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Innovating Continuous Review Policies with RFID to Minimize Obsolete Inventory

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Abstract

Inventory inaccuracy is a critical issue faced by many companies. Automated Identification Technologies (AITs) such as Radio Frequency Identification (RFID) can be utilized to alleviate the occurrence of situations such as obsolete pharmaceuticals in hospitals. RFID has been used to aid inventory management systems by providing real time availability of the item information including location and status. The benefit of RFID over barcodes is immense as it allows users to employ continuous review models while barcodes are only capable of being used in conjunction with periodic review models. Although RFID has the ability to improve inventory control policies, one must note that it is not 100 percent accurate. Factors such as metal or poor orientation can limit the readability of the tag; thus, the reliability of tag reads must be taken into account to provide more accurate inventory policies. We seek to demonstrate that although optimizing inventory policies with technologies such as RFID can improve inventory control, policies need to involve reliability information to result in an optimal policy. The goal of this paper is to develop an inventory policy based on continuous review policies that accounts for the reliability of RFID in order to minimize obsolete inventory.

Keywords
Operations research, RFID, inventory management

1. Introduction
In the information age, technological advancements such as computers have allowed users to process, analyze, and display information regarding daily processes. Entering information with regard to these processes requires manual data entry which has proven to be cumbersome, expensive, and error-prone. To minimize the errors of manual data entry, Automated Identification technologies (AITs) can be implemented within a system that deals with the movement of goods or people. Several AITs have been developed to transform the data entry issues. Applications of these AITs include product identification within consumer goods industries, Global Positioning Systems (GPS) which identifies the location of a product, and swipe cards which allow access to areas. The availability of such systems has revolutionized decision support and control systems.

The cornerstone of all inventory control systems is the capturing of data; inventory control systems are dependent on the availability of accurate and timely data from suppliers and service providers regarding the location of the shipments and the inventory levels. Data capture is the point at which AITs can add essential value to supply chain operations. Although they are not 100% reliable, AITs can improve the data capture process, and ensure that variability within the system is captured earlier as well as in a more accurate manner that allows for a more complete representation of the actual system to where shipments are, what the current inventory level is, and where is it located. This newfound accuracy allows for top management to recognize a problem more quickly; thus, these technologies allow for a more accurate assessment of the problem and addressing the problem in a more expedient manner. Earlier detection of problems allows for more options for corrective responses.

Currently, most hospitals track inventory using barcodes. The level of extra stock that is maintained in hospitals to alleviate risk of stockouts due to uncertainties in supply and demand is critical; thus, it is necessary to minimize ordering and find the optimal levels of safety stock. If too much stock such as pharmaceuticals is kept in the hospital, the administration runs the risk of carrying expired pharmaceuticals. In 2008, USA Today reported that health facilities get rid of an estimated 250 million pounds of drugs per year because they are expired [1]; thus, the monitoring of these levels is critical to the expenses of hospitals. Oftentimes, hospitals look to technology such as RFID to monitor their inventory levels, but they must also consider the reliability of RFID when constructing new inventory policies. The purpose of this paper is to investigate RFID uncertainty in conjunction with inventory control theory in order to create a more optimal (Q,R) policy which can be utilized by several healthcare organizations. Inventory control theory investigation includes traditional continuous review models.

1.1 How RFID Works

RFID systems consist of three main components: readers, antennas, and tags. The antenna emits radio signals that the tags respond to with their own unique code. The reader then receives and decodes the tag information and sends it to a computer through standard interfaces. There are three types of RFID tags: active, passive, and semi-passive [2]. Active tags are battery powered which allows for longer read ranges and a greater memory capacity. One disadvantage of active tags is that they are typically more expensive than their counterparts [3]. Passive tags have no battery and are much less expensive than active tags, but their read ranges are significantly lower than their counterparts [3]. Semi-passive tags are similar to active tags in that they have long read ranges and they are more expensive than passive tags. These tags utilize a battery to run the chip's circuitry but draw power from the reader in order to communicate. RFID operates on several frequencies: low-frequency (125 KHz), high-frequency (13.56 MHz), ultra-high-frequency (UHF) (860-960 MHz), and microwave (2.45 GHz). The frequency bands and applications can be summarized in Table 1 [4].

