THE BENEFITS OF ACCURATE, AND TIMELY DATA IN LEAN PRODUCTION ENVIRONMENTS
RFID in Supply Chain Management

Vijay K. Vemuri
C.W. Post Campus, Long Island University, 720 Northern Blvd., Brookville, NY 11548, USA

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Abstract: The usefulness of information systems critically depends on the accuracy of the data contained within it. Errors in capturing data into the information systems are particularly vexing since these errors permeate the entire information system(s), affecting every aspect of information use. The direct and indirect consequences of unreliable data did not attract much attention as there were few alternatives to reduce them. Newer technologies, especially Radio Frequency Identification (RFID), are enabling virtual elimination of data entry errors in inventory management. We investigate the effect of accurate data on the performance of supply chains utilizing lean production systems. Our simulation results indicate that time to fulfil a purchase order (cycle time) is significantly reduced by improving the quality of the inventory data. The simulation model we developed will enable us to examine other performance characteristics of a supply chain. We will also investigate the sensitivity of supply chain performance due to changes in the parameters of the model.

1 INTRODUCTION

Advances in information technology have led us to expect the availability of accurate, reliable, and timely information at a reasonable cost. Indeed, synergies between microprocessor, fiber-optics, satellite, and related technologies have increased the promise of information systems further. However, data capture still remains the weakest link in the chain of information technology tasks needed to provide accurate and timely information. A 1980's study of data capture error rates by the U.S. Department of Defence (DoD) shows that in entering 30 million characters; 250,000 errors in handwritten, 100,000 errors in keyboard, 1,000 errors in OCR, and 10 errors in barcode entries were made (Taylor, 2004). Despite the astonishing advances in information technology since the DoD study, inaccurate data still remains an elusive problem. The level of data inaccuracies in patient health care and the resulting dire consequences are startling (up to 98,000 patients die in the U.S. die every year due to medical errors (Kohn, *et al,* 2000)). Medical data errors are a leading cause of these preventable errors. Information technology can offer solutions in reducing the data errors - for example, in one study, direct data entry by physicians reduced errors by 55 percent (Wendel, 2000).

Although not to the extent those patients do, businesses also bear the consequences of inaccurate data. Due to handling of their records by many functional areas within an organization, the high volume of items, large number of transactions and exchanges of information and goods with value chain partners, inventories are especially vulnerable to data errors. Kang and Gershwin (2005) report that for a large global retailer, for an average of 49% of its Stock Keeping Units (SKUs) its inventory records did not exactly match with the physical inventories. The error rate remains high at 24% if an error of ± 5 units is tolerated.

1.1 Causes and Effects of Inventory Inaccuracy

There are many causes of inventory inaccuracies. 1) Stock loss due to obsolete inventory and theft by employees, customers and others, 2) transaction errors, 3) inaccessible inventory, and 4) incorrect product identification are often cited as the most common causes of incorrect inventory records. In retail sector, customer, employee, and customer theft is a major source of stock loss accounting for about

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1.7% of sales (Dabney, *et al*, 2004). Although stock loss, and especially loss due to theft, varies among product categories and the types of business, the inventory inaccuracies due to the causes mentioned above remains high for most companies. Inventory inaccuracies may have ripple effects in the entire organization. Lee, *et al*, 2004, cite research estimating the indirect loss due to inventory shrinkage can be more than 30 times that of direct loss. What are the probable causes of these high indirect costs? Inventories are important assets that affect many decisions of an organization. Inventory levels form a basis for decisions pertaining to when to produce, how much to produce, where and how much to transport, and many other operating decisions. The inaccuracies in inventory records will propagate through out the organization setting-off a chain of suboptimal decisions. The situation cause by inventory errors can be much worse than "garbage in garbage out," contaminating the entire processes that connect inputs and outputs of a system. If not corrected, inventory inaccuracies can lead to incorrect shelf replenishment policies, stock outs, and loss of sales.

