

# **SUPPLY CHAIN INVENTORY CONTROL: A COMPARISON AMONG JIT, MRP, AND MRP WITH INFORMATION SHARING USING SIMULATION**

Laith Abuhilal, Raytheon Systems Company  
Ghaith Rabadi, Old Dominion University  
Andres Sousa-Poza, Old Dominion University

## **ABSTRACT**

Logistics or Supply Chains play a central role in effective management. Inventory control systems play a significant role in managing supply chains. This article provides engineering managers with guidelines to choose a cost-effective supply chain inventory control system through analyzing push inventory systems (MRP), and pull systems (JIT). Simulation modeling was used to build and analyze the supply chains with stationary and cyclical demand patterns. The paper indicates the main variables that should concern the engineering manager to choose between MRP and JIT. The paper concludes that since JIT reduces the holding cost, it becomes a more cost-effective system at a wider range as the demand level increases. The results also show that when information is shared across a supply chain that implements a MRP system, the cost reduction is significant in comparison with no information sharing especially under cyclical and highly variable demand patterns.

## **Introduction**

In today's complex marketplace, the competition is between supply chains rather than individual companies. A primary consideration of Supply Chain Management (SCM) is the flow of goods from the source of raw materials to the ultimate end consumer. Inventory Management is one of the cornerstones of SCM and inventory is a key cost-contributor in any Supply Chain (SC). According to the Institute of Management and Administration (IOMA) the cost of logistics in the USA for 1993 amounted to \$936 billion. The cost of carrying inventory (including: interest, taxes, obsolescence, depreciation, insurance and warehousing) amounted to \$300 billion (Inventory Management Report, 2004). Effective management of inventories is thus a crucial function of management, and in particular, plays a pivotal role in basic Engineering Management topics, such as Quality Management and lean manufacturing.

Amongst the major methodological approaches to inventory management that engineering managers are familiar with are material requirements planning (MRP) and Just-In-Time manufacturing (JIT). Choosing the "best" inventory management system depends on numerous parameters, among the most important of which are supply chain-related parameters, such as the demand pattern, the demand level, and the inventory costs. In this article, we present a methodology on how to carry out a comparison between these two inventory management systems to select the better one.

Research has also revealed that collaboration and information sharing in the SC is of vital contribution to cost-reduction and improved planning in the SC. Information Technology and web-based applications have created the infrastructure for sharing information about demand levels and patterns, inventory positions, and other events that could have significant impact on members upstream and downstream in the SC. Collaborative SCM efforts started to take a real turn in 1996 when Warner-Lambert, a consumer goods manufacturer, and Wal-Mart, the department store, began a pilot study of collaborative planning, forecasting, and replenishment software system. This software also facilitates exchange of statistical information and promotional plans, which are utilized by other SC members (Simchi-Levi, Kaminsky, and Simchi-Levi 2000). In this article, we study the effect of information sharing on the SC cost when MRP is used. Note that in case of JIT, information has to be shared by default.

## **Overview of Inventory Management Techniques**

The ultimate goal of managing a SC is to satisfy the demand level at minimum cost. Therefore, inventory management approaches such as MRP and JIT play a key role in achieving this goal. Some research (e.g., Nahmias (1997)) found that MRP is more appropriate for companies where there are many product options, frequent engineering changes and fluctuating product system; while JIT is more appropriate in environments where relatively few product options, engineering changes, product mix changes and less variability in demand levels. Some studies attempted to integrate those two methodologies and/or compare them with different alternatives. Matsuura, Kurosu, and Lehtimäki (1995) compared MRP, JIT and OPT (Optimized Production Technology) in Finland and Japan with respect to practices applied. They found that both countries had different interpretation of these approaches and they pointed out the differences and similarities. Benton and Shin (1998) pointed out that MRP was more beneficial in

simulation-based studies such as those conducted by Krajewski et al. (1987) and Steele et al. (1995), which were based on critical factors such as setup time, lot size, labor requirements, inventory, and past due demands. Benton and Shin (1998) also briefly discussed the integration of MRP and JIT. They suggested that this hybridization is a result of the natural evolution of the production planning system derived from the JIT implementation in the US (or, conversely, implementing MRP in Japan) to exploit the advantages of both systems and achieve better performance. They summarized three factors that have contributed to the evolution of the hybrid manufacturing environment: (1) accumulated operating problems in implementing JIT manufacturing techniques, (2) researchers and companies' understanding of compatibility between the MRP and JIT systems and (3) MRP flexibility in the long term capacity planning and JIT agility in daily production control. With respect to MRP/JIT integration, they concluded that this phenomenon could be considered a natural progress in academia to develop the idealistic hybrid-manufacturing environment.