Table 1: Frequency Bands and Applications [4]

Frequency Band	**Characteristics**	**Typical Applications**
Low 100-500 kHz	Short to medium read range Inexpensive Low reading speed	Access control Animal identification Inventory control Car immobilizer
Intermediate 10-15 MHz	Short to medium read range Potentially inexpensive Medium reading speed	Access control Smart cards Library control
High 850-950 MHz 2.4-5.8 GHz	Long read range High reading speed Line of sight required Expensive	Railway vehicle monitoring Toll collection systems Pallet & container tracking Vehicle tracking

1.2 RFID vs. Barcode

There are two main AITs that are being used for inventory control: barcode and RFID. Barcode technology until recently has been the main AIT in managing inventory. As the price of RFID has decreased and general acceptance of RFID has increased, the use of RFID has slowly replaced barcode technology. There are many benefits of using RFID over barcodesl. Table 2 details some advantages of using RFID versus using barcode technology [5].

Table 2: RFID versus Barcode Technology [5]

RFID tags can be read or updated without line of sight	Barcodes require line of sight to be read
Multiple RFID tags can be read simultaneously	Barcodes can only be read individually
RFID tags are able to cope with harsh and dirty environments	Barcodes cannot be read if they become dirty or damaged
RFID tags are ultra thins, and they can be read even when concealed within an item	Barcodes must be visible to be logged
RFID tags can identify a specific item	Barcodes can only identify the type of item
Electronic information can be over-written repeatable on RFID tags	Barcodes information cannot be updated
RFID tags can be automatically tracked eliminating	Barcodes must be manually tracked for item

human error	identification, make human error an issue
RFID allows for real-time information	Barcodes must be manually scanned to obtain information

1.3 RFID Readability

Although tag reliability has improved immensely since early adopters, RFID tag manufacturers continue to produce tags that are not 100% reliable [6]. In early RFID pilots, failure rates were as high as 20% to 30% [6]. Poor performing tags can be caused by many factors, including what materials are adjacent to each tag and environmental conditions such as temperature and humidity [6].

One challenge found within the design of RFID tags is that tags are not resilient to all types of materials [3]. Metal has long been an issue for the readability of RFID tags. Radio frequency waves are unable to penetrate metal; instead, metal reflects these waves, which makes it difficult to read the tags placed on metal surfaces. Research has shown that when RFID tags are directly attached to a metal surface, they are often undetected [7]. Most liquids absorb radio frequency waves which again reduces the read range. Highly dielectric materials (liquids) and conductors (metal), even in small amounts, can drastically change the properties of a tag antenna, reducing efficiency, and shortening the read distance, sometimes to the point of becoming completely unreadable at any distance [8].

Recent research in the field of RFID reliability has pointed out weaknesses with achieving 100% read rates. Lack of 100% reliability is mainly attributed to the fact that radio frequency operates differently depending on the environment. The effect of various materials on read rates was highlighted in several recent studies and is summarized in the Table 3 below [8]:

Table 3: Effects of Different Materials on RF Field

Material	Effect on RF field
• Cardboard	Absorption (moisture), detuning (dielectric)
• Conductive liquids	Absorption
• Plastics	Detuning (dielectric)
• Metals	Reflection
• Groups of cans	Complex effects (lenses, filters), reflection
• Human body/animals	Absorption, detuning (dielectric), reflection

In the research, RFID tags were used to analyze specific variables that may affect the read accuracy of multiple tags on a pallet when driving a pallet through an RFID portal. The best read rate (100%) was achieved for paper towels; this is because of the papers' transparency to radio frequency signals [8]. Carbonated beverages in aluminum cans had the greatest difficulty in readability; they achieved a read rate of approximately 25% [9] [10]. Rice – filled jars had a higher read rate. Using secondary packaging like trays, allows for the presence of air gaps between RFID tags and primary packages; these gaps allow RFID readers to get more effective reads and also reduces interferences and reflectance by water and metal [9].

1.4 Inventory Control Policies and RFID

Information regarding the status of supply chain systems has become increasingly important. The reliability of this data has a profound impact on supply chain management. Liu, So, and Zhang developed a modeling framework to quantify the value of improving supply reliability [11]. Their findings showed that as supply reliability becomes higher, the firm has the ability to earn a higher profit [11]. RFID added to the supply chain adds another level to inventory management. Gaukler analyzed the item-level RFID in the retail supply chain and developed a model that captures the most important benefits of RFID at the retailer [12]. With his model, he showed that sharing costs of RFID does not hinder the supplier or retailer [12]. Wong and McFarlane describe possible benefits of using RFID data capture in the improvement of shelf replenishment [13]. They concluded that current shelf replenishment policies would improve with the introduction of RFID because it allows for accurate information to be available immediately. Other models incorporate RFID, but all fail to address the issue of the reliability of RFID. Below is a summary of inventory models that have been developed incorporating RFID. As seen in Table 4, no models have been created based on the reliability of RFID.

