DECISION ANALYSIS PROCESS MODEL FOR ALTERNATIVE TECHNOLOGIES EVALUATION WITHIN WAREHOUSING APPLICATIONS

A Thesis by

Olena Kolyesnik

Master's in Electronics and Telecommunications Engineering, National Aviati
University (Ukraine), 2004

Bachelor's in Electronics and Telecommunications Engineering, National Aviation
University (Ukraine), 2002

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I have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science with a major in Industrial Engineering

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Lawrence Whitman, Committee Chair

We have read this thesis
and recommend its acceptance:

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Don Malzahn, Committee Member

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Sue Abdinnour-Helm, Committee Member

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ABSTRACT

Led by competition, companies strive for competitive advantage. Accepting the value-based holistic concept of the supply chain, organizations realize the importance of increased communication flow and availability of information at any time and at any point of the supply network. Toward this end, companies are becoming more interested in automatic identification and data collection (AIDC) technology, such as radio frequency identification (RFID), which can greatly increase supply chain visibility. This thesis presents the identified issues in identification and presents the method for decision analysis for companies considering the most appropriate technology for their warehousing operations.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In today's competitive world, companies strive to achieve and keep their leadership in the market by continuously improving all stages of the supply chain. Led by their desire for improvement, companies make investments in the newest IT tools and systems.

Radio Frequency Identification (RFID) is a type of Automatic Identification Data Collection (AIDC) information technology which can provide a competitive advantage required by sophisticated supply chain management operations. Enterprises exploit RFID to develop faster supply webs which can bring cost-effective returns and greater visibility throughout the value chain. "An RFID system can be considered a wireless communication system" where "the scanner communicates with the tag by using electromagnetic waves at radio frequencies" (Keskilammi as cited in Horowitz, 2005, p.6). Proven business advantages of RFID include: labor and time reduction, increased operations accuracy, reduced inventory levels, reduced storage, handling, and logistics expenses.

Despite all the benefits of RFID, companies sometimes fail to leverage their investment in this kind of IT. Therefore, there is still an emerging need to develop new methods and techniques for implementing communication technology which would help companies make appropriate decisions about its fitness and use for particular purposes.

1.2 Thesis objective

Companies often work in an unpredictable environment suffering from the lack of communication between the components of the value chain. The objective of this thesis is to develop a decision process model to select communication technology to increase supply chain visibility. This model will help companies to define possible improvements to existing operations by implementing an appropriate type of communication method (technology).

1.3 Environmental analysis

To understand and analyze the current condition in which existing business supply chains operate, a SWOT analysis is presented on Figure 1.1, which explains strengths, weaknesses, opportunities and threats that supply webs are facing. Later, the current and desired conditions together with obstacles, strategy for reaching the desired state, and objectives that guarantee the realization of the given strategy are discussed on Figure 1.2.

1.3.1 SWOT analysis

This section explains strengths, weaknesses, opportunities, and threats associated with isolated supply chain members. An analysis of internal and external environment gives a clear understanding of the existing situation; it also defines areas of improvement related to the thesis.

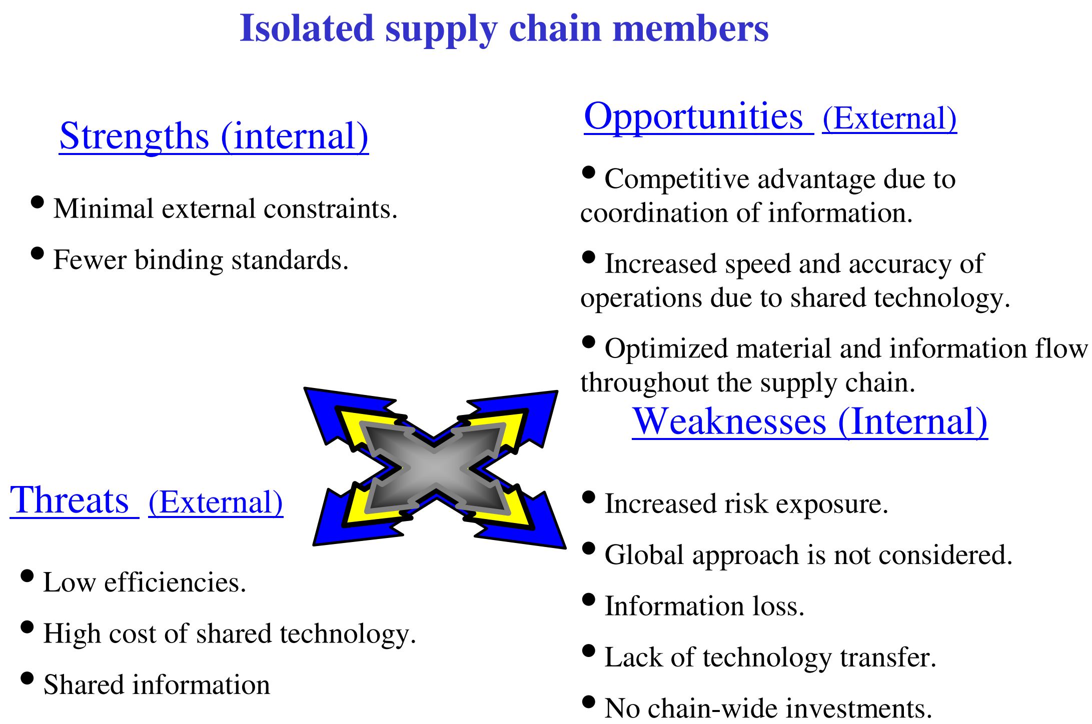

Figure 1.1 SWOT analysis of the isolated supply chain members

Strengths: The most important strength of isolated supply chain members is that they are not much affected by external constraints. This enables the strength of having fewer binding standards.

Weaknesses: Typically, isolated supply chain members have an increased exposure to numerous kinds of risk because of poor communication between supply partners. Lack of shared data and information loss are frequent throughout the chain. Often existing communication technology is not properly transferred between organizations. Each member of a supply web is concerned only about their own successes not considering global supply chain. Hence, isolated supply chain members do not make chain-wide investments.

Opportunities: Companies involved in a supply chain do not operate effectively as they are isolated. They fail to provide information at any point at any time through the supply chain. Therefore, there is a need for communication methods (technology) that address limitations of isolated supply chain members. Information availability would help to optimize material and information flow throughout the value chain. Communication technology shared chain-wide would increase the speed and accuracy of operations which is essential for the level of customer service. Coordinated information along with high speed and accuracy of operations will provide a company with a competitive advantage by increasing visibility through the web and decreasing exposure to supply chain risks.

Threats: One of the biggest threats of isolated supply chain partners is the high cost of shared technology. While some members can be benefited by new technology, others might still have doubts about getting sufficient return on investment (ROI). Operating in a vulnerable environment, isolated supply chain partners have a big threat of having low efficiencies due to lost sales (because of out of stocks), low customer service, inaccurate inventory audits, and lack of visibility to replenish the right product to the right place at the right time. Shared information is another threat of isolated supply chain members. With existing tools of capturing and distributing the data, companies fail to guarantee confidence that the right data is delivered to the right parties.

1.4 Thesis road map

This section presents the road map for the thesis. It describes the current and desired situations in the supply chain and obstacles that prevent the existing condition to reach the goal. The strategy for overcoming defined obstacles and achieving the desired condition is presented. The objectives, which are the steps for accomplishing the strategy, are described in the following section as well. Figure 2 introduces this road map.

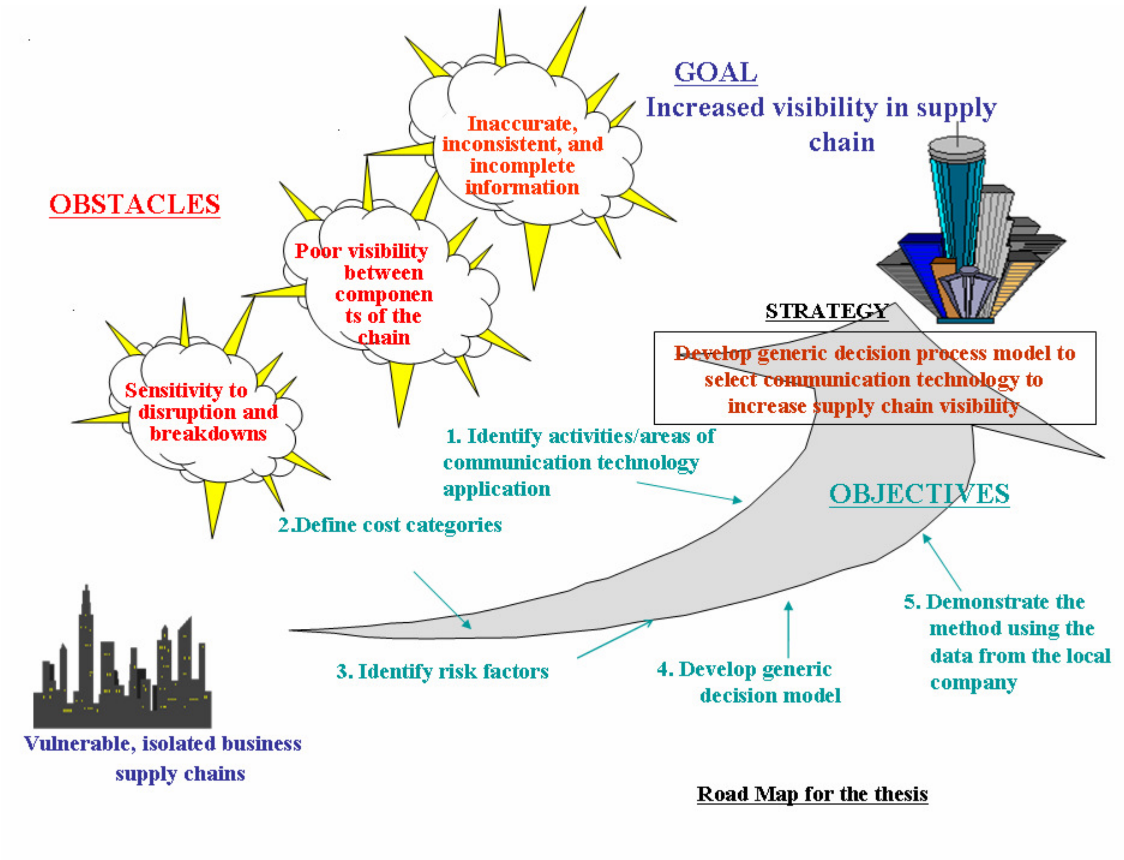

Figure 1.2 Thesis road map

1.4.1 Current condition

Modern supply chains are exposed to serious disturbances due to existing internal and external risks, which result from a lack of visibility making the supply chain more vulnerable to disruption. Another issue is that sometimes weaknesses of the system are not diagnosed on time because its parts are considered in isolation and not as part of the global supply chain.

1.4.2 Desired condition

Developing quality products/services on time is not only the objective of business success. A very valuable part of it is timely and accurate information available at any time and any point of a supply network. Therefore, the goal of each member of a supply chain is to increase visibility into their processes and measures which can help them better manage and improve operations making the system more resilient.

1.4.3 Obstacles

The obstacles that prevent the current situation from reaching the goal are described in the next section.

Sensitivity to disruption and breakdowns: Over the last ten years society has seen many unpredictable disasters. They include terrorist attacks, wars, earthquakes, economic crises, devaluation of currencies, computer virus attacks, etc. (Tang, 2006). Both natural and man-made disasters have exposed the vulnerabilities of business supply chains making them more sensitive to any kind of disruption and breakdowns.

Poor visibility between components of the chain: Lack of real-time information on all phases of inventory (on-hand, shipped, awaiting shipment, and received quantities) is a result of poor visibility of inventory. Current inventory levels tend to be bloated as a result of poor visibility into demand flowing through the supply chain. By making upcoming demand transparent to the suppliers, a company will be able to lower all of its costs and run a far more efficient supply chain.

Inaccurate, inconsistent, and incomplete information: While traveling through the supply network, goods are often exposed to unfavorable conditions such as shock, vibration, extreme environments, and mishandling. They can damage not only the product itself, but also its label containing consistent information about a product's identity, origin, destination, and other relative data. Another issue is that poor inventory information accuracy results in improper replenishment decisions, leading to out-of-stock and back orders and consequently lost sales and lower customer satisfaction.

1.4.4 Strategy

After the current and desired conditions were discussed, and obstacles were identified, a strategy is now presented as a next step to overcome obstacles preventing the current situation from becoming desired. The strategy is to develop a decision process model to select communication technology to increase supply chain visibility.

1.4.5 Objectives

Objectives are the steps for the strategy accomplishment, satisfying all the objectives helps in achieving the desired state. For this thesis, the objectives were identified as the following: identify relative activities to the processes to be analyzed; define relative cost categories; identify risk factors; develop generic decision model; demonstrate the method in the case study using data from a local company. The following paragraphs give more detailed explanation of each objective.

Identify activities/areas of communication technology application. Activities relative to considered processes, made general in current supply chain practices, will be identified. The most common processes will be chosen after studying reference material and observing processes performed at a local company. This will be accomplished in chapter 3.

Define relative cost categories: Cost categories for different kinds of technologically enabled processes along with paper-based processes will be identified in chapter 3. Cost categories will include costs related to initial investments and operational expenses.

Identify risk factors: Supply chain risk factors have to be identified and characterized in order to evaluate each type of communication technology. There will be defined risks specific to the chosen processes as well as risks affecting all processes throughout the value chain in chapter 3.

Develop generic decision model: With the use of information gathered in chapter 3 and decision tools, a generic decision model will be developed. It will help a decision maker to identify an appropriate technology (method) to increase visibility into company's processes. The model will be included in chapter 3 and reviewed by two experts.

Demonstrate the method using data from a local company: A local company will be visited and performed processes will be observed. The developed generic model will be applied to the company's processes, and possible results will be demonstrated in a case study in chapter 4.

1.4.6 Road map summary

This part of the thesis introduced the current position of inefficient isolated business supply chains as well as the goal which they strive to achieve. There are obstacles introduced which are barriers on the way of reaching the goal, and a strategy presented to overcome those obstacles. Five objectives that will fulfill the presented strategy were explained in this section.

1.5 Thesis report organization

The second chapter will include the literature review related to the thesis. It will explain the causes of inefficiencies of isolated supply chain members; will define the need for the increased visibility in supply chain. It will also give background information about supply chain, its structure, supply chain risks, typical processes performed in logistics applications. Several kinds of communication technology and their performance will be described in this chapter as well. The third chapter will introduce the generic decision model that can be used to select communication technology.

In chapter 4, results of the research will be introduced. The company is Airtechnics Inc. in Wichita, Kansas which will be used for demonstrating the method developed in chapter 3. Chapter 5 will give an overall summary for the thesis and will define future work in this area.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

To deliver the right product to the right customer at the right time is essential for the success of every industry. One of the most critical parts of this objective is the availability of timely and accurate information at any time and at any point of the supply chain. By achieving a complete visibility into processes, companies will be able to make the right decisions to overcome problems, such as high inventory levels, long lead times, and poor information sharing between components of the chain.

Information technology (IT) is a major enabler toward increasing supply chain visibility. Inspired by recent IT capabilities, companies invest a lot of resources in the newest tools and systems. Frequently, they fail to consider a detailed cost/benefit analysis before making the investment. As a result, they either do not gain expected efficiencies or the return on investment (ROI) is not leveraged in a particular time frame (Ryan, 2002). Therefore, organizations need to consider all the benefits and shortcomings of existing technologies to choose the most appropriate one.

2.2 The traditional view of the supply chain

A traditional supply chain integrates all the processes related to materials and information transfer from suppliers of raw materials to the point where finished goods are sold. The definition formulated by Whitman et al. (1999), states, “A supply chain is a web of autonomous enterprises collectively responsible for satisfying the customer by creating an extended enterprise that conducts all phases of design, procurement, manufacturing, and distribution of products.” Even though the exact interpretation of this term may slightly vary for different industries, the major elements mentioned above are common for any supply chain.

According to Markland et al. (1995) as cited in Ryan (2002) the traditional model of the supply chain involves three major components: the supplier network, the manufacturing unit, and the customer network. The supplier network includes vendors or suppliers responsible for delivery of orders (products or services) to the customer (organization). The manufacturing unit includes organizations performing conversion of raw materials into finished goods. The customer network involves the end customer which includes the distribution center, wholesaler, and consumer of finished goods. In the traditional view of a supply chain, all members are considered to be isolated, which means that each link is performing independently from other components, sharing very little information.

Poor communication between supply chain components leads to several bad consequences, such as inaccurate and incomplete information passed on from one member to another and poor visibility throughout the chain that may result in the inability to deliver products or services to the right place at the right time with the right price. Unavailability of “real-time” information results in increased risk exposure of isolated supply chain components which makes them more sensitive to different kinds of disruption and breakdowns. Therefore, it is clear why the traditional view of the supply chain and its components as distinct functional elements has been criticized by many authors. Instead, they recommend thinking “about supply chain as a whole –all the links involved in managing the flow of products, services, and information from their suppliers’ suppliers to their customers’ customers (that is channel customers, such as distributors and retailers)" (Anderson, Britt, and Favre, 1997). The same authors claim that the success of supply chain management can be measured by how well activities are coordinated across the supply chain to make each link the most profitable while increasing the customer service level.

2.3 Coordination and integration of the supply chain

Mentzer, DeWitt, Keebler, Min, Nix, Smith, and Zacharia (2001) introduce the definition of the supply chain management as, "the systematic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across business within the supply chain, for the purposes of improving the long term performance of the individual companies and the supply chain as a whole." With this definition, the authors suggest that a modern supply chain must be integrated both within each company and across organizational boundaries. In addition, Searcy, Greene, and Reeve (2004) note that the coordination within the organization is logically followed by global coordination, "facilitating change is often easier within the four walls of ones own organization than across organizational boundaries." The authors also note that intra-organizational coordination "may be one of the most difficult aspects of supply chain management" (Searcy et al., 2004). Hence, firms must understand the fundamental dynamics of supply chains and realize the importance of both kinds of organizational coordination.

Increased communication flow is extremely important to the most effective supply network performance, which can be achieved by the integration and coordination of all the links of the supply chain. Coordination of activities across the supply chain adds value for the customer as well as makes other members more profitable (Anderson et al., 1997). Activities which are incorporated in a modern value-based chain usually relate to sharing information with suppliers and customers, newest information technology, and more personalized services for customers (Ryan, 2002). The more value-added activities are included, the greater the competitive advantage of each company which is the aim of every business.

2.3.1 Information sharing- basic enabler of tight supply chain coordination

There are numerous situations when immediate information needed for a company's effective supply chain management is located within a different company's system. Unfortunately, despite efforts, many companies still remain enterprise-bounded, unable to share information essential for common success. Anderson et al. (1997) gives an example of one such company, one of the major beer manufacturers which decided to track its performance from plant to warehouse. The result was very satisfying: a fill rate of 98 percent, but downstream the supply chain performance was not so good. Twenty percent of the time retail locations were out of stock because of the poor store-level replenishment. The manufacturer now is in a rush to employ "real-time" information technology to get information that is essential to improving customer service.

This example justifies one of the principles of supply chain management defined by Anderson et al. (1997): "Develop a supply chain technology strategy that supports multiple levels of decision making and gives a clear view of the flow of products, services, and information."

Information sharing was recognized as a major enabler of the coordinated supply chain, and it has been speed up by recent advances in information technology (Lee & Whang, 2000). Even though it is a fact that a supply chain which makes decisions based on globally shared information is dominating the supply chain accommodating isolated members, it is not always easy to achieve an effectively integrated supply chain. One of the biggest hurdles is significant investments that have to be made for information to be shared, so that all the entities throughout the supply web can be effectively coordinated. Recent cost-effective information technologies (IT) include: client-server architecture, relational DBMS (data base management systems), ERP (enterprise resource planning), EDI (electronic data interchange), object- oriented programming environments, wireless communications and the Internet (Lee & Whang, 2000). The most effective ways of implementing these technologies for the coordination of the value chain elements promotes the latest advances in supply chain management.

2.4 Information technology (IT) and supply chain visibility

Many companies have realized that increased information flow can be facilitated by the recently increased information technology capabilities. As a result, they invest more in different kinds of IT in order to add to their information management more accuracy and speed. “Information technology incorporates hardware and software components that collect and analyze data in order to manage the flow of information . . . . The investment in technology helps to build value through better logistics services that are required by customers” (Ryan, 2002).

One type of IT which can improve speed and accuracy of operations across the supply chain is automatic identification and data collection (AIDC). AIDC is “a broad term that covers methods of identifying objects, capturing information about them and entering it directly into computer systems without human involvement” (“Glossary of Terms”, 2007). There are several kinds of AIDC technology, such as: barcodes, radio frequency identification, voice and optical recognition, smart card technology, and biometrics. In the scope of the thesis, though, only two kinds are considered: barcodes, as the most widely used technology, and RFID, as an emerging new technology that is expected to be the leader in the market of auto-ID technology.