Our article also deals with the effect of information sharing on the SC cost. In the late 80's, research started shifting more towards understanding the value of information sharing (e.g., Yoo (1989)). Not until the late 90's when we started to see significant research conducted in the area as a result of the capabilities that the Internet introduced. Information sharing researchers' studies have tackled the benefits of information sharing (e.g., Gavirneni et al. (1999); Lee et al. (2000)), the alliances and competition in the SC (Weng, 1999), and the impact of SC integration on operating performance (Armistead et al., 1993). In their research, Lee et al. indicated that in 1996 Troyer showed that information sharing can save up to \$14 billion in the grocery industry, whereas Chen found that the SC costs are reduced by up to 9% through sharing of information, while Lee et al. indicated a 23% cost reduction for a two level SC.

In their SC framework for critical literature review, Croom et al. (2000) identified that information sharing is necessary between buyers and suppliers, or distributors and retailers as it helps minimizing inventories and respond to fluctuation in demand in a timely manner. Yu et al. (2001) studied information sharing with SC partnership. Based on a two-stage decentralized SC comprising a retailer and a manufacturer, they studied optimal inventory control policies. They showed that the average inventory level and the expected inventory cost could be reduced when information sharing is increased. Min and Zhou (2002) presented a framework that categorizes SC work into several models. One of these categories is *IT-driven models*, which they consider as a category of high demand since IT and information sharing is a key to a SC success. They emphasized, however, that this type of model is still in its infancy and not much work has been done on it.

### **Objective Of The Study**

This paper argues that the selection of an appropriate inventory management methodology is an important task confronting an engineering manager. More specifically, this study aims to analyze SC costs under different inventory control systems. The total chain costs are studied when using JIT and MRP production systems, as well as the proposed MRP with Information Sharing system. The main SC cost drivers are the Facilities, Inventory, Transportation, and Information (Chopra, 2004). It has been assumed in this research that the number of facilities is constant while the transportation and information costs are bundled into the ordering cost. The inventory cost driver includes the ordering and holding costs. These assumptions are reasonable given that the focus of this paper is on the effect of the inventory policies on the SC costs. Numerous simulation scenarios were designed to study the impact of the inventory ordering and holding costs as well as the demand level and pattern to answer the following questions:

- Which production system provides lower total chain cost under specific SC parameters; i.e., can we come up with a “universal formula” for determining the optimal performance as a function of demand level, ordering cost, and holding cost for a given demand pattern?
- How does Information Sharing affect the SC costs, and what is the effect of the demand pattern on that influence?

In order to answer these questions, Simulation was used for building the three models, (JIT, MRP, and MRP with Information Sharing). Different SC parameters were then changed by increasing their values over a wide range and observing the effect on the SC ordering and holding costs. This enabled us to study the relationship between the SC parameters and the SC costs using Regression Analysis.

### **The Systems Models**

Three models representing the three supply chains were built to realistically mimic a three-echelon SC. SIMAN discrete-event simulation language and ARENA modeling environment were used to build the models described above. All the simulation and statistical conventions and requirements were followed thoroughly in order to build

the 95% confidence intervals (CI) of the different statistics of interest, such as the required number of replications, warm-up period required to reach steady state, and half-width to average ratio of the CI.

### The MRP-Push System

*Stationary Demand Pattern Model:* In this model, orders arrive on a daily basis with a stochastic number of required units given from a normal distribution with the specified average demand and standard deviation. The retailer utilizes an (r,q) model where the reorder point (ROP) and the economic order quantity (EOQ) are determined using equations (1) and (2), ensuring a 95% service level (i.e., the probability of no stock-outs during lead time is 95%):

$$ROP = \mu_d \times Lt + Z_{(1-\alpha)} \times \sigma \times \sqrt{Lt} \quad (1)$$

Where:  $\mu_d$  is the daily demand;  $Lt$  is the lead time;  $Z_{(1-\alpha)}$  is the factor (from the normal distribution) required to attain  $(1-\alpha)$  service level;  $\sigma$  is the standard deviation of the demand distribution.

$$EOQ = \sqrt{\frac{2 \times S \times \mu}{h}} \quad (2)$$

Where:  $S$  is the ordering cost;  $\mu$  is the average annual demand; and  $h$  is the annual holding cost per unit.

The orders come to the manufacturer in quantities of EOQ, with probabilistic inter-arrival times. The manufacturer updates the forecast on a monthly basis, utilizing the moving average forecasting technique, and the forecasts are used for updating the ROP and EOQ values.

The forecast is transformed into a weekly Master Production Schedule (MPS) through taking the proportion of the monthly forecast. The weekly MPS quantity is issued from the “Raw Materials Store” to the “Production Floor”, in order to be processed. Whenever the raw materials Inventory Position, (which is equal to On-hand Inventory plus On-Order Inventory), goes below the ROP, the EOQ is ordered from the supplier. The system does not include backlogging; hence the missed quantities are considered lost opportunities. Based on the model’s design, the lost sales are not to exceed 5% of the total orders. The ordered materials arrive to the ordering member in the SC after the respective upstream lead-time, which has a deterministic value.

