RELIABILITY TEST OF AN RFID SYSTEM FOR TOOL MANAGEMENT ON CONSTRUCTION SITES

A Thesis

by

NARESH KALLA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2007

Major Subject: Construction Management

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ABSTRACT

Reliability Test of an RFID System for Tool Management on Construction Sites.

(May 2007)

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Chair of Advisory Committee: Dr. Julian Kang

In the construction industry, one of the aspects that affect the productivity of the construction crew is the availability of tools and supplies. Unavailability of tools and supplies results in a delay of the project, which in turn increases the cost of the project. If any such delays on job sites could be reduced, it would help the construction industry in reduction of time and cost losses. The construction industry is in need of a technology that would improve the present-day tool management system (TMS) to reduce the construction costs from delays in projects.

Radio Frequency Identification (RFID) technology offers the possibility that tools and supplies, tagged with RFID devices, could be tracked down automatically. Although the potential of RFID is real, it does have limitations like any other technology. Without understanding and working with the limitations of RFID, this technology may disappoint many before its true and significant capabilities are realized. Before the technology is executed full-fledged, it needs to be tested for reliability on construction sites in particular. Researchers, from many parts of the world, have performed tests to understand the reliability of the RFID technology considering variables like metal interferences, reading range, multiple tag identification, etc. But these tests conducted could not discuss all the factors that may affect the reliability of the technology.

This paper identifies other factors that might affect the reliability of RFID technology and tests are conducted to understand the influence of these factors on the readability of the RFID tags. Number of tools and the velocity with which tools are taken across the portal are two variables that are tested for reliability of RFID. Tests are conducted using the experiment setup that resembles a construction site tool management room entrance/exit.

Results show a radical decrease in the readability of tags, while the numbers of the tools are increased gradually. And also, when the tools were taken across the RFID portal with gradual increasing velocity, the readability reduced. These results prove that both the tested parameters have an effect on the reliability of RFID technology for tool tracking.

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1 INTRODUCTION

Every construction company uses an abundance of equipment and tools both at job sites and field offices. Once the work is completed, all the items are moved to the main office or to another job site where there is a need for them. However, not all tools get transferred to the next job site, and instead get misplaced or lost. Where do these tools disappear to? Are construction companies, concerned about the loss of tools on job sites? Or does the contractor add the losses to the profit margin? It is estimated by the National Insurance Crime Bureau that the construction industry loses $1 billion annually from equipment and tool theft, increasing on average 20% annually (Zgraggen 2006). A major concern of the construction industry is tracking these tools. Tracking the tools with information such as their use, purchase date, cost, and location should help to reduce the costs due to losses. This process is extremely laborious using current systems and decreases the efficiency of a crew, yet it must be done in order to keep a project running smoothly. According to a study of BMW Construction, Inc., on an average 37% of a field supervisor's time is used in tool and material management (Jacobs 2002). If there is a process by which the amount of work put by the supervisor in tool management could be reduced, that would greatly increase the efficiency

This thesis follows the style of the *Journal of Construction Engineering and Management*.

and productivity on a construction job site. Bechtel Power Corporation loses tools worth over $200,000 annually and the project costs increase because of this loss (Zgraggen 2006). The theft and misplacement of tools could be accounted for if tool inventories were fully automated systems.

1.1 Current Processes and Issues

The most critical concern of construction site tool management process is the issue and receipt of tools from the central tool storage area (tool room). Likewise, the management of the tool inventory to track the tools on the site and those in the tool room is also important to track the costly supplies and the required tools. The objectives of these tool management processes are to:

1) manage the tools to ensure their availability when needed by the crew;
2) manage inventories so that no tool is left unused on one construction job site when it may be required by other job sites performing similar types of work; and
3) reduce loss or theft of tools and supplies by assigning worker responsibility to specific items (Kang 2005).

Present-day tool management system is mainly barcode identification system. This process of tool issue/receipt is easier as each tool on the construction site is identified by a unique Universal Product Code (UPC). The advent of the barcode system has advanced the tool inventory management system to achieve a degree of accuracy and speed. During the process of tool issue/receipt the barcode, which is firmly adhered to the tool, is read by optical scanners called barcode readers. These readers capture the unique identification number from the barcode and retrieve the data related to the tools, which is pre-registered on the barcode. Then the tool(s) is issued on the employer ID (which could have a barcode on them). This process has many disadvantages, such as, it requires a lot of human resources, is difficult to track the tools available and tools issued at a given point of time, and at the same time this process has high scope of error and is not very efficient in terms of cost and time. The process followed in tool issue/receipt using the barcode process, is illustrated in figure 1.

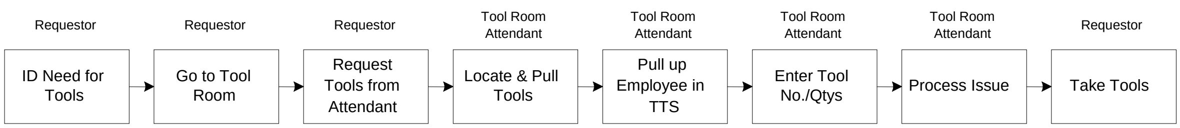

Figure 1: Tool check-in/out using current process (Kang 2005)

Not only the construction industry, but also many other industries, have observed the sudden shift in paradigm from a manually entered inventory systems to a more sophisticated technology, the barcode system. However, the process of reducing labor and the effort levels in tool issue/receipt has not yet reached perfection. There are certain problems that were identified with the barcode system of identification. These problems that plague barcode systems today are

- Dirt, intense sunlight, scratches in the barcode, and other impairments often make it difficult for readers to accurately scan the identifier on each item.
- The process still requires a dedicated attendant to take care of the tool room, which is expensive to maintain.
- Occasionally, the tool management system needs to be updated and verified. At this time, each tool in the inventory has to be scanned separately and checked with the inventory of the system, which is a complicated task.
- The size of data that could be stored on a barcode is limited, and thus does not give enough room for storing all the data required (like the date of purchase, date of issue, employee ID, date of maintenance, cost of product, owner details, etc.) on particular tools.

1.2 Importance

Tool management on construction sites is a significant factor that may affect the efficiency and productivity of the labor on sites. During the course of a construction project, it is imperative to take an inventory of all construction tools to maintain logs and understand the usability of tools on the site. These inventories track the tools that are remaining (un-issued) in the tool room and also those in field use. These inventories may be made to account for specific tools needed for completion of particular phases of the job or to ensure sufficient tools are available to begin work on new phases of a project.

Occasionally, inventories may be taken so that workers may be held accountable for the tools in their care, and to discourage loss or theft of valuable tools. Sometimes tool inventories are necessary for asset accounting purposes. Present day tool inventories are labor intensive, time consuming, and prone to error. As the number of tools and assets grow on a job site, the manual entry of tools becomes extremely inefficient because every tool on-site has to be manually recorded in the inventory one by one. The process of assigning these barcodes or serial numbers to each of the tools is very labor intensive.

In order to reduce the errors and disadvantages of using the barcode method of inventory management, many associations, researchers, and industries have started working on a new technology that would automate the whole process of tool management systems. A solution to the issue is identifying a technology that could cater to these needs of the construction industry, that has been around for a very long time and also has been tested and widely utilized in other industries. The technology that satisfied many other criteria, including the ones mentioned above is Radio Frequency Identification (RFID) technology. RFID technology uses radio frequencies, as opposed to light rays in barcodes, to identify objects tagged with RFID.

If RFID technology is applied to the current tool tracking systems (TTS), several steps in tool room issue/receipt can be eliminated. Workers who need a tool could locate it in the tool room by themselves without the assistance of the tool room attendant. When they pass the portal, the tool ID and employee ID could be scanned by the RFID reader and entered into the TTS. As shown in figure 2, no tool room attendant would be needed if RFID technology is applied to the current TTS. However, like any other technology, RFID also has some issues that need to be clarified before it is implemented full fledged.

