network.

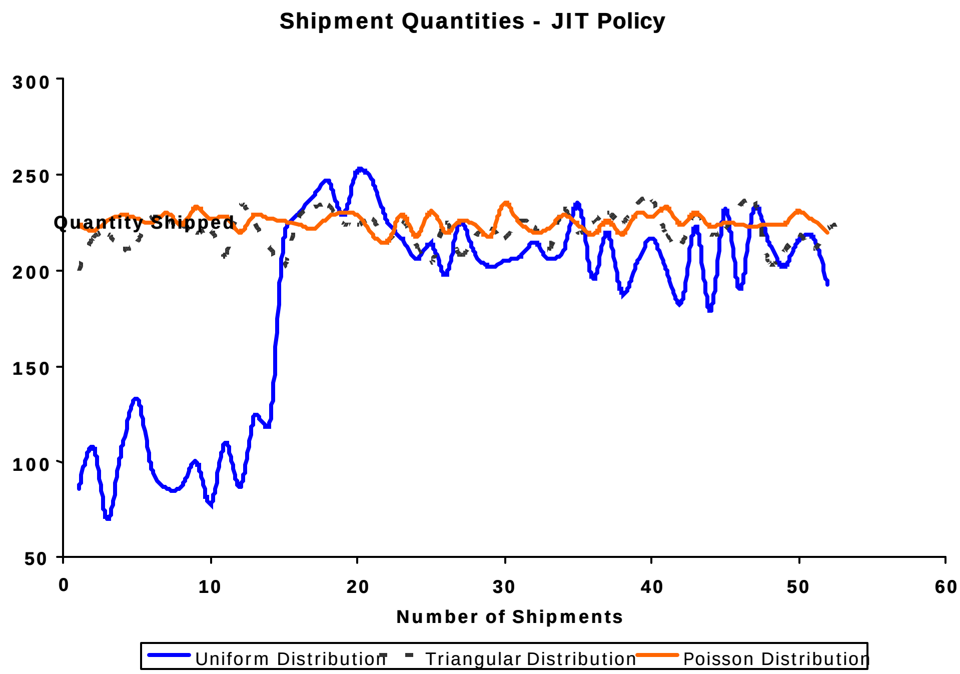

Figure 3.22 Variation in shipment quantities in JIT Policy

Table 3.12 illustrates the total quantity shipped in a JIT policy for the three demand distribution functions. The demand dataset under consideration is 1. The difference in the ordering quantities is reflected in the standard deviation whereas the mean represents the average number of units per JIT shipment.

Table 3.12 Variation in shipment quantities in JIT policy – system summary

	Uniform	Triangular	Poisson
Total Quantity Shipped	9538	11708	11713
Standard Deviation	54.38	9.18	4.37
Mean	183.43	221	225.25