2.4.1 Bar codes

Barcode technology is an optical type of AIDC that allows fast, simple and accurate data entry and data collection (Keenen, 2000). From the moment the barcode information is scanned by the barcode reader (scanner), information about an activity can be monitored in real time at a greatly increased speed comparing to manual data entry. Barcodes are highly accurate: "studies show that the entry and read error rates when using bar code technology is approximately one error in one million characters, vs. one error per every 300 characters using manual key entry" (www.zebra.com, 2007).

The first barcodes were in use in the 1950s, commercialized in the 1960s, and then gained more popularity as the Universal Product Code (UPC) was used in the grocery industry in the early 1970s ("The magic of Bar Codes.", 2001). Nowadays, barcode devices supported by new technology are employed by many companies in manufacturing, healthcare, retail, distribution and fulfillment, education, travel, and security. Barcodes consist of black and white lines or so-called "bars" which contain data, such as a serial number, part number, quantity, transaction code, and other. A variety of barcode standards for their graphical images are known as symbologies which are used by different industries according to their specific requirements. There are over 250 types of barcode symbologies with their unique attributes, but only several dozens are currently used (Keenen, 2000). The most common barcode symbologies are: linear and two-dimensional which are illustrated in figures 2.1 and 2.2.

Figure 2.1- Linear barcode (Source: www.zebra.com)

Figure 2.2- 2-D barcode (Source: www.zebra.com)

Linear barcode symbology contains black and white lines with the specified width and height. 2-D barcode symbologies can store huge amount of data by stacking linear barcodes (stacked symbologies), by combining different elements in a pattern (matrix symbologies), and by randomly combining different linear symbols (packet symbologies) (Ryan, 2002). For AIDC applications, barcode systems contain four major components: a barcode printer, a label, scanning equipment, and an external database. To derive data from the barcode, the label is scanned with an electro-optical system (scanner) by illuminating the label and analyzing the reflected beam. This data then is converted from analog to digital, processed by a decoder and sent to a software system (Ryan, 2002).

2.4.1.1 Benefits of bar coding

Keenen (2000) identified several advantages intrinsic in the nature of barcode technology: a) long-proven technology, b) unique identification for each record or object, c) one-to-one correspondence between records and metadata, d) ability to rearrange the metadata, e) improved information lifecycle and inventory management, f) space management improvements, and g) cost savings.

The disadvantages of bar coding will be described in section 2.4.2 while comparing RFID with barcodes.

2.4.1.2 What barcodes can do

Activities and functions that barcodes are used in were defined by Keenen (2000) as the following. In identification and tracking, barcodes can derive information, such as: a) what the item is; b) its characteristics (size, shape, weight, fragility, and storage requirement); c) current location; d) all previous locations; e) where it is going next; and f) large-scale movement.

In storage and lifecycle management, a barcode reads from locations, so shelved products can be used to get information about how the storage is used, how much free space is left in the facility and how quick the process of filling is (Keenen, 2000).

Barcodes can also be used for quantitative measurement which gives information about what types of records are held, percentages of overall holdings, and customer date. This process is prone to human error that can result in poor searching parameters, wrong information about usable shelf space, skewed results, and failure to verify actual holdings periodically (Keenen, 2000).

Barcode is a universally accepted, solid, and easy to use technology. It provides the best cost-effective and customer-friendly results for traditional lifecycle management when used to the fullest extent as part of an integrated program (Keenen, 2000).

2.4.2 Radio Frequency Identification (RFID)

Radio frequency identification is a type of AIDC that is gaining popularity between technologies of this kind and attaining broad interest of many companies from different industries. Similar to barcodes, RFID uses labels and scanners to extract data and is supported by IT systems which relate scanned information with a database system. The difference is that a scanner communicates with the tag (label) using electromagnetic signals at radio frequencies.

2.4.2.1 Advantages of RFID over bar coding

Gaucler (2005) identified the advantages of RFID over bar codes as: a) contactless and remote interrogation, b) no line of site required, c) multiple parallel reads possible, and d) individual items can be identified instead of an item class. The author gives an example of replacing bar codes with RFID for receiving operations in a warehouse. If RFID is used there is no need to interrupt the flow of goods by breaking the pallet, open the cases, and scanning each product because all products with tags can be identified by the RFID reader almost at the same time. Another advantage of RFID tags over bar codes is that they are more reliable and accurate than bar codes: they withstand and operate in harsh environmental conditions and can be read through different substances, such as grime, dust, or grease (Aichimayr, 2001).

A comparative analysis of RFID and barcode properties was done by Pentilla, Engels, and Kivikoski (2004); and the results are summarized in Table 2.1.

Table 2.1. A comparison of Current RFID and Barcode Technology (Source: Pentilla et al., 2004)

Parameter	Passive RFID	Barcodes
Security level	High	Low
Identification range	0.5-10 m	Few centimeters
Identification rate	Fast	Slow (human controlled)
Simultaneous multiple object identification	Yes (with an anti-collision algorithm)	No
Requirement of line of site	No	Yes
Identifier's resistance against hard environmental conditions	Yes	No
Utilization at the vicinity of metal	Yes (with specific antenna designs)	Yes, possible reflections and rereading required
Utilization in water	No (absorption and reflection of the field)	No (reflections)
Global standardization	No	Yes
Identifier's memory sizes	From few tens of bytes to several Kbytes	Few tens of bytes
Identifier's cost	Relatively low ($0.5)	Low ($0.01)
Interrogators' cost	High ($ 100-8000)	Low

2.4.2.2 The History of RFID

The first predecessor of RFID technology, radar, was invented in 1935 by Scottish physicist Sir Robert Alexander Watson-Watt. The purpose of the radar was to notify about approaching airplanes when they were still far away. The first passive RFID system was discovered by Germans: to distinguish their own planes from the enemies'. The pilots rolled their planes after they came back. This action changed the reflected radio signal sent by the radar, so the ground team could distinguish that the discovered airplanes were German ("The History of RFID Technology", 2007).

Another, more advanced RFID technology, which gained popularity in 1960s, was electronic article surveillance tags. They were used as anti-theft systems in stores: if a person paid for the purchase, the tag was deactivated; but if someone was trying to go out of the store without paying, readers, located on the exit doors, detected activated tag and sounded an alarm (“The History of RFID Technology”, 2007).

2.4.2.3 RFID Patents and Standards

The first U.S. patent for an active rewriteable RFID tag was given to Mario W. Cardullo on January 23, 1973. The same year, Charles Walton, received a patent for a passive tag which was imbedded in a plastic card and used to unlock the door (“The History of RFID Technology”, 2007). In the 1970s Los Alamos National Laboratory developed a tracking system to monitor the movement of nuclear materials. Tags were placed in transportation trucks and were captured by readers on the entrance gates of facilities. Later, in the 1980s, scientists from the same laboratory organized a company which developed automated toll payment systems (“The History of RFID Technology”, 2007).

In the beginning of the 1990s, IBM developed and received a patent for an ultra high frequency (UHF) RFID system. Due to financial difficulties at that time, IBM sold its patents to Intermec. RFID systems by Intermec were used in different applications, but did not have much success because of the high cost of technology and lack of general open standards. In 1999, the Uniform Code Council, EAN International together with Procter & Gamble and Gillette formed the Auto-ID Center at the Massachusetts Institute of Technology. Researchers were working toward lowering the costs of RFID technology which made it more accessible for different industries and businesses. The auto-ID Center developed air interface protocols, Electronic Product Code (EPC) numbering scheme, and a network to connect an object to the Internet through the attached tag (“The

History of RFID Technology", 2007). The Auto-ID center was closed in 2003, but the research work was passed to Auto-ID Labs. The same year, the Uniform Code Council received a license for this technology and jointly with EAN International created EPCglobal, an organization devoted to speed up adoption and standardization of EPC technology. Another important player in establishing standards for EPC is the International Standards Organization (ISO) which has developed RFID standards for automatic identification and item management. These standards are known as ISO 18000 series and include frequencies used worldwide: 135 KHz, 13.56 MHz, 2.45 GHz, 5.8 GHz, 860-930 MHz, 433.92 MHz ("The History of RFID Technology", 2007).

EPCglobal's Generation 2 (Gen 2) is the newest specification for UHF tags which was developed for high volume supply chain users. Gen 2 is currently reviewed to be submitted as ISO 18000-6 standard which will give the opportunity to have one general open standard ("The History of RFID Technology", 2007).

For most supply chain applications, which require longer reading distances, UHF frequencies (860-930 MHz) are the best fitted. Although, RFID systems that use lower frequencies and have a shorter reading range can communicate through water and nonconductive materials (Pentilla et al., 2004).

2.4.2.4 Components of RFID System

The major parts of RFID infrastructure include a tag which stores and distributes information, and a reader that reads and sometimes writes to a tag. The tag consists of an antenna which transmits and receives radio signals, and an integrated circuit that stores data as shown in Figure 2.3. The reader contains an antenna and a demodulator to accept incoming signals and convert them to a digital form accordingly. Further, digital information is processed by a host computer and linked with the enterprise information system which is incorporated to implement business rules (Phillips et al., 2007).

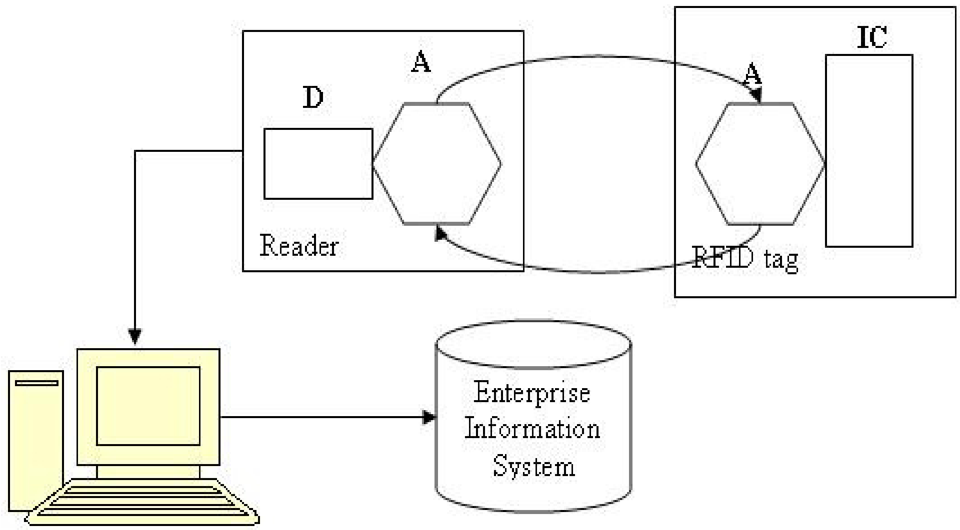

Figure 2.3- Radio frequency identification system

RFID technology has multiple applications depending on the type of a tag and a reader. Tags are classified according to the way they are powered: they can be active or passive. Passive tags derive the power for their operations from an electromagnetic field generated by the reader. The tag's antenna store captured energy in a capacitor, and then uses it to power an integrated circuit and to reflect a signal to the reader on a different frequency (Phillips et al., 2007). Active tags are powered by their own batteries which are also used to transmit a reflected signal back to the reader. They are more complex and expensive than passive tags and have limited lifecycle (due to batteries). Active tags are interoperable with more sophisticated information technology and can be used for increased data storage (Phillips et al., 2007).

Other parameters that characterize RFID technology are: communication range, read/write capabilities, and operating frequencies. Communication range is a minimum distance at which the reader is able to communicate with the tag. Read/write capabilities are defined by the type of the tag: either tags are read-only or they may accommodate writable memory (Data Processing Working Party, 2005). Operating frequencies for RFID systems vary between 135 KHz and 5.8 GHz.

2.4.2.5 Cost of RFID technology

Results of the overview of prices for RFID components, presented on the RFID Journal website ("RFID System Components and Costs", 2007) are summarized in Table 2.2.

Table 2.2. Prices for components of RFID technology

Component	Price	Depends on
Passive tag	0.2- several dollars	Frequency, amount of memory, antenna configuration, packaging around the tag
Active tags	\$10- \$50 or more	Size of battery, housing around the tag, amount of memory
Dumb UHF readers	\$500	Computing power
Intelligent UHF readers	\$500- \$3000	Computing power and data filtering
Agile UHF readers	\$500- \$3000	Protocols to communicate with the tag
Multi-frequency readers	\$3000	Operating frequencies

2.4.2.6 Issues related to RFID and its implementation

Reader collision problems are caused by interference of two or more signals which results in the RFID reader's inability to communicate with the tag within its interrogation zone (Pentilla et al., 2004). Reader-to reader collision takes place when signals from two readers interfere, which prevents the readers from functioning. Reader-to-tag collision occurs when the tag is placed in the interrogation zones of two or more readers which are simultaneously trying to catch tags signals. This may result in inefficient tag communication or a fault in identifying the tag (Pentilla et al., 2004).

Other issues resulting in very few wide-scale applications of RFID tagging were identified by Karkkainen (2003): a) the lack of systems interrogators; the lack of commencement related to sharing cost and benefits; and the lack of a common global standardization.

2.5 Warehousing. Inventory visibility

Inventory management deals with maintaining of stocks located through the supply network (Ballard, 1996). Warehouses are intermediate links connecting the manufacturing unit with the customer network. Inventory monitoring and measurement take place at this point as well as at other locations through the chain. Besides, warehouse management systems (WMS) provide an overall inventory control system with information about warehousing process, as these systems are naturally linked (Ballard, 1996). This data enables inventory managers to take corrective actions beneficial for the whole supply network.

2.5.1 Components and functions of warehousing

According to Ackerman (1990) there are three major resources incorporated into warehousing activities: space, equipment and people. There should be enough space for the smooth flow of goods, dynamic operations, and for equipment accommodation. Warehousing equipment consists of material handling devices (forklifts, conveyors, racks), and hardware and software systems used in warehouse management.

Bowersox and Closs (1996) define the fundamental functions of warehousing as movement and storage. Movement includes such activities as receiving, in-storage handling, and shipping. Storage can be planned or extended. All the activities associated with movement related to the handling of goods from the point of their arrival to the final shipment to the customer.

The second fundamental function of warehousing, storage, is related to the basic replenishment of inventory, which is planned storage; and excess of inventory not used in everyday operations which is extended storage (Bowersox et al. 1996).

2.5.2 Inventory information to be monitored and measured

Warehousing deals mostly with physical material handling and control. Nevertheless, warehouse managers have to know not only information about the location of an item, but also to maintain information about it at any point of time and place. Therefore, material flow and information flow are equally important for successful inventory management. "The monitoring and measurement of stock has to take account of both physical location and time. The loss of information on one of these results in degradation in the other" (Ballard, 1996).

According to Ballard (1996), inventory information that has to be monitored and measured, and can be divided into three categories: fixed, variable, and derived.

Fixed information assumes that information about the stock keeping unit (SKU) does not change often or does not change at all. It can include: product code, description, batch number, size, weight, storage/handling type, minimum pack quantity, picking priority, preferred store area or zone, secondary store area and zone.

Variable information –this information is about dynamic aspects which can change as often as several times per working day. It includes: unique identity of each unit loaded in stock (such as pallet number), location of each unit load, quantity of SKU's in each location, movement of each picked item, and load status.

Derived information can be obtained by analyzing fixed and variable information. It may include: movement rate per SKU, stock discrepancies, space utilization in the store, and operator productivity.

2.5.3 Warehouse data collection

All the information described above can be collected in different ways by different organizations. Some might still use a card index or paper system for some warehousing operations; others are using the most sophisticated computerized systems. Ballard (1996) described several available options for warehouse data collection as the following:

Spreadsheets and database packages. Databases are usually used to store fixed information. Both spreadsheets and databases are very useful in obtaining the derived information. The disadvantage of these methods is that they are not very good at maintaining variable information, especially at the times of the most intense activity, peak periods, information is most likely to be out of date. In addition, spreadsheets are very sensitive to human error.

Additions to inventory control software. This kind introduces additional modules to the existing inventory control software. They are applicable for the selection of put-away locations and some inventory tracking, but have certain limitations while attaining variable or derived information. Also, it can be valuable for the proper inventory monitoring if combined with other information systems.

Warehouse management software. The proper warehouse management system is the way to provide the most effective monitoring and measurement. "Warehouse management systems are designed to monitor the process of the warehouse operation, they measure what has happened as soon as it has happened and provide immediate access to the new information" (Ballard, 1996). They usually accommodate a communication technology to exchange information with the other management systems or to compare warehouse stock with the master record in the inventory system. There are two basic enablers:

Batch with paper lists. This system provides workers with instructions for different activities (such as put-away, picking and replenishment) in the form of paper lists. Confirmation about completing the action has to be done by manual data entry which makes process of monitoring delayed, because information is updated not right in the moment. Except for this disadvantage, a warehouse management system is good at keeping fixed information, recording variable information, and obtaining derived information.

Radio frequency communication. The deployment of radio frequency devices with warehouse management systems provides the most updated information and reduces operator errors. Workers receive instructions on the radio data terminals (RDTs) after confirmation of completion of the previous task. This allows real- time information in the warehouse management system which makes processes to be performed and measured with the greater accuracy.

Warehouse automation is applied with real time warehouse management systems for the monitoring the process but not for the stock count. Nevertheless, information is updated up to the second and available at any time (Ballard, 1996).

2.5.4 RFID in a warehouse

Many organizations have admitted that even though they have all the tools for successful business they still have troubles with an accurate tracking and monitoring of the large number of SKUs: "According to Symbol Technologies, poorly managed inventory causes millions of dollars in lost inventory and returns each year" (Aichimayr, 2001). Many experts claim that RFID is a cost-effective technology which saves time, improves visibility, and reduces labor costs for such warehousing operations as shipping, receiving, and inventory management.

Aichimayr (2001) identified two major applications of RFID technology: real-time locating systems (RTLS) and wireless local- area networks (LAN). RTLS allows tracking of tagged inventory through the facility by detecting the presence and location of tags. LANs operate on a bigger scale than RTLS. They are used by warehouse personnel to communicate data with the central database.

After a deep investigation in current warehousing practices, LXE Inc. came up with the general picture of RFID applications in the warehouse, which they introduced in the white paper "Mobile RFID Advantages" (2005). Figure 2.4 reflects the result of their investigation.

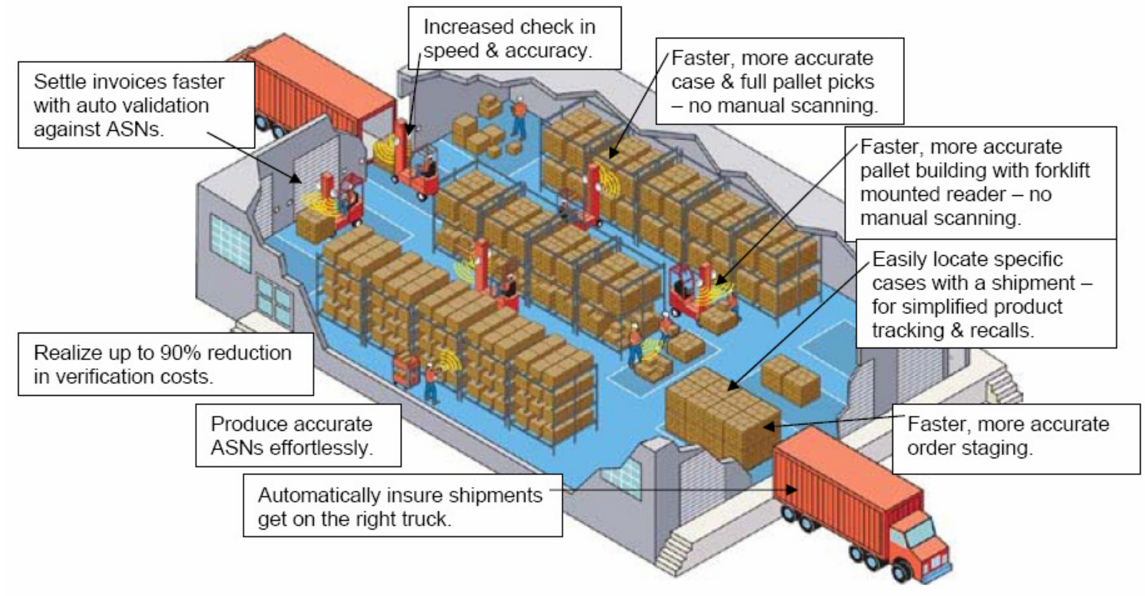

Figure 2.4- Benefits of a mobile RFID in distribution/warehousing (Source: www.lxe.com)

In receiving, the fixed reader on the dock door or a forklift mounted reader automatically identifies tags located on pallets while pallets are unloaded. Scanned information is then transmitted to the WMS to update its database. Processed information which is sent back defines items that should be cross-docked and those that go to storage.

In put away operations, RFID relates received products with their actual put away location. After cases or pallets are in the proper place, the location is automatically recorded by reading the permanent location tag and case or pallet tag.

In picking, products are automatically recorded by a reader while they are picked. Each picked item is checked by the WMS to confirm it to the purchase order and associate with the pallet which the item is placed on.

In shipping, RFID tagged inventory can be read by a fixed, vehicle-mounted, or handheld reader. Scanned data is matched by WMS with the customer order to validate quantities. The read data can also be used to provide information for an advanced shipping notice (ASN) and to settle invoices with auto validation against an ASN. RFID can also validate the truck that shipments are loaded on, if it is equipped with RFID tag.