*Cyclical Demand Pattern Model:* The cyclical pattern is employed in order to study the effect of the demand pattern on the general system behavior, and to mimic a seasonal demand pattern. This model is the same as the stationary demand model with the difference in the generation of orders and preparation of MPS. The cyclical demand is generated from a sinusoidal function with random noise given from the normal distribution, as depicted by equation (3).

$$Demand = Mean + H \times \sin(Time \times \pi / HC) + N(0, \sigma^2) \quad (3)$$

Where:  $Mean$  is the average demand rate;  $H$  is the height of the cycle;  $HC$  is the half cycle time;  $N(0, \sigma^2)$  is the stochastic “noise” generated from a normal distribution with zero mean and  $\sigma^2$  variance.

The second difference from the stationary demand model is that the weekly MPS can not be calculated using the proportion directly as in the stationary demand pattern model, but is rather calculated through dividing the area under the average demand rate for the coming week, over the area under the curve for the current month. The areas are given through integration of the demand function, which could be given through equation (4).

$$Period's Area = Mean \times Time + H \times HC / \pi \times \{(\cos(T_{NOW} \times \pi / HC) - \cos((T_{NOW} + Time) \times \pi / HC))\} \quad (4)$$

Where:  $T_{NOW}$  is an internal simulation variable that represents the simulation current clock time.

### The JIT- Pull System

The structure of the JIT model is illustrated in Exhibit 1 below.

## Exhibit 1: Description of the JIT simulation model

*Stationary Demand Pattern Model:* In this model, orders arrive with a stochastic number of required units the same way explained for the MRP Stationary model above. The retailer maintains a finished goods stock sufficient for the

demand during lead-time, plus a safety stock required to ensure a 95% service level. This is the number of Kanban cards, and is calculated using equation (1). Each of the Kanban cards is “attached” to a unit product.

The retailer uses JIT supplier-Kanban-cards, where as demand arrives, an immediate order, of the same amount, is propagated upstream to the manufacturer. The manufacturer also maintains a finished goods inventory enough to satisfy 95% service level, and each Kanban card is attached to a product unit. The units pulled from the finished goods store trigger the pulling of units from the machines through use of Kanban cards. The demand is transferred upstream, again using Kanban cards, from the machines to the raw materials store, and from raw materials store to the supplier.

All of the numbers of Kanban cards are automatically calculated and updated during the simulation runs based on the demand and the upstream cycle time/lead time.

*Cyclical Demand Pattern Model:* This model is the same as the stationary model with the exceptions that the demand is generated from a stochastic sinusoidal function, and the number of cards is calculated based on the maximum forecasted demand level during the coming week.

### **The MRP With Information Sharing Model**

Four types of information are typically shared in a SC: order, demand, inventory, and shipping information. In this article, a hybrid information-sharing model is applied, where the manufacturer has access to end-customer demand level and pattern, retailer’s inventory position, and shipment information. The suppliers have access to the manufacturer’s demand and inventory levels, and hence they can predict when and how much the manufacturers (i.e., the downstream members in the supply chain) will order. As a result, they can plan based on "exact information" as a forecast.

*Stationary Demand Pattern Model:* This model is similar to the MRP Model, with the exception that the manufacturer has access to the end-customer demand level and pattern, as well as the retailer’s Inventory Position. The manufacturer utilizes the end customer demand to determine the Retailer’s Forecast, EOQ and ROP (or alternatively this information is directly collaboratively provided by the retailer).

Knowing the ROP, EOQ, and the retailer’s Inventory Position, the manufacturer forecast can be calculated using equations (5) and (6).

$$\text{Number of Monthly Orders} = \left\lceil \frac{\{\text{Retailer Forecast} - (\text{Retailer Inventory Position} - \text{ROP})\}}{\text{EOQ}} \right\rceil \quad (5)$$

where  $\lceil \cdot \rceil$  is the integer ceiling.

$$\text{Manufacturer Forecast} = \text{Number Orders} \times \text{EOQ} \quad (6)$$

The Manufacturer Forecast is updated on a monthly basis, and is utilized for updating the manufacturer’s ROP and EOQ. The system works like that of the MRP model above.

*Cyclical Demand Pattern Model:* This model is the same as the MRP cyclical model with the exception that manufacturer’s forecast is updated using equations 3 and 4.

### **Results**

During the initial stages of the simulation runs, an important finding was depicted, namely that the decision of which production system is more cost effective, was similar for any Ratio of the Ordering Cost/ Holding Cost, regardless of the values of ordering and holding costs. Exhibits 2 and 3 highlight the fact that the breakeven point occurs at the same ratio (of 500 in this example), regardless of the ordering, holding, and total chain cost. Hence, the Ratio is the main driver that needs to be studied rather than the individual ordering and holding costs.

#### **Exhibit 2: Effect of increasing ratio through increasing Ordering Cost**

#### **Exhibit 3: Effect of decreasing ratio through decreasing Holding Cost**

### **Results at Stationary Demand Pattern**

*Comparison between JIT and MRP:* Simulation runs at different demand levels illustrated that at each demand level, there exist a breakeven ratio after which the JIT model becomes more costly, and the SC is better off using an MRP system. Those breakeven points, as intuitively anticipated, exist due to the nature of the JIT system, which reduces the inventory levels through continuous ordering resulting in increased ordering costs. An example of the breakeven point is shown in Exhibit 4 below at an annual demand level of 7,280 units.

