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Fuzzy rule-based system for the economic analysis of RFID investments

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ABSTRACT

Radio frequency identification (RFID) technology introduces the opportunity for increased visibility by facilitating easy tracking and identifying of goods, assets and even living things. The number of RFID applications and users in various fields are growing. However, high investment cost and inadequate technical capability still remain as challenges for RFID system implementations. That being the case, fair evaluation of savings associated with increasing performance and investment costs has a great role in the success of RFID projects. In this study, a systematic framework for the economic analysis for RFID investment is proposed. In this method, the elements of cost and benefits are determined in order to measure the value of an RFID investment. The expected increase of customer order is determined in terms of delivery accuracy and delivery time via a fuzzy rule-based system. The Monte-Carlo simulation method is used to determine the expected net present value (NPV) of RFID investment. A case study is constructed on the basis of expert conception to illustrate the proposed method.

1. Introduction

Radio frequency identification (RFID) is a technology that incorporates the use of electromagnetic or electrostatic coupling in the radio frequency (RF) portion of the electromagnetic spectrum to uniquely identify an object, animal, or person. The principal advantages of RFID system are the non-contact, non-line-of-sight characteristics of the technology. Tags can be read through a variety of visually and environmentally challenging conditions such as snow, ice, fog, paint, grime, inside containers and vehicles and while in storage. RFID systems are emerging as a practical means of auto-identification in a wide variety of applications from access control to animal tracking. RFID systems are likely to supersede bar codes in some applications and complement bar codes in others (Roberts, 2006).

An RFID system consists of three components: an antenna and transceiver (often combined into one reader) and a transponder (the tag). The antenna uses radio frequency waves to transmit a signal that activates the transponder. When activated, the tag transmits data back to the antenna. The data is used to notify a programmable logic controller that an action should occur. The action could be as simple as raising an access gate or as complicated as interfacing with a database to carry out a monetary transaction. Radio frequency identification (RFID) systems is regarded as key to the success in supply chain management, no matter which product or industry is considered. Therefore, RFID systems gained popularity and implemented for distribution, manufacturing, warehousing processes, even in industries such as defense and healthcare.

The history of this technology goes back to 1939. During World War II, the British wanted to distinguish between their own returning aircrafts and those of the enemy, thus they placed transponders on their aircrafts which would be able to respond appropriately to interrogating signals from base stations. This was called the identity friend or foe (IFF) system and is widely considered the first use of radio frequency identification (Dittmer, 2004). The first commercial use of the RFID began in the 1960's with the development of the electronic article surveillance (EAS) equipment by the companies Sensormatic, Checkpoint and Knogo to prevent the theft of merchandise. In the 1970s developers, inventors, companies, academic institutions, and government laboratories began working actively on RFID, and notable advances were being realized at research laboratories and academic institutions. In 1990's RFID saw the wide scale deployment of electronic toll collection in the United States and the installation of over three million RFID tags on rail cars in North America (Landt, 2005). Subsequent to the announcement of US. Department of Defense that RFID technology held the potential to revolutionize "In-Transit-Visibility" and the "Total Asset Visibility" in supply chains, many technology vendors were encouraged to push forward RFID development for commercial purposes (Liard, 2003). However, the value of RFID technology for managing business supply chains has only been recognized in recent years. The business press has since proclaimed that RFID marks a commercial innovation with the potential to soon replace barcode technology in the supply chains of numerous industries.

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Incited by those developments and promises, companies from varying industries planned RFID adoption aiming to exploit cost saving potentials and new business opportunities.

As costs in the semiconductor industry decrease and data communication standards improve, the use of RFID technology has increased. The cumulative number of RFID tags sold over the last 60 years is 3.752 billion, with 27% sold in 2006 and 19% in 2005. The market is expected to rise to $27.88 billion in 2017 (Das & Harrop, 2007).

RFID pilot projects have recently been carried out in various industries. The UK-based retailer Marks & Spencer plans to extend its successful item level RFID tagging program from 42 to 120 stores by spring 2007, on the way to tagging all 350 million items of apparel sold yearly. Galeria Kaufhof, a division of Metro Group, launched RFID-based shopping services for customers at its store in Essen, Germany. An entire floor of the department store was outfitted with Electronic Product Code (EPC) RFID technology, enabling customers to use RFID enabled dressing rooms and displays and a smart mirror that had previously been available only for demonstration purposes (Wessel, 2007). Airbus has already begun RFID projects. Since 2006, when the company started its phase-one deployment, it has saved millions of euros each year by cutting process cycle times, eliminating paperwork, and reducing inventory (Wasserman, 2007). Deutsche Post World Net (DPWN) launched a project to develop passive RFID tags incorporating a small, rewritable display for use on mail containers. These D-RFID tags will be used as part of an RFID application under development to track DPWN's 6 million yellow shipping containers. The company utilizes the crates to carry the 70 million letters that pass through its 84 distribution centers each day (Wessel, 2006). In an effort to reduce costs and improve patient safety and services, numerous hospitals and medical centers have deployed RFID technologies to track high-value assets, patients, medical records, blood products, and beds. Early press releases by many companies outlined ambitious timelines for the implementation of RFID along their entire supply chains (Collins, 2006). However, several years after the first releases, very few projects have been completed, indicating that the process of RFID adoption and diffusion along supply chains is more complex than generally anticipated. And it is also not easy to quantify the expected benefits of RFID integrated systems since many are strategic and intangible. Therefore, in this study a fuzzy rule-based system is proposed to calculate the revenue increase of an RFID integrated system. And the Monte-Carlo simulation method is used to calculate the expected net present value (NPV) of an RFID investment.