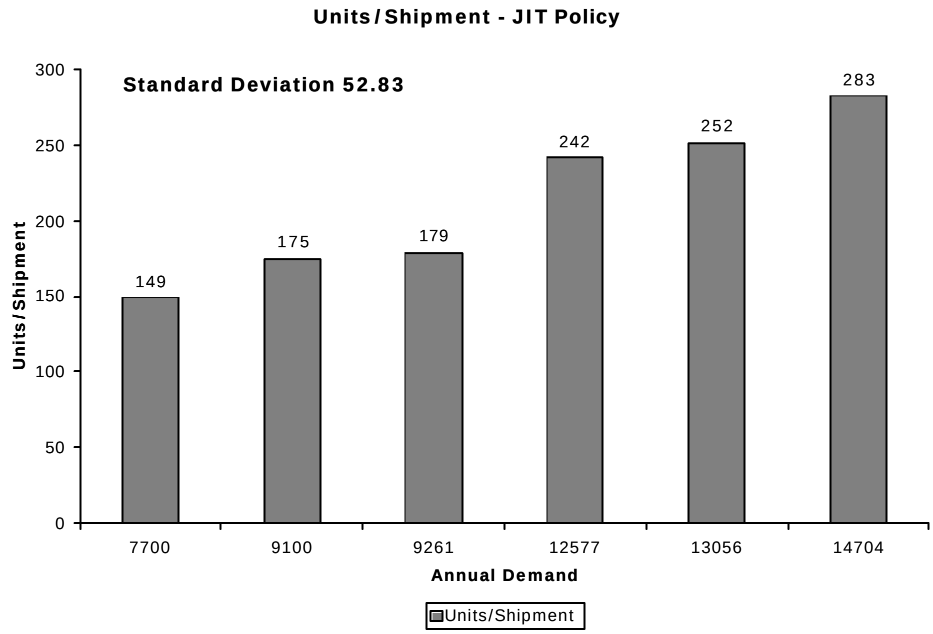

Figure 3.23 Units/Shipment in a JIT ordering policy

Figure 3.24 illustrates the difference in shipment quantities between a JIT and a VMI policy for differing levels of annual demand. JIT policies consistently involve not only more items shipped, but also more shipments (Figure 3.25). With increasing globalization of supply chains, JIT ordering policies can involve substantial costs with respect to transportation. Figure 3.25 also illustrates that, instead of proactively dealing with increasing demand, a JIT ordering policy continues to use weekly delivery schedules that lead to a large variance in shipment quantities. In the case of a sudden spike or decrease in demand, tremendous pressure is placed on the delivery carrier to maximize transportation capacity with minimal costs. JIT ordering policies are often a refinement of EOQ based policies (Sandhwani, 1994).

