Economic Order Quantity Modeling using Automatic Identification Technologies

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Abstract— Automatic identification technologies (AIT) such as barcodes and radio frequency identification (RFID) are commonly used in inventory management. However, these AITs have operational limitations due to their system reliability with respect to the transponder or tag readability. This research introduces a model for a system reliability approach that evaluates the impact of AIT system on economic order quantities (EOQ). We introduce the model with deterministic demand and then we introduce a real-world application that demonstrates the model's usage for NASA's International Space Station (ISS). The information for the described scenario is derived from research funded by NASA EPSCOR. Results indicate that AIT, specifically RFID, system reliability have a significant impact on the cost for sending, storing, and consuming inventory on ISS operations and other weight driven and expensive operations. The model presented lays inroads for the use of AIT systems for better improving inventory control models.

Keywords— RFID, Inventory control, EOQ, RFID Reliability

1. Introduction

The challenges associated with managing inventory, determining inventory policies, and maintaining systems that provide the economically optimal amount of inventory is a complex problem faced by many organizations throughout the supply chain. Management fully recognizes the strategic importance of evaluating all costs related to inventory. The challenge of most inventory management systems is to capture timely information on the inventory amounts and maintain the timely location and status of the inventory. Automatic identification technologies such as the barcodes and radio frequency identifications (RFID) have been used to capture inventory data for these types of systems, allowing for reduced variability in expected inventory amounts, expected location, and expected inventory statuses. These in turn allowed operations to reduce excess ordering costs for lost inventory reduce labor cost with reduction in worker's searching for inventory, and allowed management to make strategic supply decisions because of confidence in the inventory levels that reduced the bullwhip effect. A strategic framework for automatic identification technologies particularly for RFID is detailed in Jones and Chung [12].

"One of the most popular automatic identification technologies, RFID has generated substantial interest on the part of industry primarily due to two mandates – one from the private sector (Wal-Mart) and another from the public sector (DoD) – detailed in publications such as Infoweek, and Computerworld [32]. Many manufacturers have adopted the technologies (especially RFID) more because of mandate than choice. As a result, many companies use the two technologies for simple functions such as product tagging and tracing, providing distribution visibility to customers (e.g., allowing customer track a shipment as it moves through the supply chain). Manufacturers have not yet determined how to benefit from advanced RFID applications. The real-time information provided by RFID systems can be effectively used to design and operate logistical systems on a real-time basis in direct response to constantly changing information. The impacts of RFID are demonstrated by the RFID Logistics Application Framework which comprises of three levels decision systems including the

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Strategic, Intermediary, and Tactical decision support systems [12].

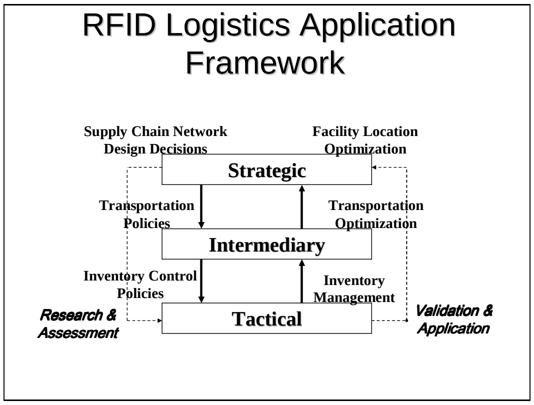

Figure 1 RFID Logistics Framework [12]

At the tactical level, real-time data provided by RFID systems are used to develop revised on-demand solutions. The increased use of RFID in the logistics chain will mean on-demand availability of the most current information and will have a major impact on dynamic inventory replenishment for manufacturing and warehousing operations. It is clear a logistical system, like any other system, is subject to external and internal disturbances. Internal disturbance is caused by delays or breakdown in company managed transportation infrastructure (e.g., truck unavailability due to repair; operator availability; company managed warehouse rendered in-operational due to hardware failures; and software glitches). External disturbance is caused by factors beyond the control of an organization (e.g., disruptions due to catastrophic events such as hurricane, major snowstorm, tornado, or earthquake; significant disruptions in fuel supply; price increases; and unusual congestion in a network link). An example is the increase in gas prices due to oil inventory reduction caused by pipeline damage during Hurricane Katrina.

