An Inventory Cost Model of a Government Owned Facility using Fuzzy Set Theory

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Abstract

This project incorporates fuzzy set theory into developing a methodology for quantifying costs associated with performing physical inventory procedures. While the project topic was developed through a direct application to a particular facility, the paper extends this scope by presenting a methodology that is capable of being applied to most warehouses or product distribution centers. Various methods of data collection are described, with a focus on utilizing fuzzy set theory for areas where data is not easily obtained.

Keywords
Physical inventory, Triangular fuzzy numbers, Time measurement

1. Introduction

Quantifying a total cost associated with physical inventorying procedures is often a difficult task. These costs are frequently lumped into a single figure, and tracing the costs back to the activities that drive them requires detailed analysis. The activities within physical inventories consume resources at different rates, as some activities take more time and effort than others do. Physical inventory procedures in the context of a warehouse or distribution center often involve many activities and are not limited to simply conducting physical counts of stored merchandise. A methodology to ascertain the cost associated with the physical inventorying process is needed to provide organizations with valuable information about their internal inventory procedures.

The topic originated as a research project conducted by the University of Arkansas and a government organization. Due to the nature of the sensitive cost information, the name of this facility cannot be disclosed. The intent of the paper is to outline the methodology used to develop a cost model that represents all costs incurred through the daily inventory operations. This methodology, while specific to the direct application, is then broadened to promote use within similar types of facilities where inventory costs are not known with a high degree of precision. The first step in this methodology is to identify the activities that consume resources, either of direct monetary value or expenditures of physical labor with correlating costs. Depending upon the specific inventory activity to be performed, various techniques can be implemented to collect data on the process. Traditional time measurement is described and used when permissible by the activity, while fuzzy data collection is described for those activities where a traditional time study is not feasible.

The majority of historical data for the project application were recorded at the macroscopic level, but data that depicted resource consumption at the activity level were not available. Analysis of the inventory activities that consume resources was completed in efforts to outline procedures that could be used to collect data on each activity. This process is described to promote use of this application to similar types of facilities that routinely incur costs from physical inventory procedures. It is expected that applying fuzzy set theory to gather data on physical inventory procedures that possess inexact information will enable the proposed methodology to be applied to a variety of similar circumstances in warehouses or distribution centers.

2. Literature Review

Relevant literature is reviewed to provide the reader with the types of applications of fuzzy set theory and physical inventory procedures. Many such applications have been completed, with each providing unique insight on the diverse range of instances where fuzzy set theory is deemed appropriate for the situation.

2.1 Physical Inventorying Procedures

Numerous industry experts have examined physical inventory costs by using a variety of methods. A widely used technique is to gather information from commercial industry by using a surveying approach. A recent survey conducted [1] reported that to complete physical inventories, 30% of the participants in the study are spending $1000 or less annually, 43% spend $1000 to $10,000, 15% spend $10,000 or more, and 12% did not know how much annual inventory operations cost their particular organization. While these statistics may be useful, the overall size of the participant organizations was not taken into account. It is evident that larger organizations need to allocate more funding to physical inventorying procedures than smaller organizations to maintain a comparable level of inventory accuracy. Other such approaches have been used to conduct surveys with commercial representatives within the same industry to gain perspective on various techniques used to maintain inventory accuracy. A survey of discount store retailers [2] found that half of the survey respondents use physical inventories exclusively, while the other half uses physical inventories in conjunction with cycle counting methods. Eighty percent of the survey participants conduct wall-to-wall inventories every year, 13% conduct this procedure semi-annually, and 7% conduct this procedure on a quarterly basis.

Inventory operations are typically considered non-value added activities, but are crucial in maintaining efficient cost management of any organization. Tsujimura *et al*. [3] assert that the most important issue for inventory control is to find an inventory policy that minimizes the total cost. Ordering costs from suppliers commonly vary based upon differences in item cost and shipping distances. To address this issue, a genetic algorithm was employed to solve inventory control problems with multiple items and multiple suppliers. Multi-item inventory models can be created under specific assumptions, most often applied with constant demand and infinite replenishment. Das *et al*. [4] created an inventory model using these assumptions with restrictions on storage area, total average shortage cost, and total average inventory investment cost, and solved the model using geometric programming and gradient-based nonlinear programming methods.