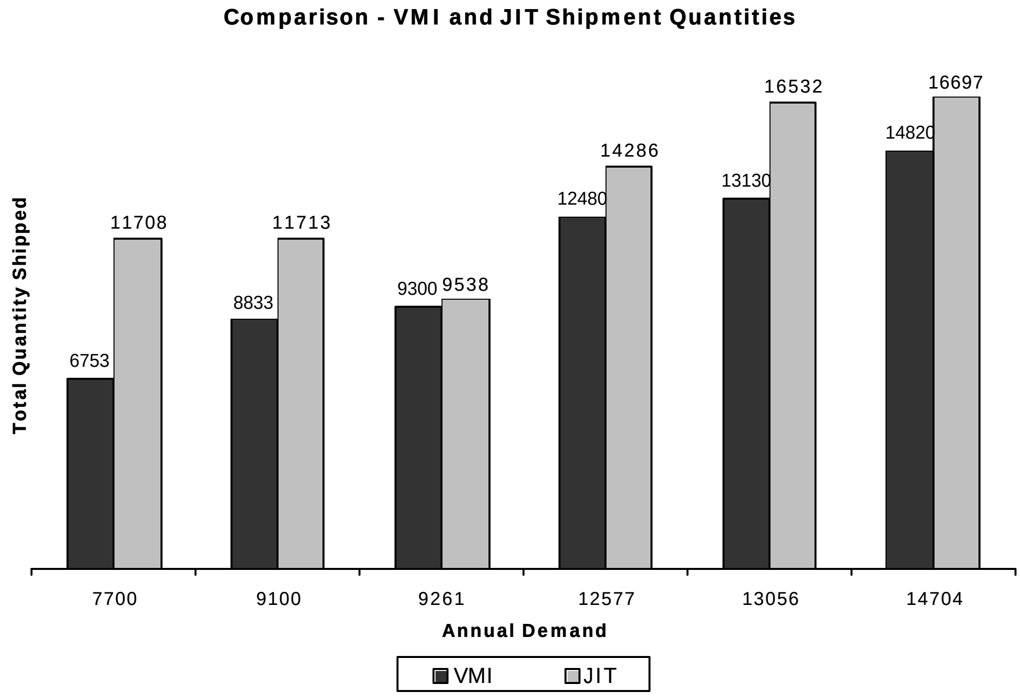

Figure 3.24 Comparison of VMI and JIT shipment quantities

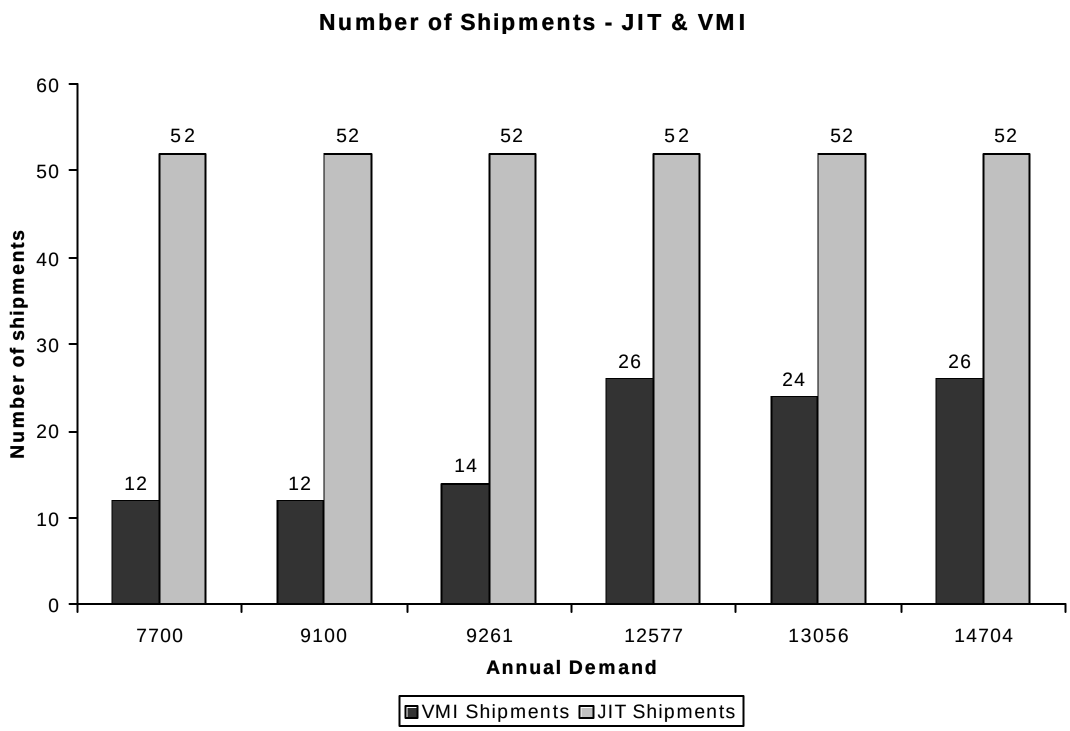

Figure 3.25 Comparison of number of shipments – JIT & VMI

Figure 3.26 shows the difference between shipping in FTL and LTL modes in JIT ordering policies. Figure 3.27 portrays the use of FTL shipping at the cost of reduced transportation capacity utilization. Transportation capacity utilization is the ratio of the average units/shipment to one FTL truck capacity (assumed in this case to be 1000 units). JIT organizations often use FTL shipping to minimize transportation costs, forgetting that use of FTL shipments for frequent deliveries leads to a dramatic drop in transportation capacity utilization (Yang, 2003).