Medis Health & Pharmaceutical Services Inc. implemented an electronic radio frequency communication system to track movement of goods on pallets, in totes, and on conveyors in fourteen of their warehouses (Aichimayr, 2001). As a result, the company increased the processing volume of each warehouse, increasing the accuracy of receiving, put away, and replenishment to about 99.9%. Other benefits Medis gained from this implementation were shortened turnaround, eliminated shipment errors, reduced product returns, and decreased amount of safety stock (Aichimayr, 2001).

In warehousing applications, RFID can bring all the benefits associated with reduction of manual labor requirements, cost savings and improved accuracy of operations. RFID technologies promise to generate a positive return on investment. Despite all predictions, many experts think that this technology is not beneficial for everyone. Therefore, a cost/benefit analysis should be done for each planned implementation (Aichimayr, 2001). The study that was completed by the Wireless LAN Association reveals that “average payback time for initial cost of wireless LAN installations was 8.9 months across all industries” (Aichimayr, 2001). Companies can leverage their investment in RFID systems by starting out slowly with a flexible RFID infrastructure and later adding new applications. As implementations grow, inventory visibility increases accordingly, which benefits all supply chain operations.

2.6 Enterprise Performance Measurement Methodology (EPMM)

According to Presley et al., 1997, to support implementation, which involves justification, monitoring and management of the proposed system, the performance measurement and management system (PMMS) should merge the goals, performance measures, and the feedback together. The enterprise performance management methodology (EPMM) is a methodology that was developed to combine the features of current PMMS and address the most of their weaknesses (Presley, et al., 1997). As noted by Presley et al. (1997), “a typical use of the EPMM would be to first use its justification capability to select a system to be implemented and then to monitor its effect on the enterprise through its impacted activities”. The one of the major requirements of the EPMM is clearly defined objectives, strategies, and processes for the overall enterprise.

2.6.1 Phases of EPMM

In general, EPMM is divided into five major phases: identify system and transition impact, estimate costs and benefits, perform justification analysis, audit decision, and track performance (Presley et al., 1997). The decision analysis process that will be described in the next chapter is considered to be a part of EPMM as they both pursue the same objectives: they are used to integrate strategic (analytical) metrics with the traditional cost metrics to gain the weighted score for the alternative. Nevertheless, the decision analysis process is only a part of the EPMM as it includes only the first three phases defined by Presley et al. (1997); the phases are described below.

Identify system and transition impact. On this phase the enterprise activities and strategies affected by the proposed system are identified. Areas of transition impact include: product, process, organization, culture, and technology. System impact is defined as effect of the analyzed system on the overall enterprise.

Estimate cost and benefits phase. Analysis can be performed using activity based approaches to derive the cost in an accurate manner. Strategic data may be quantified by using relative importance weighting, analytical hierarchy process (AHP), or importance perceptions.

Perform justification analysis. The activity based approaches and strategic data are combined in an evocative manner providing the documented results, organized in a business case, to the decision maker. The output of this phase is a decision on the alternative suggested for implementation.

2.7 Enterprise Resource Planning (ERP) projects evaluation

ERP projects are between the most popular IT investments in today's world. Anand Teltumbde (2000) offers a methodological framework for dealing with the complex problem of their evaluation. It incorporates a decision making process based on Nominal Group Technique (NGT) and evaluation method involving the Analytic Hierarchy Process (AHP). As noted by author, the evaluation criteria for ERP project are usually general for different organizations, but their internal relationships are organization specific. The evaluation criteria were defined to accommodate the desired ERP characteristics as following: strategy fit, technology, change management, risk, implementability, business functionality, vendor credentials, flexibility, cost, and benefits.

The framework for evaluation contains the following seven steps: creation of organizational infrastructure, constitution of the repertoire of ERP products, preparation phase, context setting phase, evaluation and selection phase, approval of the selection, and mid-course evaluation (Teltumbde, 2000). This framework is flexible and can accommodate different processes for which the method can be easily re-modified. In addition, the process requires gathering of fundamental information about alternative projects, which guarantees the most appropriate alternative is chosen. Nevertheless, the success of the project mostly depends on the trust and support within the working team along with the overall inter-organizational readiness.

2.8 Summary

Supply chain visibility is one of the most important factors affecting the performance of the whole supply network. Optimized material and information flow due to increased visibility in all operations will definitely benefit all supply chain members. A major enabler of real-time supply chain visibility is AIDC technology.

Adoption of new auto-ID technology, such as RFID will help supply chain partners integrate and coordinate their internal and external activities and strategies resulting in lowered overall system cost and improved customer service level (Chuang and Shaw, 2005).

The capabilities of RFID are enormous, but most companies prefer to choose a wait-and-see strategy on the way of RFID implementation because of the uncertain return on investment. Therefore, before the actual implementation takes place, an organization has to clarify some RFID priorities, such as costs, technology infrastructure, standardization, and the implementation roadmap (Chuang and Shaw, 2005).

CHAPTER 3

METHOD

3.1 Introduction

This chapter will describe the method used for the research. The decision analysis process, shown on Figure 3.1 (modified from Clemen & Reilly, 2001) was performed in order to develop the decision making model. The steps include: identify the decision situation and objectives, discover and identify the alternatives, perform economic analysis, perform subjective evaluation, choose the best alternative, perform sensitivity analysis, check if further analysis needed, and offer the chosen alternative for implementation.

Additional steps that are included in the model are: estimate the uniform equivalent annual cost (UEAC) for each kind of technology as a part of economic analysis and evaluate intangible benefits of each of the alternatives through the analytic hierarchy. Conclusions based on comparison analysis of the three alternatives will be made after sensitivity analysis has been performed. All the steps are explained in detail in further sections of this chapter.

3.2 Decision situation

This phase of the decision process implies that the decision maker has to identify the decision situation and to understand his (or her) objectives in that situation. The problem of poor supply chain visibility arises in the overall vulnerable environment containing isolated supply chain members, where no internal or external coordination is considered. Minimum information sharing and poor visibility result in increased probabilities of supply chain risks. The problem statement for this research is to develop a decision process model to select communication technology to increase visibility into warehousing/ distribution center operations.

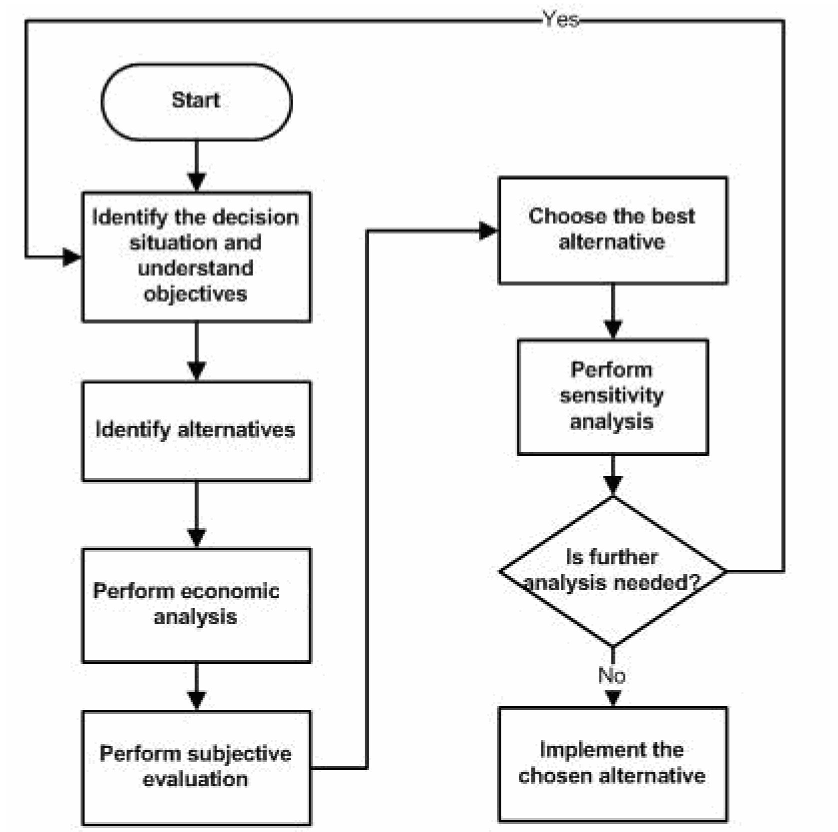

Figure 3.1. A decision- analysis process flowchart (Clemen & Reilly, 2001).

3.2.1 Fundamental and means objectives

A set of multiple objectives for the decision process is going to be analyzed, and objectives are separated into means and fundamental. This separation is important because there are objectives that reflect what really needs to be accomplished and those that just help to achieve other objectives (Clemen & Reilly, 2001).

3.2.1.1 Fundamental objectives

Fundamental objectives are usually organized into hierarchies, as shown in Figure 3.2. The first, upper level contains the most general objective for the company: to make money now and in the future. The next, lower level, represents fundamental objectives that explain the meaning of the higher- level fundamental objective. “Customer satisfaction” and “Maximize the profit” describe the aspects of making money from the company’s perspective.

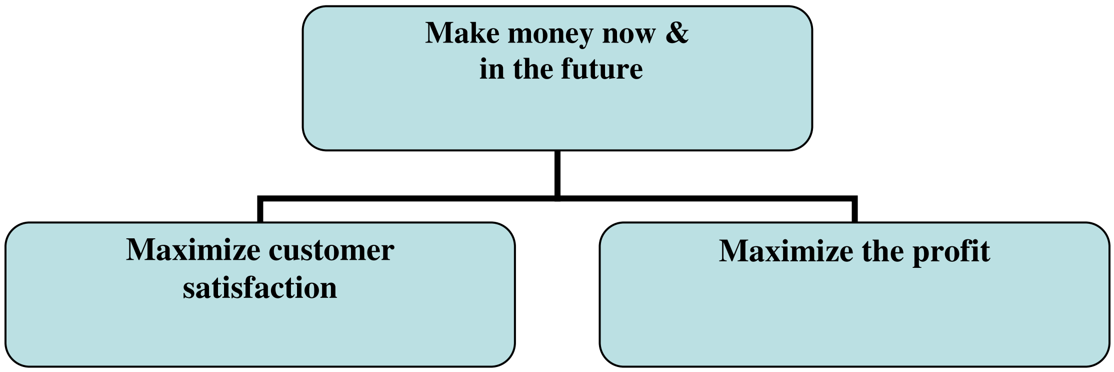

Figure 3.2. A fundamental – objectives hierarchy

“The lowest level fundamental objectives will be the basis on which various consequences will be measured” (Keeney, 1992). Overall, fundamental objectives explain why one cares about the decision situation and what criteria must be used in evaluating alternatives.

3.2.1.2 Means objectives

Means objectives are constructed into networks. This kind of structure is explained by the fact that means objectives can be connected to several objectives, and they help achieve those objectives. Means objectives, moving away from fundamental objectives, answer the question “How this can be achieved?” On the other hand, moving toward fundamental objectives, each objective answers the question: “Why is that important?” This question helps to differentiate means and fundamental objectives, and shows the connection between objectives.

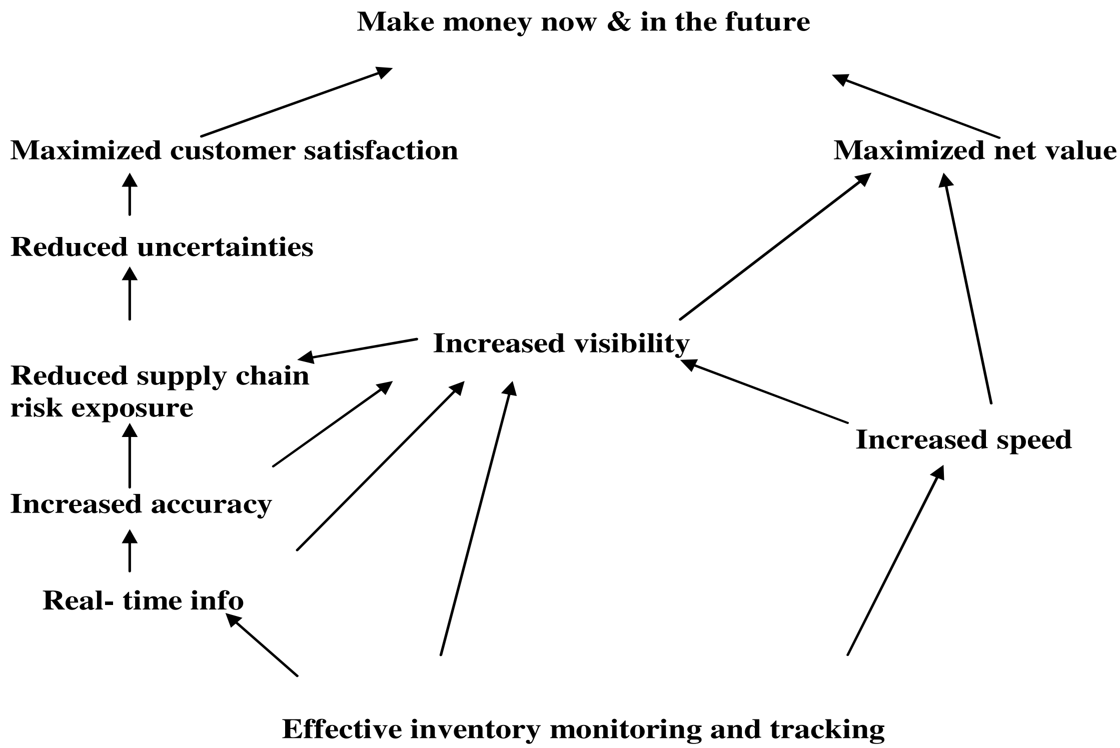

Figure 3.4. A means objectives network.

If answer for this question is: “It is important because it is fundamentally important, it is what we care about”, then the objective that was analyzed is a fundamental objective (Keeney, 1992).

In the given situation the most current objective for materials management is effective inventory monitoring and tracking: misplaced or lost inventory delays, shipments and routine of warehousing activities (Figure3.4). These also affect overall supply chain performance. Answering the question “Why is effective monitoring and tracking important?” one can say that it can provide the most updated, “real-time” information; it can increase speed and visibility into all performed operations. Real-time information, in turn, contributes to visibility and accuracy of the available information. Increased accuracy is another important component of inventory visibility. Inventory accuracy and overall visibility directly contribute to reduction of risks affecting not only warehousing activities but also the overall supply chain. This will create a less exposed supply chain environment as a result of reduced uncertainties which, in turn, will allow the decision maker to make confident and predictable decisions. The big part of those decisions affect customer satisfaction, such as fulfilled promise date; and it affects overall on time deliveries. A satisfied customer creates a loyal customer, which means future business for the company.

From the other side, increased visibility and speed of operations as a result of effective inventory monitoring will contribute to increased net value. This allows the company to get more output in smaller amount of time, which means more business, more bookings and more profit.

It is important for the decision maker to distinguish between the means and fundamental objectives, so that the appropriate fundamental objectives are specified in the decision model. The means network, from the other side, can sometimes replace a fundamental objective, and if it is difficult to measure, it can serve as a tool for measuring the value of alternatives (Keeney, 1992).

3.3 Identification of alternatives

There are three alternative decisions that have to be compared in order to choose one, the most fitted in the current circumstances. These alternatives are: whether to choose bin locations, bar codes, or RFID technology for warehousing operations.

3.3.1 Fixed bin locations

Fixed bin locations method was chosen to compare with automatic identification methods because this method is used by the local company, Airtechnics Inc., and the model will be verified using the data from this organization. Bin locations method assumes that all incoming parts are assigned with particular location in the warehouse.

Information about received orders is manually entered into the system. Each step of the warehousing process flow involves the worker's intervention. A warehouse management system (WMS) is not considered to control the flow of inventory. The overall heavy dependence on human and manual processes can result in significant bottlenecks that will raise a company's costs and slow down production. The process flow in Appendix A shows the sequence of steps performed in the warehouse from the moment when goods are received to the final shipment.

3.3.2 Bar codes

Bar codes were considered in the decision model because they are the most widely used technology for supply chain applications including warehousing data collection. A company's success with implementation of bar codes can be defined and measured by accuracy of information, automation, tracking, and control of material flow. Every received box would have a printed bar code label. The overall modified process using bar code scanning is shown in the Appendix 2.

3.3.3 RFID technology

RFID is accepted to be a newly emerging wireless technology which holds "the promise of closing the information gaps in the supply chain" (Angeles, 2005). RFID enables real-time supply chain visibility and mobility of its major elements: processes, people, information, documents, and communications. These are important for the most effective supply chain management (Angeles, 2005). The process flow diagram, attached in the Appendix 3, is modified from the original diagram using RFID for inventory tracking.

3.4 Economic analysis

This section presents an overview of decision process for economic evaluation of different kinds of technology with regard to the project lifecycle. After discussions with the faculty advisor, the planning horizon was defined to be seven periods, from year 1 to year 8. The major characteristics of economic evaluation that will be examined are:

- Basic concepts of investment evaluation, including minimum attractive rate of return (MARR), cash flows over the planning horizon and cost measures.
- Methods of economic evaluation, such as net present value (NPV) method and uniform equivalent annual cost (UEAC) method.
- Depreciation and tax factors that affect cash flows.

3.4.1 Minimum attractive rate of return (MARR)

Minimum attractive rate of return (MARR) "is the minimum rate of return at which the owner is willing to invest. Investment opportunities yielding less than MARR are considered not worthwhile" (Collier & Glagola, 1998). The concept of MARR is generally used to reflect the most accurate number that should be used for the project evaluation (Collier & Glagola, 1998). In a private company, MARR is specified by higher management and usually reflects *the opportunity cost of capital* of the firm, the market interest rates, and the risks associated with investment opportunities (Hendrickson, 2003). "The opportunity cost reflects the return that can be earned from the best alternative investment opportunity foregone" (Hendrickson, 2003).

In the process of building the economic models, MARR will be estimated after reviewing relevant case studies and discussion with faculty advisor.

3.4.2 Net present value (NPV) calculation

The net present value or present worth (PW) criterion is used to compare present worth of all cash inflows with the present worth of all cash outflows associated with an investment project (Park, 1997). All cash inflows and outflows over the planning horizon are discounted to the present at an interest rate that is usually equal to MARR. NPV is the difference of the present worth of these two flows which determines whether or not the project is an acceptable investment. NPV as a function of interest rate will be found according to Degarmo et al. (1997) by discounting future amounts to the present with the interest rate over the appropriate period (years):

$$NPV = F_0(1+i)^0 + F_1(1+i)^{-1} + F_2(1+i)^{-2} + \ldots F_k(1+i)^{-k} = \sum_{k=0}^{N} F_k(1+i)^{-k} \qquad (3.1)$$

Where i – effective interest rate, or MARR

k – index for compounding period ($0 \leq k \leq N$) or service life of the project

F_k - future cash flow at the end of the period k

N- number of periods in the planning horizon.

If the present equivalent of cash inflows minus cash outflows is greater or equal to zero, the project is economically feasible, otherwise- not acceptable (Degarmo et al., 1997).

3.4.3 Uniform Equivalent Annual Cost (UEAC)

The annual equivalent worth (cost) criterion is used for measuring investment worth by determining equal payments on an annual basis (Park, 1997). The UEAC value will be determined by multiplying the net present value (NPV), defined in the previous section, by an appropriate capital recovery factor.

This operation will be performed in Excel using the PMT function which calculates the payment for a loan based on constant payments and constant interest rates. Present value, interest rate (MARR), and total number of payments are used in this function for UEAC calculation. This cost is a measure of the negative attribute of alternative projects, thus its value should be minimized.

3.4.4 Depreciation

Depreciation represents the loss in value of a property (technology in this case) over the period of time. Market value of an item as a function of time is a good measure of the depreciation of the actual value (Courtland & Glagola, 1998). The method of accounting for depreciation, considered in the research, is the double declining balance (DDB) method, which implies that annual depreciation is taken as 2.0 (or 200 percent rate) times the current book value and divided by the total years of economic life. This accelerated depreciation method allows the larger part of the cost of depreciation to be written off in the beginning years and less in the later years (Courtland & Glagola, 1998).

According to Modified Accelerated Cost Recovery System (MARCS), recovery periods (depreciation life) will be determined for each kind of considered technology. "The recovery period is the time period over which capital cost is recovered (depreciated)" (Courtland & Glagola, 1998). This period is usually shorter than the planning horizon (for the quicker write-off); therefore, calculations will be performed only for those periods.

3.4.5 Tax rate and tax savings

For the decision maker: the investor, taxes are very important part of the overall system cost. They have to be considered while estimating costs versus income on any investment (Courtland & Glagola, 1998). Tax rate, which is a combination of federal and state income taxes, was assumed to be 33 percent after revision of Internal Revenue Service (IRS) tax rate schedule for year 2007.

After the tax rate is defined, tax savings will be calculated as a negative of tax rate multiplied by the sum of costs involved (operational expenses, error cost, and depreciation), except the initial investment.

Other components of the economic model that have to be calculated or estimated include:

- Company's yearly growth. This number (percentage) will be estimated based on the reviewed literature and will be used for the generic economic model. The actual number will be available after visiting the company and will be used for model verification.