2.2 Fuzzy Set Theory Applications in Inventory Problems

In efforts to deal quantitatively with uncertainty and imprecision in data sets, Lotfi Zadeh [5] introduced fuzzy set theory in 1965. This theory uses logic rules to represent subjective human data by quantifying inexact information. Often, physical inventorying procedures possess large amounts of process variability and human perception as to the time it takes to complete a certain activity. Industry experts have utilized fuzzy set theory for creating cost models pertaining to physical inventorying procedures in a variety of applications. Roy and Maiti [6] have applied fuzzy programming techniques and membership functions to develop a fuzzy Economic Order Quantity (EOQ) model with limited storage capacity where demand is related to the unit price. In this application, the production setup cost varies with the quantity of items produced and purchased, and fuzziness is introduced in both storage area and objective function. Vujosevic *et al.* [7] have developed a similar EOQ formula where the inventory cost is fuzzy. Their efforts for this application were based upon the fact that numerous types of uncertainties and imprecision exist in real inventory problems, and uncertainties exist that cannot be appropriately modeled by using probability theory.

In situations where an exact quantity or value is not known, the use of triangular fuzzy numbers can be used to represent the possible values. A triangular fuzzy number (TFN) is a special type of fuzzy number with three parameters: smallest possible value, most promising value, and largest possible value [5]. These parameter values are used to encompass all possible numbers for a given situation, and allow mathematical operations to be performed on inexact data sets. This technique is well suited for applications involving inventory control models, where many of the variables in the process, such as setup cost, carrying costs, and shortage costs, may be fuzzy in nature where the costs are not known with any degree of certainty. Yager [8] proposed an approach to find the mean value of a fuzzy number so that calculations can be performed on fuzzy models. Extension of this work by Dubois and Prade [9] introduced a working definition, “The mean value of a fuzzy number is a closed interval bounded by the expectations calculated from its upper and lower distribution functions.” This insight enables the use of TFNs in inventory control models where collected data is fuzzy in nature. A graphical example of a TFN is given in Figure 1, where a_1, a_2, and a_3, correspond to smallest possible value, most promising value, and largest possible value, respectively.

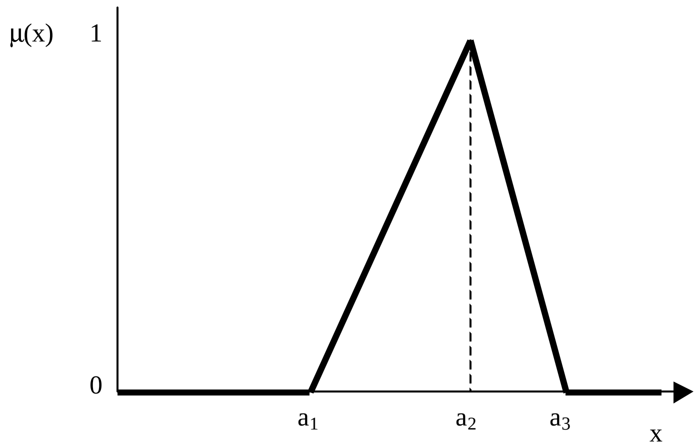

Figure 1. Triangular Fuzzy Number A = (a_1, a_2, a_3)

Fuzzy set has been applied to a variety of different situations where uncertainty is prevalent, but little work incorporating fuzzy set theory and the costs associated with physical inventory operations has been conducted. Most completed work in this area has been developing cost models based upon fuzzy parameter values and solving these models with differing techniques. The content of this paper provides the reader with a methodology to ascertain the physical inventorying costs in a fuzzy environment based upon the activity.

3. Methodology

The methodology for the project application was developed to accommodate the specific needs of the facility under examination, but is applicable for any warehouse or distribution center where physical inventory costs need to be quantified. The end result of this application was the development of a recommended financial resource standard quantifying the amount of funding necessary for the facility to conduct their daily inventory operations. In achieving the end result, important aspects of the process are described based upon the development and advancement of the project scope. In the subsequent sections, data collection for each aspect of the physical inventorying procedure is depicted as to provide insight on how to quantify costs based upon the activities that drive them.