Inventory costs in the supply chain can be greatly affected by a lack of supply chain coordination, commonly referred to as the bull-whip effect. Different operations may seek to minimize their cost, or maximize their profit, and pass on inefficiencies to the next operation. For example, in the Logistics framework a warehouse manager making a tactical-level decision may seek to minimize receiving labor and create a large queue of inbound trailers (an intermediate-level decision) to wait for unloading. Also, a transportation manager (intermediate) may set trailer load plans that require each trailer to occupy a facility dock door, inevitably creating the need for a larger facility (strategic-level decision). The bull-whip effect on inventory is demonstrated by excess inventory in warehouses (tactical) due to lack of confidence in forecasts given by corporate sales (strategic). RFID technologies provide an opportunity to reduce the uncertainty leading to the bull-whip effect through more real-time information. Given the costs of holding excess inventory in capital, obsolescence (or spoilage), handling costs, occupancy costs, pilferage, damage, taxes, and insurance, it may be worthwhile to use real-time information in evaluating inventory reduction."

2. Literature Review

2.1 Real-time Replenishment Using RFID

Inventory modeling is complex; thus, the work proposed in this application is focused on the components impacted by the continuous availability of information. Research suggests transactional errors lead to variability in planning and inflate the need for safety stock. Iglehart and Morey [10] provided the foundational modeling approach that addressed inventory inaccuracy due to transactional errors. Their goal was to reduce transactional error with predefined stocking policies and buffer stock. It was inferred that RFID's primary benefit is the reduction of transactional errors. The transaction error included excess inventory due to miscounting of inventory and using buffer stock to meet service for these errors.

The drawbacks in the model are that it buffers stock and time intervals, effectively creating two buffers [18]. Kök and Shang introduced an inventory replenishment problem with an inventory audit policy that adjusted for transactional errors [1]. Similar to Iglehart and Morey, Kök and Shang buffered order time and inventory over interval times [10], [1]. Kang and Gershwin introduced a simulation study that uses available inventory levels and considered errors related to shrinkage [16]. Their continuous review (Q, R) system was approximated with a periodic-review system. Fleisch and Telkamp introduced multiple sources of inventory inaccuracies that included theft, loss, and incorrect deliveries [5]. These ideas were expanded by Atali, Lee, and Ozer using an analytical model that considers three sources of discrepancies (shrinkage, misplacement, and transactional errors) jointly [38]. Lee and Ozer expanded their model to include the effects of RFID on those three areas

[38]. The previous assumptions of RFID improvements in shrinkage, misplacement, and transactional errors were limited to the assumption of a fixed infrastructure of antennas and readers operational environment, and lacked the ability to a real-world operation with baseline data. Other researchers such Gauzkler utilize similar continuous review application models to determine inventory levels in a real-time manner [11].

Many researchers have evaluated the classical EOQ models accounting for imperfect production process, quantity discounts with transportation, imperfect quality and inspection error [2], [23]. Lee and Lee present a Supply Chain RFID Investment Evaluation Model for understanding RFID value creation, measurement, and maximization of the technology [11]. This research is similar to the study by Lee and Lee to address the reliability of automatic identification technologies in inventory modeling [11].

2.2 Reliability of RFID

The limitation of using RFID technology in inventory management is the tag readability; even though the technology has improved immensely since early adopters, RFID tag manufacturers continue to produce tags that are not 100% reliable [26]. In early RFID pilots, failure rates were as high as 20% to 30% [26]. Poor performing tags differ depending on many factors, including the type of materials are adjacent to each tag and environmental conditions such as temperature and humidity [26].

One challenge found within the design of RFID tags is that tags are not resilient to all types of materials [34]. Metal has long been an issue for the readability of RFID tags. RF waves are unable to penetrate metal; instead, get reflected by it, 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 [6]. Most liquids absorb RF 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 irrespective of the distance [27].

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 [27] - [13].

Jones and Silveray demonstrated that test type, distance, number and placement of antennas, and movement of items impacted tag readability on NASA items tagged with RFID [13]. They evaluated the item-level tag readability when stowed in cargo transfer bags (CTB) and cardboard boxes. Additionally, they reported that only 84% of the tags were read when the CTBs were held in static position and 92% of the tags were read with movement and concluded that 100% read rates are unlikely with RFID systems. The reliability of RFID system is critical to decision making within the RFID Logistics Application Framework [12].

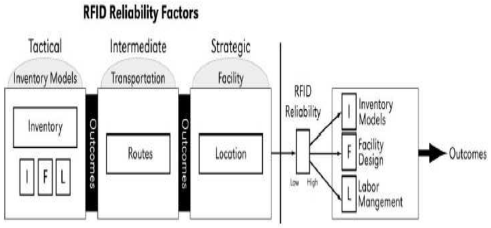

Figure 2 RFID Reliability Factors [12]

This research investigates the influence of RFID reliability factors on inventory models at a tactical level.