- Initial investment. This cost is comprised of the capital investment and installation fees. The capital investment involves costs of hardware, software, middleware, and will be explained in detail for each kind of technology. Depreciation of equipment is also included in cost items for this category. Installation includes physical installation of equipment, tuning, integration costs, maintenance, creation of new workflows, and training of personnel.

- Number of transactions per year (performed by each kind of technology). The first action to estimate the number of transactions is to identify the potential areas of application and related activities. The potential areas include warehouse operations: receiving, put away, picking and shipping.

The next step is to identify all activities that have to be performed by each kind of technology in each of the listed operations. Further, the amount of inventory that flows through the warehouse has to be estimated. This will be based on the received daily number of boxes: items which potential labels (or tags) can be applied to. According to the estimated number of boxes (received per year) the number of labels (or tags) per year will be calculated.

After analyzing all the activities that have to be performed by each kind of technology, the number of transactions for the first year can be calculated by multiplying the number of labels (tags) into the number of activities they are involved in through all the warehousing processes. The number of transactions for following years will be automatically generated in the Excel spreadsheet according to the company's growth.

- Cost per transaction (for each kind of technology): this cost will be estimated according to the cost of labor time spent on each transaction. First, average time for performing each transaction will be estimated. Then, average time will be multiplied by a worker's salary (in consistent units).

- Operating expenses associated with yearly transaction costs: this number will be generated on the Excel spreadsheet by multiplying the cost of transaction by the number of transactions for each period.

- Error rate (for each kind of technology). Average error rate will accommodate the error rate of the equipment, defined in the literature (or manufacturer specification), and the human error of the personnel working with the particular kind of technology.

- Cost of error: the cost of error will be calculated according to the error cost worksheet developed by Pearce & Bushnell (1997). Several kinds of activity errors that will be considered while estimating the cost of errors will include: receiving activity errors, shipping activity errors, mis-identification and locating errors, and others.

3.5 Subjective evaluation. Analytic Hierarchy Process (AHP)

After the costs for the proposed solutions have been estimated there is a need to assess the benefits and the risks to prioritize defined alternatives, so that the finally chosen alternative will satisfy the complete set of objectives introduced in the multi-attribute decision making problem.

AHP is the process based on a holistic approach where all the factors and criteria involved are built into a hierarchy allowing for dependencies (Agrawal & Shankar, 2002). “The AHP is about breaking a problem down and then aggregating the solutions of all the subproblems into a conclusion. It facilitates decision making by organizing perceptions, feelings, judgments, and memories into a framework that exhibits the forces that influence a decision” (Saaty, 1994).

The AHP- based decision making process described in this work incorporates the following steps defined by Saaty, 1994:

1) Structure a problem with a model that shows the problem’s key elements and their relationships.

2) Elicit judgments that reflect knowledge, feelings, or emotions.

3) Represent those judgments with meaningful numbers.

4) Use these numbers to calculate the priorities of the elements of the hierarchy.

5) Synthesize these results to determine an overall outcome.

6) Analyze sensitivity to changes in judgment.

3.5.1 Structure of the hierarchy

A graphical summary of the AHP model is shown on the figure 10. The overall objective is to increase customer satisfaction, which can be reached by improved warehousing activities. To evaluate customer satisfaction, three criteria have been considered: risk, inventory, and order fulfillment. The next step is to identify the attributes for each criterion.

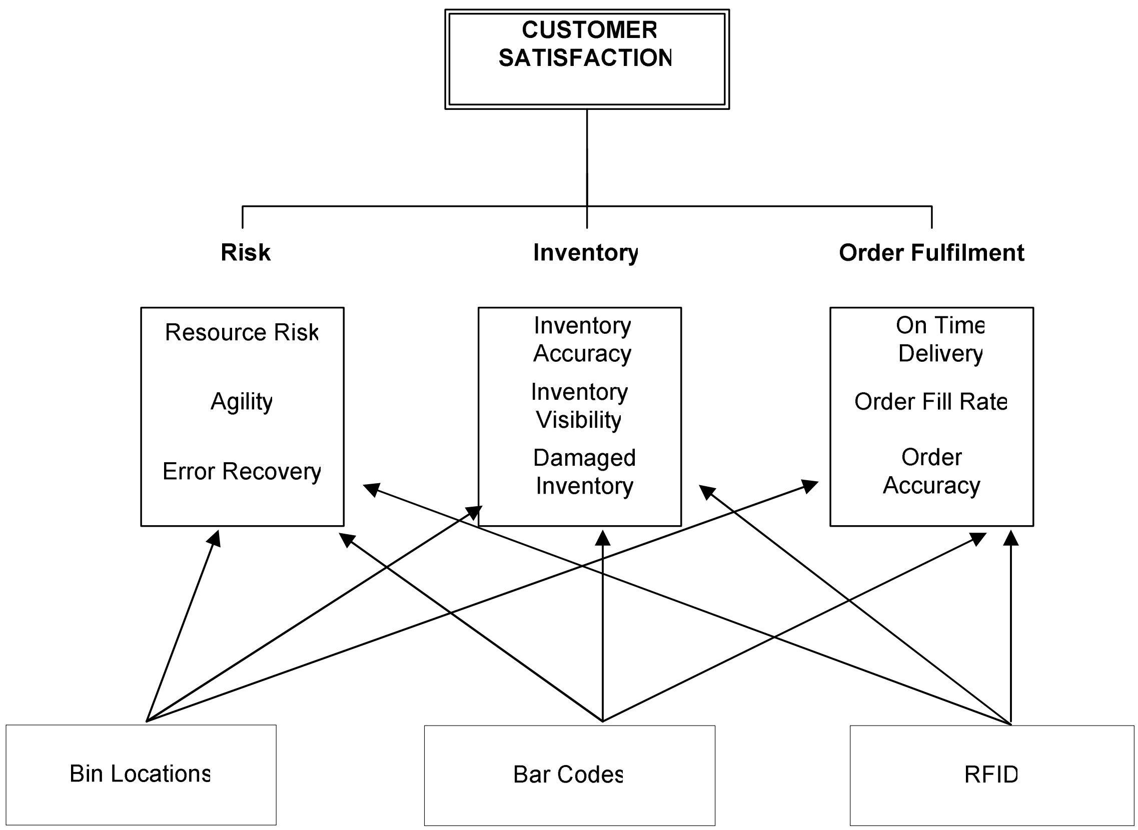

Figure 3.5. Analytic hierarchy.

As an illustration, in the given research three attributes for each criterion were defined. Criteria, attributes and their interrelationships were defined based on personal experience as well as by discussions with faculty advisor, co-workers at Airtechnics Inc., and the supervisor (director of materials) at Airtechnics Inc.

3.5.1.1 Risk

All businesses are affected by different types of risk. Nevertheless, within the decision process framework, only three of them were considered to have the most effect on the overall warehousing/distribution operations discussed in chapter 2. Those risks include: responsiveness (agility), resource risk, and error recovery.

Error recovery. A lot of activities (especially not automated ones) in distribution are prone to different kinds of errors. Errors, as a result of not using any communication (identification) technology, will lead to the following failures: the wrong item in the pick location, insufficient quantity to fill the order (stockouts), mis-picks, rush orders, special orders sent to stock instead of being cross-docked, issuing credits for wrong shipped items, extra freight charges, and so on. All these consequences are potential risks resulting from error prone processes.

Error recovery assumes all the actions that have to be performed to correct the error neglecting the time and cost that they consume. These actions may include (Pearce & Bushnell, 1997):

- calling supplier
- labeling and repacking material
- generating shipping document
- paying shipping charges
- generating second purchase order (PO)
- processing credit

- receiving return, and other.

All the procedures included in corrective actions lower the overall efficiency of performed operations consuming time and resources.

Resource risk. Resource risk, in this case, is referred to as human resource risks that can affect any business. According to Marshall & Alexander (2005), “human resource risks are events that prevent employees from fulfilling their responsibilities and thus keep the business from operating at full efficiency.” Human resource risks may include: death, disability (temporally or permanent), divorce, management error/incompetence, unexpected temporary leave, poor employee management practices, and employee turnover (Marshall & Alexander, 2005). All the above mentioned resource risks directly affect the overall performance and customer satisfaction. Therefore, they have to be taken into account while performing analytical evaluation.

Agility. “The ability to successfully manufacture and market a broad range of low-cost, high-quality products and services with short lead times and varying volumes that provides enhanced value to customers through customization. Agility merges the four distinctive competencies of cost, quality, dependability, and flexibility” (APICS Dictionary, 12-th edition). Within the concept of agility, warehouse automation provided by communication technology (described in chapter 2) is viewed as one of the major criteria for the risk evaluation. Automation offers the flexibility to handle multiple distribution activities in more efficient way (Baker & Halim, 2007).

3.5.1.2 Inventory

Inventory has been chosen as one of the parameters that directly affect customer satisfaction (McGinnis, 2003). The three most important measures from this category were chosen: inventory accuracy, inventory visibility, and damaged inventory. Inventory accuracy is assumed to equal actual quantity per system reported quantity; inventory visibility is equal to receipt entry time minus physical receipt time; and damaged inventory is measured as cost of total damage divided by inventory value, or:

$$InventoryAccuracy = \frac{ActualQuantity}{reportedQauntity} \quad (3.2),$$

$$InventoryVisibility = receiptEntryTime - PhysicalreceiptTime \quad (3.3),$$

$$DamagedInventory = \frac{TotalDamage,\$}{InventoryValue(Cost)} \quad (3.4).$$

3.5.1.3 Order fulfillment

Order fulfillment is another characteristic of warehousing performance affecting customer satisfaction (McGinnis, 2003). The measures of order fulfillment were defined as on time delivery, order fill rate, and order accuracy. On time delivery equals to number of orders on time divided by total orders shipped; order fill rate is number of orders filled complete over number of total orders shipped; and order accuracy is error- free orders divided by total orders shipped, or:

$$OnTimeDelivery = \frac{OrdersOnTime}{TotalOrdersShipped} \quad (3.5),$$

$$OrderFillRate = \frac{OrdersFilledComplete}{TotalOrdersShipped} \quad (3.6),$$

$$OrderAccuracy = \frac{ErrorFreeOrders}{TotalOrdersShipped} \quad (3.7).$$

3.5.2 Judgments and comparison

The next step of the AHP is to compare attributes in a pair-wise manner with respect to an upper level criterion responding with the number on a scale one to nine by using a square matrix shown in Table 3.1

Table 3.1. Pair-wise comparison matrix for risks

Risks	Resource	Agility	Error recovery	**e-Vector**
Resource	1	0.33	3	**0.258285**
Agility	3	1	5	**0.6369856**
Error recovery	0.33	0.2	1	**0.1047294**

According to Saaty, 1994, each comparison signifies the dominance of the element in the column on the left over an element in the raw on top. The 3-by-3 matrix has three 1's on the diagonal for comparing elements with themselves, three comparisons, and three reciprocals. The fundamental scale shown in table 3.2 is a scale of absolute numbers used in judgments while comparing importance of two elements with respect to an upper level criterion. The priorities (e-vectors) are obtained by raising the matrix to larger powers, then adding the judgment values in each raw and dividing by the sum of all the judgments.

Table 3.2. The fundamental scale (Saaty, 1994)

Intensity of importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgments slightly favor one activity over another.
5	Strong importance	Experience and judgments strongly favor one activity over another.
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice.
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it.
Reciprocal of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared to *i*	A comparison mandated by choosing the smaller element as the unit to estimate the larger one as a multiple of that unit.
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix.
1.1-1.9	For tied activities	When elements are close and nearly indistinguishable; moderate is 1.3 and extreme is 1.9.

The next level of priorities is obtained by weighting priorities of this level by the priority at the level above. In a given example, next level of priorities for risk, inventory and order fulfillment will be weighted by priorities for customer satisfaction. The overall priorities of the alternatives (Bin locations, Bar code, and RFID) will be achieved by weighting priorities for all the attributes by the priorities for parent criteria or subcriteria in terms of which they are compared and then adding. This, altogether, will give twelve comparison matrixes.

All the resulting comparison matrixes as well as calculation of overall priorities will be introduced in Chapter 4 and will be performed by the means of Excel spreadsheets.

3.5.3 Consistency of judgments

Judgments in the three-by-three and bigger matrixes may not always be consistent. According to Saaty, 1994, numerical inconsistencies can result from uncertain or poor judgments of the decision maker made while comparing some of the elements. As a measure of consistency the same author introduced consistency index (*CI*):

$$CI = \frac{(\lambda_{\max} - n)}{n-1} \qquad (3.8)$$

Where n - number of comparisons, $\lambda_{\max}$ - Principal E- value, obtained from the summation of products between each element of E- vector and the sum of columns of the reciprocal matrix. For consistent reciprocal matrix it is proven that $\lambda_{\max} = n$ (Saaty, 1980). $\lambda_{\max}$ will be determined for each of the twelve matrixes. Each matrix will have three comparisons or n=3. Therefore, the expected value of $\lambda_{\max}$ is 3.

CI is further used to determine consistency ratio (*CR*) - a value for comparing the inconsistency of the set of judgments in particular matrix (Saaty, 1994):

$$CR = \frac{CI}{RI} \qquad (3.9)$$

Where *RI* – is a random consistency index, generated by Saaty (1980) to compare with CI. Inconsistency is accepted tolerable error if *CR* value is less than ten percent. If it is otherwise, then there is a need to collect more information and reexamine the hierarchy.

3.6 Choosing the best alternative

In the proposed method graphical comparison of alternatives was chosen to pick the most appropriate one. The values which going to be compared for each alternative are uniform equivalent annual cost (UEAC), as a result of economical analysis, and AHP values, as a result of subjective evaluation. The most preferable alternative will be the one that has the highest weighted value and the lowest cost.

3.7 Sensitivity analysis

Sensitivity analysis is performed in the research to find out a sense of the possible outcomes of the alternative investments proposed in the method. According to Degarmo et al. (1997), sensitivity analysis is explained in engineering economy studies as a very useful in decision making nonprobabilistic technique that can provide information about the potential impact of uncertainties in estimated values. General phases of sensitivity analysis, outlined by Collier and Glagola (1998), include the following steps:

1. List the variables most likely to affect the estimated future costs
2. Specify a probable range over which these variables may fluctuate
3. Determine the effect on the estimated future cost figures of the variables fluctuating over their probable range.

Following the sensitivity analysis described in Park (1997) the process was started with the best case scenario, developed in the sections above, while calculating UEAC, and reflecting the most likely values of input variable. Then, specific variable of interest is changed by specified percentages above and below the calculated most likely value, while keeping other contributing variables constant. Next, the new value of UEAC is calculated for each of those values. The results of sensitivity analysis will be plotted on the sensitivity graphs and presented in chapter 4.

Sensitivity analysis performed in this phase helps to identify the most critical factors affecting UEAC. These several parameters are further analyzed by performing sensitivity analysis for mutually exclusive alternatives where UEAC values of all alternatives are plotted over the range of each variable- one plot for each variable. This kind of analysis will be performed to gain more effective result, reflecting different range of uncertainty for each variable and giving the idea how they can be changed to improve the UEAC value and overall value of a particular alternative.

3.8 Summary

This chapter represented the decision analysis process developed to evaluate three alternatives. The major advantage of this method is that it assesses both tangible and intangible benefits of each of the alternatives. Two noteworthy methods, UEAC from engineering economy studies and the AHP from decision making perspective are combined in the decision analysis process to gain the most consistent judgment while evaluating defined alternatives.

In the end of chapter 4, a conclusion and the recommendations about implementation of particular alternative will be drawn based on outcomes and sensitivity analysis of the three models. Investment profit measures will be compared as well.

CHAPTER 4

RESULTS

Chapter four presents the results of the method using estimated data, the results of observations of a company's processes and numbers recommended by faculty advisors, and survey responses gathered from the company's supervisors. First, a hypothetical model is created which uses estimated data. Second, the same process is repeated using actual numbers from Airtechnics Inc. Finally, the possible range of variations of cost and value for each of the alternatives will be discussed and shown graphically.

4.1 Hypothetical Model

The hypothetical model involves data from observations of Airtechnics processes and numbers suggested by faculty advisors. As it was described in chapter three, the model consists of two major phases: multi attribute analysis using economic evaluation and Analytic Hierarchy Process (AHP). The results of each phase are illustrated in the following sections.

4.1.1 Economic Analysis using Uniform Equivalent Annual Cost (UEAC) - estimated data

According to guidelines introduced in the method, UEAC is calculated for each of the alternative technologies. For the further information both estimated and survey input parameters for UEAC calculation are shown in Table 4.0 in Appendix B. Initial data for bin location alternative include numbers shown in Table 4.1:

Table 4.1 Input data- bin locations (estimated data).

MARR=	8%
Transactions/yr	120,000
Growth	10%
Cost/Trans	$0.24
Cap Investment	$0
Installation	$0
Number of tags	24,000
Cost/Tag	$0.01
Error Rate (probability)	0.33
Cost/Error	$30
Tax Rate	33%

Table 4.2 presents the economic evaluation process which includes calculations of the parameters needed to determine UEAC. First, using the estimated current number of transactions (#) and the company's growth (%), the number of transactions per each year (#) is calculated. Next, operation expenses are calculated by multiplying the number of transactions (per particular year) with the cost of transaction ($).

Table 4.2 Economic Evaluation- bin locations (estimated data).

Year	Inv	Trans* 1000	Op Ex/Trans cost	Error/yr	Error Cost	Tax Savings	Total Cost	PV
0	$240						$240	$240
1		120	$28,800	396	$11,880	-$13,424	$27,256	$25,237
2		132	$31,680	436	$13,068	-$14,767	$29,981	$25,704
3		145	$34,848	479	$14,375	-$16,244	$32,979	$26,180
4		160	$38,333	527	$15,812	-$17,868	$36,277	$26,665
5		176	$42,166	580	$17,394	-$19,655	$39,905	$27,159
6		193	$46,383	638	$19,133	-$21,620	$43,895	$27,662
7		213	$51,021	702	$21,046	-$23,782	$48,285	$28,174
8		234	$56,123	772	$23,151	-$26,160	$53,113	$28,696
							NPV	$215,715
							UEAC	$37,538

Further, errors per year and error cost for each year are determined. Errors per year are found by multiplying the number of transactions with error rate (#) which is predefined for the kind of technology used. In the bin locations case, error rate is considered to be equal to human error rate (%) as the majority of transactions are performed manually. Error cost per year is later found by multiplying the number of transactions with cost per error. The cost per error is assumed to accommodate the cost of all the activities that have to be performed in order to correct the error. The parts of this cost were explained in more detail in chapter three. The average error cost for any alternative was estimated to be $30.00 per error according to the suggestion of the Director of Material and the Accounting Manager.

Depreciation of the actual value, which is loss in value of the technology over time, is not considered in this case. Capital funds which would stand as the value of the technology exposed to depreciation were not invested, and the bin location method has been in use by the company for a while. The economic analysis for this technology estimates how much it costs for the company to handle transactions using this technique.

Taxes, which are an important part of the total system cost, are expressed in negative numbers and marked as tax savings because this part of the cost is returnable. This parameter is determined by multiplying the sum of the yearly system costs (transactions cost, error cost, and depreciation) with the tax rate. The tax rate was assumed to be 33%.

The total cost for each year is found by adding all the costs associated with the spending for the current year. These costs include initial investment, operating expenses, error cost, and tax savings. After the total cost is calculated, present value for each year is further determined taking into account the minimum attractive rate of return (MARR) which was assumed to be 8%. The net present value for the period of eight years is further found by adding present values for each year. The UEAC is finally found by the means of Excel PMT function which involves MARR, number of periods, and NPV.

In a similar manner, using all the above mentioned steps UEAC was determined for barcode and RFID technology. The results of the mentioned calculations are shown in Tables 4.3- 4.4. Although initial investment for bar codes ($24,220) was much lower than for RFID ($74,680), the UEAC for bar codes came out to be $26,583, and for RFID it was $19,002. This difference in outcome can be explained by the fact that the use of RFID technology reduces the number of transactions and their cost as well, as they are interrelated. Also, the number of errors per year for RFID is much lower that for barcodes, which makes the total error cost go down for RFID.