3.1 Background Information

While the name of the facility under examination cannot be disclosed, it is important to provide some background information about the operations at this location. The facility is one of several distribution centers located in various parts of the country. It contains a wide variety of products that range in size, shape, function, and cost, with all distribution centers containing over 4 million different stock-keeping units (SKU). Small products such as hardware (bolts, nuts, washers, etc.) are stored in bulk storage bins, while larger products are stored on shelves, racks, or floor-stacked pallets. The facility adheres to strict inventory accuracy standards, partaking in scheduled and unscheduled inventories on a regular basis. Scheduled inventories are random sample based inventories used as a performance measure for overall inventory accuracy. They occur on a routine time interval, with a set number of scheduled inventories per year. Unscheduled inventories are inventories that are performed on an as needed basis, and aid in supporting third-party customer requests, documenting problems with current procedures, and resolving discrepancies between recorded stock levels and actual quantities on hand. The major difference between the two types of physical inventories is the reason why they are being performed, but the actual process for conducting scheduled and unscheduled inventories is identical. Physical inventories are just one component of the facility's inventory control program, and other aspects of this program are given in Figure 2.

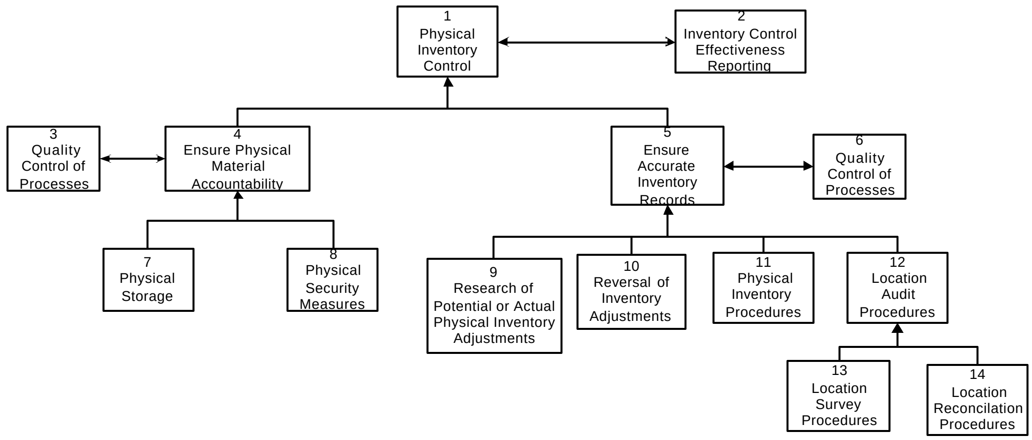

Figure 2. Components of Physical Inventory Control

While physical inventorying is one component that consumes resources, other components were identified as important areas that warranted investigation. Causative research is the process of investigating and documenting discrepancies in the inventory records. Similarly, but performed for different reasons, denial research involves investigating the causes behind a stock denial, an instance where an order can not be adequately filled due to a lack of available stock at the item location.

3.2 Identification of Core Activities

After the examination of all physical inventory components, three areas were identified as having a significant impact on the financial resources of the facility. This can be considered the most important aspect of the methodology, as all future developments are related to this decision. The identification process was conducted by interviewing multiple personnel who have a strong knowledge of the important activities. When performing a similar type of process, it is important to document discrepancies in opinions. These recorded discrepancies allow for justification of why some activities were included in the quantitative process and why some were excluded. As a result of the interviewing process, three areas were selected based upon the received responses from facility management personnel:

1. Physical Inventorying procedures,
2. Causative Research processes, and
3. Denial Research processes.

The data collection processes used to gather information for each activity was based upon the individual characteristics of that particular activity. Data for activity 1 was gathered using traditional time measurement, while data for activities 2 and 3 used a triangular fuzzy number elicitation method, as a time study could not be implemented due to the nature of these activities.

3.3 Description of Activity Data Collection

Physical inventory counts are regularly performed at the facility for a variety of reasons. Regardless of the root cause, the procedure is basically the same for conducting the inventory. A first count is performed to compare the recorded stock level with the actual counted stock level. If these figures match, the process for that particular item concludes. If there is a discrepancy between these two figures, a second count will be conducted in a manner similar to that of a first count. While some of these tasks require a finite period to complete, others take place instantly and do not have any associated time. When observing this process, information about each activity was recorded so that a total time to conduct an inventory could be determined. As a result, it was found that the majority of the time to conduct physical inventories was consumed in three distinct tasks. It is important to document the process observations of each task in order to gain perspective on the steps that consume resources. For the project application, two sets of physical inventories were conducted on different days and in different locations. The first set of observations recorded a total of 32 occurrences, and the second set recorded a total of 9 occurrences, yielding a total of 41 physical inventory observations.