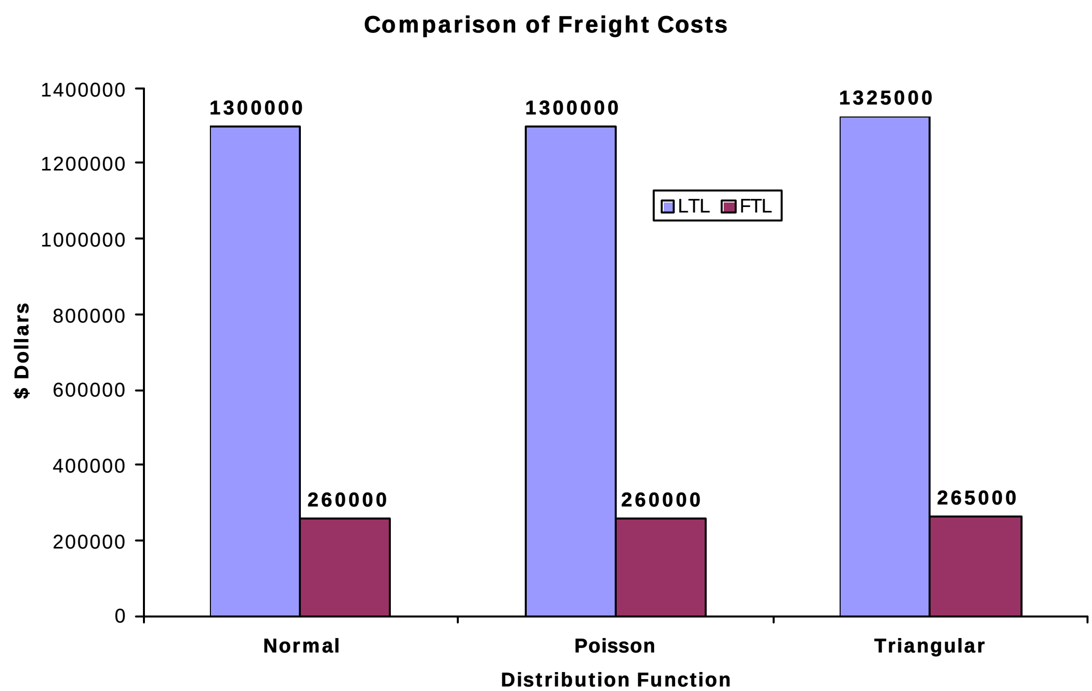

Figure 3.26 Difference in using FTL and LTL shipment modes for the JIT ordering policy

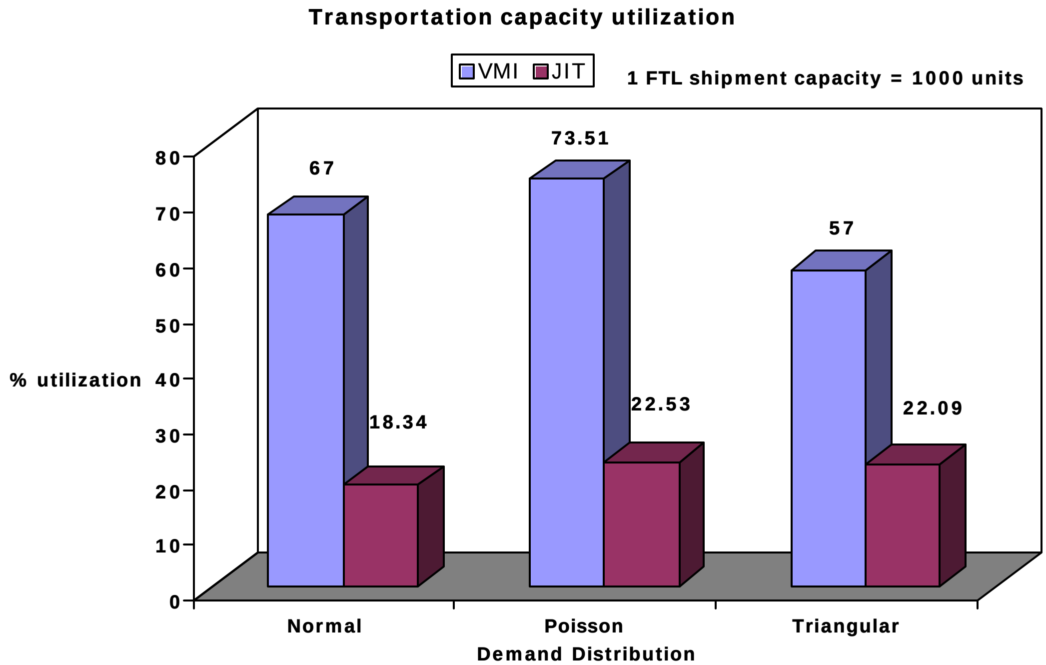

Figure 3.27 Transportation capacity utilization comparison

3.7.3 Inventory Re-Routing

Sandhwani (1994) used a spreadsheet solution to illustrate that the inventory reduction in JIT policies is merely the result of pushing inventory back into the distribution channels so that it is held by the supplier.

An examination of the average inventory between the JIT and the VMI policy indicates that the VMI policy has higher average inventory than the JIT policy.