Table 4.3 Economic evaluation- barcodes (estimated data)

Yr	Inv	Trans	Op Ex/Trans cost	Errors/r	Error Cost	Depr	Tax Savings	Total Cost	PV
0	$24,220							$24,220	$24,220
1		120,000	$24,000	39.600	$1,188.00	$5,714	-$10,198	$14,990	$13,880
2		132,000	$26,400	43.560	$1,306.80	$4,082	-$10,490	$17,217	$14,760
3		145,200	$29,040	47.916	$1,437.48	$2,915	-$11,020	$19,458	$15,446
4		159,720	$31,944	52.708	$1,581.23	$2,082	-$11,751	$21,775	$16,005
5		175,692	$35,138	57.978	$1,739.35	$1,487	-$12,661	$24,217	$16,482
6		193,261	$38,652	63.776	$1,913.29	$1,062	-$13,737	$26,828	$16,906
7		212,587	$42,517	70.154	$2,104.61	$759	-$14,976	$29,646	$17,298
8		233,846	$46,769	77.169	$2,315.08		-$16,198	$32,886	$17,768
								NPV	$152,766
								UEAC	$26,583

Table 4.4 Economic evaluation- RFID (estimated data)

Yr	Inv	Trans	Op Ex/Trans cost	Errors/Yr	Error Cost	Depr	Tax Savings	Total Cost	PV
0	$74,680							$74,680	$74,680
1		96,000	$7,680	2.880	$86.40	$7,766	-$5,126	$2,641	$2,445
2		105,600	$8,448	3.168	$95.04	$5,547	-$4,650	$3,893	$3,338
3		116,160	$9,293	3.485	$104.54	$3,962	-$4,409	$4,989	$3,960
4		127,776	$10,222	3.833	$115.00	$2,830	-$4,345	$5,992	$4,404
5		140,554	$11,244	4.217	$126.50	$2,021	-$4,419	$6,951	$4,731
6		154,609	$12,369	4.638	$139.15	$1,444	-$4,604	$7,904	$4,981
7		170,070	$13,606	5.102	$153.06	$1,031	-$4,881	$8,878	$5,180
8		187,077	$14,966	5.612	$168.37		-$4,994	$10,140	$5,478
								NPV	$109,198
								UEAC	$19,002

The results of economic evaluation based on estimated data show that the smallest UEAC was achieved for RFID technology- $19,002; UEAC for barcodes was larger- $26,583; and UEAC for bin locations was the largest- $37,538. To find out the factors that affect the UEAC the most and the impact of their variability on the possible outcome, the sensitivity analysis was further performed.

4.1.2 Sensitivity analysis for UEAC – estimated data

The results of changing each variable of interest by the range of 50- 200 % and the visual results of calculation of UEAC for each of those values are shown in figures 4.1- 4.3.

The common pattern is noted on all the above figures: UEAC for all types of technology used in the research is strongly dependent on the number of transactions and their cost. The company's growth also has a similar impact on UEAC for all alternatives. Tax rate has the opposite to above mentioned variables impact on the cost, the higher the taxes the lower the cost, and otherwise.

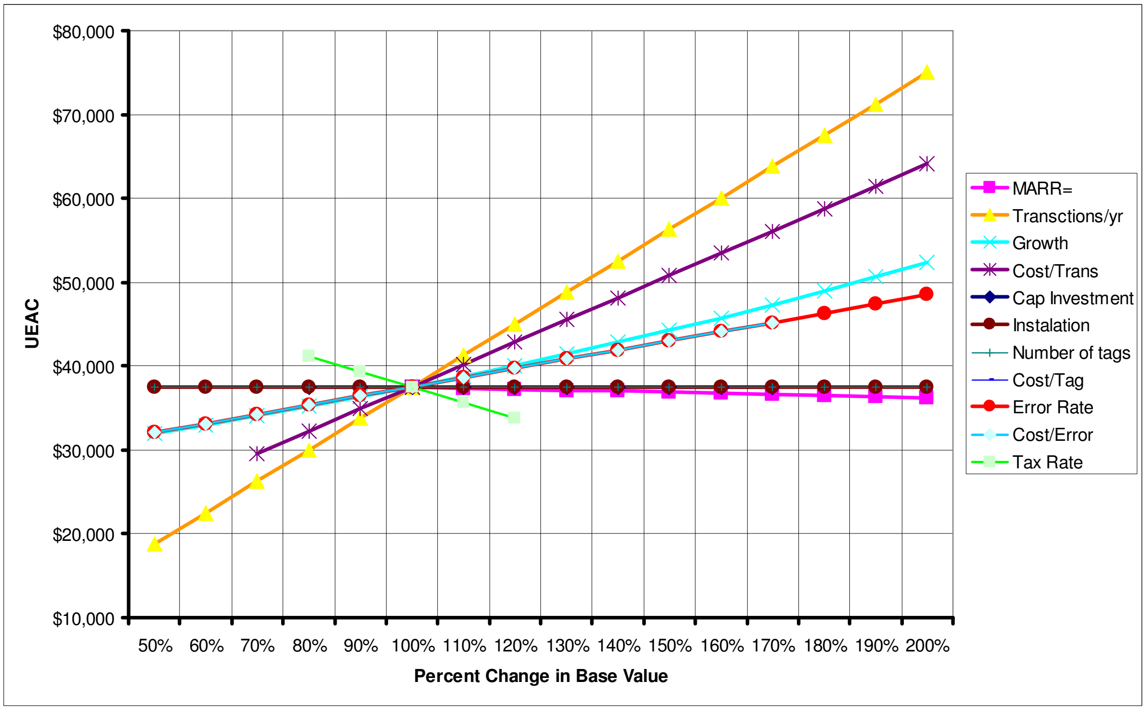

Figure 4.1 Sensitivity analysis for UEAC- bin locations.

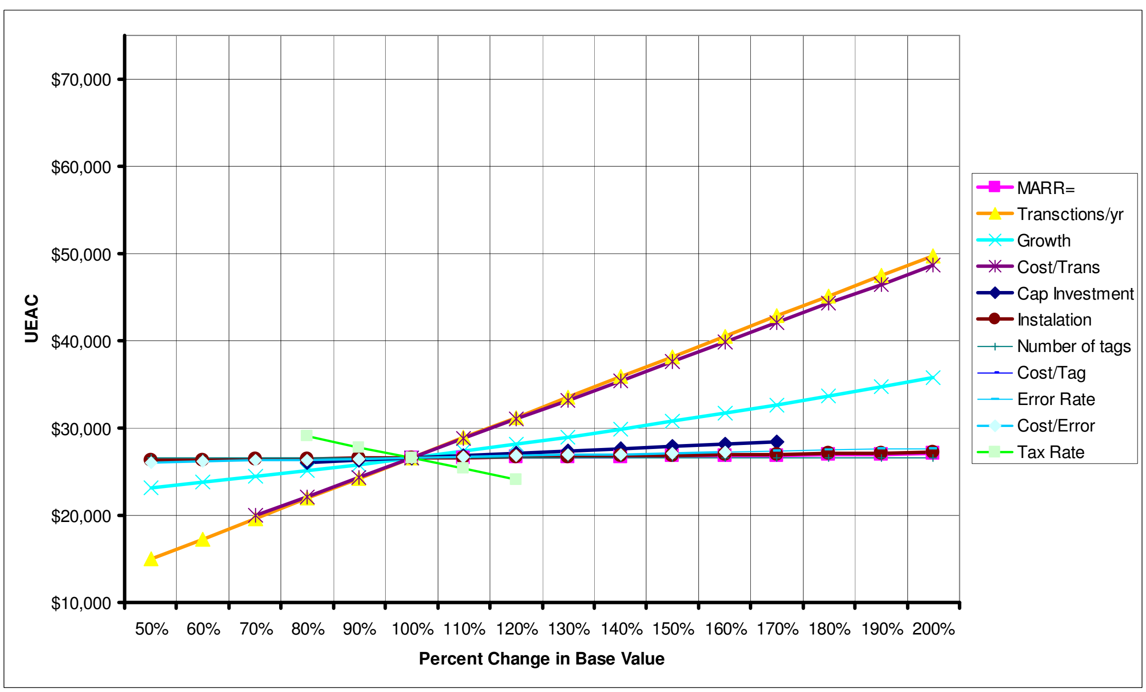

Figure 4.2 Sensitivity analysis for UEAC- barcodes.

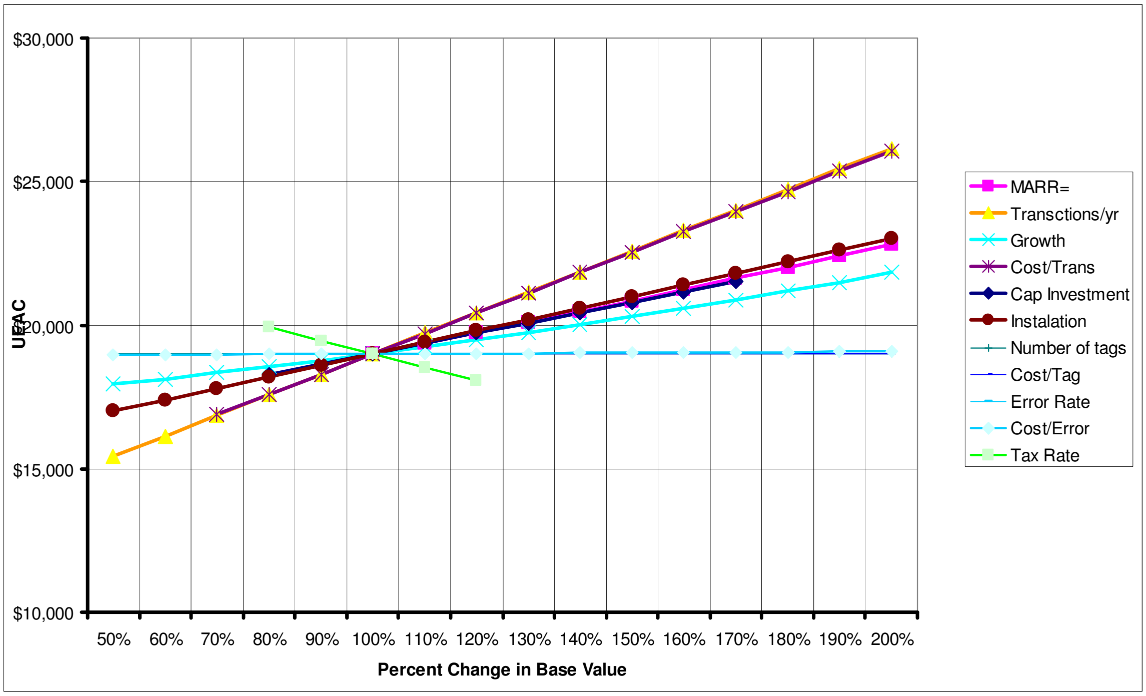

Figure 4.3 Sensitivity analysis for UEAC- RFID

Nevertheless, some differences can be noted: UEAC for bin location is also strongly dependent on error rate and error cost which is not the case for barcodes and RFID. From the other side, UEAC for RFID is strongly dependent on MARR, capital investment, and installation, which do not have any impact on UEAC for bin locations and have very little impact on UEAC for barcodes. The number of tags and their cost is not noted to have any significant effect for any of the models.

4.1.3 Subjective Multi Attribute Analysis using Analytical Hierarchy Process (AHP)-estimated data

The AHP- based decision making process described in chapter three (p.46) was performed in order to gain weighted values of the presented alternatives. The first two steps were performed in chapter three: the problem was structured and the key elements and their relationships were identified. The overall objective and the criteria for its evaluation were defined as well as the attributes for each criterion. The relation of each alternative with all criteria and attributes is included in the hierarchy as well. According to step number two, criteria and attributes were explained in detail reflecting the knowledge and ground for importance comparison.

To represent the judgments in meaningful numbers and calculate the priorities of the elements of the hierarchy the first step was to compare three criteria with respect to the overall objective. For this, each raw of the matrix is raised to power 1/3 as there are three comparison criteria. Further, E-vectors (or priorities) are found by dividing each element of the previous column (Table 4.7) by the sum of those elements. The last two columns reflect the calculations performed to estimate the consistency index where M is the initial 3-by-3 matrix and N is the column containing E-vectors.

Table 4.7 Pair-wise comparison matrix for customer satisfaction.

CUSTOMER SATISFACTION	Risk	Inventory	Order fulfillment	Raw^(1/3)	E-vector(N)	M*N	(M*N)/E
Risk	1	0.167	0.2	0.32183	**0.07796**	0.241206	3.09402
Inventory	6	1	3	2.62074	**0.63484**	1.9642	3.09402
Order fulfillment	5	0.333	1	1.18563	**0.28720**	0.88861	3.09402
				4.12820			
						Lambda	3.09402
						CI=	0.047

The obtained priorities for each of the criteria shown in the column marked E-vector are consistent because lambda is equal to three and the consistency index is within the acceptable range (less than ten percent).

The second step is to perform similar pair-wise comparison for the attributes of each of the criteria. The results of such comparison are reflected in Tables 4.8- 4.10 in Appendix C. The next step was to determine priorities of the alternatives (bin locations, barcodes, and RFID) with respect to each of the all mentioned attributes. Tables 4.11-4.19 in Appendix C show the result of the comparison of alternatives.

After all priorities had been found and judgments were checked for consistency, the next action was to multiply priorities for the criteria with priorities of each of the attributes. The result of this multiplication is reflected in the second column of Table 4.20. Next, the results of previous multiplication are multiplied with the priorities of alternatives for each of the attributes (columns 3-5 in table 4.20). The results are shown in the columns 6-8 in the Table 4.20. Finally, the contents of each resulting column are added, and the three final values for each of the alternatives are reached.

Table 4.20 Calculation of the final values of alternatives.

		AHP Evaluation			**Weighted Values**		
	Weights	BIN	Bar code	RFID	BIN	Bar code	RFID
Resource	0.020	0.674	0.226	0.101	**0.013**	0.004	0.002
Agility	0.049	0.072	0.279	0.649	0.004	0.014	**0.032**
Error recovery	0.008	0.122	0.320	0.558	0.001	0.003	**0.005**
Inventory accuracy	0.252	0.097	0.333	0.570	0.024	0.084	**0.143**
Inventory visibility	0.344	0.060	0.231	0.709	0.021	0.080	**0.244**
Damaged inventory	0.039	0.191	0.261	0.548	0.008	0.010	**0.022**
On time delivery	0.111	0.125	0.379	0.496	0.014	0.042	**0.055**
Order fulfillment rate	0.049	0.249	0.334	0.416	0.012	0.016	**0.020**
Order accuracy	0.127	0.060	0.302	0.638	0.008	0.038	**0.081**
Final values					**0.104**	**0.291**	**0.604**

4.1.4 Sensitivity of AHP

From the AHP calculations it can be noted that RFID dominated other alternatives in almost all parameters (attributes). Therefore, the major uncertainty to examine is the uncertainty at the top level of the value hierarchy, the relative importance of risk, inventory, and order fulfillment.

The table function was used to generate the values of the alternatives- similar to UEAC sensitivity analysis. The difference is that instead of using percent change in the values, the level of importance of the alternatives was changed from zero to one. The calculation performed by means of table function calculates the value of each alternative as the criteria (risk, inventory, or order fulfillment) importance is changed. The results of this process are reflected in Figures 4.4- 4.6.

As it can be noted from Figure 4.4 that with the increased importance of risk the value of RFID slightly decreases, the value of barcodes decreases even less, and the value of bin locations definitely increases and at the highest point of importance of risk it becomes the same as the value of barcodes. With the increased importance of inventory the value of RFID increases, the value of barcodes slightly decreases, and the value of bin locations decreases to some extend as well. With the increased importance of order fulfillment RFID value decreases, barcode value increases, and bin locations value remains almost the same. Comparing the overall pattern of dependency of alternative's values with importance of criteria of customer satisfaction one can make a conclusion that the value of RFID remains the highest among other alternatives.

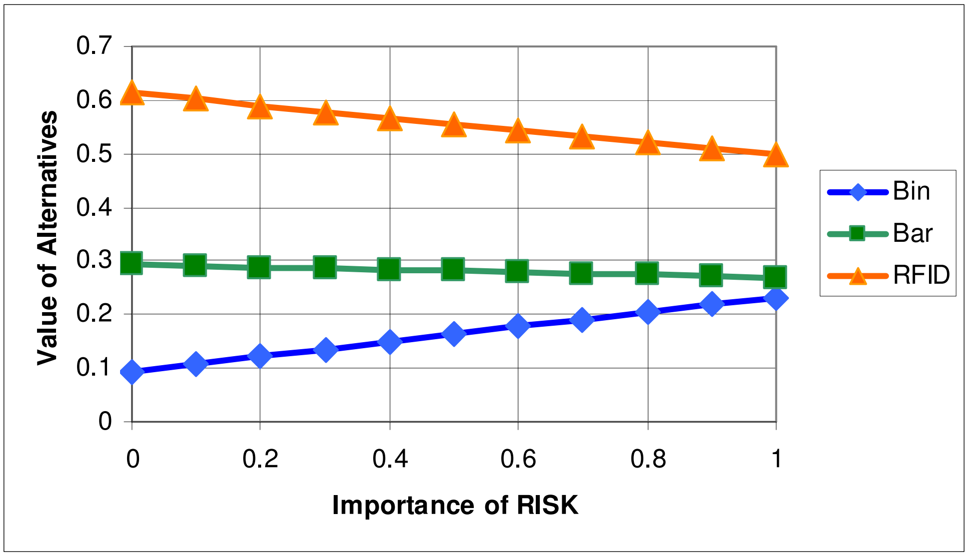

Figure 4.4 Value of alternatives vs. importance of risk.

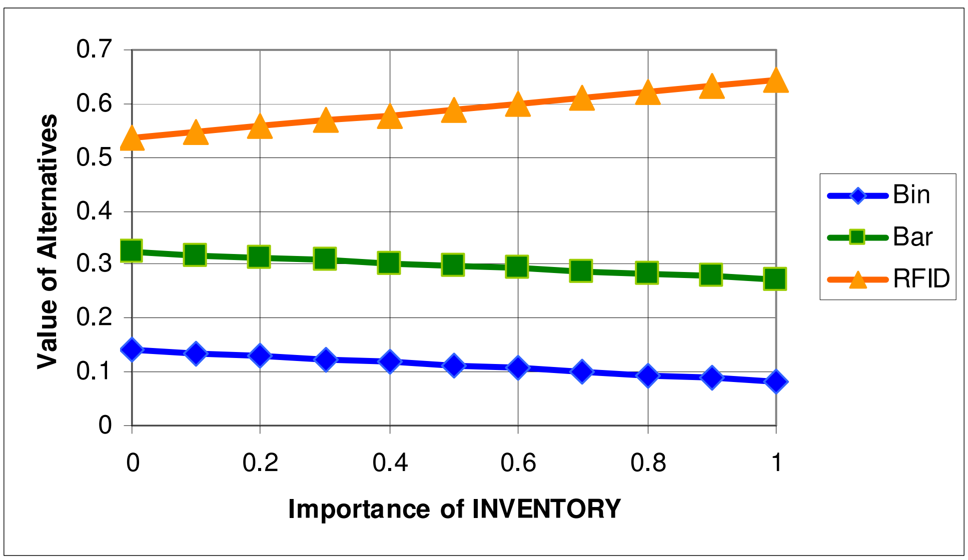

Figure 4.5 Value of alternatives vs. importance of inventory.

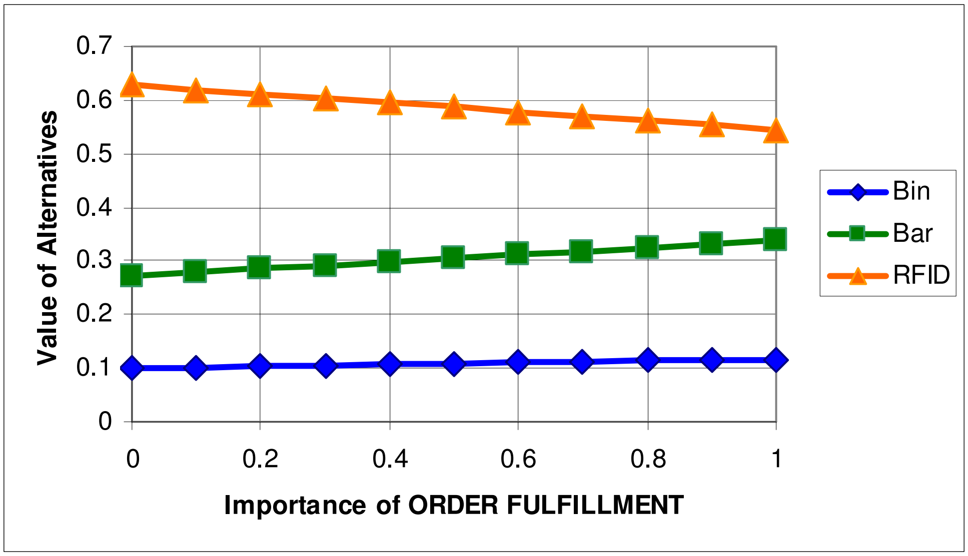

Figure 4.6 Value of alternatives vs. importance of order fulfillment.

4.1.5 The Best Alternative (estimated data)

To compare the alternatives and pick the most preferable one, the results of economical analysis and analytical hierarchy process were plotted on the same graph illustrated in Figure 4.7. Analyzing this graph, a conclusions can be made that bin locations method has very little value but the most expensive to operate. Barcodes have more value and, even with the investment being considered, this technology less expensive for the company. RFID alternative is being dominant in this case as has the greatest value and smallest UEAC.