3. Research Methodology

From the previous research and specifically the aforementioned RFID Reliability factors model we seek to address the tactical inventory control components with this research. We specifically will use the gap in accounting for system reliability of automatic identification technologies to determine inventory policy. In this article, the fundamental research question *"What is the impact of automatic identification system reliability on the economic order quantity?"* is investigated. Based on previous research on RFID systems [13], [6], [33] we hypothesize that the EOQs of passive and active RFID systems are different. Many industries utilize both active and passive RFID systems in parallel.

H_{01}: EOQ of passive RFID system is not different from the EOQ of active RFID system

H_{02}: EOQ of the parallel combination system is not different from the EOQ of standalone RFID systems

The hypotheses were evaluated by comparing the means using t statistic at a 95% confidence interval using Microsoft Excel.

4. AIT System Reliability Model

4.1 Approach

In this research we utilize the following steps in our approach;

1) We identify the AIT technologies that are most relevant to the situation

2) We determine the reliability of the suggested AIT technology

3) We utilize the AIT system reliability model to determine the EOQ_r model with respect to reliability

4) We evaluate the impact of the EOQ_r in comparison to the baseline EOQ

4.2 Methods for determining the AIT system reliability model

The methods used for creating the AIT system reliability model rely on theories in quality that focus upon reliability determination and theories in inventory control that describe the process of using total cost to determine the most economic quantity to order. We will demonstrate further derivation of the model in step 3 of our approach.

4.2.1 Identification of the AIT technologies

For this transcript we identified barcode, passive RFID, active RFID, and ultra-wide band sensor technologies. Given some of the findings from our research we limit this paper to comparing passive and active RFID technologies.

4.2.2 Determination of the reliability of the AIT systems

We will use long term reliability values for the RFID systems described that were previously determined in on-going research from research labs that has performed these calculation over the last 9 years. The following equations were used to determine the long term reliability for the passive and RFID technologies:

$$r_{ijkl} = \mu + \tau_i + \beta_j + \gamma_k + \omega_l + \varepsilon_{ijkl} \qquad (1)$$

Where

r_{ijkl} = *Reliability of RFID System*

μ = *Overall Mean*

τ_i = *RFID reader power signal of a system*

β_j = *Distance of the tag from the RFID reader*

γ_k = *Tag Orientation*

ω_l = *Type of Material*

ε_{ijkl} = *Overall Error*

For efficient inventory management within a supply chain, most industries utilize both active and passive RFID systems in parallel. High value assets and lots/batches are tagged with active RFID tags and lesser value items or cases are tagged with passive RFID tags. For this reason, we calculated reliability of a parallel system which included both active and passive RFID systems using the reliability theory for parallel system.

$$r_c = (r_a \text{ x } r_p)/ (r_a+r_p) \qquad (2)$$

Where

r_c = *Reliability of the Parallel Combination System*

r_a = *Reliability of an active system*

r_p = *Reliability of a passive system*

The reliabilities for the active and passive RFID systems are unique to the type of system as the operating frequency of active system is 433 MHz and passive systems operate at 915 MHz.

4.2.3 Use the AIT System Reliability to Model Economic Order Quantity (EOQ_r)

In this step we provide the process used for deriving an economic ordering quantity using the AIT system reliability that was computed in the previous step. Inventory control theory was used to derive the economic order quantity based on the total inventory cost. The total inventory cost function is given by

$$Y = \text{Setup Cost} + \text{Holding Cost} + \text{Product Cost} \qquad (3)$$

The setup cost, also known as the ordering cost (A), is a function of ordering frequency. The holding cost (h) is function of the inventory level which will be inversely affected by the AIT system reliability (r). The product cost (c) is the cost associated with tagging each item with AIT which is a fixed cost. Therefore the total cost function is given by:

$$Y = (AD/Q) + (h/r)(Q/2)+cD \qquad (4)$$

Where

Y = *Total inventory cost*

D = *Expected demand per year (in units).*

Q = *Replenishment quantity (in units).*

r = *Reliability of the AIT*

A = Setup cost (in dollars).
h = Annual unit holding cost (in dollars per unit per year).
c = product cost of an item (in dollars per unit).