#### **Exhibit 4: The supply chain cost at annual demand of 7,280 units.**

Simulation scenarios were run with annual demand levels ranging from 910 to 10,910 units at 500 unit increments. The corresponding breakeven points are depicted in Exhibit 5. The relationship between the ratio and the demand level could be fitted to a model using linear regression as shown in Exhibit 5. This regression line gives the breakeven ratio for a range of demand levels, after which the JIT model becomes less cost-effective. Using the regression model, one can predict the breakeven ratio for a certain demand level without the need to run the simulation.

#### **Exhibit 5: Fitted curve of breakeven points at the different demand levels.**

The reason that the breakeven points' values increase with increasing the demand level is that in the JIT model the demand is continuously propagated upstream, so the ordering cost (say, per year) is somewhat stationary at a fixed ordering cost. Hence, the holding cost becomes the overriding factor, and since JIT reduces the overall holding cost, it would become more cost-effective at a wider range of ratios as the demand level increases, causing the breakeven points to increase.

*Analysis of the Value of Information Sharing at Stationary Demand Pattern.* At a stationary demand pattern, the value of information sharing was proved to be of minimal magnitude. Example of the simulation results is shown in Exhibit 6 below at an annual demand level of 3,640 units. Although there seems to be a slight increase in SC cost for MRP with information sharing, there was not significant statistical evidence to conclude so. This Exhibit is an example of one annual demand level. For some other demand levels, the MRP with information sharing showed slight decrease in SC cost, which again, was not statistically significant to make conclusions on the relationship.

#### **Exhibit 6: Analysis of Information Sharing at a stationary demand of 3640.**

### **Results at Cyclical Demand Pattern**

At a cyclical demand pattern, Information Sharing was proved to be of significantly beneficial value. An example of the simulation results is shown in Exhibit 7 at a 1,820 average annual demand. In this specific example, the minimum cost reduction attained by information sharing was 22%.

#### **Exhibit 7: Analysis of Info-Sharing at a cyclical demand with average of 1,820 units.**

The cost reductions attained from sharing information, over the MRP system with moving average forecasting technique, was quantified via the simulation experiments, and the results are summarized in Exhibit 8. The minimum cost reduction percentage was 17% and the relationship seemed to follow a concave pattern, but that might rather indicate that the value of information sharing might not increase indefinitely.

#### **Exhibit 8: Savings of Information-sharing over MRP with moving average forecast.**

### **Conclusions**

Managing supply chains is a crucial component of engineering management. Selection of the correct inventory control system has a strong impact on how a system is managed, and on the eventual outcomes. This paper

demonstrates that the appropriateness of an inventory management system is contingent on the situation in which it is being applied and gives an indication of some of the variables that need to be required in the selection process. The study highlighted the fact that the decision of using JIT-pull or MRP-push Inventory Control system depends on several variables, amongst the most important of which are the inventory costs, demand pattern, as well as the average demand level. In future research, other factors such as company's policies, risk attitude, and relationship with suppliers (e.g., whether they can or willing to work in JIT mode or not) can be considered.

It was found that for a certain required service level, the ratio of the Ordering Cost to Holding Cost is a main driver that could be utilized as a decision variable, while the average demand level is the other main variable. Regression fitting was proposed as an approach for providing generic methodological guidelines for choosing the more cost-effective inventory control system. The generic behavior using this approach was reasonably in compliance with the research in the field, and the upward trend was explained through the fact that JIT has a somewhat stable ordering cost, making the holding cost the overriding factor. Since JIT reduces the holding cost, it would become more cost-effective at a wider range as the demand level increases.

The value of Information Sharing was analyzed, and the study showed that the value of information sharing is maximized at cyclical and highly variable demand patterns, while its effect is statistically significant at a stationary demand pattern. The cost reductions attained from sharing information, over the MRP system with moving average forecasting technique, was quantified via the simulation experiments, and the minimum reduction percentage was 17%.