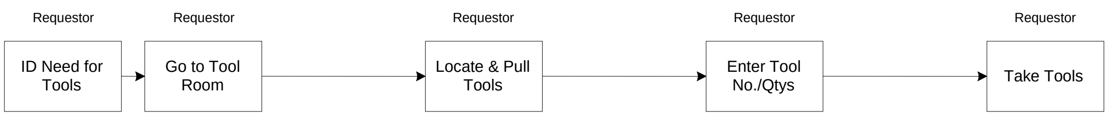

Figure 2: Tool check-in/out process improvement by RFID technology (Kang 2005)

1.3 RFID in the Construction Industry

Recently in the construction industry, the utilization of RFID technology has been suggested to make up for the weak points in the current tool tracking systems. The ability of RFID technology to identify multiple tags in a short time is expected to replace barcode systems in many industry applications. Because no line of sight is required between the reader and the tag, unattended reading stations can be set up to identify objects regardless of their orientation to the reader. Simultaneous processing, automatic unattended reading, and the ability to store and process information locally are the main performance characteristics that set the uniqueness of RFID.

A white paper produced by the CII in 2002 proposed that RFID technology would improve the material handling process by eliminating manual data entry and by facilitating automated solutions (Jaselskis 2000). Recent research conducted in conjunction with the FIATECH Smart Chips project concluded that RFID technology has the potential to both improve the efficiency and accuracy of current material tracking processes, and eventually could establish a more complete automation of these processes (Song *et al.* 2004). In the research conducted in juxtaposition with the FIATECH Smart Chips project, the main focus was on a few areas of testing the reliability of RFID technology in the construction industry. The tests specifically addressed the signal read distances, metal interference, and tag congestion.

1.4 Problem Statement

The purpose of the study is to evaluate the reliability of RFID technology in tool tracking for the construction industry considering variables like speed through the portal and number of tools, over barcode technology.

1.5 Research Motivation

Radio Frequency Identification (RFID) technology is used in many industries and has been proven successful for the past many years. This technology is ad-hoc when it comes to the construction industry in particular.

There are many uncertainties among the users in the construction industry regarding the reliability of the RFID system. Using this technology for tool tracking on construction sites would prove beneficial to the players in the industry at different levels. Implementation of this technology is just a few steps behind; and requires reliability tests specific to the construction industry. Many researchers have tested the reliability of this technology using different parameters; FIATECH, a non-profit consortium, has produced many white papers to report the results of RFID reliability tests. In a significant research conducted by Kang (2005) with the FIATECH, and Smart Chips found that RFID tags attached to the metal tools sitting in the field storage box were detected accurately. In most ideal situations, the RFID technology worked fairly well in the areas in which they were specifically tested, but there were certain circumstances where the RFID technology seemed to not be working to the extent it had been speculated to work. The results of these tests had ignited the curiosity as how certain new factors would affect the reliability of this technology in the construction industry. Kang (2005) recommended in the report that the number of tools taken across the RFID portal system and the velocity with which the tools are taken across the portal could be hidden variables which need testing and which may lead to the reason for the malfunctioning of RFID technology. These recommendations are the basis for the development of a unique methodology to test RFID technology.

1.6 Research Objectives

The key issue to be investigated is an RFID technology's reliability and efficiency in tool tracking. The objectives of this research are to test the effects of

- the number of tools taken across the portal, and
- the velocity at which the tools pass the portal.

1.7 Research Hypothesis

The null hypotheses for this research are

1. The number of tags identified by the RFID reader is proportional to the number of tags passing the portal at the same time.
2. The number of tags identified by the RFID reader is proportional to the speed with which the tags are taken across the portal.
3. The number of tags identified by the RFID reader is proportional to the speed with which the tags are taken across the portal and the number of tools passing the portal, together.

The alternative hypotheses states the following

1. The number of tags identified by the RFID reader is inversely proportional to the number of tags passing the portal at the same time.

2. The number of tags identified by the RFID reader is inversely proportional to the speed with which the tags are taken across the portal.
3. The number of tags identified by the RFID reader is inversely proportional to the speed with which the tags are taken across the portal and the number of tools passing the portal, together.

2 LITERATURE REVIEW

2.1 History of RFID

RFID is not a new technology for other industries such as defense, security, transportation, supply chain management, etc. RFID has its roots in early military identification systems, and is based on an array of technological innovations that began in the early 1940s. The work that is most often cited as the first insight into the potential of RFID is Harry Stockman's "Communication by Means of Reflected Power," a paper published in October 1948. Later this idea was developed and the first U.S. patent on RFID was approved for Mario Cardullo in January 1973 (Shepard 2005).

IBM developed an ultra-high frequency (UHF) RFID system in the1990s. This system presented longer read range (up to 20 feet) and faster data reading capacity. Because of many factors like the reluctance to change from existing systems and the high capital cost of the UHF, IBM ran out of business in no time. IBM sold its patent to an emerging company, Intermec. Intermec used RFID systems in many applications, from warehouse tracking to farming. However, in late1990s the cost of installing RFID was high and didn't match the economic limitations of industry("History of RFID Technology" 2005).

In 1999, RFID had a re-birth in the research world when the Uniform Code Council, EAN International, Procter & Gamble, and Gillette financially supported the establishment of the Auto-ID Center at the Massachusetts Institute of Technology (MIT) (Shepard 2005). The basic research motivation of

Auto-ID was to work on low cost RFID technology for supply chain management. The institute came up with a new idea to reduce the costs associated with RFID by using only a serial number on the tag. This idea flourished in the market and made drastic changes in the way RFID was perceived. Since then, the Auto-ID Center has contributed greatly toward the research and development of RFID technology. “Between 1999 and 2003, the Auto-ID Center with the support of many industries developed two air interface protocols (Class 1 and Class 0), the Electronic Product Code (EPC) numbering scheme, and a network architecture for looking up data associated with an RFID tag on the internet” ("History of RFID Technology" 2005)

The Auto-ID Center passed its research responsibilities on to Auto-ID Labs, a non-profit research lab with its headquarters at MIT, in 2003. In 2007, the Auto-ID Labs are the leading global network of academic research laboratories in the field of networked RFID. These labs comprise seven of the world's most renowned research universities including MIT, located on four different continents ("Auto-ID labs at MIT" 2007).

2.2 RFID System

Radio Frequency Identification (RFID) is a term that is extensively used to describe a system that transmits the identity (in the form of a unique serial number) of an object or person wirelessly, using radio waves (Goodrum and

McLaren 2003). For the RFID system to work accurately for the application it is used for, there are certain components that need to be installed and matched properly. First, the right tag has to be chosen for the application and then appropriate readers should be installed. These two components should be combined by using middleware to screen the data received by the reader. The readers can read the same tag several times during the time of reading and the middleware helps to screen such data and show the necessary information for the end user. These are the major components of the RFID system, but the RFID system does not always works appropriately with these components; in some applications there could be more components that are used to integrate the RFID application with the enterprise software that is used for the specific application in the company ("RFID System Components and Costs" 2006).

2.2.1 Components

The RFID system consists of four main components: a tag, a reader, an antenna, and a scanner. The purpose of the tag is to store information such as the item purchase date, cost, warranty, owner, etc., so this data could be retrieved when needed. The antenna is a part of the tag and the basic purpose of this component is to transmit the data from the tag to the reader once the tag is activated; this also receives signals from the reader, which are radio frequency waves. The reader also has an antenna, which picks up the radio frequency waves from the tag. For some systems, the antenna on the reader transmits an electromagnetic field that will activate the tag so that it will begin to transmit the information to the reader. The scanner, which is attached to the antenna on the reader, amplifies the signals being transmitted between the reader and the tag and activates the reader to begin receiving data. The reader receives the information and stores it or converts it to digital output so the operator can retrieve the information immediately. RFID can store much more information than a typical barcode and can transmit the information for a much longer distance. The reader stores the information and can transmit this information either wirelessly or through fiber optics to a computer terminal for long-term storage, useful processing, and communication between terminals that are not on the job site (Jaselskis 2000).