This paper starts with the review of relevant literature about RFID implementations and fuzzy rule-based systems. Section 3 provides an overview about the analysis of cost and benefits of RFID investments. The real life problem that the authors dealt with and the model proposed due to this problem are introduced in Sections 4 and 5, respectively. In the following section, the fuzzy rule-based system is presented. In Section 7, the results of the Monte-Carlo simulation are analyzed and discussed. Finally, Section 8 presents the conclusions and outlines further research.

2. Literature review

Since RFID technology has recently received an emerging attention, there is a growing literature on RFID technology. Several researchers have examined the impact of RFID technology on inventory and supply chain management. In general, literature containing an analytical assessment of RFID technology is fairly limited; the research studies have mainly focused on the inventory function and the effect of taking inventory discrepancies into account. However, some studies have concentrated on cost-benefit analyses of RFID implementation. In this context, Delanuay, Sahin, and Dallery (2007) classify the errors causing inventory discrepancies in supply chains and defined four types of errors. The first is permanent shrinkage in the physical stock due to theft, obsolescence, or breakage. The second is misplacement, which is temporary shrinkage in the physical stock that can be replaced after every counting or after every period. The others are the randomness of the supplier yield and the transaction type. The random yield of the supplier is a permanent loss or surplus in the physical inventory due to supplier errors, and transaction type errors affect the information system differently than the first three errors, which modify the physical inventory. Most studies in this area use the simulation method to measure the effects of inventory inaccuracy on supply chain performance. Kang and Gershwin (2005) use simulations to emphasize the problem of shrinkage in physical inventory that may increase lost sales because of items being unexpectedly out of stock. They find that with an error rate of theft as small as 1% of the average demand, the disturbance led to 17% of demand lost. Fleisch and Tellkamp (2005) examine the relationship between inventory inaccuracy and performance in a retail supply chain, considering more error types than the previous study. They simulate a three echelon supply chain with one product in which end-customer demand is exchanged between the echelons, and studied how incorrect deliveries, misplacement, theft, and unsaleable goods affect inventory inaccuracy, the out-of-stock level, and the costs related to inventory inaccuracy. The results of the study show that inaccuracies caused by theft appear to have the biggest impact on supply chain performance compared to inaccuracies caused by unsaleable goods or low process quality. They propose using RFID technology to reduce the impact of inventory inaccuracy. Lee, Cheng, and Leung (2004) use simulations to study the effects of inventory accuracy on inventory reduction and level improvement in a three echelon supply chain considering the (s,S) policy decisions, unlike other studies. They find that using RFID technology, average inventory held decreased by 16%, and total back orders decreased by 22% when the (s,S) policy decisions are made with accurate inventory information. Wang, Liu, and Wang (2007) carry out a simulation to evaluate the impact of an RFID system on inventory replenishment of the TFT-LCD supply chain in Taiwan. The results indicate that the RFID-enabled pull-based supply chain could effectively achieve a 6.19% decrease in the total inventory cost and a 7.60% increase in the inventory turnover rate. Some researchers have also dealt with the optimization of inventory systems considering data inaccuracies. Rekik, Sahin, and Dallery (2008) optimize an inventory management model by considering a single period Newsvendor problem with inaccuracies in the inventory. They compare three approaches. In the first approach, the retailer is unaware of errors in the store. In the second approach, the retailer is aware of the errors and optimizes its operations by taking this issue into account. The third approach deals with the case where the retailer deploys an advanced automatic identification technology such as RFID to eliminate errors.

A few studies have focused on cost-benefit analyses of RFID systems. Kok, Donselaar, and Woensel (2008) compare the cases with and without RFID in terms of costs. In this study, an analytical model is built which calculates the break-even prices of an RFID tag. It is shown that these break-even prices are closely related to the value of the lost items, the shrinkage fraction, and the remaining shrinkage after implementation. Bottani and Rizzi (2008) quantitatively assess the impact of RFID technology and EPC systems on the main processes of the fast moving consumer goods (FMCG) supply chain. A three-echelon supply chain was examined, composed of manufacturers, distributors, and retailers using FMCG. A feasibility study was carried out using the data from a questionnaire survey. Results of the feasibility study show that RFID and EPC implementation was still not profitable for all eche-