2 RFID

The consequences of inventory record inaccuracies extend beyond cost of reconciling inventory system counts and physical counts. Raman, *et al,* (2001) report that in two stores they studied, inventory inaccuracies reduced profits by 10% and 25%. Substantial inventory errors were present despite the use of modern information systems for inventory management.

Technology provides a solution to mitigate the problems due to inventory inaccuracies. RFID provides solutions to track and manage inventory items in the entire transformation process from raw materials to finished products. It enables wireless exchange between tagged items and a reader. Unlike barcodes, RFID tracking does not require line-of-sight, and accommodates greater distances between reader and the tag. The array of RFID applications within businesses include manufacturing, asset management, production tracking, inventory control and logistics. RFID enables improvements of internal efficiencies of many business processes. For example, the "group select" feature of RFID utilizes information contained in the RFID tags for locating containers with a particular product in a large shipment consisting of many different types of products..

2.1 RFID and Inventory Accuracy

RFID may not be able to eliminate all stock losses, but it can identify discrepancies in system and physical inventories and recalibrate these accounts much more efficiently than periodic inventory audits. By establishing connectivity with the products real-time inventory information can be obtained. The accuracy of the data extends beyond physical presence of the inventory item within the premises. By embedding expiration data of perishable products and other information in the RFID tags other causes of inventory inaccuracies such as obsolescence, damage, and expiry can be detected and inventory records can be updated in real-time. Incidence of data entry errors mentioned above are much less prevalent in RFID data entry. The DoD study reports that the use of transponders (RFID tags), on the average, results in one error in entering 30 million characters. The RFID technology has advanced since the DoD study and the error rates are expected to be even less – resulting in virtual elimination of inventory record inaccuracies.

3 RFID IN SUPPLY CHAIN MANAGEMENT

Due to their ability to preserve information in their tags across organizational boundaries, RFID can be useful in tracking and managing inventories over the entire supply chain. Retailers can achieve lower stockouts, cost savings and increased responsiveness. Distribution centres and warehouses can improve accuracy and reduce costs due to automated routing, and cross-docking. Manufacturers in the supply chain can also benefit from the RFID tags by using them in their receiving, shipping and inventory management. Suppliers can set the automated identification in motion by sending their shipments with tags. These tags can also be useful for suppliers in their own shipping operations and inventory management. That is, every echelon in the supply chain can achieve better planning, control, and coordination with automated identification. The RFID technology can nearly eliminate inventory record inaccuracies and improve visibility of inventory data across the entire supply chain. In addition sharing of information each member of the supply chain can get timely, accurate information at a low cost.

3.1 Prior Research

Two streams of prior research is relevant for this study. The first deals with inventory errors and their effect on inventory management. Iglehart and Morey (1972) consider the combined effect of inventory errors, safety stock and frequency of inventory counts, service levels and inventory costs. They derive the level of safety stock and frequency of inventory count to minimise total costs of holding and inventory count while maintaining a desired service level. The present paper and the others studies dealing with RFID in supply chains attempt to answer what happens in the limit if inventory errors tend to zero, or cost of inventory count tends to zero and frequency of inventory count tends to infinity. However, these are very difficult issues to tackle analytically and simulations are used to answer the above questions. Ganeshan, *et al*, 2001 deals with forecasting error (similar to inventory errors) on supply chain performance. Their simulation results confirm that forecasting errors have a significant impact on service levels and cycle time of a supply chain.

Three other recent papers have a direct connection to this study. All of them deal with inventory errors on the supply chain and how RFID technology by nearly eliminating inventory affects different supply chain performance measures. Kang and Gershwin, 2005 compare different methods to cope with inventory inaccuracies. They compare stockout percentage and average inventory using 1) additional safety stock, 2) manual inventory verification, 3) manual reset of the inventory count, 4) periodic write-down to reflect stock loss, and 5) automatic inventory identification. Not surprisingly, the last choice achieves the best trade-off between low stockout and low levels of inventory cost.

Lee, *et al*, 2004 study a supply chain consisting of a retailer, distribution centre, and a manufacturer. They mainly study the impact of inventory accuracy and inventory replenishment policies on inventory levels at each echelon. They find that inventory levels are more stable and lower with RFID inventory tracking.