2.2.2 Tags

There are two fundamental types of RFID tags, active tags and passive tags, as shown in figure 3. Active tags are equipped with a battery and can transmit the RF signal periodically as far as 300 ft without depending on any external power sources. The active tag's operational life depends on the battery life. Most current commercial active RFID tags are expected to work for approximately five years. A typical active tag is shown in figure 3-a. Passive tags do not require a battery. Instead, they acquire the power needed for transmitting the RF signal from the RF energy emitted by the reader. More powerful readers are therefore needed for passive tags. Since passive tags do not use the internal battery for operation, they can be produced less expensively and their operational life cycle is normally longer than that of active tags. A typical passive tag is shown in figure 3-b.

Most tags can be written to and read. However, there are tags that are read-only. These tags are usually passive; they only store a small amount of information, and are useful in identification only. Since they are not rewriteable, their usefulness is limited to identification, and not for changing data information.

a. RFID Active tag

b. RFID Passive tag

Figure 3: RFID tags

2.2.3 Reader

The reader is what the system uses to read the transmitted data from the tags. The type of tag being read determines what type of reader is required. A passive tag requires the reader to have an antenna that generates an electromagnetic field, which activates the tag so that it can transmit the radio frequency data information. Also, a tag that is rewriteable requires the reader to have an antenna to transmit data back to the tag. The reader processes the information it receives and stores the data electronically. The data can also be converted to digital output so that the operator can view the data manually and make any necessary adjustments or corrections and send information back to the tag (Goodrum and McLaren 2006).

2.2.4 Antenna

The antenna, if required for a passive tag, transmits an electromagnetic field, which activates the tag, as shown in figure 4. The antenna also receives the data from the tag and sends it to the reader. There is also an antenna on the tag, that receives the required power from the electromagnetic field, which in turn allows a passive tag to transmit the data. Tags also require an antenna to transmit the information to the reader and to receive information from the reader if it is a rewriteable tag.

Figure 4: RFID exciter antenna (Kang 2005)

2.2.5 Scanner

The scanner is part of the reader and is attached to the antenna. It filters and amplifies data signals from the tags to establish longer reading ranges and to receive data only from certain desired tags. It is also the part of the reader that initiates the magnetic field, which is generated by the antenna.

2.2.6 Reading Range

The reading range of RFID differs with the specification of the system such as the frequency of the tags, and it also depends on whether the tag is active or passive. The less expensive passive RFID tags have a reading range of only one foot. However, a typical passive tag can transmit information up to six feet. Active tags can have a range of over sixty feet. The active tags have a larger reading range than the passive tags, because they are internally powered and do not rely on the electromagnetic field to be activated.

The reading range may vary slightly due to different conditions and the environment. Reading through different materials may lessen the reading range due to interference. Also, the weather may affect the reading range. Thunderstorms and steel structures can significantly decrease the reading range of either active or passive tags (Goodrum and McLaren 2003).

2.2.7 Operating Frequencies

RFID devices can be classified into three operating frequency categories: low frequency, high frequency, and ultra-high frequency. Low frequency transmitters operate at a frequency of 125 kHz and have a reading range of about one foot. High frequency transmitters operate at a frequency of 13.56 MHz and have a reading range of around three feet. Ultra-high frequency transmitters operate at a frequency of 433 MHz, 868 MHz, 915 MHz, or 2.45 GHz and have a reading range of 30 feet and more (Zebra 2002). Higher frequency RFID devices have a longer reading range.

Higher frequency tags cost more than passive tags. They offer a longer reading range, higher reading speeds, are not noise sensitive, but require a more direct line of sight and are orientation sensitive. Lower frequency transmitters have a slower reading speed, a lower reading range, are noise sensitive, but are more easily readable through materials and are not orientation sensitive (Shepard 2005).

2.3 Uses of RFID

Radio frequency Identification (RFID) technology has been around for many years, however, it has been too expensive for many consumer applications. That's beginning to change as the technology is more exposed to the consumers and uses of RFID are lately understood by different sectors of many industries. This technology has numerous applications in various industries across the world. Business applications and consumer applications are the main divisions in RFID application. The business applications include use of RFID in asset tracking, manufacturing in part identifications, supply chain management, retailing, payment systems, security, and access controls to name a few. On the other hand, as a consumer application it is used in every walk of life such as in toll-way passes, speed passes at gas stations, bus passes, keyless entry, commercial laundry, etc. Recently, two companies launched a trial of Near Field Communication technology (using RFID) in Seoul, Korea, that will let participants use their mobile phones to download music, unlock doors, and pay for goods and services (Goodrum and McLaren 2003).

2.4 Benefits of RFID

RFID offer many advantages over using barcode reading technology. They offer a non-line of site reading capability and the ability for the tag to store and transmit information. They can also operate in less than ideal conditions, including dirty, harsh, wet and hazardous environments, and they can function properly in extreme temperatures ranging from –40^{o}C to 200^{o}C (Jaselskis 2000).

RFID technology eliminates the necessity for manual data entry. They offer the availability for easy adjustments to the data without having to update every computer. Since the data are stored on the tag, whenever the tag is read the same data will be available, even if the reader has never previously been in contact with the tag. RFID devices can make automatic adjustments and solve problems without manual supervision. They can assist in automation solutions and building information management structures. They can read through most materials, except metal. They can integrate business process flows, have reprogramming capabilities, and can be used in material management and identification. Using RFID for material management and identification decreases the labor necessary for these activities and enhances access control (Jacobs 2002).

RFID offers a much larger storage capacity than bar codes. Bar codes are limited to approximately twenty characters of data storage, while a typical active RFID tag can store up to 32 KB of data, or approximately 500,000 characters. Even the smallest passive RFID tag can hold 39 bits of user data, allowing 550 billion items to be uniquely tagged and read in about 100 milliseconds (Mamo 2004).

2.5 Limitations of RFID

2.5.1 Standardization

There are a number of implementation issues with RFID technology; the first and foremost importance has to be assigned to the standardization between different manufacturers' tags. Tags are manufactured by different agencies and companies to provide the technology for different sectors of industries. Tags made from different manufacturers often will not be able to communicate with each other, and different types of readers are required for each type of tag. This type of problem will most commonly persist in the industries where the materials are sent from one company to another and the company at the receiving end will not be able to read the tags. Currently, the Auto ID Labs, headquartered at the Massachusetts Institute of Technology, are leading an international effort in the standardization of RFID devices and their connectivity with other information technologies (Shepard 2005).

2.5.2 Metal and Liquid Interference

According to white papers issued by the Construction Industry Institute (CII) in 2001, there is a common conception that RFID signals are hindered by metals and liquids. Liquids tend to absorb the electromagnetic energy needed to power the chip, while metal tends to reflect them in unpredictable ways. Both problems can cause interference in the RFID signal sent by a chip to the reader. And there is a fear among the users of the technology for the construction industry because most tools are made of metal.

2.5.3 Reading Range

The reading range of a good quality RFID transmitter could reach up to twenty meters, which can be achieved only with an active tag. Passive tags can only transmit up to two meters, which limits the capabilities of data collection. Many times, it is not accessible to be within the required reading range, such as reading underground tags, or tags that are high off of the ground. This presents a problem in that the tags are useless unless they can be accessed and read at any desired moment (Jacobs 2002).

2.5.4 Costs

RFID technology's drastic reduction in the cost of production over the past few years, combined with improvements in sensitivity, range, and durability, has enabled widespread use of RFID in the logistical planning and operation of supply chain processes (Stone *et al.* 2000). With this the world has seen technology's move into adoption of services such as security and access control, tracking, monitoring/management, and the construction industry. Wal-Mart announced they it would require their top 100 suppliers to put RFID tags on shipping crates and pallets in early 2005, and announced that they will expand their RFID efforts to their next 200 largest suppliers by January 1st, 2006. Each tag would store an Electronic Product Code (EPC) which is a barcode successor that would be used to track products as they enter Wal-Mart's distribution centers and then in turn are shipped to individual stores. As the world's largest company in terms of revenue, Wal-Mart in one decision changed the strategic foundation of many companies and instigated huge market arenas for RFID.