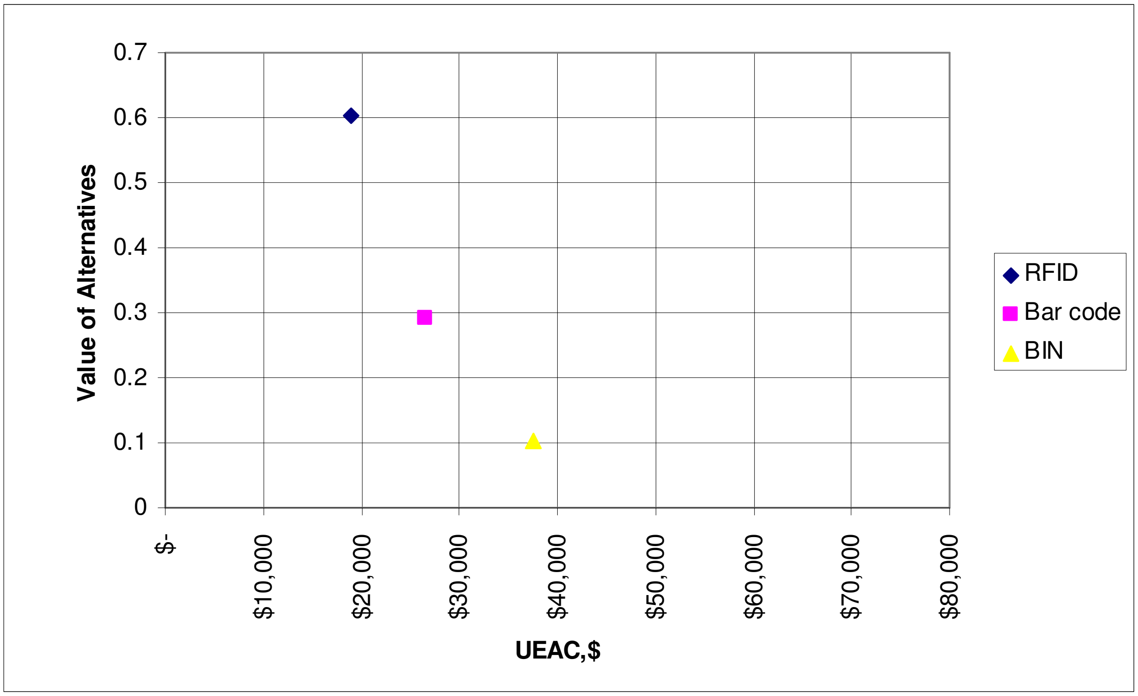

Figure 4.7 Value of alternatives vs. UEAC

The circled areas surrounding the current alternatives positions in Figure 4.8 define the possible range of variability of both parameters: change in value of alternatives and change in UEAC. Even with these parameters being changed the RFID alternative remains dominant, both value and cost are the most preferable.

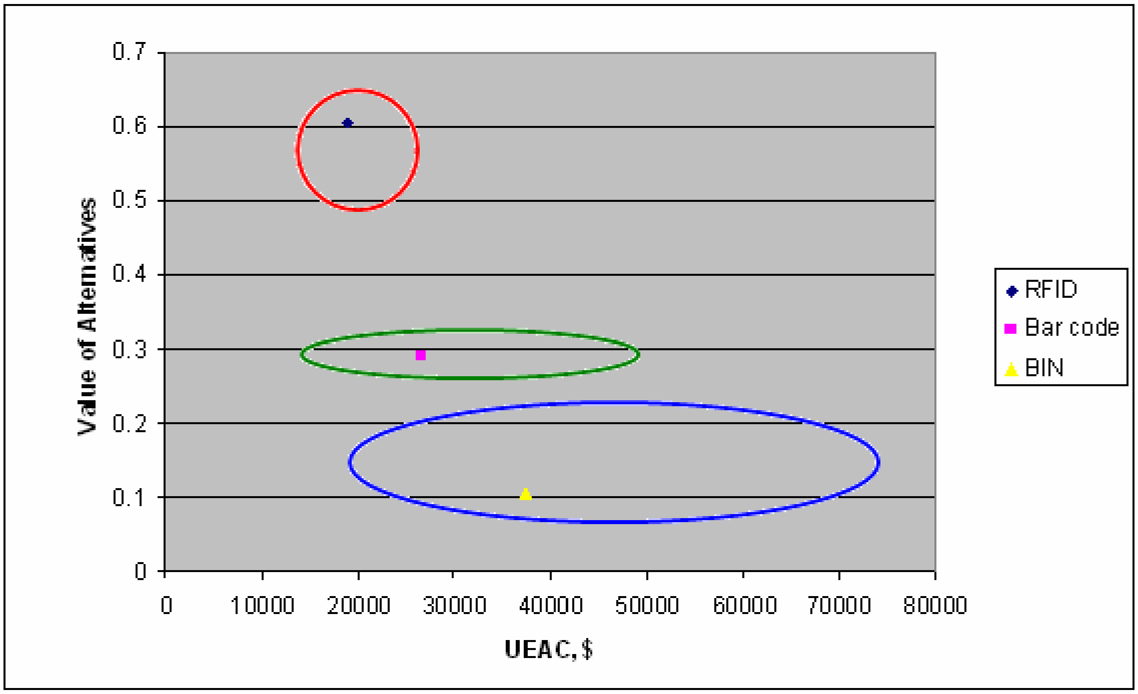

Figure 4.8 Value of alternatives vs. UEAC- the possible range of variability (estimation).

4.2 Model based on survey data

Presented above results are based on pure estimation. The second model presented in the current section is based on more accurate data which was collected from the company's professionals. Both, economical input parameters and AHP judgments were agreed with or suggested by Airtechnics supervisors.

4.2.1 Uniform Equivalent Annual Cost (UEAC) - survey data

After introducing the method to Airtechnics authorities the suggestion was made about estimation of some of the input parameters. In fact, it was suggested to relate transactions per year with the yearly shipments multiplied by 1.5. The company's growth was recommended 13% instead of the previously used 10%. The cost of transactions went higher than in estimated calculations because of the higher actual labor rate. The number of tags was suggested to use is equal to the average number of inventory items, and is the same for all kinds of technology (RFID tags are not considered to be reusable). All the other parameters are considered to remain the same as in the hypothetical model. An example of input data for bin location calculations is reflected in Table 4.21.

Table 4.21 Input data- bin locations (survey data).

MARR=	8%
Transactions/yr	112,053
Growth	13%
Cost/Trans	$1.45
Cap Investment	$0
Installation	$0
Number of tags	35,000
Cost/Tag	$0.01
Error Rate	0.33
Cost/Error	$30
Tax Rate	33%

The process of calculation of UEAC is identical to the one described in section 4.1.1. The process of this calculation is shown in Table 4.22 (for bin locations). Similar calculations for barcodes and RFID are illustrated in Tables 4.23- 4.24 of appendix B.

Table 4.22 Economic evaluation- bin locations (survey data).

Yr	Inv.	Trans.	Op Ex/Trans cost	Error/ yr	Error Cost	Tax Savings	Total Cost	PV
0	$350						$350	$350
1		112,053	$162,477	370	$11,093	-$57,278	$116,292	$107,678
2		126,620	$183,599	418	$12,535	-$64,724	$131,410	$112,663
3		143,080	$207,467	472	$14,165	-$73,138	$148,493	$117,879
4		161,681	$234,437	534	$16,006	-$82,646	$167,797	$123,336
5		182,699	$264,914	603	$18,087	-$93,390	$189,611	$129,046
6		206,450	$299,353	681	$20,439	-$105,531	$214,260	$135,020
7		233,289	$338,269	770	$23,096	-$119,250	$242,114	$141,271
8		263,617	$382,244	870	$26,098	-$134,753	$273,589	$147,812
							NPV=	$1,015,055
							UEAC=	$176,635

The results of economical evaluation show that the UEAC value for each alternative became much higher than in the hypothetical model. To find out what change in the input parameters caused change in the cost the sensitivity analysis was performed.

4.2.2 Sensitivity analysis for UEAC – survey data

Similar to the sensitivity analysis performed in section 4.1.2, each variable of interest was changed by the range 50- 200%. The results of dependency of UEAC on the change in input parameters are reflected in Figures 4.8- 4.10.

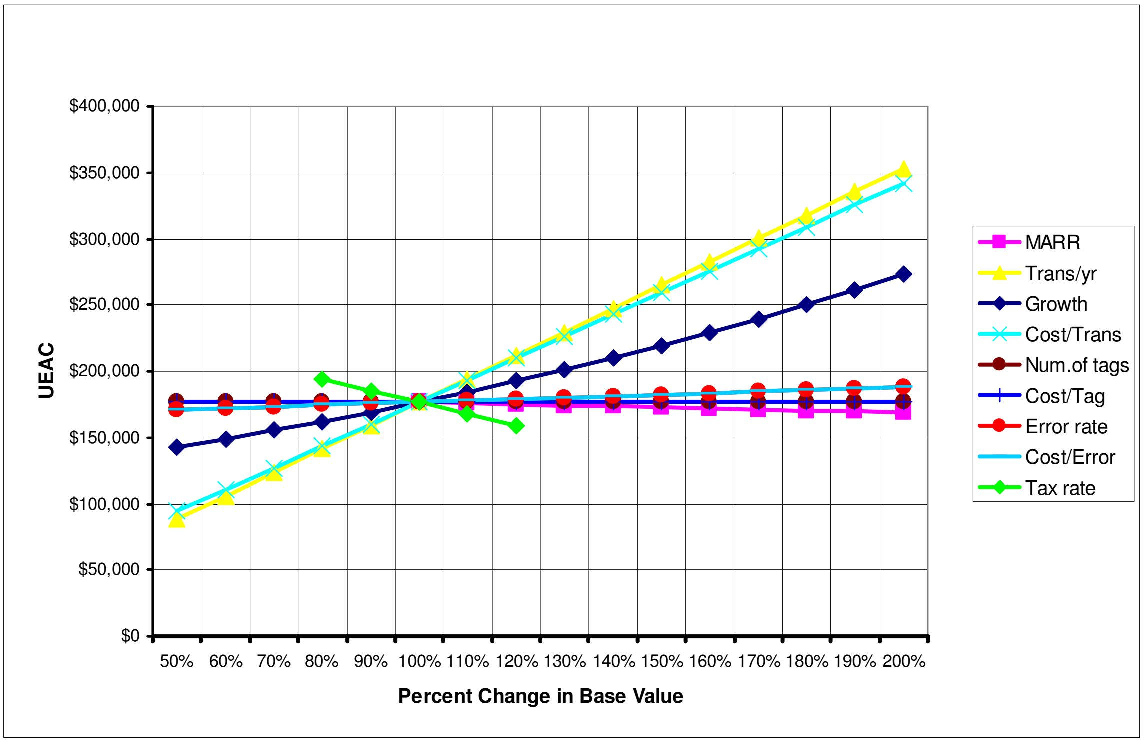

Figure 4.8- Sensitivity analysis for UEAC- bin locations.

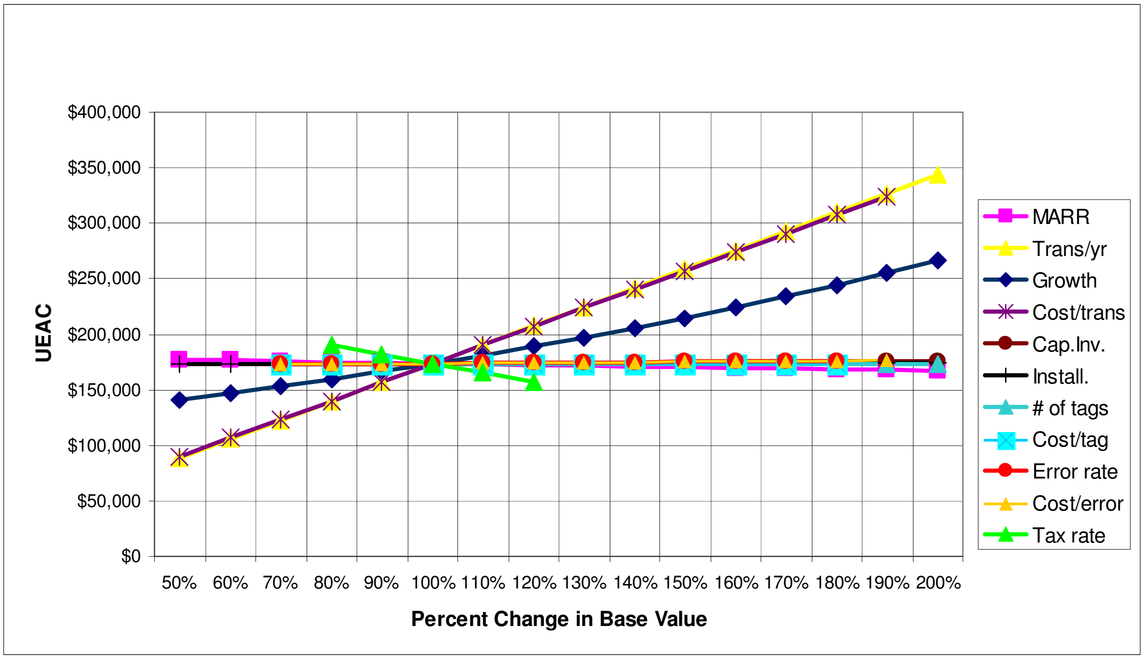

Figure 4.9- Sensitivity analysis for UEAC- barcodes.

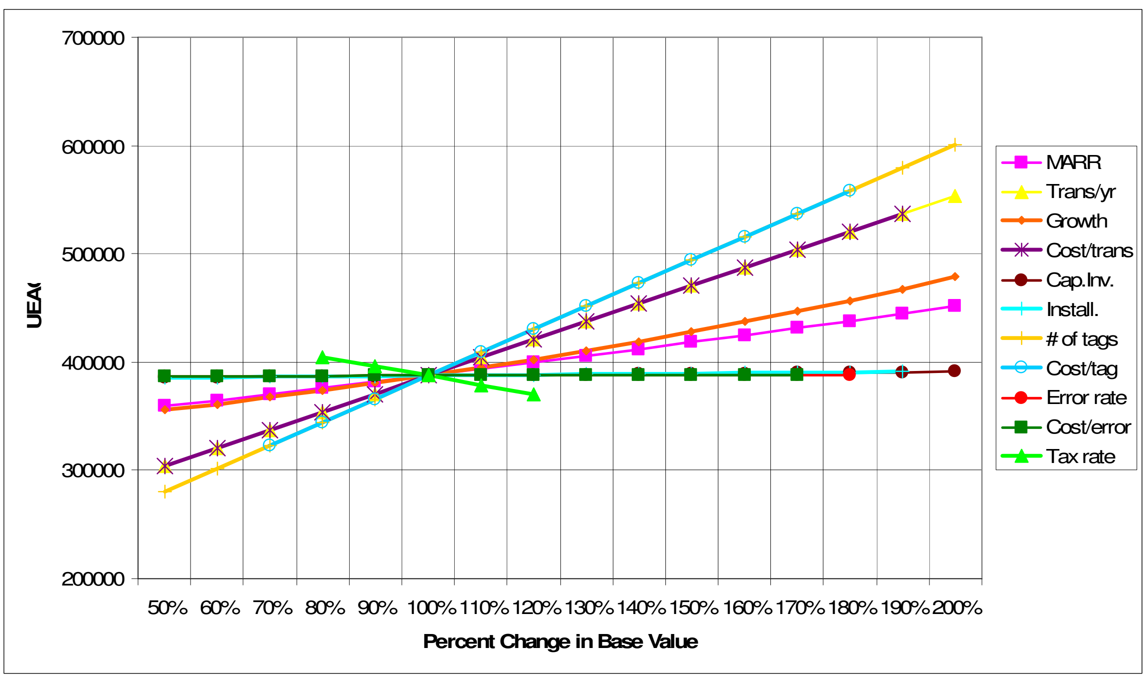

Figure 4.10- Sensitivity analysis for UEAC-RFID.

Sensitivity graphs for bin locations and barcodes alternatives are noted to have similar dependency: UEAC is strongly dependent on the number of transactions, their cost, and company's growth. All other parameters do not seem to have any significant impact on UEAC for both alternatives. Sensitivity graph for RFID shows that UEAC is dependent on transactions and company's growth as well. Nevertheless, it appears to have other, stronger affecting UEAC parameters. Those parameters are the number of tags and their cost. MARR is noted to have more significant impact on UEAC than is had in the previous two alternatives.

The overall sensitivity analysis performed in this section gives understanding that UEAC is greatly dependent on the number of transactions and their cost. The company's growth affects operating expenses as well the number of transactions as they are interrelated. Therefore, the company's growth is also very important parameter in the process of UEAC calculation.

The sensitivity graph for RFID shows that the number of tags and their cost significantly affect UEAC as the cost of RFID tags is much higher that the cost of bin location and barcode labels; at the same time the number of tags is significant and is equal for each kind of technology. MARR is another important parameter affecting the investment in the kind of technology as RFID. The higher the investment the more important MARR- can be concluded from the sensitivity graph for RFID.

4.2.3 Analytical Hierarchy Process (AHP) - survey data

After discussion AHP with Airtechnics supervisors it was decided that the structure of the problem and the major objective and criteria defined in the method to remain the same as they represent the real situation at Airtechnics. The survey data that was used for this part of the research represent the judgments for the comparison matrixes made by Material Director. The process of calculating the priorities is identical to the one described in section 4.1.3 of this chapter. The results of this process are revealed in Tables 4.23- 4.35 of Appendix C.

After the priorities have been found and consistency was proven the priorities for the criteria were multiplied with the priorities of the attributes. Further, the results were multiplied with the priorities of the alternatives for each of the attributes. The results of all the mentioned multiplications are shown in Table 4.36.

Table 4.36 Calculation of the final values of alternatives

		AHP evaluation			**Weighted Values**		
	Weights	BIN	Bar code	RFID	BIN	Bar code	RFID
Resource	0.004	0.072	0.279	0.649	0.000	0.001	**0.003**
Agility	0.015	0.072	0.279	0.649	0.001	0.004	**0.009**
Error recovery	0.048	0.090	0.394	0.516	0.004	0.019	**0.025**
Inventory accuracy	0.048	0.066	0.404	0.530	0.003	0.019	**0.025**
Inventory visibility	0.156	0.090	0.394	0.516	0.014	0.061	**0.081**
Damaged inventory	0.015	0.142	0.391	0.466	0.002	0.006	**0.007**
On time delivery	0.131	0.086	0.297	0.618	0.011	0.039	**0.081**
Order fill rate	0.045	0.081	0.188	0.731	0.004	0.008	**0.033**
Order accuracy	0.538	0.086	0.297	0.618	0.046	0.160	**0.332**
					0.086	**0.318**	**0.596**

The final values of bin locations, barcodes, and RFID technologies are accordingly 0.086, 0.318, and 0.596, almost the same weights that were gained for estimated data.

4.2.4 Sensitivity analysis AHP

Even though weights of the alternatives are almost the same and the dominance of RFID is clear, there is still a need to examine the relative importance of risk, inventory, and order fulfillment by performing sensitivity analysis.

Sensitivity analysis for AHP based on the judgments offered by the company's professionals is performed in a similar manner as the sensitivity analysis explained in section 4.1.4. The graphical results of this process are illustrated in Figures 4.11- 4.13.

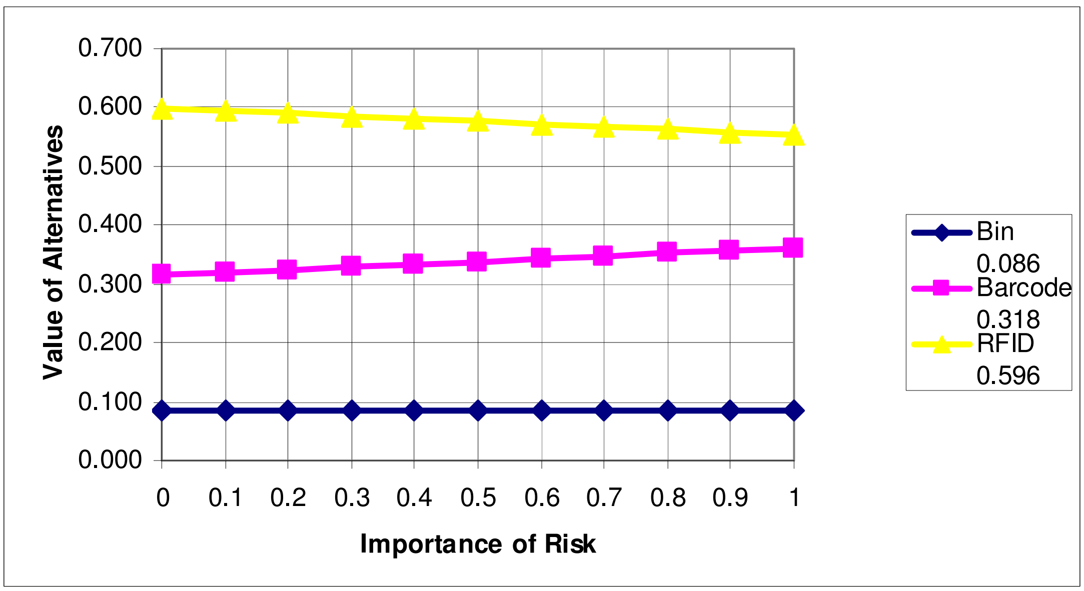

Figure 4.11 Value of alternatives vs. importance of risk.