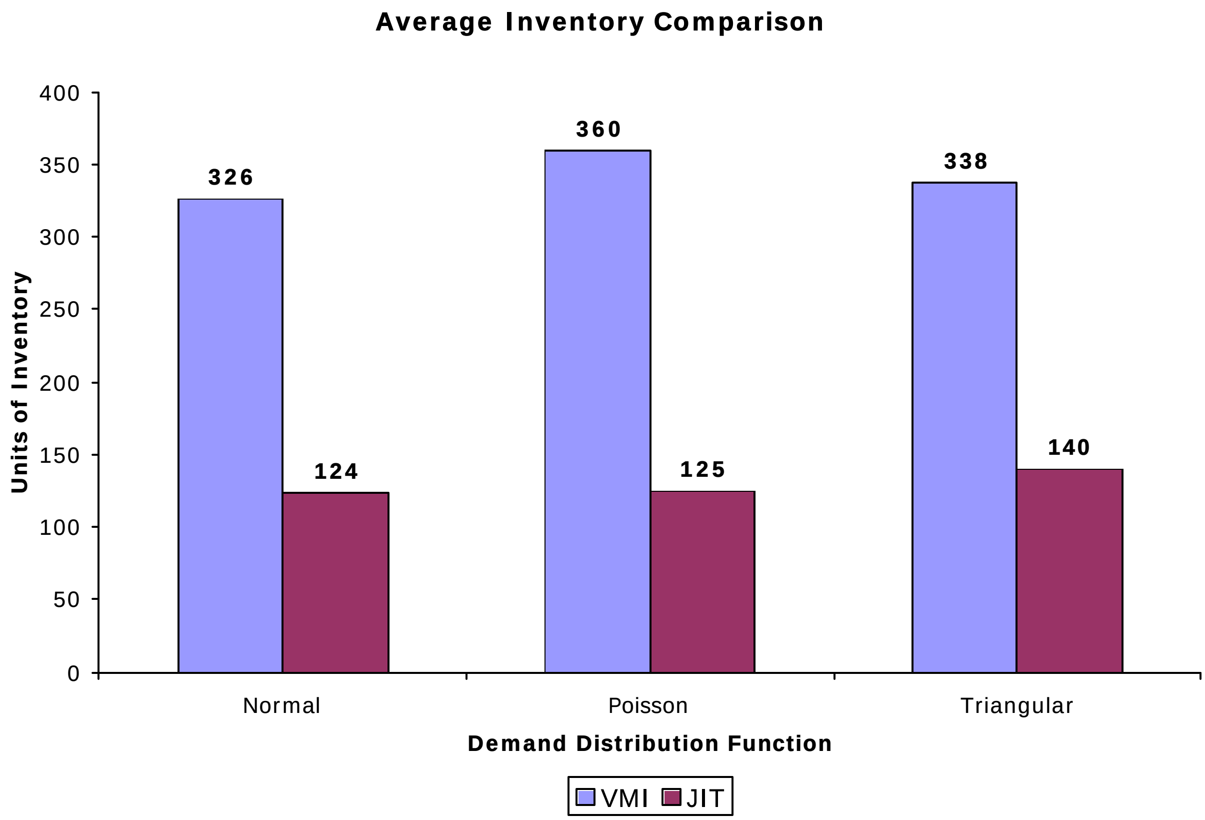

Figure 3.28 Average Inventory Comparisons

Yang (2003) showed a high correlation between the inventory levels and service efficiency (measured in terms of system stock outs). Figure 3.29 graphically illustrates the service efficiency level of the two policies. The service efficiency levels of the two policies are more or less similar across the three distribution functions. This indicates that the JIT policy has inventory buffers to protect the system against stock outs. Unlike the VMI policy which uses supplier collaboration and third party distribution centers, JIT pushes the inventory buffers in the distribution channel to keep inventory costs low (Sandhwani, 1994).