In 2007, RFID has reached most of the mid-sized companies all over the world and is been identified as the most emerging technology of the decade. Many companies, like Caterpillar, Verichip, and the U.S. army have started investing in implementing RFID in many different applications and RFID has become a multi million dollar market.

2.6 RFID in Other Industries

RFID has been utilized by many applications around the world for a very long time by different sectors. The most widespread use of this technology is found in transportation, security, postal services, retail marketing, supply chain management, manufacturing, and defense.

2.6.1 Transportation

The transportation department, especially in the United States, has been utilizing the RFID system for tollways, fuel dispensing, traffic management, and fee collections for a long time. RFID is one of the intelligent systems that is utilized to reduce the travel time on highways and at the same time increasing the efficiency of fee collections. Many cars have pre-purchased RFID tags, which are placed on the windshield. When the car passes through the toll gate, which acts as a RFID reader portal, the tag is identified and is registered to store the starting point of toll. When the car exits from the tollway, a similar reader gate identifies the exit point and charges appropriately. The fuel-dispensing units also have a similar process of charging for the fuel you purchase at the gas stations, which cuts down the time of dispensing very quickly. If every car in the country is equipped with RFID tags, the roadways could become a much better place to drive in the future. The traffic volume on roads could be easily calculated just by installing a RFID reader at every critical junction and the high traffic could be diverted automatically using display screens. The end user can save huge amounts of time by installing RFID tags on cars which could be used to pay the registration or any other fees, and which expire automatically after a certain amount of time (Goodrum and McLaren 2003).

2.6.2 Security

Transportation and security together make up 30% of the total market sector of RFID (Jacobs 2002). Security systems are critical to prevent access of unauthorized personnel, shoplifting, auto, art and jewelry theft, and to track expensive assets while shipping, etc. A RFID tag attached to an identification card and programmed could prevent unauthorized personnel from entering restricted areas. In more intense situations, like the federal government research units or defense units human implanted RFID tags are been used to increase security. The implementation of RFID reduces the risk of security for facilities (Goodrum and McLaren 2003).

3 THE METHODOLOGY AND TEST CONFIGURATION

As the implementation of RFID technology is in process on construction sites, the number of tools taken across the portal at a time can't be controlled. This variable will consider the reliability of technology while being tested with multiple tags passing the portal.

The RFID hardware and the software developed to support the construction industry were based on certain assumptions about the time lag for the tools to pass through the portal. So, the velocity at which the tools will be taken across the portal may have some effects on the readability and efficiency of the RFID systems.

After these variables were identified, the next step in the research process is to identity the appropriate experiment setup. While designing the experiment setup, the type of outputs the experiment would give should be estimated and designed to be readable and analyzed. Once the design of the experiment is done the experiment needs to be performed and the outputs will be recorded. These outputs are raw data that need to be analyzed to present conclusions on the research hypotheses.

3.1 RFID Portal Configuration

The prototype RFID portal used in our test is composed of four motion sensors, one SRA exciter antenna, one R3 controller, and data processing software. The process of the RFID portal's detecting the RF signal and manipulating its corresponding data is:

1) The motion sensors detect the crew movement as they enter into the RFID portal.
2) Receiving the signal from the motion sensors, the R3 controller generates the RF signal of 307 kHz and emits it through the SRA Exciter Antenna to wake up active tags.
3) Awakened by the RF signal transmitted from the SRA Exciter Antenna, active tags emit the RFID signals of 433.92 MHz.
4) The R3 controller detects the RF signals transmitted from active tags and sends the tag IDs to the data processing system.
5) The data processing system retrieves tool information associated with these tag IDs from the database and presents it on the display.

4 EXPERIMENT DETAILS

The RFID system that was used in testing the parameters was provided by eXI Wireless in Richmond, British Columbia. Houndware Corporation, which is a leading RFID software vendor, provided the software for the testing. The RFID tool tracking system was selected based on several factors like the signal range, the size of tags, compliance with the construction industry, etc.

4.1 Experiment Setup

The experiment was carried out at the lab where the RFID system was set up. It involves the RFID portal system setup, shown in figure 5. RFID tags and software were provided by Houndware Inc.

To perform this experiment, a system was fabricated with a tool that would pass the portal at constant velocities. A 0.5 horse power motor was attached to a gear system to slow down the speed of rotation from 100 rotations per second to 5 rotations per second. A set of drums with different diameters were fabricated out of cardboard and timber to be attached to the gear system to achieve the required constant velocity, while pulling the trolley with each drum. A metal trolley with wheels was used and a track was made of PVC pipes to guide the trolley through the portal. This whole system was set up as shown in figure 5.

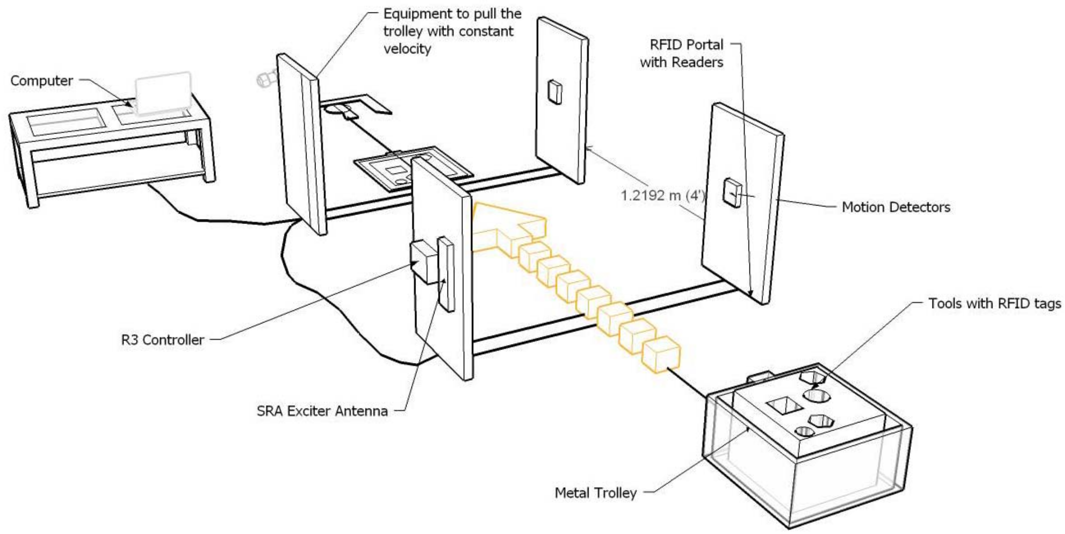

Figure 5: Experiment setup

4.2 Assumptions and Limitations

The experiment assumes the following conditions:

- The maximum velocity of a human being passing the portal is assumed to be 1.5 m/sec (5.4 Km/Hr).
- The variations in the movement of the trolley are assumed to be negligible, and thus are recorded as uniform motion.

The experiment assumes the following limitations:

- The experiment will be carried out with a metal trolley containing a maximum of seven tools.

- The variation of the velocity at which the trolley passes the portal, is at an interval of 0.5 m/sec.
- The distance between the portals is fixed at four feet center to center.

4.3 Experiment Protocol

The reliability of RFID technology has to be proved under variables like speed through which the tools are taken through the portal and the number of tools that are taken across the portal at a given point in time. As shown in the schematic diagram in figure 6, the metal trolley contains the active RFID tags, and the trolley is pulled towards the portals; when the trolley crosses portal A, the tag is activated by the R3 controller via SRA Exciter Antenna. While the tag is between portal A and B, it radiates radio frequency waves at 433.92 MHz frequency. This active tag stops emitting the waves after passing through portal B. During this period, while the tag is between portals A and B, the RFID tag signal is captured and processed by the middleware, which identifies the tag details.

