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OUT OF SPACE

Using RFID, simulation and other IE methods to control inventory for NASA

INVENTORY ACCURACY IS CRITICAL FOR NASA ASTRONAUTS in space. In 2004, astronauts onboard the International Space Station (ISS) nearly had to de-man their outpost because consumables replenishment was uncertain. Researchers at the RFID Supply Chain Lab (RFSCL) in the University of Nebraska's Department of Industrial Engineering decided to tackle this problem.

This article shows how optimizing inventory policies with technologies such as radio frequency identification (RFID) can improve inventory control, how to use discrete-event simulation to demonstrate the impacts of real-time inventory policy in space, and how real-time inventory control can impact life on Earth.

Inventory problems in space

The motivation behind the study described in this article is the explosion of Space Shuttle Columbia on Feb. 1, 2004. After this accident occurred, space missions were postponed due to investigation of the disaster. Astronauts aboard the ISS were instructed to reduce their daily calorie intake by approximately 300 calories. Astronauts burn approximately 3,200 calories a day, so this reduced them to less than 2,900 calories. This inventory control policy and others may have contributed to the danger of a premature termination of a costly space mission. It is estimated that this could have cost the taxpayers who fund NASA up to $450 million.

A high level of inventory accuracy is critical for NASA astronauts to survive in space. After the inventory issues, NASA had to re-evaluate inventory control policies to ensure that future astronauts would not be forced to eat less when inventory is not available.

Although launches are critical for astronauts' survival, the estimated $450 million cost of a space launch is difficult to ignore. The high cost of launches demonstrates that the de-manning of an outpost due to food shortages would be detrimental to NASA's budget. This same concept can be applied to warehouses and retail stores where shortages of inventory can result in lost sales and too much inventory can cause more supply than demand.

Astronauts onboard the ISS use manual auditing and barcode scanning to track perishable inventory (consumables), which presents a challenge because periodic inventory audits are labor intensive, time consuming, and may provide inaccurate measures. Currently, researchers are investigating "automated inventories," which allow for inventory audits to occur remotely without the need for human intervention. Given the demand uncertainty of astronaut food consumption, this study seeks to demonstrate how these automated inventories can optimize efficiencies.

The following sections will show the benefits of automated inventory management by using a discrete-event simulation model and introduce an inventory policy equation known as the economic order quantity (EOQ). The EOQ determines the optimal amount of stored inventory given information such as cost of food (inventory), amount of food consumed and frequency of shipments to space.

Calculating the amount of food in space

The EOQ is the number of units an organization should add to inventory with each order minimizing the total costs of inventory. A common way of thinking about this is determining when you should go to the grocery store based on how much food is in the refrigerator.

You will need three pieces of information to calculate the

EOQ (noted as Q*): annual demand (D), ordering costs (A), and holding costs (h or iC). For our study, annual demand is the amount of food astronauts consume in a year, ordering costs include the cost of the item and the logistics to send it into space, and holding costs include hold-in-storage-on-ground or warehousing costs. The holding costs are calculated by the loss of money incurred by holding the inventory, so it is generally calculated as the cost of one item (C) multiplied by the cost of money (i) in the form of interest to store it (generally 37 percent interest).

$$Q^* = \sqrt{\left(\frac{2AD}{h}\right)}$$

A visual representation of the cost and ordering quantity can be seen in Figure 1. Q* represents where the optimal ordering quantity occurs.

EOQ can be categorized in two ways: as a periodic review system or as a continuous review inventory system. Which system is used depends on how often you get information and how often you can order. The idea is that if you only go periodically, you will need more inventory. If it is continuous, then you can be more automatic. If the refrigerator tells you that you are out of milk and sends a message to your iPhone, you can buy milk before you come home. Previously, continuous models have been theoretical, but with technologies such as RFID, use of these continuous models has become more of a reality so the refrigerator can send the message. This automation will reduce the tab for replenishing inventory by minimizing costs such as transportation and manual inventories.