## References

- Benton, W.C and Shin Hojung, "Manufacturing Planning and Control: The evolution of MRP and JIT integration," *European Journal of Operational Research*, 110 :3 (November 1998), pp.411-440
- Chopra, Sunil, Peter Meindl, *Supply Chain Management, Strategy, Planning, and Operation*, 2<sup>nd</sup> edition, Prentice Hall, (2004)
- Croom, Simon, Romano Pietro, and Giannakis Mihalis, "Supply Chain Management : An Analytical framework for critical literature review," *European Journal of Purchasing & Supply Management*, 6:1 (March 2000), pp.67-83.
- Gavirneni, Srinagesh, Kapuscinski, Roman, and Tayur, Sridhar. "Value of Information in Capacitated Supply Chains," *Management Science*, 45:1(January 1999), pp. 16-24.
- Krajewski Lee. J., King, Barry E., Ritzman, Larry.P. and Wong Danny .S., "Kanban, MRP and shaping the manufacturing environment," *Management Science*, 33:1 (January 1987), pp.39-57.
- Lee, Hau L., So, Kut C., and Tang, Christopher S, "The Value of Information Sharing in a Two-Level Supply Chain," *Management Science*, 46:5(May 2000), pp. 626-643.
- Armistead, Colin and Mapes, John, "The Impact of Supply Chain Integration on Operating Performance", *Logistics Information Management*, 1993 Volume: 6 Number: 4.
- Matsuura, Haruki, Kurosu, Seiji, and Lehtimäki Allan, "Concepts, practices and expectations of MRP, JIT and OPT in Finland and Japan," *International Journal of Production Economics*. 41(1995) pp. 267-272.
- Min Hokey, and Zhou Gengui, " Supply Chain Modeling: Past, Present and Future," *Computers & Industrial Engineering*. 43(2002), pp. 231-249.
- Nahmias, Steven, *Production and Operations Analysis*, 3<sup>rd</sup> edition, Irwin Publishing (1997).
- Simchi-Levi, David, Kaminsky, Philip and Simchi-Levi, Edith. *Designing and Managing the Supply Chain- Concepts, Strategies, and Case Studies*. McGraw-Hill, (2000).
- Steele Daniel C., Berry William L., and Chapman Stephen N, " Planning and control in multi-cell manufacturing," *Decision Sciences*, 26:1(1995), pp.1-33.

Weng, Z. Kevin. *Manufacturing and Distribution Supply Chain Management: Alliances and Competition*, Marketing Science Institute, (1999).

Yu, Zhenxin., Yan, Hon, and Cheng, Edwin T.C. "Benefits of Information sharing with supply chain Partnerships," *Industrial Management & Data Systems*, 101 :3(2001), pp. 114-119.

Yoo, Sangjin. "An Information System for Just-In-Time," *Long Range Planning*, 22:6 (1989) pp.117-126.

Anonymous, "Inventory Management Report", Inventory Management Report, Institute of Management and Administration, August, 2004 found at: [http://www.ioma.com/pub/IMR/2004\\_08/1587689-1.html](http://www.ioma.com/pub/IMR/2004_08/1587689-1.html)

### **About the Authors**

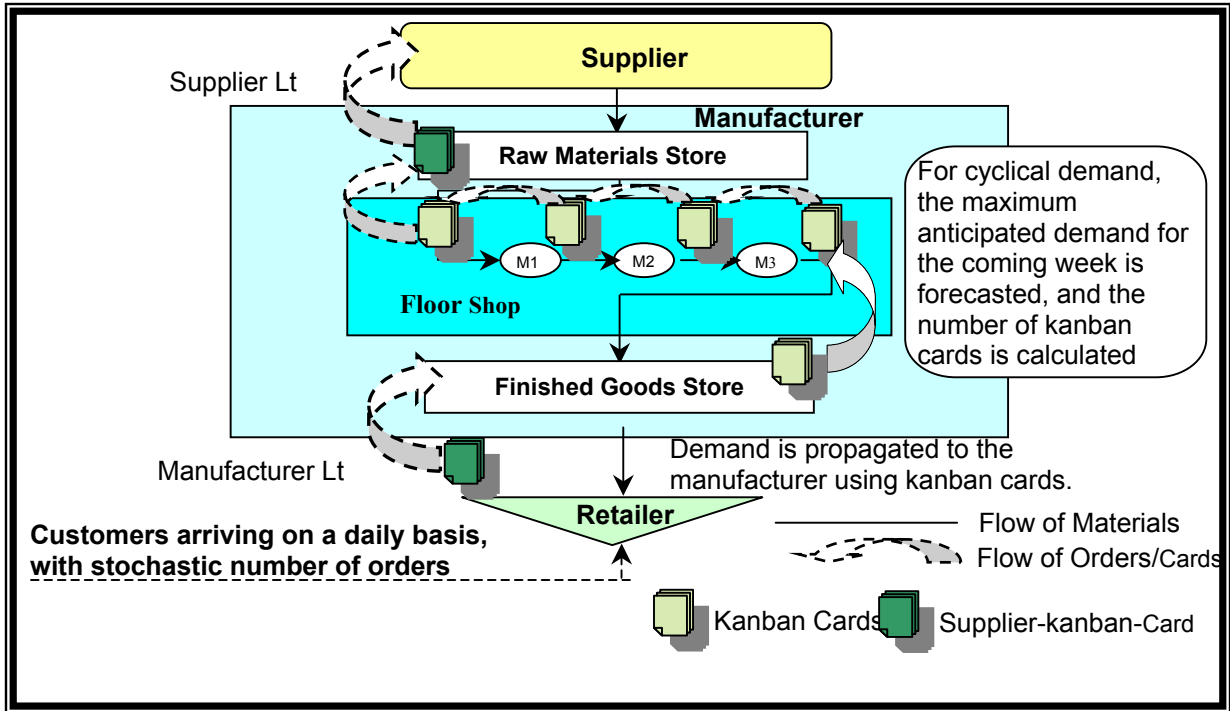
Laith Abuhilal is an industrial engineer at Raytheon Systems Company, Modeling and Optimization group. His main responsibility is building capacity simulation models. He is working on his Ph.D. in Operations Research at Southern Methodist University; he received an M.E. and B.S. degrees in Industrial Engineering from University of Florida and University of Jordan respectively. His areas of interest include Supply Chain Management, Optimization and Heuristics, and Simulation applications.