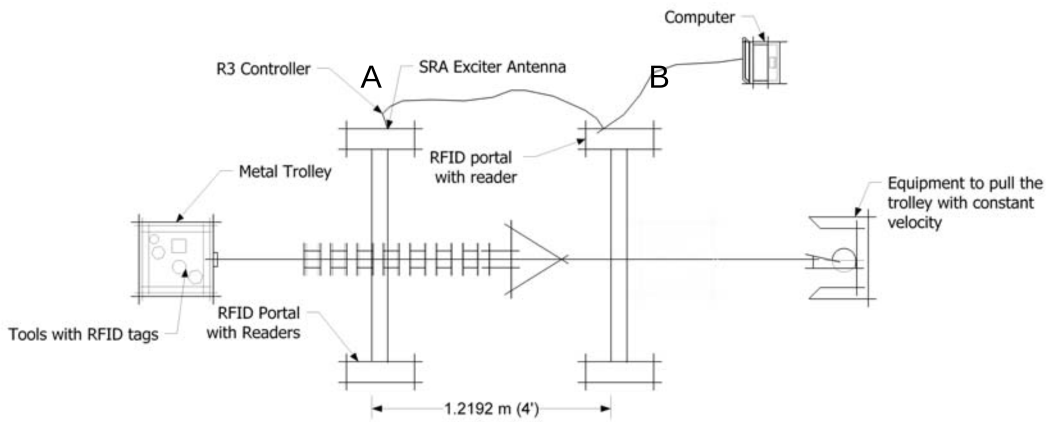

Figure 6: Experiment setup; schematic diagram

The distance between the portals (A &B) is fixed at 1.2192 meters (four feet) center to center. The RFID system and the software used for the test were manufactured and developed with a pre-assumption that the person carrying the tools would remain between the portals for at least 2 seconds. The experiment was designed in a way that the trolley moves between portals with a velocity increasing from 0.1 m/sec to 1.5 m/sec (which means the trolley stays between the two portals from 12.19 seconds to 0.81 seconds). This configuration was chosen to challenge the available technology and prove the possibilities of reliability reduction with an increase in velocity.

The number of tools carried by the trolley is also a variable to test the reliability of RFID technology. The trolley was loaded with a varied number of tools between one and seven. The trolley was made to run between the portals for 30 times with each possible combination of seven different numbers of tools, four different velocities, and 30 trails, which make it 840 (7 tools x 4 velocities x 30 trails) times in total, to achieve considerably consistent results. The readings were recorded on a table of 7X30 matrixes with the number of tools as the index on the rows and number of trails on columns. The readings taken were the number of tools identified successfully by the portal each time the trolley passes the portal.

4.4 Test Results

The results of the experiment were in much consistency with the speculated results. When the testing was carried out with the trolley passing the portal with a velocity of 0.1 m/sec (0.23 miles/hour), the RFID technology gave 95%-100% accuracy levels in detecting the tools passed through the portals. The trolley was between the portals for approximately 12.2 seconds with this velocity. The levels of accuracy were comparatively low when the test was progressed and seven tools were passed through the portal at the same time. The recorded values of percentage of detection are listed in table 1.

Table 1: Recorded values with velocity of 0.1 m/sec

Number of Tools	**Total No. of Readings**	**Total Trail (30) X No. of Tools**	**% of Detection**
1	29	30	96.67
2	60	60	100.00
3	88	90	97.78
4	120	120	100.00
5	150	150	100.00
6	177	180	98.33
7	200	210	95.24

The second part of the test was conducted with the trolley passing the portal with a velocity of 0.5 m/sec (1.2 miles/hour). During this phase of the experiment, the RFID tags were successfully detected 100% until the number of tools was increased to five, at which time there was a small diminution in the accuracy of the detection. The trolley was between the portals for approximately four seconds with this velocity. This reduction in the accuracy levels started gaining impetus by the time the number of tools under testing were six and seven, which raised the eyebrows of the speculators. The recorded values of percentage of detection are listed in table 2.

Table 2: Recorded values with velocity of 0.5 m/sec

No. of Tools	**Total no. of Readings**	**Total Trails (30) X No. of Tools**	**% of detection**
1	30	30	100.00
2	60	60	100.00
3	90	90	100.00
4	120	120	100.00
5	133	150	88.67
6	169	180	93.89
7	191	210	90.95

The third part of the test was conducted with the trolley passing the portal with a velocity of 1.0 m/sec (2.24 miles/hour). When the testing was conducted with a number of tools from 1 to 3, the results were between 96%-100%. But the scenario of diminution of the accuracy levels kept continuing when the number of tools was increased with the same constant velocity. The trolley was between the portals for 0.6 seconds with this velocity. The results were in contrast with the ideal situation of 100% accuracy and came down to an unexpected 53.8% of detections through 82.7% and 72.2%. The recorded values of percentage of detection are listed in table 3.

Table 3: Recorded values with velocity of 1.0 m/sec

No. of Tools	**Total no. of Readings**	**Total Trails (30) X No. of Tools**	**% Detection**
1	29	30	96.67
2	60	60	100.00
3	87	90	96.67
4	87	120	72.50
5	124	150	82.67
6	130	180	72.22
7	113	210	53.81

The last and fourth part of the test was conducted with the trolley passing the portal with a velocity of 1.5 m/sec (3.35 miles/hour). The trend continued in this phase of the experiment also and the results were much more deviating from the ideal graph. The trolley was between the portals for 0.4 seconds with this velocity. The max accuracy was achieved during this part with 1 tool passing the portal, which was 86.67%. The accuracy levels collapsed with the increase in the number of tools from 2 through 7 and reached a detection percentage of 49.52%. The recorded values of percentage of detection are listed in table 4.

Table 4: Recorded values with velocity of 1.5 m/sec

No. of Tools	**Total no. of Readings**	**Total Trails (30) X No. of Tools**	**% of detections**
1	26	30	86.67
2	48	60	80.00
3	72	90	80.00
4	87	120	72.50
5	115	150	76.67
6	117	180	65.00
7	104	210	49.52

5 ANALYSIS OF THE EXPERIMENTAL RESULTS

During the experiment, the data collected were the number of successful detections in each trail and the number of tools that were tested with each velocity. These values were cumulated for all the 30 repetitive trails and the data was taken as one entity for each combination of velocity and number of tools together. This variable, velocity, was identified to be a fixed variable, as the limits of the parameters were fixed during the experiment. The number of tools is a continuous variable with numbers varying between one through seven. This combination of variables could be tested using multiple regression models. The multiple regression models help to understand the effect of the individual variables on the results and also the effect of all variables together, which would satisfy the requirements of the research.

5.1 Statistical Model

The following variables were used in the equation from the experiment result data for statistical analysis. Standard Statistical Procedures for Social Studies (SPSS) were used to analyze the data.

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon$$

y = reliability of the RFID technology (percentage detection)

x_1 = Number of tools used in the each test run

x_2 = Velocity of tools passing through portal

ε = error

$\beta 0$ = Intercept for the model

$\beta 1$ = Partial Slope (coefficient of X1 term)

$\beta 2$ = Partial slope (coefficient of X2 term)

5.1.1 Assumptions for the Regression Model

The following are the assumptions taken while considering testing the model for regression.

- Variance for all ‘i’ is equal.

This assumption is tested using bp syntax (Breusch- Pagan or Koenker).

- The ε_i‘s are independent.

This assumption is tested using the DW (Durbin- Watson) Test.

- ε_i is normally distributed.

The errors are normally distributed is the assumption that will be tested using Shapiro-Wilk or Kolmogorov tests.

5.2 Test Results of the Data Using Statistical Model

The p-value of the tests for normality using the standardized residuals is 0.065, which is more than 0.05. The normal P-P plot of regression of standardized residuals, shown in figure 7 below, gives a clear graphical indication that the residuals are normally distributed. The SPSS test outputs can be seen in Appendix 2. This concludes that the residuals are normally distributed, proving that the assumption of normality is satisfied.