The researchers seek to use traditional EOQ techniques to support NASA inventory replenishment efforts. The envisioned model will provide the ability to calculate the appropriate reorder point and the optimal reorder quantity to ensure instantaneous replenishment of inventory with no shortages. This study is aligned with NASA procedural requirements, which state that "stock replenishment shall be in accordance with [Federal Property Management Regulation] requirements and shall use EOQ principles." Moreover, the requirements provide the parameters for the EOQ model by stating "a review point for each stocked item shall be established, using a formula that provides at least 90 percent assurance that an out-of-stock condition shall not occur." These guidelines support NASA's use of the EOQ policies, but unfortunately errors still occur.

Currently, NASA uses manual counting and barcode technologies to track items such as crew clothing, office supplies and hygienic supplies at the bag level, but not at the item level. These items are stowed in cargo transport bags (CTB).

The research team is investigating the use of RFID technologies to eliminate the manual tasks associated with the aforementioned techniques. Planned results include an RFID system that allows for "crew-free" automated inventories that require astronauts minimal time and labor to reduce excessive inventory weight for the space payloads. According to NASA public documents, menu planning for shuttle flights begins eight to nine months before the launch date of the cargo shuttles. Varieties of American and Russian foods go through a series of investigations before packaging and installation for space missions. These investigations include sampling, evaluating and subjective ranking according to preference by the astronauts. Through these investigations, necessary improvements can be made.

At the conclusion of this phase, NASA personnel do not have an effective system that measures quantity of assets packaged for usage. The research will lead to eliminating the daily logging of inventory while maintaining high inventory accuracy.

RFID basics

RFID technologies originated from radar theories that were discovered by the Allied forces during World War II and have been commercially available since the early 1980s. Over the last two decades, RFID has been used for a wide variety of

OPTIMAL ORDER QUANTITY

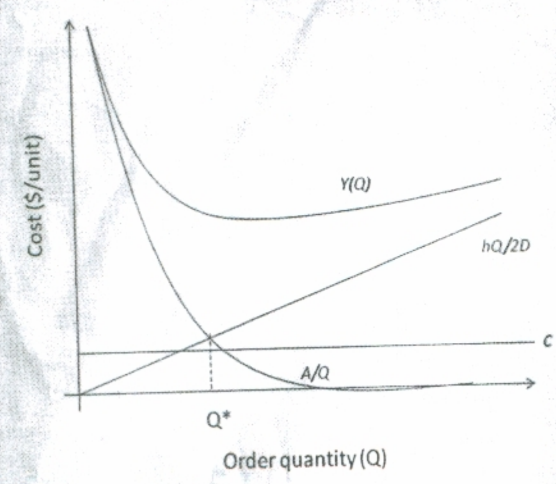

Figure 1. A visual representation of the cost and ordering quantity, where Q* represents the location of the optimal ordering quantity

applications such as highway tolls, cattle tracking and transportation freight tracking. Until recently, the technologies were considered expensive and limited, but as the tags, readers and the associated equipment costs continue to decrease, a growing number of organizations have begun to explore the feasibility of using RFID systems. Hospitals, retail stores and warehouses are seeking to implement this technology to reduce lost inventory and support tracking items.

RFID also can be integrated with real-time location systems (RTLS) to identify and locate items. Companies are taking advantage of this technology because it provides the most accurate measure and has the ability to pinpoint where items are located. RFID technology works through electromagnetic communication between a reader (interrogator) and a tag (transponder). A tag with internal memory storage is attached to an object. The tag contains critical information pertaining to the object, such as a serial number, manufacture date or item-identifying information.

An interrogator emits an electromagnetic field and when a tag enters the field, the information stored on the tag is transmitted back to the interrogator. In general, when the reader emits a radio frequency signal, any corresponding tag within range of the reader will detect the signal. Once a tag has verified the signal, it replies to the reader indicating its presence. RFID can locate misplaced items at a reduced cost.