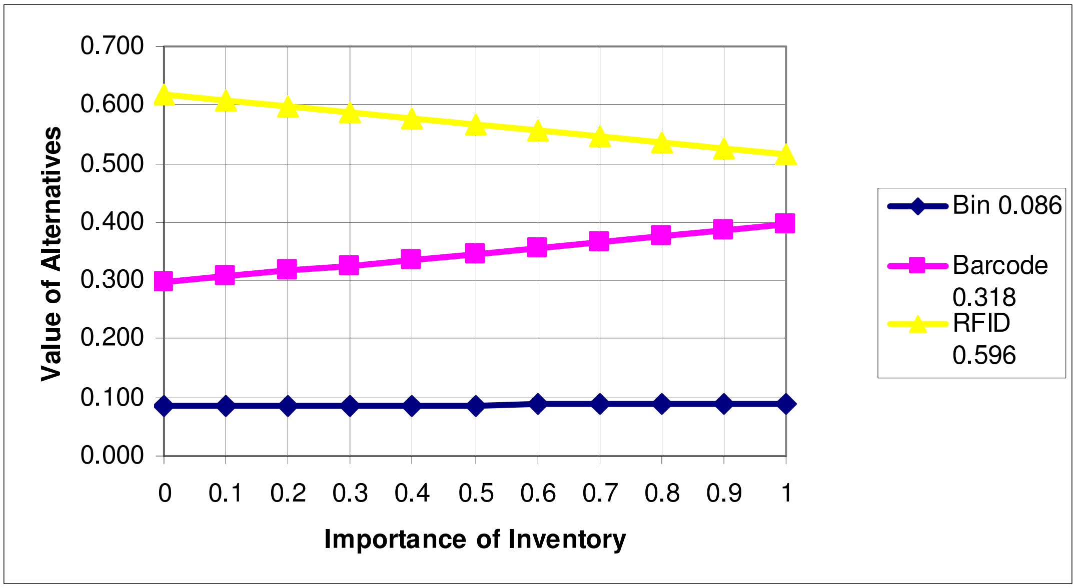

Figure 4.12 Value of alternatives vs. importance of inventory.

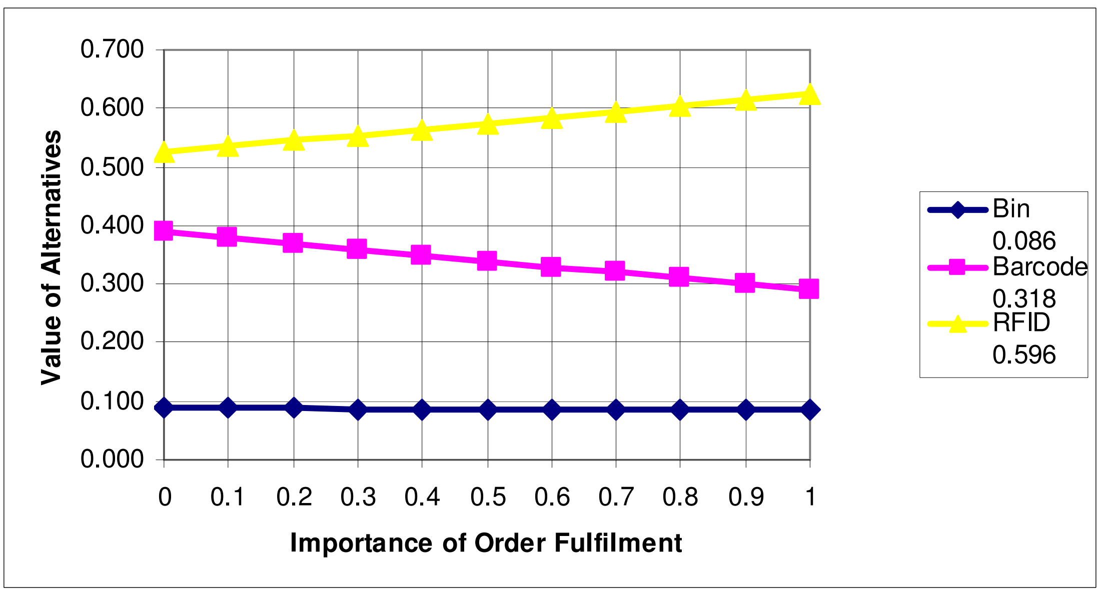

Figure 4.13 Value of alternatives vs. importance of order fulfillment.

Although the alternatives weights for survey data were spread similarly to the weights for estimated data, the importance of the top value criteria affects alternatives differently. For example, importance of risk (Figure 4.11) does not have much effect on bin locations and RFID, but it increases value of barcode alternative. The importance of inventory (Figure 4.12) lowers the value of RFID and increases the value of barcode alternative not affecting bin locations significantly. The importance of order fulfillment affects barcodes and RFID in an opposite manner- increases the value of RFID and decreases the value of barcodes again not affecting bin locations notably.

Presented above sensitivity graphs illustrated how the value of the alternatives changes with the change in importance of the top level criteria. Nevertheless, none of the data series within the graph intersect which means that at this level of cost no changes in importance factors can change the total value. In this case RFID has the dominant value, barcode has less value, and bin locations alternative has the least value.

4.2.5 The best alternative (survey data)

After the economic analysis and AHP evaluation were performed along with sensitivity aspects, the results of both processes were compiled on a single graph in Figure 4.14 showing the value of each alternative and the corresponding values of UEAC. Comparing bin locations and barcodes one can say that although these alternatives are in the same cost range, barcode alternative has much greater value than bin locations. RFID, from the other side, has the greatest UEAC and the most value among other alternatives.

The next graph was plotted to find out the possible range of variability of each plotted parameter showing the decision maker all the possible choices. The circled areas surrounding the current alternatives positions in Figure 4.15 indicate that RFID alternative retains the best performance parameters although UEAC is the highest among other alternatives.

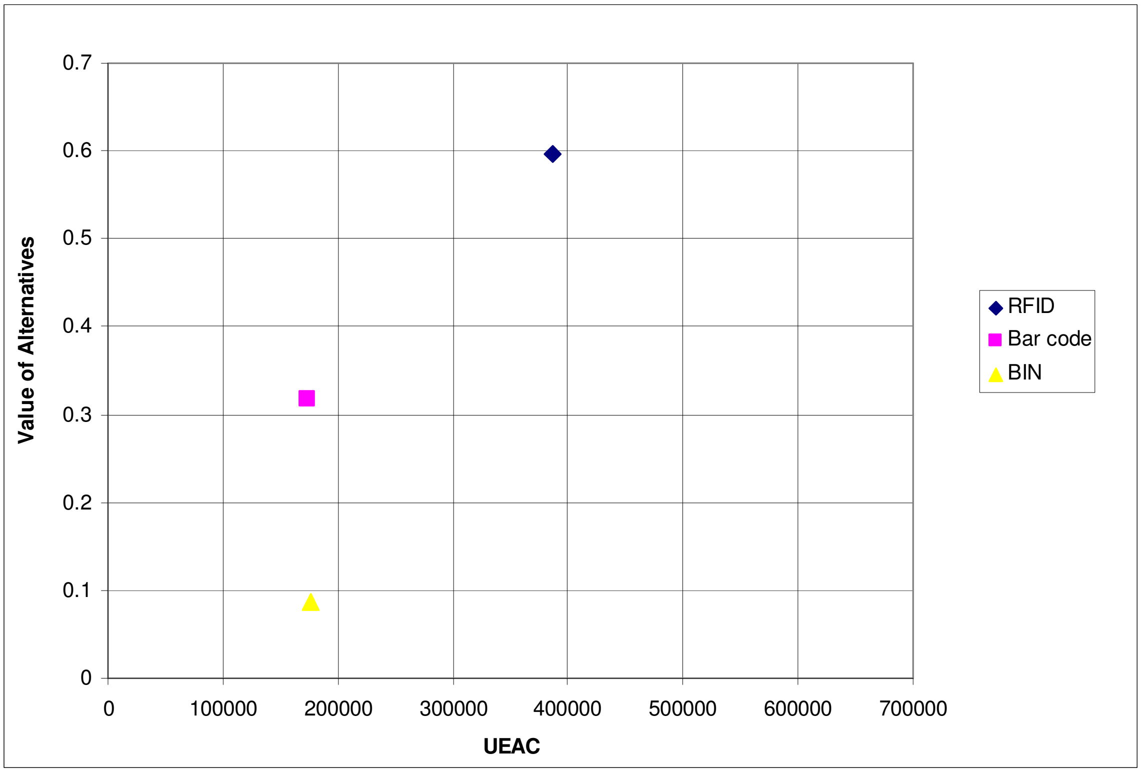

Figure 4.14 Value of alternatives vs. UEAC.

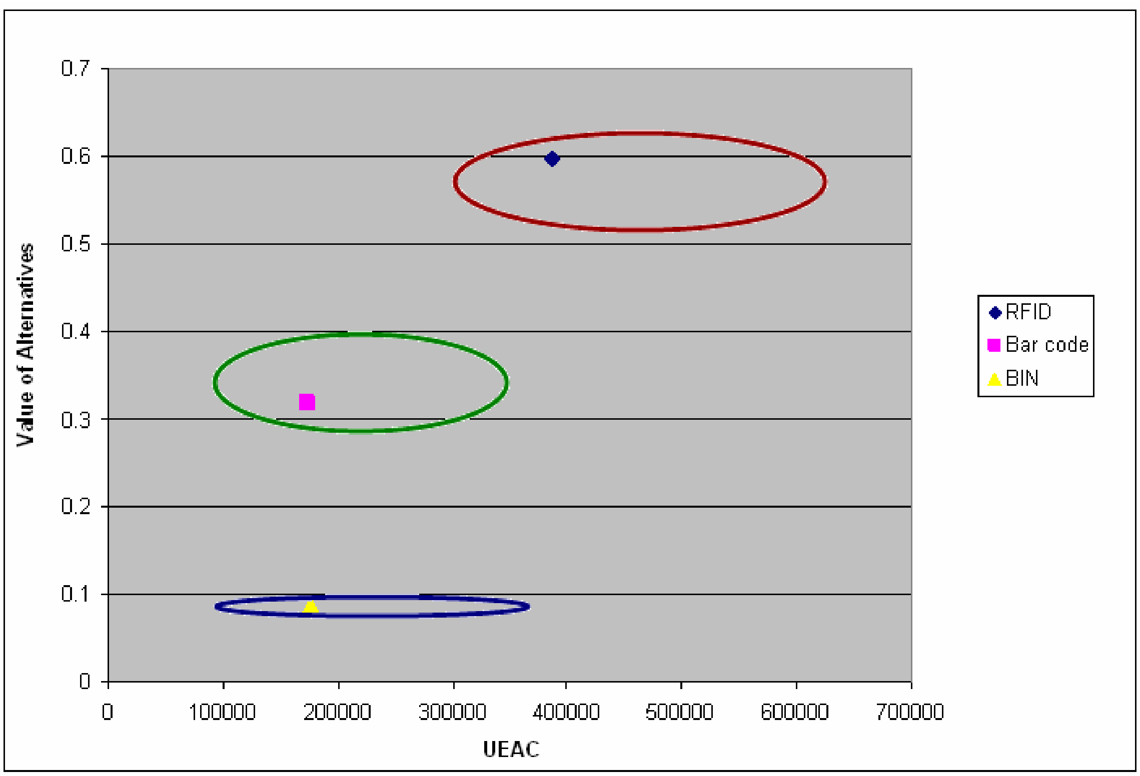

Figure 4.15 Value of alternatives vs. UEAC- the possible range of variability (survey).

4.3 Conclusions

Chapter three introduced the two sets of data for demonstration of the method. The outcomes of both of the trials had proven that UEAC is mostly dependent on the number of transactions and their cost. These two parameters have to be determined in the very accurate way as the economical model is the most sensitive to them.

According to survey results the company can notably improve inventory and risk criteria by going with barcode technology; this transition does not require a lot of investment and greatly improves performance parameters. From the other side if they want to improve the order fulfillment which seems to be the most essential performance parameter, they have to go with RFID technology that requires much more to invest.

CHAPTER 5

DISCUSSION

5.1 Conclusions

Innovative technologies such as RFID have the ability to add value along the entire supply chain by improving the mobility of the major aspects- people, information, documents, and communications (Angeles 2005). Applications of the method described in this research can be as narrow as consideration of the technology for one type of operation within the company, or more global, as a cooperative decision of several supply chain partners. Any of the applications are beneficial for the entire supply network because they contribute to its overall improved performance.

The introduced method incorporates the wide range of benefits of formal decision analysis. The first and the most obvious one is that this method allows consideration of both, the tangible and intangible benefits of alternatives. Second, the process involves a more straightforward economic analysis and does not require elaborate economic models. Third, the method is flexible and includes many supply chain factors; therefore, can be adopted for application in any of the value chain areas. Last, the technique is accessible. Both economic analysis and AHP are simple, thus the application does not require a consultant's involvement and can be performed by practitioners.

Although the presented method holds a variety of benefits, there are several shortcomings that have to be taken into account while applying the described decision making techniques. First, the way parameters are partitioned into economic and subjective parts can have an impact on the outcome. For example, the cost of an error could have been one of the parameters of either the subjective or the economic evaluation. In the presented study, this parameter was chosen to be the part of economic evaluation. Second, different ways of doing the sensitivity analysis can have an impact on the results. There is no prescription for choosing which way is the best for a given situation. Therefore the way of doing the sensitivity analysis can be another matter of concern. Lastly, the outcome of the decision analysis method does not guarantee finding the best solution. As the result of analysis, the decision maker has to realize the tradeoffs or accept the case where the dominance is obvious (as the dominance of RFID alternative was dominant for the majority of the parameters in the presented situation).

5.2 Future work

The future work that can be done for the further development of this method is to create a standard set of score sheets for different areas of application within the supply chain. Each will include the most appropriate set of input parameters for each application. This process will create sub methods specific to value chain areas.

The value and the cost of each alternative compared in this research were considered within a single firm. The future trend in this direction may include the comparison of the values of alternatives for two or more supply chain partners. In this case, the problem would be to apportion cost as a function of a value received from the dominant alternative technology in the supply chain.

Results of the both trials have shown the strong dependency of the cost on the number of transactions. Hence, instead of doing a standard ABC inventory analysis and choosing RFID one would perform a Pareto analysis on the number of transactions because the cost of the system is the most sensitive to this parameter. If the area of application of the technology is considered to be other than warehousing the cost may be more sensitive to other parameters which may be studied further as well. A company's management may be thinking in terms of layered alternatives which would result implementation of different technologies for different pieces of inventory, such as RFID for only high value items, bar codes for same day shipment products, and so on. Therefore, the presented method can be modified to assess a multiple technology implementation in future research.

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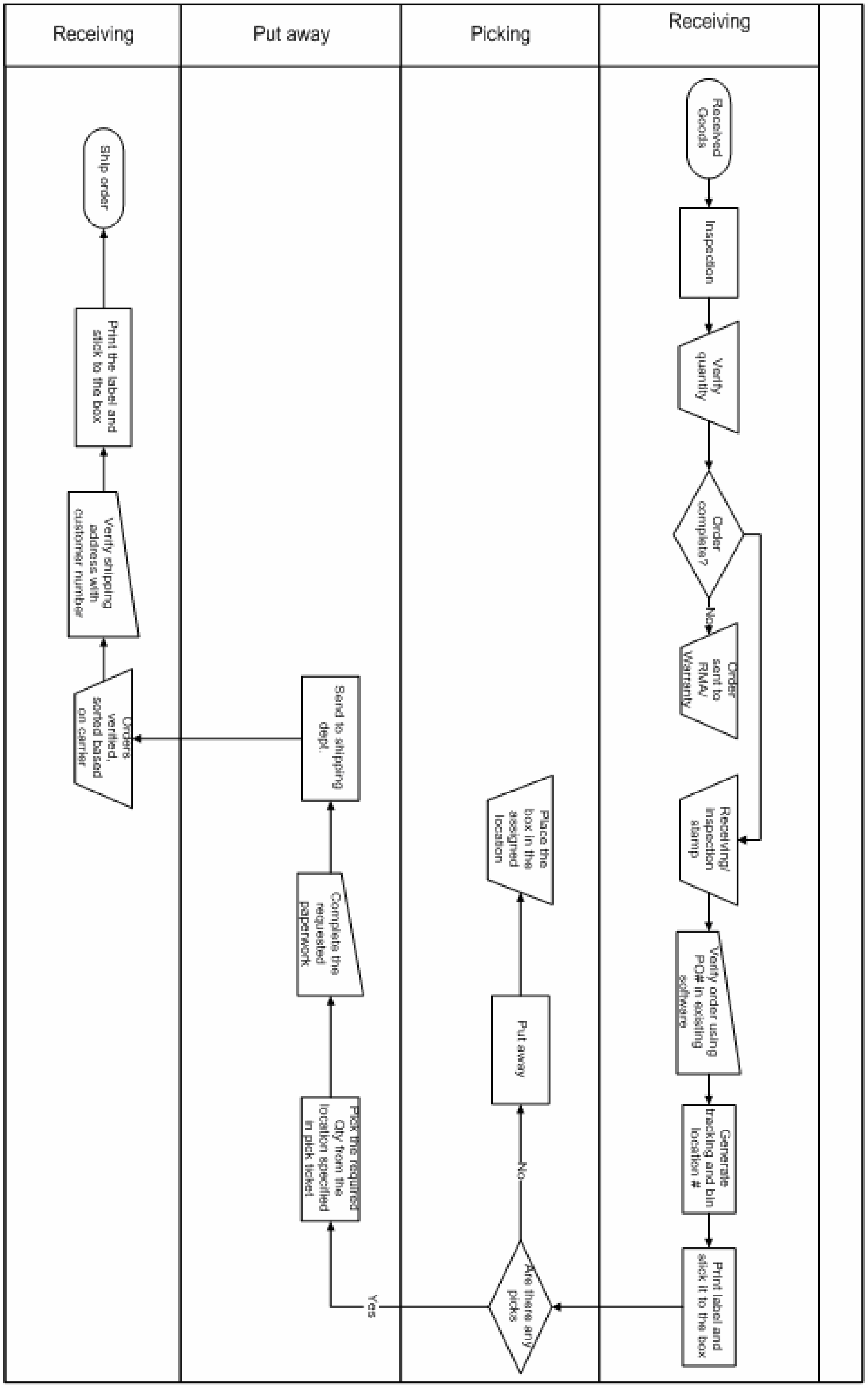
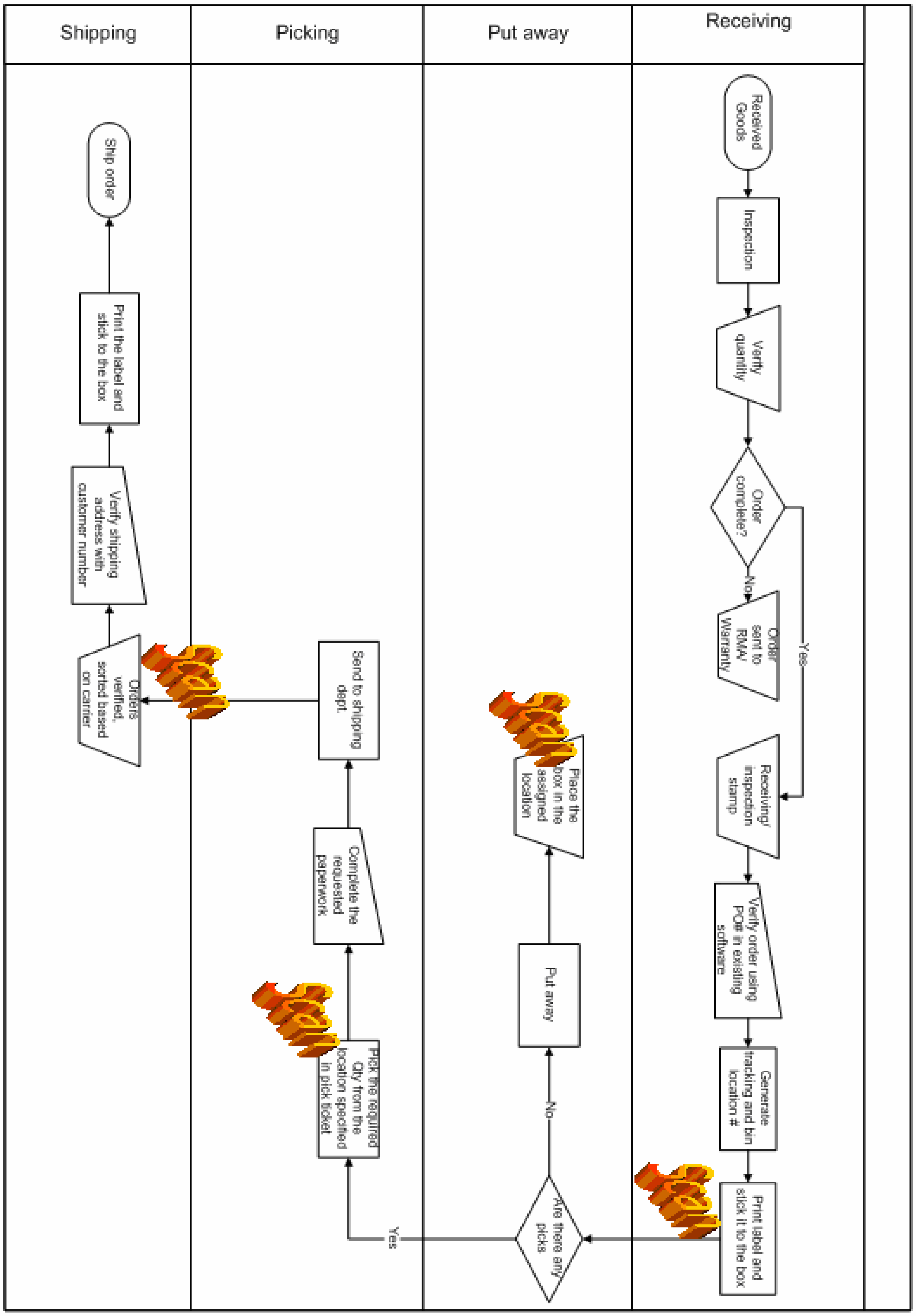
APPENDICES