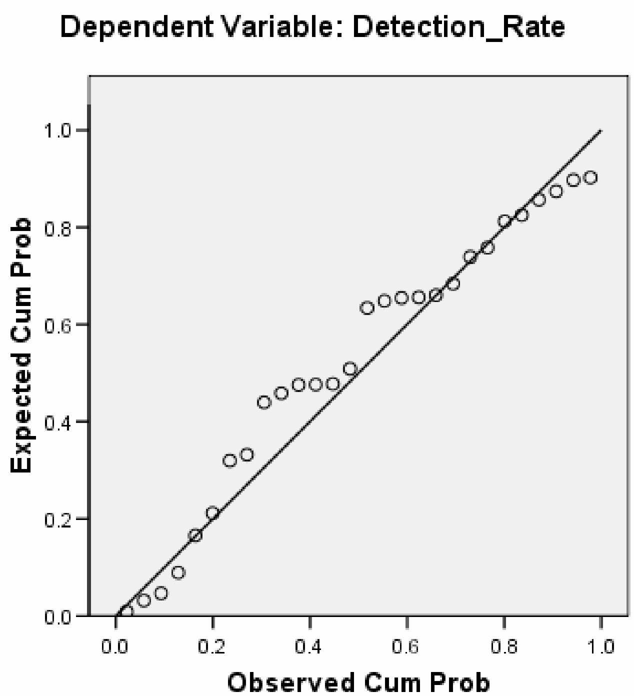

Figure 7: Normal P-P of regression standardized residuals from SPSS

The ε_i's (error terms) are independent. This assumption is tested using the DW (Durbin-Watson) Test. The SPSS gives a result of 1.361 for the DW test, which is shown in figure 8 below. As the DW value is greater than 1, the assumption that the error terms are independent is significant.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.860[a]	.740	.719	7.80348	1.361

a. Predictors: (Constant), velocity, number

b. Dependent Variable: Detection_Rate

Figure 8: SPSS output showing the Durbin-Watson values

To test the variance for all ***i*** bp syntax (Breusch- Pagan or Koenker) was used and the test results show the Breusch-Pagan test for Heteroscedasticity (CHI-SQUARE df = P) value to be 1.532 with the significance level of Chi-square df=P (H0: homoscedasticity) equal to 0.4648. This gives a clear indication that variances are homogenous. The test results of running bp syntax with the data are shown attached in the Appendix 1.

This proves all assumptions to run a regression on the data collected during the experiment. Three different regression models were run on the data for testing the three hypotheses. The first one was to test the combined effect of the parameters on the resulting variable and the other two models tested the individual effects on the resulting variable. The detailed output from SPSS is attached as Appendix 2 for reference.

The results of the regression show a R^2 value of .740, which is not a very good R^2 value, but a reasonably good value for the conclusions to be made using the values produced by testing the model in SPSS.

The significance values for the model are 0.00, which is less than 0.05 this means that with 95% confidence we can conclude that there is some affect of the independent variables (reliability of RFID technology) on dependant variables (number of tools and velocity with which they were taken across the portal).

Using the output (as shown in Appendix 2), we can also analyze the effects of individual parameters on the readability of the RFID tags. The effect of both the parameters (number of tools and the velocity) is significant as the significance value for both the variables is 0.00, which is less than 0.05. This means that with 95% confidence we can conclude that there is an effect of the parameters on the results.

Using the results for the regression we can complete the regression equation as follows by the following values

ε (error) = 2.503

$\beta 0$ (Intercept for the model) = 116.651

$\beta 1$ (Partial Slope (coefficient of X1 term)) = -3.562

$\beta 2$ (Partial slope (coefficient of X2 term)) = -19.393

The final regression equation with coefficients is

$$y = 116.651 - 3.562\,(x_1) - 19.393\,(x_2) + 2.503$$

y = reliability of the RFID technology (percentage detection)

x_1 = Number of tools used in the each test run

x_2 = Velocity of tools passing through a portal

5.3 Effects of the Parameters

The results of the experiment showed two clear trends. Firstly, when the number of tools passing the portal was increased after a limit, the RFID sensors were unable to detect the tools successfully at all points of time. The accuracy of the detection diminished from 100% to 90.1%, even when the tools remained between the portals for more than 2 seconds. This scenario is clearly demonstrated with the help of a line graph in figure 9. Secondly, when the velocities of the trolley carrying the tools was increased from 0.1 m/sec through 1.5 m/sec, the results almost repeated and the accuracy in detection diminished as the velocity was increased. The percentage of the successful detections decreased from 97% to 45% on an average. We can observe the trends in the reliability in figure 10. We can infer from the results that the two parameters together have an effect on the readability of RFID tags. There is a clear diminution of detection rates when both factors are considered at the same time. This trend is clearly demonstrated in figure 11. These values determine that the reliability of the RFID technology depends greatly on the velocity and the number of tools passing the portal.