Table 4: Inventory Models with RFID

Model Type	**Description**	**Inclusion of RFID Reliability Factor**
Shelf Replenishment [13]	Improved information data capture allows for better shelf-replenishment	No
Item-Level [12]	RFID improves supplier and retailer relationship at no added cost to either	No
Emergent Reorder [14]	Use of RFID allows for an emergent order policy	No

2. Methodology

Developing a model that includes the reliability of RFID requires several steps. To begin with, the theoretical model was developed by evaluating different known inventory control theories. To validate the theoretical model, an empirical model will be developed with known pharmaceutical data using barcodes. Finally, two comparisons will be made: a comparison of the current pharmaceutical model, the continuous review model, and the continuous review model with reliability based on total cost and a comparison of reorder points of the continuous review model with reliability based on measured and actual inventory.

When developing the theoretical model, several models were considered, but two models in particular aided in the design on the proposed model. As stated before, models are classified as periodic or continuous. Utilization of RFID allows for the use of continuous review models because RFID can monitor inventory levels continuously. The demand was the second parameter to consider when developing the model. Demand can either be certain or uncertain. Since we are dealing with a real word situation and most times demand is uncertain, we decided the model should take into account uncertain demand. There are two main models that deal with uncertain demand: (Q, R), (s, S), and the News Vendor Model. The two models have several assumptions. The (s, S) model does not allow reordering to occur when the inventory level is exactly at R. The (Q, R) model with shortages allowed was the best model because the assumptions were most like the real world issues faced by inventory managers. Figure 1 shows the algorithm of developing the model.

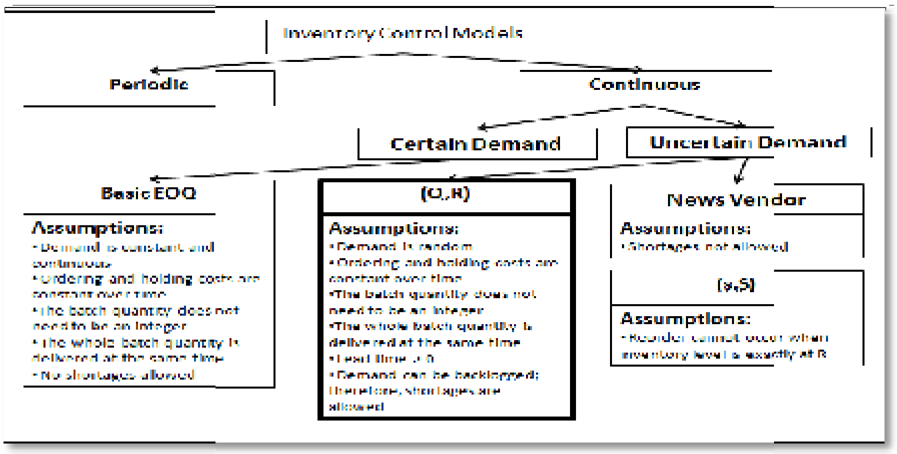


Figure 1: Algorithm of Model Development

The notations used throughout the paper are summarized below.

- Q = quantity
- R = reorder point
- H = holding cost
- K = ordering cost
- c_B = shortage cost

- P = purchase cost
- L = lead time
- D = demand
- E[D] = expected demand
- E[B_r] = expected shortage at reorder point r
- E[X] = expected demand during lead time

2.1 (Q, R) Policy with Shortages

By utilizing a (Q, R) policy, we can continually track the inventory level, and place an order of size Q at any point over the time horizon when the on-hand inventory is at or below R. When shortages are allowed, we can utilize a model that includes shortage costs. The first assumption is that the inventory policy follows a continuous review model. The second assumption is that demand, *D*, is stochastic and is random continuous variable of annual demand (E[*D*], σ_d). The on-hand inventory at time *t* is represented by O(*t*). The third assumption is that $I_A(t)$ the actual inventory at time *t* follows a uniform distribution. We can assume uniformity because the demand at t is constant.

A total cost of the model is represented as

TC(Q,R) = expected values of (holding cost + shortage cost + order cost).