APPENDIX A



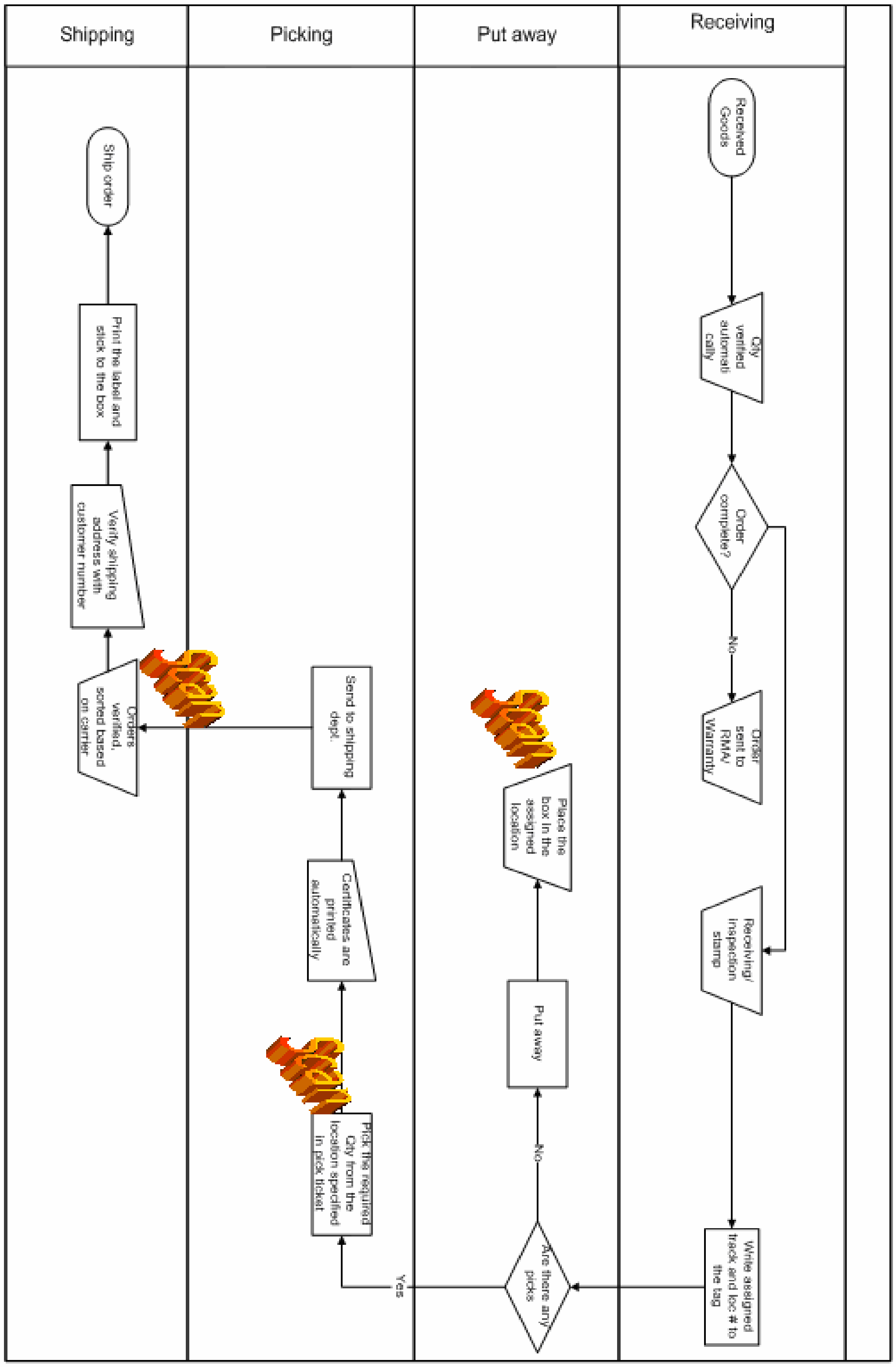
Material flow in the warehouse (original, BIN locations)

APPENDIX A (continued)



Material flow in the warehouse (modified, bar codes)

APPENDIX A (continued)



Material flow in the warehouse (modified, RFID)

APPENDIX B

Table 4.0 Input parameters for UEAC evaluation- estimated and survey data.

Input Parameters	Bin Location		Bar Code		RFID	
	Estimated	Survey	Estimated	Survey	Estimated	Survey
MARR	8%	8%	8%	8%	8%	8%
Transactions/Yr	120,000	112,053	120,000	298,808	96,000	224,106
Cost/Trans	$0.24	$1.45	$0.20	$0.55	$0.08	$0.73
Cap. Investment	$0	$0	$20,000	$20,000	$27,180	$27,180
Installation	$0	$0	$3,500	$3,500	$23,000	$23,000
Number of Tags	24,000	35,000	24,000	35,000	700	35,000
Cost/Tag	$0.01	$0.01	$0.03	$0.03	$35	$35
Error Rate (probability)	0.33	0.33	0.033	0.033	0.003	0.003
Cost/Error	$30	$30	$30	$30	$30	$30
Tax Rate	33%	33%	33%	33%	33%	33%
Comp. Growth	10%	13%	10%	13%	10%	13%

APPENDIX B (continued)

Table 4.23 Economic evaluation- barcodes (survey data)

Year	Inv.	Trans	Op Ex/Trans cost	Errors/ Yr	Error cost	Depr.	Tax savings	Total cost	PV
0	$24,550							$24,550	$24,550
1		298808	$164,344	99	$2,958.20	$5,714	-$57,096	$110,207	$102,044
2		337653	$185,709	111	$3,342.77	$4,082	-$63,734	$125,318	$107,440
3		381548	$209,851	126	$3,777.32	$2,915	-$71,460	$142,169	$112,858
4		431149	$237,132	142	$4,268.38	$2,082	-$80,349	$161,051	$118,377
5		487199	$267,959	161	$4,823.27	$1,487	-$90,509	$182,273	$124,052
6		550534	$302,794	182	$5,450.29	$1,062	-$102,071	$206,173	$129,924
7		622104	$342,157	205	$6,158.83	$759	-$115,195	$233,121	$136,024
8		702977	$386,638	232	$6,959.48		-$129,887	$263,710	$142,474
								NPV=	$997,744
								UEAC=	$173,622

Table 4.24 Economic evaluation- RFID (survey data)

Year	Inv.	Trans	Op Ex/Trans cost	Errors/ Yr	Error cost	Depr.	Tax Savings	Total Cost	PV
0	$1,275,180							$1,275,180	$1,275,180
1		224106	$163,597	7	$201.70	$7,766	-$56,616	$107,183	$99,243
2		253240	$184,865	8	$227.92	$5,547	-$62,911	$122,182	$104,751
3		286161	$208,897	9	$257.54	$3,962	-$70,329	$138,826	$110,205
4		323362	$236,054	10	$291.03	$2,830	-$78,928	$157,417	$115,706
5		365399	$266,741	11	$328.86	$2,021	-$88,800	$178,270	$121,327
6		412901	$301,418	12	$371.61	$1,444	-$100,067	$201,722	$127,119
7		466578	$340,602	14	$419.92	$1,031	-$112,878	$228,144	$133,120
8		527233	$384,880	16	$474.51		-$127,167	$258,188	$139,491
								NPV=	$2,226,143
								UEAC=	$387,382

APPENDIX C

PAIR-WISE COMPARISON MATRIXES

Table 4.6 Pair-wise comparison matrix for risks (estimated data).

Risks	Resource	Agility	Error recovery	Raw^(1/3)	E (N)	M*N	(M*N)/E
Resource	1	0.333	3	1	**0.25829**	0.784802	3.03851
Agility	3	1	5	2.46621	**0.63699**	1.935488	3.03851
Error recovery	0.333	0.2	1	0.40548	**0.10473**	0.318222	3.03851
				3.87169			
						Lambda	3.03851
						CI=	0.01926

Table 4.7 Pair-wise comparison matrix for inventory (estimated data).

Inventory	Inventory accuracy	Inventory visibility	Damaged inventory	Raw^(1/3)	E (N)	M*N	(M*N)/E
Inventory accuracy	1	0.67	7	1.67388	**0.39621**	1.19238	3.00945
Inventory visibility	1.5	1	8	2.28943	**0.54192**	1.63119	3.01004
Damaged	0.143	0.125	1	0.26138	**0.06187**	0.18621	3.00974
				4.22469			
						Lambda	3.00974
						CI=	0.00487

Table 4.8 Pair-wise comparison matrix for order fulfillment (estimated data).

Order fulfillment	On time delivery	Order fulfillment rate	Order accuracy	Raw^(1/3)	E (N)	M*N	(M*N)/E
On time delivery	1	3	0.67	1.26201	**0.38777**	1.19194	3.07388
Order fulfillment rate	0.33	1	0.5	0.55032	**0.16909**	0.51991	3.07478
Order accuracy	1.5	2	1	1.44224	**0.44314**	1.36297	3.07570
				3.25459			
						Lambda	3.07479
						CI=	0.03739

Table 4.9 Pair-wise comparison matrix for alternatives with respect t resource (estimated data).

Resource	BIN	Bar code	RFID	Raw^(1/3)	E (N)	M*N	(M*N)/E
BIN	1	4	5	2.71442	**0.67381**	2.07922	3.08577
Bar code	0.25	1	3	0.90856	**0.22554**	0.69595	3.08577
RFID	0.2	0.33	1	0.40548	**0.10065**	0.31060	3.08577
				4.02846			
						Lambda	3.08577
						CI=	0.04288

Table 4.10 Pair-wise comparison matrix for alternatives with respect to agility (estimated data).

Agility	BIN	Bar code	RFID	Raw^(1/3)	E (N)	M*N	(M*N)/E
BIN	1	0.2	0.143	0.30571	**0.07193**	0.22045	3.06489
Bar code	5	1	0.333	1.18563	**0.27895**	0.85496	3.06489
RFID	7	3	1	2.75892	**0.64912**	1.98947	3.06489
				4.25027			
						Lambda	3.06489
						CI=	0.03244

Table 4.11 Pair-wise comparison matrix for alternatives with respect to error recovery (estimated data).

Error recovery	BIN	Bar code	RFID	Raw^(1/3)	E (N)	M*N	(M*N)/E
BIN	1	0.33	0.25	0.43679	**0.12196**	0.36810	3.01829
Bar code	3	1	0.5	1.14471	**0.31962**	0.96470	3.01829
RFID	4	2	1	2	**0.55842**	1.68549	3.01829
				3.58150			
						Lambda	3.01829
						CI=	0.00915

Table 4.12 Pair-wise comparison matrix for alternatives with respect to inventory accuracy (estimated data).

Inventory accuracy	BIN	Bar code	RFID	Raw^(1/3)	E (N)	M*N	(M*N)/E
BIN	1	0.25	0.2	0.36840	**0.09739**	0.2946	3.02460
Bar code	4	1	0.5	1.25992	**0.33307**	1.0074	3.02460
RFID	5	2	1	2.15443	**0.56954**	1.7226	3.02460
				3.78276			
						Lambda	3.02460
						CI=	0.01230

Table 4.13 Pair-wise comparison matrix for alternatives with respect to inventory visibility (estimated data).

Inventory visibility	BIN	Bar code	RFID	Raw^(1/3)	E (N)	M*N	(M*N)/E
BIN	1	0.2	0.11	0.28114	**0.06033**	0.18528	3.07127
Bar code	5	1	0.25	1.07722	**0.23115**	0.70991	3.07127
RFID	9	4	1	3.30193	**0.70852**	2.17606	3.07127
				4.66029			
						Lambda	3.07127
						CI=	0.03563

Table 4.14 Pair-wise comparison matrix for alternatives with respect to damaged inventory (estimated data).

Damaged inventory	BIN	Bar code	RFID	Raw^(1/3)	E (N)	M*N	(M*N)/E
BIN	1	0.769	0.33	0.63530	**0.19143**	0.57473	3.00228
Bar code	1.3	1	0.5	0.86624	**0.26102**	0.78366	3.00228
RFID	3	2	1	1.81712	**0.54755**	1.64389	3.00228
				3.31866			
						Lambda	3.00228
						CI=	0.00114

Table 4.15 Pair-wise comparison matrix for alternatives with respect to on time delivery (estimated data).

On time delivery	BIN	Bar code	RFID	Raw^(1/3)	E (N)	M*N	(M*N)/E
BIN	1	0.33	0.25	0.43679	**0.12513**	0.375393	3.00007
Bar code	3	1	0.77	1.32148	**0.37857**	1.135724	3.00007
RFID	4	1.3	1	1.73248	**0.49630**	1.488954	3.00007
				3.49074			
						Lambda	3.00007
						CI=	0.000035

Table 4.16 Pair-wise comparison matrix for alternatives with respect to order fill rate (estimated data).

Order fill rate	BIN	Bar code	RFID	Raw^(1/3)	E (N)	M*N	(M*N)/E
BIN	1	0.714	0.625	0.76428	**0.24929**	0.74834	3.00184
Bar code	1.4	1	0.77	1.02501	**0.33433**	1.00363	3.00184
RFID	1.6	1.3	1	1.27650	**0.41637**	1.24988	3.00184
				3.06579			
						Lambda	3.00184
						CI=	0.00092

Table 4.17 Pair-wise comparison matrix for alternatives with respect to order accuracy (estimated data).

Order accuracy	BIN	Bar code	RFID	Raw^(1/3)	E (N)	M*N	(M*N)/E
BIN	1	0.17	0.11	0.26457	**0.05977**	0.18104	3.02906
Bar code	6	1	0.4	1.33887	**0.30246**	0.91618	3.02906
RFID	9	2.5	1	2.82310	**0.63777**	1.93184	3.02906
				4.42654			
						Lambda	3.02906
						CI=	0.01453

Table 4.23 Pair-wise comparison matrix for customer satisfaction (survey data).

CUSTOMER SATISFACTION	Risk	Inventory	Order fulfillment	Raw^(1/3)	**E (N)**	M*N	(M*N)/ E
Risk	1	0.2	0.14	0.306	**0.0668**	0.2126	3.1828
Inventory	5	1	0.2	1	**0.2184**	0.6954	3.1828
Order fulfillment	7	5	1	3.271	**0.7147**	2.2748	3.1828
				4.576777			
						Lambda=	3.1828
						CI=	0.0914

Table 4.24 Pair-wise comparison matrix for risks (survey data).

Risks	Resource	Agility	Error recovery	Raw^(1/3)	**E (N)**	M*N	(M*N)/E
Resource	1	0.20	0.143	0.306	**0.0668**	0.2126	3.1828
Agility	5	1	0.2	1	**0.2185**	0.6954	3.1828
Error recovery	7	5	1	3.271	**0.7147**	2.2748	3.1828
				4.577			
						Lambda=	3.1828
						CI=	0.0914

Table 4.25 Pair-wise comparison matrix for inventory (survey data).

Inventory	Inventory accuracy	Inventory visibility	Damaged inventory	Raw^(1/3)	**E (N)**	M*N	(M*N)/E
Inventory accuracy	1	0.2	5	1	**0.2185**	0.6954	3.1828
Inventory visibility	5	1	7	3.2710	**0.7147**	2.2748	3.1828
Damaged inventory	0.2	0.143	1	0.3057	**0.0668**	0.2126	3.1828
				4.5768			
						Lambda=	3.1828
						CI=	0.0914

Table 4.26 Pair-wise comparison matrix for order fulfillment (survey data).

Order fulfillment	On time delivery	Order fill rate	Order accuracy	Raw^(1/3)	**E (N)**	M*N	(M*N)/E
On time delivery	1	5	0.143	0.8939	**0.1840**	0.6061	3.2948
Order fill rate	0.2	1	0.143	0.3057	**0.0629**	0.2073	3.2948
Order accuracy	7	7	1	3.6593	**0.7531**	2.4813	3.2948
				4.8589			
						Lambda=	3.2948
						CI=	0.1474

Table 4.27 Pair-wise comparison matrix for resource (survey data).

Resource	BIN	Bar code	RFID	Raw^(1/3)	**E (N)**	M*N	(M*N)/E
BIN	1	0.2	0.143	0.3057	**0.0719**	0.2204	3.0649
Bar code	5	1	0.333	1.1856	**0.2790**	0.8550	3.0649
RFID	7	3	1	2.7589	**0.6491**	1.9895	3.0649
				4.2503			
						Lambda=	3.0649
						CI=	0.0324

Table 4.28 Pair-wise comparison matrix for agility (survey data).

Agility	BIN	Bar code	RFID	Raw^(1/3)	**E (N)**	M*N	
BIN	1	0.2	0.143	0.3057	**0.0719**	0.2204	3.064888
Bar code	5	1	0.333	1.1856	**0.2790**	0.8550	3.064888
RFID	7	3	1	2.7589	**0.6491**	1.9895	3.064888
				4.2503			
						Lambda=	3.064888
						CI=	0.032444

Table 4.29 Pair-wise comparison matrix for error recovery (survey data).

Error recovery	BIN	Bar code	RFID	Raw^(1/3)	**E (N)**	M*N	(M*N)/E
BIN	1	0.2	0.2	0.3420	**0.0902**	0.2721	3.0183
Bar code	5	1	0.67	1.4938	**0.3938**	1.1886	3.0183
RFID	5	1.5	1	1.9574	**0.5160**	1.5575	3.0183
				3.7932			
						Lambda=	3.0183
						CI=	0.0091

Table 4.30 Pair-wise comparison matrix for inventory accuracy (survey data).

Inventory accuracy	BIN	Bar code	RFID	Raw^(1/3)	**E (N)**	M*N	(M*N)/E
BIN	1	0.143	0.143	0.2733	**0.066102**	0.199516	3.018295
Bar code	7	1	0.667	1.6711	**0.40422**	1.220055	3.018295
RFID	7	1.5	1	2.1898	**0.529678**	1.598724	3.018295
				4.1341			
						Lambda=	3.018295
						CI=	0.009147

Table 4.31 Pair-wise comparison matrix for inventory visibility (survey data).

Inventory visibility	BIN	Bar code	RFID	Raw^(1/3)	**E (N)**	M*N	(M*N)/E
BIN	1	0.2	0.2	0.3420	**0.0902**	0.2721	3.0183
Bar code	5	1	0.67	1.4938	**0.3938**	1.1886	3.0183
RFID	5	1.5	1	1.9574	**0.5160**	1.5575	3.0183
				3.7932			
						Lambda=	3.0183
						CI=	0.0091

Table 4.32 Pair-wise comparison matrix for damaged inventory (survey data).

Damaged inventory	BIN	Bar code	RFID	Raw^(1/3)	**E (N)**	M*N	(M*N)/E
BIN	1	0.33	0.33	0.4807	**0.1424**	0.4283	3.0077
Bar code	3	1	0.77	1.3215	**0.3914**	1.1772	3.0077
RFID	3	1.3	1	1.5740	**0.4662**	1.4022	3.0077
				3.3763			
						Lambda=	3.0077
						CI=	0.0038

Table 4.31 Pair-wise comparison matrix for on time delivery (survey data).

On time delivery	BIN	Bar code	RFID	Raw^(1/3)	**E (N)**	M*N	(M*N)/E
BIN	1	0.2	0.2	0.3420	**0.0856**	0.2685	3.1356
Bar code	5	1	0.33	1.1856	**0.2969**	0.9309	3.1356
RFID	5	3	1	2.4662	**0.6175**	1.9363	3.1356
				3.9938			
						Lambda=	3.1356
						CI=	0.0678

Table 4.32 Pair-wise comparison matrix for order fill rate (survey data).

Order fill rate	BIN	Bar code	RFID	Raw^(1/3)	**E (N)**	M*N	(M*N)/E
BIN	1	0.333	0.143	0.3625	**0.0810**	0.2481	3.0649
Bar code	3	1	0.2	0.8434	**0.1884**	0.5774	3.0649
RFID	7	5	1	3.2711	**0.7306**	2.2393	3.0649
				4.4770			
						Lambda=	3.0649
						CI=	0.0324

Table 4.33 Pair-wise comparison matrix for order accuracy (survey data).

Order accuracy	BIN	Bar code	RFID	Raw^(1/3)	**E (N)**	M*N	(M*N)/E
BIN	1	0.2	0.2	0.341995	**0.085631**	0.2685	3.1356
Bar code	5	1	0.33	1.185631	**0.296865**	0.9309	3.1356
RFID	5	3	1	2.466212	**0.617504**	1.9363	3.1356
				3.993838			
						Lambda=	3.1356
						CI=	0.0678