In order to calculate the optimal quantity, we determine the local minimum of the total cost function by taking the first order derivative with respect to quantity (Q) and equate it to zero.

$$\partial Y/\partial Q = (-AD)/Q^2 + (h/2r) = 0 \tag{5}$$

$$EOQ_r\ (Q^*) = Sqrt\ (2rAD/h) \tag{6}$$

From Eq. (6) the optimal quantity of items to be shipped during NASA space mission can be computed accounting the AIT system reliability. In this manuscript, we used the NASA data on food consumption that were publicly available as a case representation. The demand for food items for 3 astronauts on a 90-day space mission was indirectly computed as 7,147 items using the sample 21-day meal-plan from an 81-day menu. The ordering cost (A) was not explored in detail for this manuscript and was assumed to be the launch cost which listed as 450 million dollars on the NASA website. The holding cost was assumed to be $1 for calculations.

The goal of the paper is to demonstrate the need for accounting AIT system reliability in ordering quantity. However, the high cost value associated with NASA operations may not be optimal to demonstrate the use of the model proposed here. For this reason, we first demonstrate the use of EOQ_r using simulated data from a manufacturing warehouse. The total demand was assumed to be 24,000 units/ year which included 1000 high value assets. The following assumptions were made:

A = $8
h = $0.8
D= 24000 units/year
c = $0.1 for passive and $25 for active
r = 75%

4.2.4 Evaluation of the impact of the EOQr with baseline EOQ

The optimal ordering quantities based on the reliabilities (EOQ_r) of active RFID, passive RFID and parallel combinations systems were calculated for a set of 14 trials. The mean EOQ_r for the different systems were statistically compared using the t-test assuming unequal variance at a 95% confidence interval. The formula for calculating the test statistic is given by

$$t= (\mu_1-\mu_2)/SQRT\ [(s_1^2/n_1) + (s_2^2/n_2)] \tag{7}$$

Where
μ_1 = *Mean EOQr of AIT System 1*
μ_2 = *Mean EOQr of AIT System 2*
s_1^2 = *Sample Variance of AIT System 1*
s_2^2 = *Sample Variance of AIT System 2*
n_1 = *Number of observation for AIT System 1*
n_2 = *Number of observation for AIT System 2*

We also compared the optimal ordering quantities obtained from the Classical EOQ, with the EOQ_rs for passive, active and combination RFID system at a 95% confidence level.

4.3 Test Bed

This research was performed at RFID research laboratories at the University of Nebraska Lincoln, University of Texas at Arlington and NASA. Preliminary data on system reliabilities were from the research by the authors at the University of Nebraska – Lincoln that was funded by the NASA EPSCoR. Additional data is collected from the on-going research at the University of Texas at Arlington, NASA-JSC, and the NASA-ISS. Currently, the RFID reliabilities are being tested aboard the NASA – ISS. The data collected were analyzed using advanced statistics and Minitab

5. Results

5.1 Identification of the AIT technologies

From the previous research, passive and active RFID systems were evaluated. Passive RFID systems include Alien Gen 2 Squiggle, Avery Gen 2 AD G12, Rafsec "G2" Short Dipole, Omron Gen 2 Wave, Rafsec Frog G2, and Impinj Thin Propeller. SAVI ECHO Point, and RF Code M200 were the only two active RFID systems identified for this manuscript

5.2 Determination of the reliability of the AIT systems

A generic reliability equation for the AIT systems was developed as shown below:

$$r = 4.646 - 1.188\,(\text{Reader Power}) - 1.437\,(\text{Tag Distance}) - 1.021\,(\text{Tag Orientation}) - 3.021\,(\text{Material}) \quad (8)$$

Reader power, tag distance, tag orientation and the material property negatively impacted the RFID system's reliability. Material had the highest effect followed by distance, reader power and orientation in order. Based on Eq. (8) and (2) the reliabilities of passive, active, and parallel combination of RFID systems for the different trials are summarized in Table 1.

Table 1 Sample System Reliabilities and RFID Systems

Passive	**Active**	**Combination**
50%	69%	85%
75%	92%	98%
75%	100%	75%
50%	92%	50%
100%	100%	100%
75%	85%	96%
100%	100%	100%
100%	100%	100%
75%	77%	94%
75%	85%	96%
100%	100%	100%

The average reliability of the passive system was 82%, and the active RFID system was 92%. The parallel combination system with both active and passive RFID systems had an average reliability of 97%.

5.3 Use the AIT System Reliability to Model Economic Order Quantity (EOQ_r)

Table 2 summarizes the EOQ_r and the Total cost for the different AITs evaluated using the simulated data.