Ghaith Rabadi, Ph.D., is an assistant professor at Old Dominion University in the Department of Engineering Management & Systems Engineering. Dr.Rabadi received his Ph.D. and M.S. in Industrial Engineering from the University of Central Florida in 1996 and 1999 respectively. He received a B.S. in Industrial Engineering from the University of Jordan, Amman, Jordan. His research interests include scheduling, supply chain management, operations research, simulation, optimization, and engineering management. He is a member of ASEM, IIE and INFORMS.

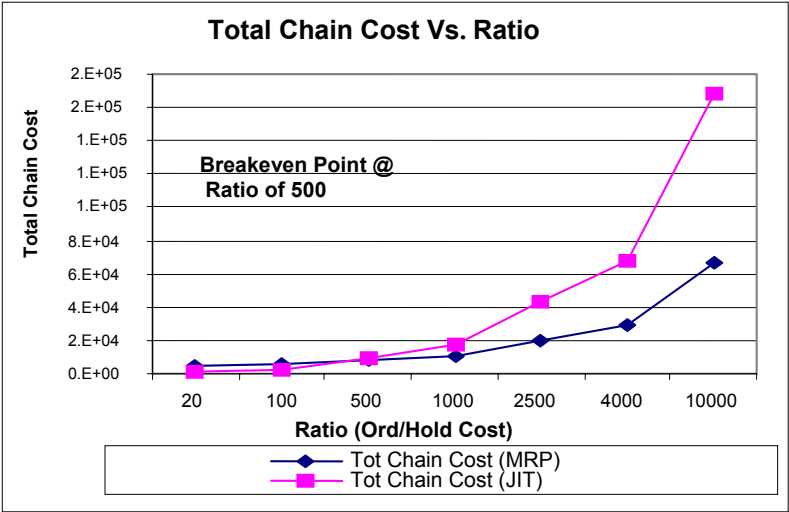
Andres Sousa-Poza, Ph.D., is an Assistant Professor at Old Dominion University in the Department of Engineering Management. Prior to entering academia, he worked in the manufacture of food processing facilities, and in the production of dry food products. He has international projects and management experience in Western and Eastern Europe, Southern Africa and the United States of America.

Contact: Dr. Ghaith Rabadi, Engineering Management and Systems Engineering Department, Old Dominion University, 241 Kaufman Hall, Norfolk, VA 23529, phone: (757) 683-4918, fax (757) 683-5640, email: [grabadi@odu.edu](mailto:grabadi@odu.edu)

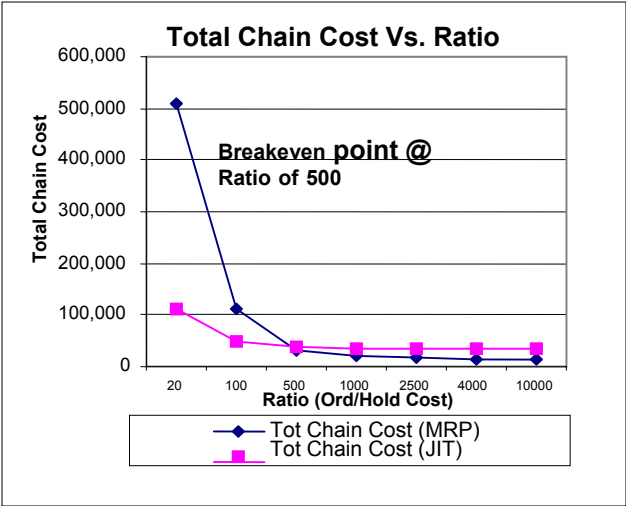
**EXHIBITS**



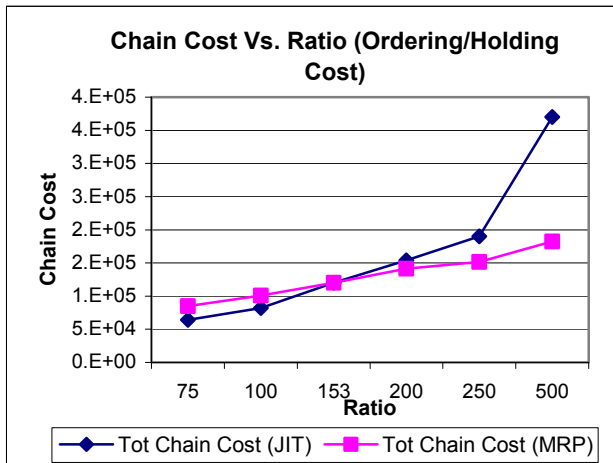
**Exhibit 1: Description of the JIT simulation model**