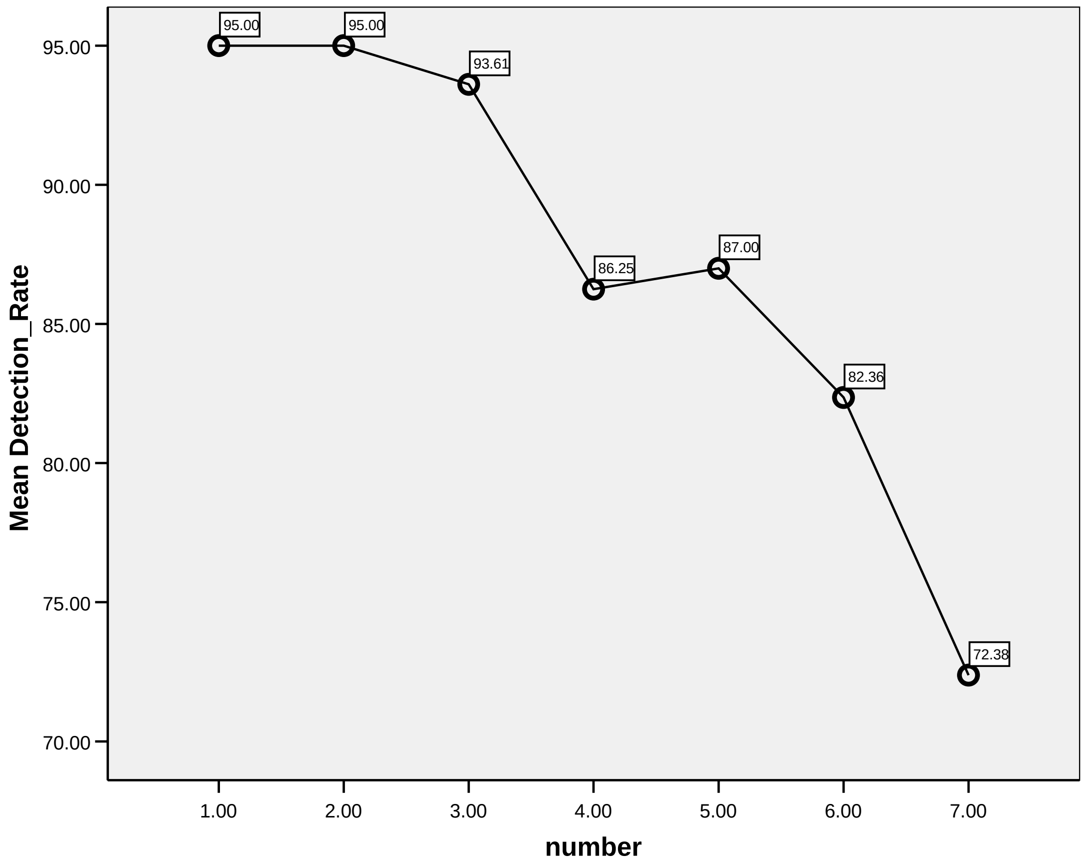

Figure 9: Line graph showing the detection rates vs. number of tools

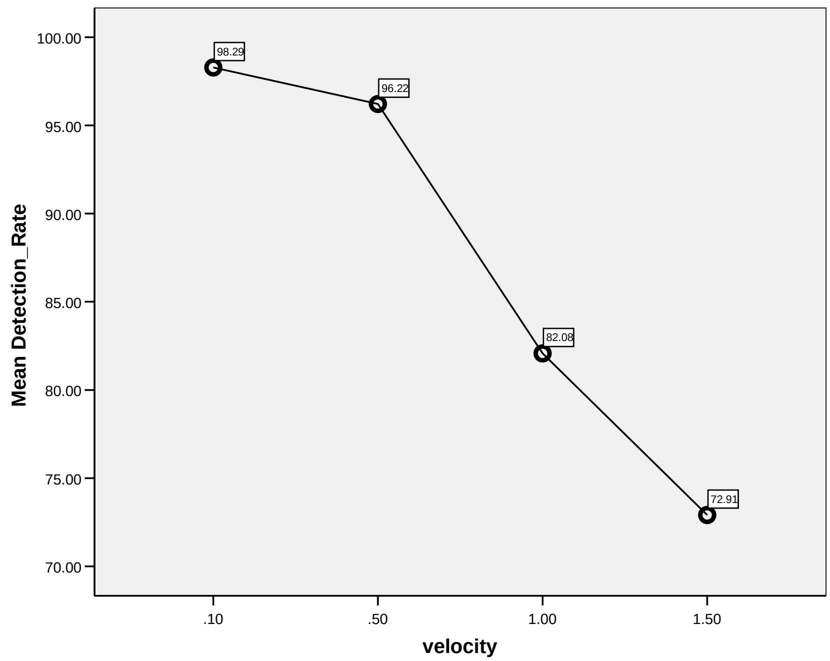

Figure 10: Line graph showing the detection rates vs. velocity

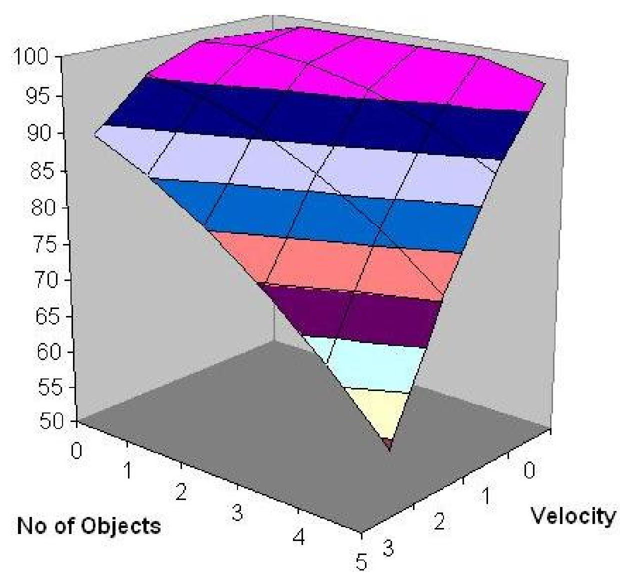

Figure 11: Graph showing the detection rates vs. velocity & number of tools

6 CONCLUSIONS

The statistical analysis proved that the results reject the null hypotheses with 95% confidence interval. The affects of the tested parameters on the reliability of the RFID technology are as follows.

1. The number of tags identified by the RFID reader is inversely proportional to the number of tags passing the portal at a time.
2. The number of tags identified by the RFID reader is inversely proportional to the speed with which the tags are taken across the portal.
3. The number of tags identified by the RFID reader is inversely proportional to the speed with which the tags are taken across the portal and the number of tools passing the portal, together.

RFID technology is proven not so efficient when it is tested against the parameters like the number of tools taken across the portal and the velocity with which they pass the portal. RFID technology has been tested earlier for reliability while the tags were placed stationary and was proven dependable with high detection rates. However, when the tests were conducted with the tags moving between the portals the results were not so remarkable. The radical drop in the readability of tools when the parameters are varied is of concern to the researchers and the construction industry. One of the main reasons for these low detection rates could be the time tools have between the portals, for the system to detect all the tools. This shortcoming in RFID technology could possibly be rectified by increasing the time duration of tools between the portals. One possible method to achieve this is by introducing a sliding door system at the entrance/exit of the tool room. This sliding door shall serve the purpose of maintaining certain time lag between tools entering the portal and exiting the portal.

There is speculation regarding generalization of the results of the experiment to the total RFID technology, as the test was conducted using a system designed for the construction industry tool management. This system has a built-in constraint that might have influenced the results of the experiment. In order to answer these questions, further investigation is required.

6.1 Recommendations

As the null hypotheses is rejected at different levels of testing performed in this thesis, it is recommended to perform certain other tests to understand more significant reasons for the failure. The following recommendations may prove to be important for the world of emerging technologies of the construction industry.

- Studying the digital signals of the RFID system and the electronic configuration might be useful for understanding the reasons for failure of the tests.
- Several other parameters could be identified for testing the reliability of RFID specific to the construction industry.

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APPENDIX 1

THE DATA COLLECTED DURING THE EXPERIMENT PROCESS

Table A (i): The data collected with 0.1 m/sec Velocity

No. of Tools/ Trails	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6	6	6	6	6	3	6	6	6	6	6	6
7	7	7	7	7	7	7	7	7	7	7	7	6	7	7	7	7	7	7

Table A (ii): The data collected with 0.1 m/sec Velocity (cont…)

19	20	21	22	23	24	25	26	27	28	29	30
1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	2	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6	6	6	6	6
7	7	7	7		7	7	7	7	7	5	7

Table B (i): The data collected with 0.5 m/sec Velocity

Tools	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	4	5	3	4	2	4	3	3	5	5	5	5	4
6	6	6	6	6	5	6	6	6	6	5	6	3	6	6	5	4	6	6
7	6	6	7	6	7	7	7	7	7	7	6	5	7	7	7	7	7	7

Table B (ii): The data collected with 0.5 m/sec Velocity (cont…)

18	19	20	21	22	23	24	25	26	27	28	29	30
1	1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4	4
4	5	5	5	5	5	5	5	5	4	4	3	5
6	4	6	6	6	6	6	6	5	6	6	6	6
7	6	7	7	7		6	7	7	7	7	5	5

Table C (i): The data collected with 1.0 m/sec Velocity

Tools	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	2	3	3	3
4	4	1	4	2	4	2	3	3	3	3	2	3	4	4	3	2	3	4
5	5	5	3	4	3	5	4	4	3	5	5	5	4	3	5	5	4	3
6	6	6	4	4	3	4	1	4	4	3	4	5	4	4	6	3	4	5
7	7	4	6	3	3	3	3	3	4	1	3	3	3	4	3	3	2	1

Table C (ii): The data collected with 1.0 m/sec Velocity (cont…)

19	20	21	22	23	24	25	26	27	28	29	30
1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	2	3	3	3	3	3
4	2	2	4	0	1	4	4	3	3	4	2
5	5	3	3	3	5	4	5	5	4	3	4
5	5	6	6	4	6	5	5	4	3	1	6
1	5	7	5	4	4	3	6	7	5	4	3

APPENDIX 2

TEST RESULTS FOR VERIFYING ASSUMPTIONS

The SPSS output for testing the assumptions of regression model for the data shown in Appendix 1.