Using RFID to determine EOQ for NASA

Several steps were conducted in order to determine an RFID-based EOQ model that would allow for more accurate replenishment scheduling. The model developed for NASA consumable food planning policy consists of the following five-step approach:

1. Calculate the calories consumed by the astronauts.
2. Construct a simulation model that determines the annual amount of food consumed.
3. Determine safety stock values.
4. Integrate the annual demand and the costs into an EOQ model.
5. Run a sensitivity analysis that varies demand and cost.

Step 1: Calculate the calories consumed by the astronauts. Data collected from the 12 expeditions that followed the 2004 space station food shortage was used to calculate the calories that were consumed by each astronaut aboard the ISS annually.

Currently, there are no measures to calculate how much food each astronaut consumes per day. NASA estimates that astronauts onboard consume anywhere from 1,900 calories (small woman) to 3,200 calories (large man) per day, for a total of three meals, while other sources estimate 3,000 calories are consumed on average per day. Therefore, a customized calorie intake was used for the astronauts with regard to their ages, heights, weights and exercise levels using a calorie calculator.

Records of astronauts' heights and weights were unavailable for this study because of the confidential nature of the information; thus, general guidelines provided by NASA and statistics provided by the National Center for Health Statistics (NCHS) were used to generate that data. Statistical software found that triangular distributions best fit the height and weight data of both males and females. These specifications were used to

RFID VS. BARCODES

There are many benefits of using RFID over traditional methods of inventory control. The following chart, based on a chart by Rusty L. Juban and David C. Wyld, details some advantages to using RFID instead of barcode technology.

RFID	Barcodes
Can be read or updated without line of sight	Require line of sight to be read
Multiple tags can be read simultaneously.	Can only be read individually
Can cope with harsh and dirty environments	Cannot be read if they become dirty or damaged
Are ultra thin and can be read even when concealed within an item	Must be visible to be logged
Can identify a specific item	Can only identify the type of item
Allows electronic information to be overwritten on tags	Information cannot be updated.
Can be automatically tracked, eliminating human error	Must be manually tracked for item identification, making human error an issue
Allows for real-time information	Must be manually scanned to obtain information

THE RIGHT AMOUNT

Number of astronauts	Safety stock (lbs.)			Total food inventory (lbs.)	
	One day	Annual	10 years	Annual	10 years
1	0.5714	208.5714	2,085.7143	622	6,222
3	1.7143	625.7143	6,257.1429	1,867	18,667
6	3.4286	1,251.4286	12,514.2857	3,734	37,334
7	4	1,460	14,600	4,356	43,557

Figure 2. An estimate of the total food inventory aboard the ISS

generate the heights and weights of the astronauts. The final input necessary for estimating the caloric consumption in a day was the amount of exercise. According to NASA, astronauts are required to exercise two hours a day.

Results: Forty-five astronauts participated or are currently participating in Expeditions 15 to 26, and some astronauts participated in more than one mission. To review the expeditions, astronauts and estimates of pounds of food consumed per day, go to *www.iienet.org/magazine/feb2011/jones/figures*. The data was used to determine a distribution for pounds of food consumed per day. A triangular distribution was again found to be the best fit for the pounds of food consumed by each astronaut per day.

Step 2: Construct a simulation model that determines the annual amount of food consumed by astronauts. To determine an inventory policy that accurately depicts the astronauts' food consumption aboard the ISS, simulation was used to estimate the ISS's annual demand for food. Currently, there is no measure in place to determine the annual demand of food. By using simulation, we can estimate approximately how much food is consumed with regard to the average number of astronauts in orbit and their caloric intake. To model the annual food demand, the amount of food each astronaut consumed per day was needed. Simulation software was used to simulate a year on the ISS.

Results: The simulation study showed that the average annual demand of food is 2,480 pounds. Knowledge of the annual demand allows for the application of the EOQ model.