Fleisch and Tellkamp, 2005 use simulations to study the impact of inventory inaccuracy on a retail supply chain. They disaggregate the sources of inventory inaccuracy into its component factors (theft, unsaleables, and misplaced item and incorrect deliveries) and study their impact on probability of out-of-stock and cost of inventory inaccuracies. Their results indicate that theft is the most important factor impacting supply chain performance and the level of unsaleable items do not affect supply chain performance significantly.

Two additional studies are also relevant for this research as they study the performance of supply chains with imperfect information. Chen, *et al*, 2000 study the effect of sharing of customer demand information at every stage of the supply chain and conclude that information sharing will mitigate the so called bullwhip effect (amplification of demand variability along the supply chain away from the customers). Their analytical model and simulation results show that sharing of customer demand forecasts reduces forecasting errors resulting in softening of bullwhip effect; however, reduced forecasting error will not completely eliminate the bullwhip effect.

Joshi, 2000 in his masters' thesis develops a comprehensive framework to improve visibility of information in supply chains by reducing the delays in information flows.

4 MOTIVATION AND RESEARCH QUESITONS

The recent surge in RFID implementations raises the questions regarding supply chain performance and RFID. Supply chains are complex dynamic systems with complex flows of products and information. With uncertainties at, and complex interactions between, various levels it is nearly impossible to analytically solve research questions. Simulation models facilitate tight control of research environment and ability to manipulate extraneous factors resulting in excellent internal validity. However, genralizability, or external validity of simulation studies are low. Most of the simulation studies reviewed above do not model "pull" production environments where customer demand sets the production process in motion. Lean production systems and just-in-time inventory management are characterized by "pull-type" production processes. Lee, *et al*, 2004 consider a production system operating under "push" system and the retailer using a "pull" system.

In this study will concentrate on "pull" system where the inventory movement is triggered by customer demand. In these systems stockout rate, service level or fill rate is not an appropriate performance measure since the customer generates an order and waits for the fulfilment of the order. Appropriate performance measure is these supply chains is the cycle time for inventory. The cycle time in the supply chain refers to the time it takes to fill an order.

The research question of interest in this study is: What is the effect of RFID deployment in a supply chain characterized by pull type production

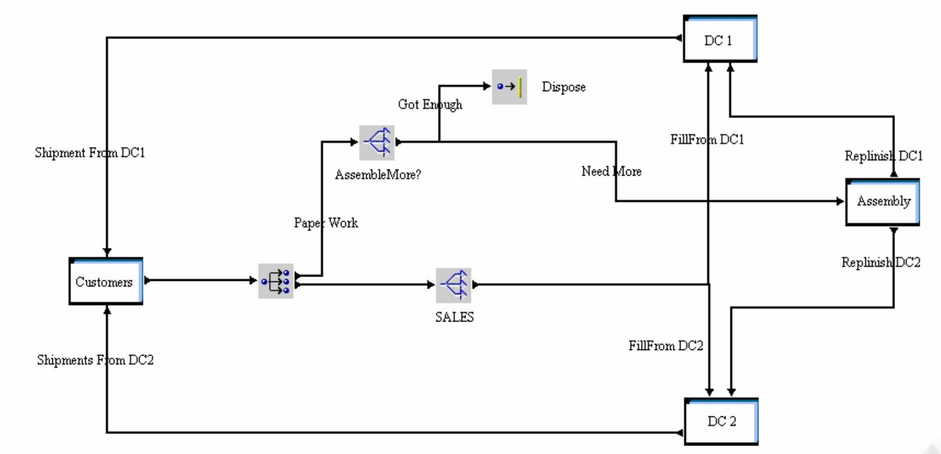

Figure 1: Top Level Supply Chain Model.

environments on the customer order cycle time? This question is relevant since the predominant trend is to implement pull type production environments with just-in-time inventory management. In these environments inventory errors are expected to be critical since level of inventories are kept to a minimum. A typical strategy of carrying extra safety stock to cope with inventory errors is contrary to the motives for implementing lean environments.