The new (Q, R) policy requires the calculation of each value and the inclusion of the reliability factor. To calculate the cost attributed to holding inventory, one must determine the average inventory on hand O(*t*). The $I_A(t)$ is approximately equal to O(*t*) since determining the optimal reorder point and order quantity minimizes the average number of back orders relative to the average inventory on hand [15]. Since $I_A(t)$ follows a uniform distribution, the steps for finding expected value (Equation (3)) can be seen in Equation (1) and Equation (2).

$$E[I_A(t)] = \frac{[\;(\;) \qquad (\;)\;]}{} \tag{1}$$

$$E[I_A(t)] = \frac{[(\quad [\;] \quad) \; (\quad [\;]]}{} \tag{2}$$

$$E[I_A(t)] = \quad - \quad [\;] + \quad /2 \tag{3}$$

Substituting the equation of (*R-E[X]+Q*) is allowed because the initial inventory level is at or below *R,* and we have ordered *Q* units demonstrating that the initial inventory is at *R* + *Q*. We also must account for the demand so we subtract E[*X*] [15]. We account for this value because the lead time *L* is greater than 0, so we have a positive demand value arriving between the time we place an order and the time we actually receive the order [15].

Finally the holding cost can be calculated by multiplying *H* by E[$I_A(t)$] to arrive to Equation (4).

$$\text{Expected holding cost} = H^*(\quad - \quad [\;] + -) \tag{4}$$

The expected annual shortage cost is equal to the expected shortage cost per cycle times the expected number of cycles per year [15]. See Equation (5).

$$\text{Expected shortage cost} = c_B E[B_r]^* \frac{[\;]}{} \tag{5}$$

The notation c_B in Equation (5) is the cost incurred for each unit short.

Finally the expected annual order cost is seen in Equation (6).

$$\text{Expected order cost} = K(E[D]/Q) \tag{6}$$

Combining all the costs, we can get the total cost as seen in Equation (7).

$$TC(Q, R) = H^* (\quad - \quad [\;] + -) + c_B E[B_r]^* \frac{[\;]}{} + K(E[D]/Q) \tag{7}$$

This cost must be minimized to find the optimal Q and R values. To do this, we must take the derivative with respect to *Q* and the derivative with respect to *R* and set both equations equal to 0 as seen in Equation (8).

$$\frac{(\;,\;)}{} = \frac{(\;,\;)}{} = 0 \tag{8}$$

The derivative with respect to *Q* is difficult to calculate because the E[B_r] is challenging to determine. Winston states that in most cases this value is so small that we can assume the optimal quantity *Q*, *Q**, is the same as Equation (9) [15].

$$Q^* \approx \sqrt{\frac{\quad [\;]}{}} \tag{9}$$

Determining the optimal value of *R* is a little more difficult. Marginal analysis can be used to determine the reorder point [15]. If we assume a given value of *Q*, the expected annual ordering cost is independent of *R*; therefore, by determining a value of *R* that minimizes the total cost, we can concentrate on minimizing the sum of the expected annual holding and shortage costs. Suppose we increase the reorder point from R to $R + \Delta$, the expected annual holding cost will increase marginally as seen in Equation (10).

$$H^* \quad + \Delta - \quad [\ ] + - \ - H^*(\quad - \quad [\ ] + -) = H\Delta \tag{10}$$

If we increase the reorder point by a small amount, the expected annual stockout costs will be reduced [15]. Since the lead time demand is at least R during any cycle, the number of stockouts during the cycle will be reduced by Δ units. Increasing the reorder point results in the reduction of stockout costs by c_B during a fraction P(X >= R) of all cycles [15]. Since there are an average of E[D]/Q cycles per year, increasing the reorder point from R to $R + \Delta$ will reduce the expected annual stockout cost by Equation (11).

$$\frac{\Delta \ [\ ] \quad (\quad)}{} \tag{11}$$

The optimal R is the value of R which marginal benefit equals marginal cost as seen in Equation (12).

$$\frac{\Delta \ [\ ] \quad (\quad)}{} = H\Delta \tag{12}$$

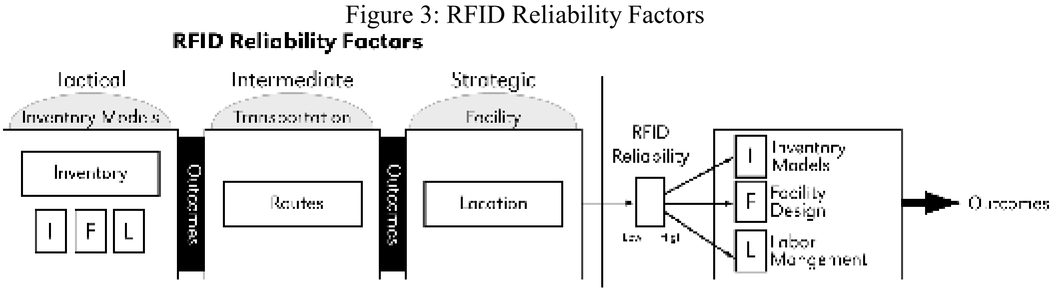
The final equation is seen in Equation (13).