Step 3: Determine safety stock values. The safety stock level is a predetermined quantity based on EOQ months of supply, which is in addition to normal replenishment lead-time and operating level requirements. Approximately 2,000 extra calories per day are packed for each crew member for emergency purposes. This acts as the safety stock for the food inventory. Since part of the food is always sent before the crew arrives at the space station and the rest on the next scheduled shuttle, we assume that replenishments are delivered at once with constant lead-time. Using the EOQ model with a general estimate of the cost for launching a space shuttle per mission given as $450 million, the optimal quantity can be determined. Unfortunately, the breakdown of this cost in terms of ordering and holding costs is unavailable.

Results: The safety stock along with the total food inventory was found to help determine an appropriate EOQ model. These values can be found in Figure 2.

Step 4: Integrate the annual demand and the costs into an EOQ model to determine the optimal quantity. The cost for launching a space shuttle per mission is given as $450 million; however, no breakdown of this cost in terms of ordering and holding costs is available due to confidential information. Once the costs are broken down, the annual pounds of food consumed found from simulation can be used to determine an optimal order quantity.

Results: The optimal quantity for six astronauts with an annual food demand of 2,480 pounds was found to be 1,217 pounds, which is the amount of food that should be ordered each time an order is placed to minimize costs.

Step 5: Run a sensitivity analysis that varies demand and cost. In order to estimate how the optimal quantity varies relative to the total cost of a mission, two sensitivity analyses were conducted. The first analysis was conducted based on an average of six astronauts with a mean time in orbit of 179 days. Varying this cost by 50 percent, 33 percent, 25 percent, 10 percent, 5 percent and 1 percent gives the optimal amounts for each value. The second analysis varied the number of astronauts from one to seven while keeping the total cost of $450 million equivalent to six astronauts.

Results: In the first analysis, varying cost by 100 percent, 50 percent, 33 percent, 25 percent, 10 percent, 5 percent and 1 percent gives the optimal amounts of 1,217, 609, 402, 304, 122, 61, and 12 pounds, respectively, as seen in Figure 3. Lower-

SENSITIVITY ANALYSIS (based on six astronauts)		
1. Varying cost and keeping the optimal quantity constant		
Percent of $450 million	**Estimated total cost (U.S.D. millions)**	**Optimal quantity/EOQ (lbs.)**
100	450	1,217
50	225	609
33	148.5	402
25	112.5	304
10	45	122
5	22.5	61
1	4.5	12
2. Varying demand and keeping cost constant		
Varying number of astronauts	**Annual demand (lbs.)**	**Estimated total cost (U.S.D. millions)**
1	414	75
3	1,241	225
6	2,482	450
7	2,896	525

Figure 3. Sensitivity analysis of estimated optimal quantity against total shuttle cost

ing the cost of the mission leads to the shipment of smaller amounts of food. Although this is a favorable option since there would be more room allotted for equipment for experiments, this option would require several replenishments (increase in the number of orders) of food over the entire mission, which would result in an increase in costly launches.

The second analysis, which shows a variation of demand while keeping cost constant, showed that the fewer the astronauts, the smaller the cost. Consequently, seven astronauts required $525 million, an increase of 16.67 percent in cost, while one astronaut required $75 million and three required $225 million, which is a decrease of 83.33 percent and 50 percent, respectively.

Real-time RFID on Earth

RFID systems gained popularity through implementation in retail and logistics operations driven mainly through mandates from Wal-Mart and the U.S. Department of Defense. With the acceptance of standards sponsored by the International Organization for Standardization (ISO), GS1 and the DASH7 Alliance, the technology is gaining momentum for automated nonlogistics operations. For example, hospitals are investing in these technologies to track assets such as wheelchairs, IV pumps and patients.

Using RFID to automate inventory counts and location of inventory is an efficient means for most organizations to use the technology on ground or in space.

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Web exclusive

MAKING IT HAPPEN

Showing it is serious about its RFID efforts, NASA recently installed an RFID system at its Langley Research Center in Langley, Va., to take inventory of important data center and lab assets such as servers and switches. Read more about the implementation at *www.iienet.org/magazine/feb2011/NASA-RFID*.