Causative research is performed for a variety of root causes and involves investigating sources of error in the inventory process. This process involves a much greater degree of variability in the time required for completion when compared to the previous inventory area for several reasons. The cause of a record discrepancy is not always repetitive, and differing amounts of time can be spent in the investigation process. Causative research cases can also require that the case is not resolved or worked on in a continuous process. Contacting personnel at different locations will often entail waiting for a response, and the particular case must be set aside until the needed information is obtained. Therefore, performing a traditional time study on the activities would not allow for a valid representation of the time required for completion. In addition, measuring this process with stopwatch analysis would not reflect the actual time involved with each case since many cases cannot be worked in a consecutive flow of tasks. An informal interview process was conducted with inventory personnel dedicated to performing this activity. Three inventory workers dedicated to causative research cases were asked the same three questions so that data could be collected in the form of a triangular fuzzy number.

1. What is the smallest amount of time that it takes to complete one causative research case, if it could be completed in a continuous fashion?
   - *Responses:* ½ hr., 1 hr., 1 hr.
2. What is the most promising amount of time that it takes to complete one causative research case, if it could be completed in a continuous fashion?
   - *Responses:* 2 hrs., 2 ½ hrs., 3 hrs.
3. What is the largest amount of time that it takes to complete one causative research case, if it could be completed in a continuous fashion?
   - *Responses:* 1 day, 3 days, 4 days (8 working hrs. per day)

These data elicitations can be translated into a TFN by averaging the responses of each of the three questions, thereby obtaining smallest possible (a_1), most promising (a_2), and largest possible (a_3) values. The data can then be defuzzified by various methods. One widely used method is to calculate the centroid of the fuzzy number to obtain a single output value [7]. Another defuzzification technique, proposed by Dubois and Prade [9], is to calculate the mean value for the data interval to associate a quantity of time with the activity. The use of a particular defuzzification technique depends upon the type of collected data, and the desired output of the calculation.

Denial research is a result of a denial being issued for a particular item, and takes place after the denial is issued. A denial occurs when there is insufficient stock to fill a customer order, and can occur for a variety of reasons. The purpose of denial research is to investigate the root cause of a denial by investigating and reviewing archive records and transaction history of items. The process is similar to causative research, but it is being performed for a different reason. As with the previous process, collecting time data on this activity would not effectively represent the actual process. A similar triangular fuzzy number approach was used to gather information on the denial research process, and three different inventory workers, dedicated to conducting denial research, were asked the same three questions.

1. What is the smallest amount of time that it takes to complete one denial research case, if it could be completed in a continuous fashion?
   - *Responses:* 3 min., 5 min., 15 min.
2. What is the most promising amount of time that it takes to complete one denial research case, if it could be completed in a continuous fashion?
   - *Responses:* 10 min., 15 min., 25 min.
3. What is the largest amount of time that it takes to complete one denial research case, if it could be completed in a continuous fashion?
   - *Responses:* 15 min., 45 min., 2 hrs.

As with the causative research process, the data elicitations can be translated into a TFN by averaging the responses of each of the three questions to obtain the smallest possible (a_1), most likely (a_2), and largest possible (a_3) values. Defuzzifying the data interval by one of the described techniques will allow for a finite amount of time to be associated with the denial research process.

4. Conclusions

Applying fuzzy set theory and using triangular fuzzy numbers for gathering imprecise data on physical inventory procedures allows for the quantification of activity costs. The unique application presented is capable of being applied to similar situations where the costs to perform daily inventory operations are not known. In the process methodology, it is important to identify those activities that consume resources and to study these activities in detail. When observing these activities, performing time measurement studies will provide accurate data and should be used whenever possible. However, some physical inventory activities are fuzzy in nature, and collecting data is not always a straightforward procedure. Using the described methodology will allow for data to be collected on these activities in effort to correlate a cost figure that accurately represents the actual process.

5. Issues for Further Investigation

At the time of the paper's submission, the collected data was under analysis and fuzzy arithmetic computation. While this paper outlined the methodology used to gather physical inventory data in a fuzzy environment, future IERC submissions will continue this work to present an entire model based upon these techniques.

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