5 SIMULATION METHODOLOGY

The supply chain we model consists of two customers calling at random for varying amounts of goods. The marketing department receives the calls and sends the orders to nearest distribution centre (DC): DC1 for customer 1, and DC2 for customer 2. If enough units are not available at the closest DC, the sales order is sent to the other DC. Replenishment at the DCs are based on (s, S) policy, if the inventory level drops below s units, an order is sent to bring the inventory level to S units. The timing of a purchase order is triggered by incoming purchase orders. The products are manufactured in the Assembly department. Figure 1 shows overall flow of goods and information and the location of the decisions made. Each of the rectangles represents a business process within the supply chain and includes subprocesses. Due to space limitations, the details contained within these subprocesses are not shown, but implements the description of the supply chain above.

We used SimProcess 4.2 program to conduct the simulations. This modelling environment enabled us to easily construct hierarchical business processes, activity based costing for allocating overhead costs and optimisation routines to determine optimal strategies within the simulation environment.

Table 1 shows the model parameters and their distributions.

Table 1: Model Parameters.

	Customer 1	Customer 2
Order Generation	Normal (5, 1) Hours	Normal (2.5, 1) Hours
Order Size	Uniform (25, 100)	Uniform (50, 200)
	s	S
Replinishment at DC1	200	500
Reprinishment at DC2	500	2,000
	Distance to DC1	Distance to DC2
Production Time	1 minute per unit	

In order to answer the research question, simulations are run under two different assumptions. Under the first assumption, inventory shrinkage takes place but the RFID system will detect the shrinkage immediately and the inventory replenishment decisions are made based on the correct level of inventory in stock. This scenario is compared with cycle times attained when the system is not aware of the inventory loss.

Many use Retail Security Survey (Dabney, *et al*, 2004) estimate of 1.7% of gross annual sales as the annual loss due to inventory shrinkage. However, mistakenly, they apply this percentage to inventory levels (Lee *et al*, 2004, and Fleisch and Tellkamp, 2005). Based on average turnover ratio of about 5 and gross profit ratio of 70%, inventory shrinkage is closer to 12% of inventory levels. Inventory shrinkage cannot go undetected forever. We assume that once every quarter (at the time of preparation of quarterly financial statements) the shrinkage will be detected and the information system is corrected to reflect actual count. Many use quarterly reset of the system inventory for the detection of inventory shrinkage. We simplify this situation by running simulation for a quarter at a time. To mitigate the effect of initial conditions, and to obtain steady state results, we use a warmup period of 10 days (run length is 120 days). To obtain robust results we repeated the simulation for 25 quarters.

6 RESULTS

Table 2 compares cycle times with incorrect inventory records and perfect inventory counts obtained by deploying RFID technologies.

Table 2: Comparison of Supply Chain Performance.

	Accurate Inventories	**Inaccurate Inventories**
Mean	2.002 Hours	2.646 Hours
Standard Deviation	1.125 Hours	1.165 Hours
Sample Size	25	25

Hypothesis test resulted in a t-value of 1.988 and a p-value of .026. Based on these statistics we conclude that accurate inventories result in lower cycle time and faster fulfilment of purchase orders. The analysis of the simulation results is not yet completed. Sensitivity of cycle times to manufacturing times, capacities and other important parameters are being established. Other important supply chain performance criteria are being examined. The framework and the model we have established so far will enable us to extend the analysis of supply chain performance measures with accurate inventory counts now possible with RFID tags.

7 CONCLUSIONS

Our research addresses important issues related to the role of RFID in supply chain management. Accurate inventory data is especially important in lean manufacturing environments as large inventory buffers and excess safety stock are not available to forgive inventory inaccuracies. Our simulation model consisting of a pull production environment concludes that the cycle time (time it takes to fill a purchase order) is reduced by accurate inventory counts. The performance of a supply chains using alternative performance criteria and the sensitivity of performance to parameters of the production environment are currently developed.

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