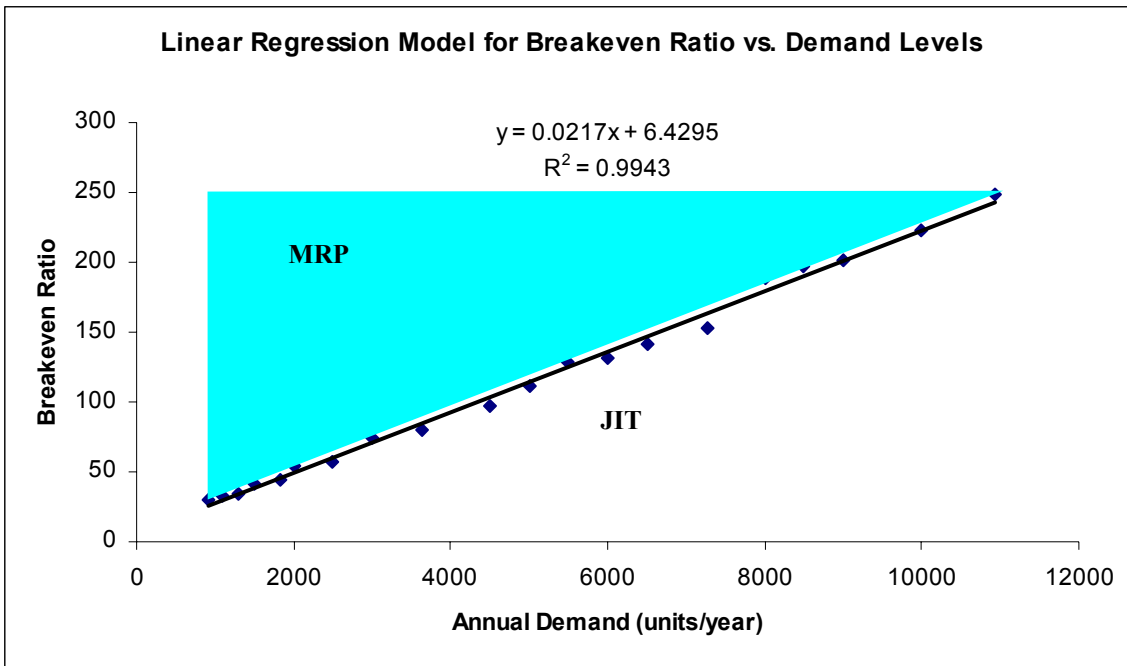
**Exhibit 2: Effect of increasing ratio through increasing Ordering Cost**



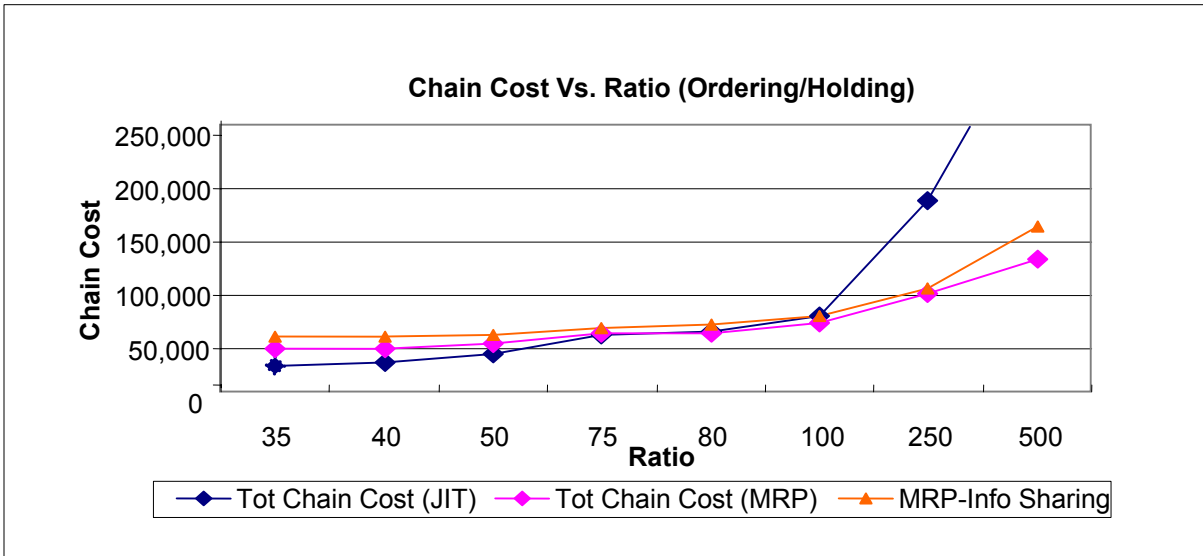
**Exhibit 3: Effect of increasing ratio through decreasing Holding Cost.**