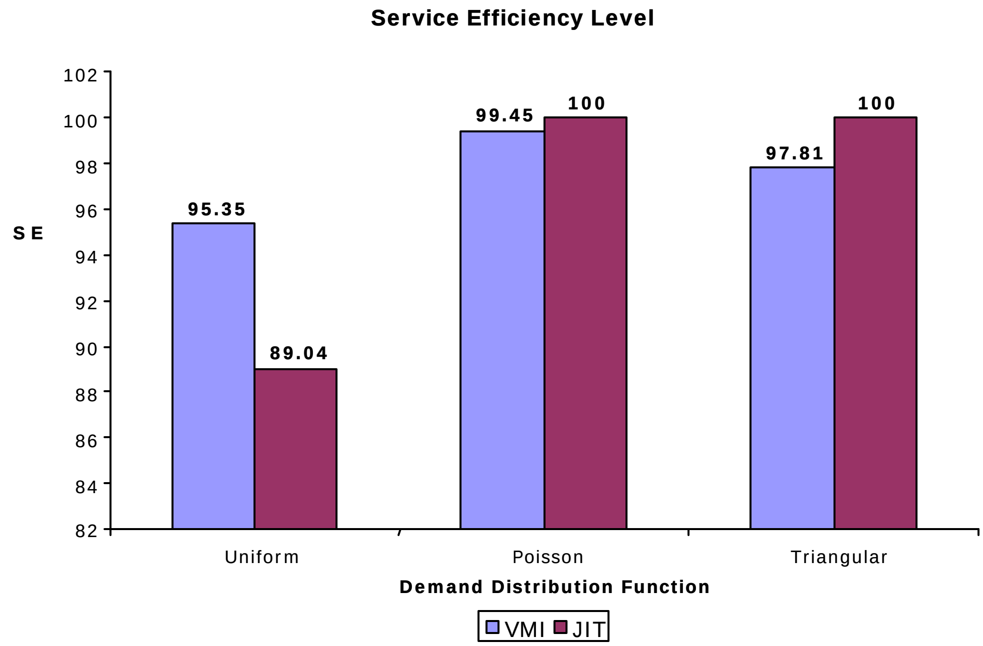

Figure 3.29 Service efficiency Comparison – JIT and VMI

S E refers to the Service Efficiency

CHAPTER 4. CONCLUSIONS

4.1 SUMMARY

The goal of the thesis is to develop a best alternative ordering policy for a single manufacturer-single supplier supply chain. This thesis provides a basic understanding with respect to the development of an ordering policy for a single manufacturer-single supplier supply chain with known lead time and variable demand. This was answered in two steps. First, a database application system was constructed incorporating VMI logic. Second, using the results from the database systems, a best alternative ordering policy for a single manufacturer-single supplier system was developed using statistical analysis of four ordering policies – EOQ, Monthly, JIT and VMI-under three demand distribution functions – Uniform, Triangular and Poisson. This analysis involved comparing the performance of the four ordering policies under the three demand distribution functions under a variety of inventory performance measures. All the cost data have been assumed from Goyal (2002). The software used for the analysis was Microsoft Excel. The planning horizon for the system was one calendar year. Once the data were set up in spreadsheets, 2 axis graphs were used for policy comparisons. Two sets of demand data have been used for each ordering policy.

4.2 FINDINGS FROM THE CURRENT DEMAND DATA

There is no one single answer with respect to the development of a best alternative ordering policy for a single manufacturer-single supplier supply chain system operating under known lead time and variable demand. For the **current dataset**, using results from Suri (2002), the EOQ based ordering policy is discounted because in each case, the coefficient of variation is greater than 0.2. The monthly ordering policy provides high levels of service efficiency at the cost of high inventory carrying costs. Monthly ordering policies are useful only in situations where an organization needs service efficiency of close to 100% and it is worthwhile to carry high daily inventories to meet the service efficiency levels. Sandhwani (1994) used a spreadsheet solution to illustrate that the inventory reduction in JIT policies is merely the result of pushing inventory back into the distribution channels so that it is held by the supplier. For the current datasets, section 3.7.2 illustrates that, instead of proactively dealing with increasing demand, a JIT ordering policy continues to use weekly delivery schedules that lead to a large variance in shipment quantities. In the case of a sudden spike or decrease in demand, tremendous pressure is placed on the delivery carrier to maximize transportation capacity with minimal costs. The results in section 3.5 and 3.6 are for the two demand datasets. Although the demand datasets have been randomly generated, the costs are assumed values from the literature. The results ***would*** change for a different set of assumed values.