$$P(X >= R) = \frac{}{[\ ]} \tag{13}$$

2.2 Proposed Model with Reliability

Introducing RFID technology into the inventory management system, adds a level of uncertainty to the previous model and a model to be used by hospitals must take into account this uncertainty when creating an inventory policy. Figure 3 depicts the effect reliability has on inventory control.

Figure 3: RFID Reliability Factors



The introduction of a reliability constant within a common (Q, R) model may lead to a more accurate inventory policy in comparison to a simple EOQ model or a common (Q, R) model. Using the reliability information from previous research, we can build upon current (Q, R) policies. This research introduces the influence of RFID technology and its associated reliability factor into the cost function, and evaluates its impact on inventory levels. In order to take into the account the reliability of RFID technology, new values for the (Q, R) policy must be determined based on the accuracy of the inventory measured. Reliability of RFID does not only affect reorder points, the optimal quantity, but it also affects the total cost and levels of safety stock. By utilizing a (Q, R) policy, we can continually track the inventory level, and place an order of size Q at any point over the time horizon when the on-hand inventory is at or below R. By acknowledging the fact that the measured inventory may not be an actual depiction of the true levels, a policy can be adapted that reduces the total cost. Developing a new model requires assumptions that must be met for the model to work successfully. The first assumption is that the policy is a continuous review policy. The introduction of RFID allows for a real time view of the inventory levels that can be monitored continuously throughout the time horizon. The second assumption is that demand D is stochastic and is random continuous variable of annual demand (E[D], σ_d). The on-hand inventory at time t is represented by O(t). The third assumption is that $I_A(t)$ the actual inventory at time t follows a uniform distribution. We can assume uniformity because the demand at t is constant.

Since $I_M(t)$ represents the measured inventory, these values must be adjusted to account for the reliability of the RFID tags. A tag can either be read or not read, where reading a tag can be seen as a success while not reading a tag can be seen as a failure. Given that Y is a random variable of the number of tags read, we know that Y follows a binomial distribution where n equals the number of tags and p equals the probability that a tag will be read; thus, the expected value of inventory read at t is p*I(t). Let us assume that p is equal to α where $0 \leq \alpha \leq 1$. The measured inventory value is $\alpha * I_A(t)$ where $I_A(t)$ is the actual inventory level at t. To convert to the measured value to the actual inventory level, you must divide by α; therefore the relationship seen in Equation (14) holds

$$I_A(t) = I_M(t)/\propto \tag{14}$$

Using this relationship, we can substitute and get Equation (15).

$$E[I_A(t)] = \frac{[\quad (\,) \qquad /\propto \quad (\,) \qquad /\propto]}{} \tag{15}$$

Since α is a constant, we can pull the value out of Equation (15) to get Equation (16)

$$E[I_A(t)] = \frac{[\quad (\,) \qquad (\,) \qquad]}{\propto} \tag{16}$$

Then, we can further simplify to get Equation (17).

$$E[I_A(t)] = \frac{[(\quad [\,] \quad) \;(\quad [\,]]}{\propto} \tag{17}$$

Further simplification yields Equation (18).

$$E[I_A(t)] = \frac{[(\quad [\,] \quad /\,)]}{\propto} \tag{18}$$

Finally the holding cost can be found by calculated by multiplying *H* and $E[I_A(t)]$ as see in Equation (19).

$$\text{Expected holding cost} = H*\frac{[(\quad [\,] \quad /\,)]}{\propto} \tag{19}$$

Combining all the costs, we can get the total cost as seen in Equation (20).

$$TC(Q,R) = H*\frac{[(\quad [\,] \quad /\,)]}{\propto} + c_B E[B_r]*\frac{[\,]}{} + K(E[D]/Q) \tag{20}$$

Following similar steps as before, we find that Equation (21) shows the optimal quantity.