Table 2 Summary of EOQr and Total Cost for Simulated Data

	Passive	Active	Combination
EOQ_r	600	600	600
Total Cost	3,040	600,577	27,940

From the table it is evident that total cost is dependent on the type of system used for a given reliability as the total cost is directly proportional to the tag cost.

For the NASA data, the optimal ordering quantities vary with type of system and their average reliability. Table 3 summarizes the average reliabilities of the active, passive and combination RFID systems. It is evident that with increasing reliability the total cost is reduced with increased ordering quantity.

Table 3 Average EOQr and Total Costs for the different RFID systems

	Reliability	EOQr	Total Cost
Passive	82%	2,284,456	$2,855,139
Active	92%	2,432,860	$2,830,901
Combination	97%	2,502,122	$2,582,563

5.4 Evaluation of the impact of the EOQ_r with baseline EOQ

Comparing the mean EOQs for the different systems in Table 2, we identify that the EOQs with passive RFID systems were statistically significant from the EOQs with the parallel combination RFID systems. However, the mean EOQs with passive RFID system, and active RFID system were not different based their reliabilities. Similarly, the EOQs with active RFID system and with the parallel combination RFID systems were also not statistically significant based on reliabilities.

Table 4 Comparison of Mean EOQs for the different systems

	t-statistic	Significance
Passive - Active	-1.87	NS
Passive-Combination	-3.14	<0.0001
Active-Combination	-1.76	NS

From the evaluations, we fail to reject the hypothesis on the equality of optimal quantities for passive and active systems, and conclude that the optimal ordering quantities are different based on the system reliability.

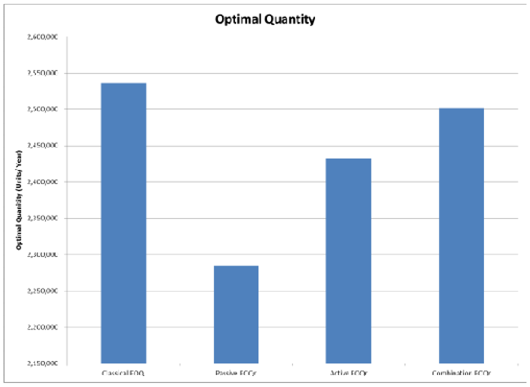

Figure 3 Comparison of Optimal Quantity with Classical EOQ and EOQr

From the comparison of the optimal quantity for classical EOQ and EOQ_r Figure 3, we reject the hypothesis that optimal quantity with classical EOQ is not different from the EOQ_r and conclude that classical EOQ overestimates the optimal quantity.

6. Discussion

The model introduced provides key insights to determining the correct amount of inventory to send from key points in the supply chain and it adds the idea that AITs and the reliability of the AITs will impact the economies of scale for sending quantities of inventory. The concepts described here can be expanded to any AIT technologies with RFID. AIT technologies that utilize RFID are becoming more accepted and are the AIT of choice for many organizations. Its ability to create man less inventory control is expanding. Future work for this model is to re-evaluate the total cost function for using RTLS that may impact the cost of the systems that are more expensive but may greatly reduce the labor component of handling inventory. The RFID based RTLS that is currently being researched by the authors would capitalize on crew free inventories. This paper utilized the NASA ISS research to demonstrate the impact of system reliability on NASA operations, but we also demonstrated in the methods section a practical use in a more common manufacturing scenario. The results for NASA in this paper indicate that a combined passive and active RFID system or a combined AIT system would be the most economical. The case for using this model for applications on ground and not in space may not be more difficult to determine than the NASA scenario. The assumptions used for converting food consumption to a dollar value can be expanded to integrate weight determined systems reliability into future derivations of this model.

7. Conclusion

This paper focuses on developing an inventory model with an RFID reliability factor for a deterministic demand. However, demand is stochastic based on consumer consumption and needs that has not been accounted in this paper. Another limitation of this paper is that the model was validated using publicly available NASA data and needs to be investigated using true information from their suppliers and other relevant information. In summary, the main objective of this study was to evaluate the impact of the RFID reliability factor on the economic order quantity. There is little to no information available on the reliability factors on inventory policies, which are unique to industries. The model developed would benefit from further validation using data from other industries before generalizing. From the model developed, the economic order quantities are affected by system reliabilities which have further impact on the total inventory costs. Findings from this study lay inroads in inventory control modeling. The concepts presented in this paper needs to be extended to other stochastic inventory control modeling particularly based on backorder and service levels.

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