4.3 SUPPLY CHAIN OF THE FUTURE

The key point in this research is that coordination is the key to survival in today's global, dynamic environment. Operations managers are faced with demands to improve service levels while simultaneously lowering costs. Managers are faced with managing increasingly complex supply chain networks that include multiple suppliers, manufacturing sources, warehouses, and transportation providers; not to mention an array of product variations. Coordination among these disparate players is key to success. It is no longer acceptable to create plans for only one enterprise. Traditional distribution requirements planning (DRP) tools are not up to today's planning challenge because DRP creates distribution plans without considering the costs and constraints that exist within logistics networks. It is important to note that there is no single correct answer in supply chain management. It is important to look at supply chain systems from a holistic view. Too often, supply chain managers break a system into constituent parts and then vertically integrate it upward without focusing on the system interfaces. It is the management of these system interfaces, like the interface between production and distribution that will define the success or failure of organizations in the future. It is only a collaborative effort between all the supply chain constituents that could create a “synchronized supply chain.”

A supply chain of the future should address the flaws in current systems by producing,

- a collaborative, real-time process that links customers, suppliers and partners together, reducing the overall process cycle-time,
- a tactical plan that takes into account multiple sites, costs, constraints, real-time inputs, and actions,
- a schedule that is “forward” looking and allows for realistic completion dates,
- a way to accommodate customer demands while keeping sight of business goals,
- a plan that optimizes capacity and in the process, decreases costs and increases the bottom line,
- a system that produces actions and alerts that are meaningful, prioritized and related to all levels of the system, thus showing planners the best way to solve problems, and
- a plan that takes into account variable lead times and considers multiple ways to manufacture products and can take into account possible substitutions in real-time.

4.4 FURTHER DIRECTIONS FOR RESEARCH

The entire VMI system has limitations with respect to the assumptions, particularly those related to inventory costs. These costs are assumed values and the accuracy and precision of the results are bounded by the assumptions behind these costs. The VMI system can be further enhanced by the use of mechanisms to reflect dynamic pricing and the ability to vary cost information and analyze new results. External factors like customer satisfaction, global economic demands, adverse weather affecting loss of shipments, etc have to be built into the system so that a truly collaborative supply chain system can be formed. The VMI system also further needs to be studied in the case of variable lead time. Since forecasting is the engine that drives any sort of production, it is also important to incorporate a forecasting module, particularly a collaborative forecasting and replenishment model in the VMI system which acts as the driver for production. Finally, the entire application system needs to be tested in an actual organization to understand the practical considerations behind implementation of a VMI strategy. This implementation also needs to include actual performance benchmarking against the system the company is actually using.

Finally, this thesis includes a demonstration VMI system. It also includes performance analysis of the VMI system when compared to other known ordering policies. The study done for this thesis will be a strong platform for someone who is interested in working in collaborative supply chain management. Using the conceptual framework in this thesis as a base, a thorough VMI system can be built.

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APPENDIX

Appendixes A through C give the inventory availability calculations for the first thirty five days for each of the three demand distribution functions.

APPENDIX A – UNIFORM DISTRIBUTION						
			Inventory Availability			
Days	**Date**	**Demand**	**EOQ**	**Monthly**	**JIT**	**VMI**
1	1-Jan	42	158	1384	285	728
2	2-Jan	36	122	1348	249	692
3	3-Jan	41	81	1307	208	654
4	4-Jan	45	36	1262	163	606
5	5-Jan	44	-8	1218	119	562
6	6-Jan	41	-49	1177	79	521
7	7-Jan	39	-88	1138	39	482
8	8-Jan	37	-125	1101	285	445
9	9-Jan	38	-163	1063	247	407
10	10-Jan	38	-201	1025	209	369
11	11-Jan	42	-243	983	167	327
12	12-Jan	45	-288	938	122	282
13	13-Jan	41	357	897	81	241
14	14-Jan	44	313	853	37	197
15	15-Jan	36	277	817	285	161
16	16-Jan	45	232	772	240	116
17	17-Jan	38	194	734	202	78
18	18-Jan	44	150	690	158	604
19	19-Jan	36	114	654	122	568
20	20-Jan	39	75	645	83	529
21	21-Jan	40	35	575	43	489
22	22-Jan	37	-2	538	285	452
23	23-Jan	37	-39	504	248	415
24	24-Jan	36	-75	465	212	379
25	25-Jan	39	-114	426	173	340
26	26-Jan	43	-157	383	130	297
27	27-Jan	43	-200	340	87	254
28	28-Jan	47	-245	295	42	209
29	29-Jan	40	-285	255	285	169
30	30-Jan	43	358	212	248	129
31	31-Jan	38	320	174	212	88
32	1-Feb	40	280	130	173	48
33	2-Feb	45	235	1315	130	3
34	3-Feb	36	199	1279	87	537
35	4-Feb	40	159	1239	42	497