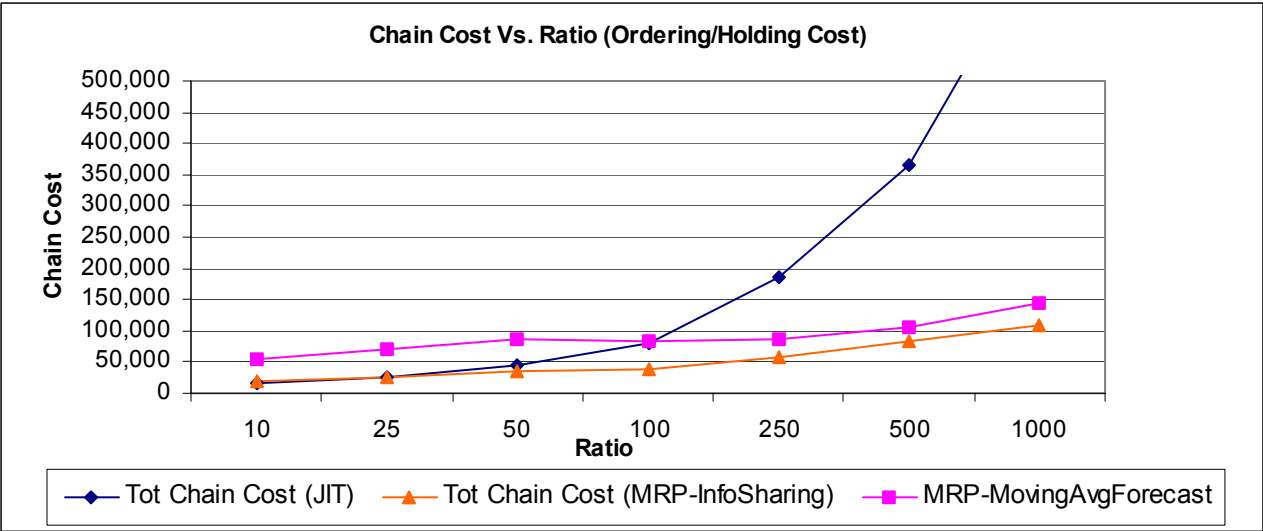
**Exhibit 4: The supply chain cost at annual demand of 7,280 units.**



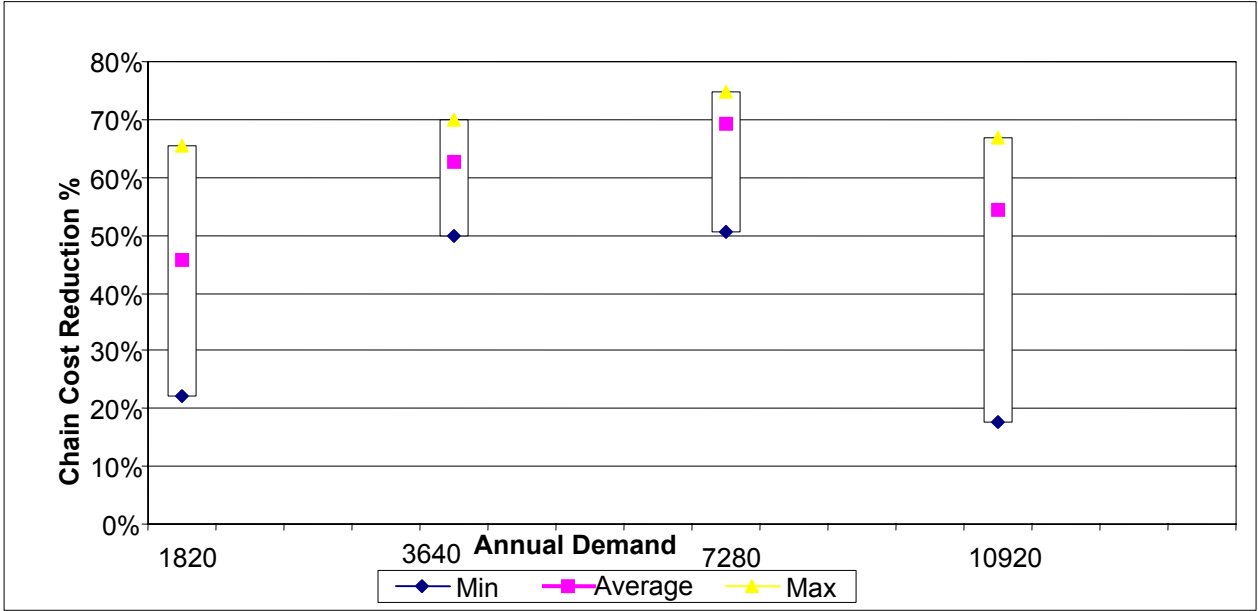
**Exhibit 5: Fitted curve of breakeven points at the different demand levels.**



**Exhibit 6: Analysis of Information Sharing at a stationary demand of 3640.**



**Exhibit 7: Analysis of Info-Sharing at a cyclical demand with average of 1,820 units.**



**Exhibit 8: Savings of Information-sharing over MRP with moving average forecast**