$$Q^* \approx \sqrt{\frac{}{\propto \quad [\,]}} \tag{21}$$

Determining the optimal value of *R* is done in a similar manner as before, we get Equation (22)

$$H/\propto* \quad + \Delta - \quad [\,] + - \; - H/\propto*(\quad - \quad [\,] + -) = H\Delta/\propto \tag{22}$$

In a similar fashion as before, the optimal *R* is known to be the value of *R* when marginal benefit equals marginal cost as seen in Equation (23).

$$\frac{\Delta \;[\,] \quad (\quad)}{} = H\Delta/\propto \tag{23}$$

The final equation is seen in Equation (24).

$$P(X >= R) = \frac{}{\propto \;[\,]} \tag{25}$$

3. Conclusions

AITs have shown their value when introduced in supply chains by increasing visibility. RFID, one such AIT, boasts real-time location and status of items unlike barcodes which do not have those abilities. By adding RFID, more accurate inventory policies can be created. Unfortunately, RFID has disadvantages. Its lack of 100 percent reliability leads to inaccurate measures of inventory levels. By creating an inventory model that accounts for that inaccuracy, hospital costs can be reduced by eliminating the money wasted on expired drugs.

Organizations are often faced with the challenge of implementing an inventory management system that accurately and efficiently manages their inventory. Without proper knowledge of inventory control techniques and deployment of automated technologies, these management systems would not give organizations the benefit of reducing their costs and accurately monitoring their inventory. There is a demonstrated need to develop an inventory policy that accounts for the reliability of RFID for high-cost organizations because inaccurate inventory management can lead to dire consequences.

A gap exists in the literature when accounting for the reliability of RFID in inventory control policies. Although many proponents of RFID gloss over the reliability of RFID, researcher must aknowledge that RFID is not 100% reliable; this is not to say that using RFID causes large scale inaccuracies, but like all systems, there is room for error. The proposed model presented in this paper seeks to address these gaps by presenting a model that considers the reliability of RFID and optimizes order quantity and reorder point based on likely inventory values. The model addresses the uncertainty of RFID read rates faced by organizations that implement RFID within their inventory management systems.

References

1. Donn, J, Mendoza, M. & Justin P. "Health facilities flush estimated 250M pounds of drugs a year." *USA Today*. 14 September 2008.

2. Angeles, R. (2005). RFID Technologies: Supply-Chain Applications and Implementation Issues. *Information Systems Management, 22(1),* 51-65.
3. Want, R. (2006). An introduction to RFID technology. *IEEE Pervasive Computing, 5(1),* 25-33.
4. Roberts, C.M. (2006) Radio frequency identification (RFID). *Computers and Security*, 25(1):18-26.
5. Juban, R. L. and Wyld, D.C. (2004) Would you like chips with that?: a consumer perspectives of RFID. *Management Research News*, *26(11/12)*, 29-44.
6. Shutzberg, Larry. (2004). Analyzing RFID's Reliability and Stability Limitations. *InformationWeek*.
7. Floerkemeier, C., & Lampe, M. (2004). Issues with rfid usage in ubiquitous computing applications. *IEEE Pervasive Computing*, *3(1)*, 188-193.
8. Singh, E., Vorst, K., & Tripp, K. (2009). Rfid tag readability issues with palletized loads of consumer goods. *Packaging Technology Science*, *22*, 431-441.
9. Singh, S.P., McCarney, M., Singh, J., & Clarke, R. (2008). Rfid research and testing for packages of apparel, consumer goods and fresh produce in the retail distribution environment. *Packaging Technology Science*, *21*, 91-102.
10. Singh, J., Holtz, R., Singh, S.P., & Saha, K. (2008). Effect of unitization and product types on readability of tagged packages of consumer goods. *Journal of Applied Packaging Research*, *2*(3).
11. Liu, Shaoxuan, Kut C. So, Fuqiang Zhang. 2009. The e®ect of supply reliability in a retail setting with joint marketing and inventory decisions (forthcoming). *Manufacturing & Service Operations Management*.
12. Gaukler, G., Seifert R., W.H. Hausman 2007. Item level RFID in the retail supply chain. Production and Operations Management 16. 65-76
13. Wong, C.Y. and D. McFarlane, (2005). RFID Data Capture and its Impact on Shelf Replenishment, AutoID Labs Whitepaper.
14. Gaukler, G., Ozer, O and Hausman W.H. 2004. Order progress information: Improved dynamic ordering policies to appear in Production and Operations Management.
15. Winston, W. L. (2004). *Introduction to probability models: operations research*. Duxbury Pr.