APPENDIX B – TRIANGULAR DISTRIBUTION						
			Inventory Availability			
Days	**Date**	**Demand**	**EOQ**	**Monthly**	**JIT**	**VMI**
1	1-Jan	38	162	162	285	667
2	2-Jan	39	123	123	246	628
3	3-Jan	34	89	89	212	594
4	4-Jan	33	56	56	179	561
5	5-Jan	39	17	17	140	522
6	6-Jan	32	-15	-15	108	490
7	7-Jan	38	-53	-53	70	452
8	8-Jan	26	-79	-79	285	426
9	9-Jan	34	-113	-113	251	392
10	10-Jan	32	-145	-145	219	360
11	11-Jan	33	-178	-178	186	327
12	12-Jan	29	-207	-207	157	298
13	13-Jan	43	397	-250	114	255
14	14-Jan	32	365	-282	82	223
15	15-Jan	43	322	-325	285	180
16	16-Jan	31	291	-356	254	149
17	17-Jan	40	251	-396	214	109
18	18-Jan	33	218	-429	181	581
19	19-Jan	40	178	-469	141	541
20	20-Jan	35	143	-504	106	506
21	21-Jan	35	108	-539	71	471
22	22-Jan	44	64	-583	285	427
23	23-Jan	44	20	-627	241	383
24	24-Jan	36	-16	-663	205	347
25	25-Jan	36	-52	-699	169	311
26	26-Jan	45	-97	-744	124	266
27	27-Jan	37	-134	-781	87	229
28	28-Jan	41	-175	-822	46	188
29	29-Jan	28	-203	-850	285	160
30	30-Jan	36	-239	-886	249	127
31	31-Jan	27	381	-913	222	97
32	1-Feb	40	341	135	182	57
33	2-Feb	29	312	106	153	28
34	3-Feb	32	280	74	121	501
35	4-Feb	37	243	37	84	464

APPENDIX C – POISSON DISTRIBUTION						
			Inventory Availability			
Days	**Date**	**Demand**	**EOQ**	**Monthly**	**JIT**	**VMI**
1	1-Jan	29	171	1221	245	651
2	2-Jan	39	767	1182	206	612
3	3-Jan	35	732	1147	171	577
4	4-Jan	35	697	1112	136	542
5	5-Jan	34	663	1078	105	508
6	6-Jan	39	624	1039	63	469
7	7-Jan	34	590	1005	29	435
8	8-Jan	37	553	968	245	398
9	9-Jan	35	518	933	210	363
10	10-Jan	30	488	903	180	333
11	11-Jan	32	456	871	148	301
12	12-Jan	36	420	835	112	265
13	13-Jan	31	389	804	81	234
14	14-Jan	39	350	765	42	195
15	15-Jan	28	322	737	245	167
16	16-Jan	30	292	707	215	137
17	17-Jan	37	255	670	178	100
18	18-Jan	34	221	636	144	546
19	19-Jan	35	186	604	109	511
20	20-Jan	40	146	561	69	471
21	21-Jan	39	107	522	30	432
22	22-Jan	45	62	477	245	387
23	23-Jan	28	34	449	217	359
24	24-Jan	40	-9	409	177	319
25	25-Jan	34	-40	375	143	285
26	26-Jan	30	-70	345	113	255
27	27-Jan	40	-110	305	73	215
28	28-Jan	19	-129	286	54	196
29	29-Jan	34	-163	252	245	162
30	30-Jan	44	-207	208	201	118
31	31-Jan	30	398	179	171	88
32	1-Feb	32	366	1196	139	56
33	2-Feb	36	330	1160	103	20
34	3-Feb	39	291	1121	64	461
35	4-Feb	41	250	1080	23	420