Tests of Normality

	Kolmogorov-Smirnov(a)			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Standardized Residual	.151	28	.099	.931	28	.065

a Lilliefors Significance Correction

DW test results

Model Summary(b)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	**Durbin-Watson**
1	.860(a)	.740	.719	7.80348	**1.361**

a Predictors: (Constant), velocity, number
b Dependent Variable: Detection_Rate

Bp test syntax

Regression SS
3.0645

Residual SS
56.3456

Total SS
59.4102

R-squared
.0516

Sample size (N)
28

Number of predictors (P)
2

Breusch-Pagan test for Heteroscedasticity (CHI-SQUARE df=P)
1.532

Significance level of Chi-square df=P (H0:homoscedasticity)
.4648

Koenker test for Heteroscedasticity (CHI-SQUARE df=P)
1.444

Significance level of Chi-square df=P(H0:homoscedasticity)
.4857

APPENDIX 3

SPSS OUTPUTS OF THE REGRESSION MODEL

SPSS output for the Regression tested on the data in appendix 1

Notes

Comments		
Input	Data	C:\Documents and Settings\burlesos\My Documents\Research\Thesis\test data.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	29
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		REGRESSION /DESCRIPTIVES MEAN STDDEV CORR SIG N /MISSING LISTWISE /STATISTICS COEFF OUTS CI R ANOVA /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT Detection_Rate /METHOD=ENTER number velocity /RESIDUALS DURBIN HIST(ZRESID) NORM(ZRESID) /SAVE COOK LEVER ZRESID .
Resources	Elapsed Time	0:00:01.53
	Memory Required	1676 bytes
	Additional Memory Required for Residual Plots	648 bytes
Variables Created or Modified	ZRE_1	Standardized Residual
	COO_1	Cook's Distance
	LEV_1	Centered Leverage Value

Descriptive Statistics

	Mean	Std. Deviation	N
Detection_Rate	87.3719	14.73144	28
number	4.0000	2.03670	28
velocity	.7750	.53584	28

Correlations

		Detection_Rate	Number	velocity
Pearson Correlation	Detection_Rate	1.000	-.493	-.705
	Number	-.493	1.000	.000
	Velocity	-.705	.000	1.000
Sig. (1-tailed)	Detection_Rate	.	.004	.000
	Number	.004	.	.500
	Velocity	.000	.500	.
N	Detection_Rate	28	28	28
	Number	28	28	28
	Velocity	28	28	28

Variables Entered/Removed(b)

Model	Variables Entered	Variables Removed	Method
1	velocity, number(a)	.	Enter

a All requested variables entered.
b Dependent Variable: Detection_Rate

Model Summary(b)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.860(a)	.740	.719	7.80348	1.361

a Predictors: (Constant), velocity, number
b Dependent Variable: Detection_Rate

ANOVA(b)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4337.051	2	2168.525	35.611	.000(a)
	Residual	1522.359	25	60.894		
	Total	5859.410	27			

a Predictors: (Constant), velocity, number
b Dependent Variable: Detection_Rate

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	116.651	3.949		29.542	.000	108.519	124.784
	number	-3.562	.737	-.493	-4.831	.000	-5.081	-2.044
	velocity	-19.393	2.803	-.705	-6.920	.000	-25.165	-13.621

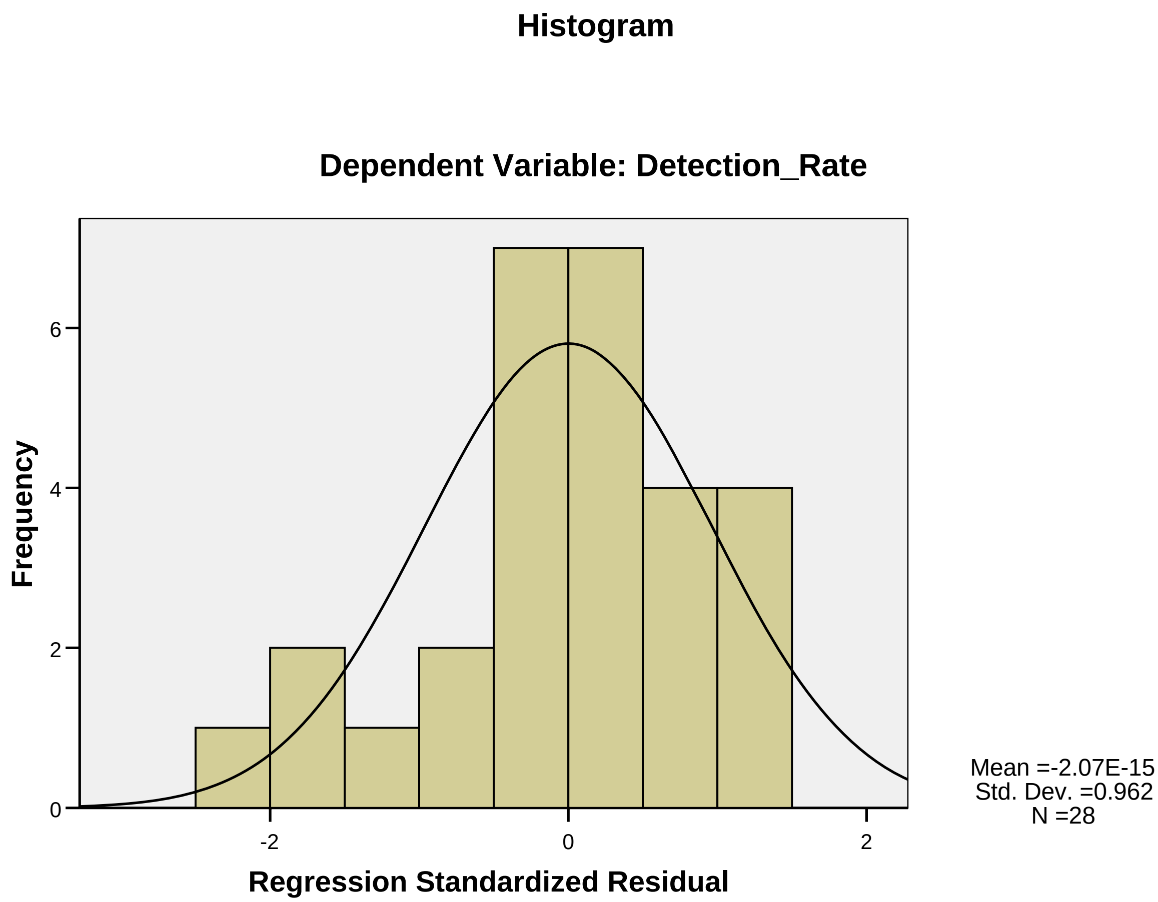
a Dependent Variable: Detection_Rate

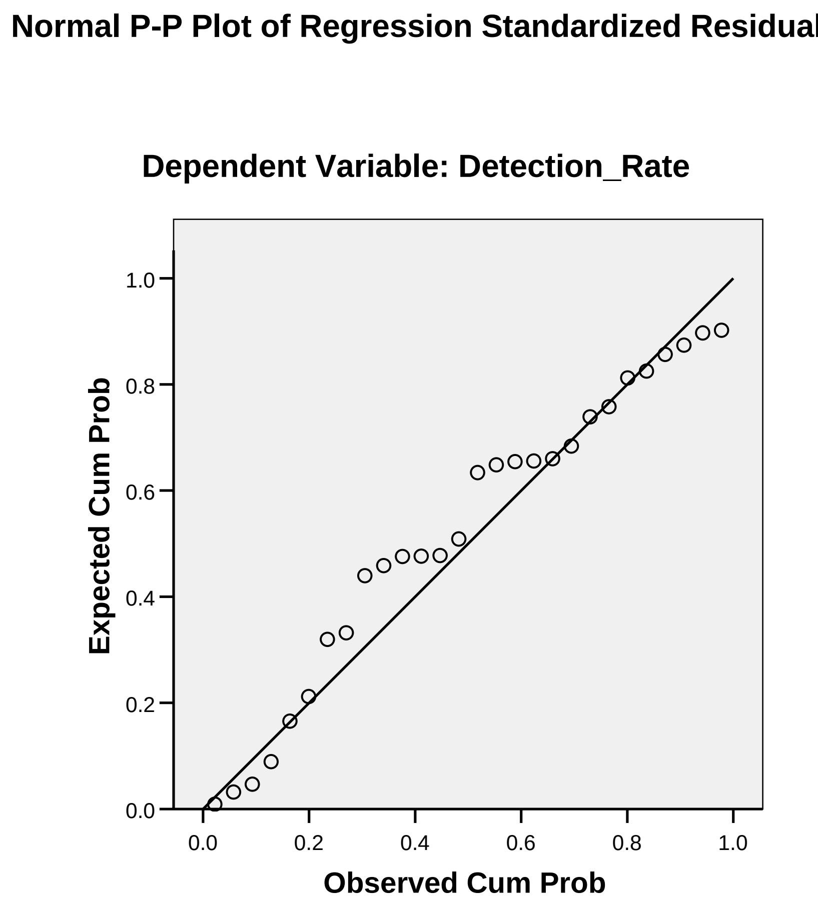
Residuals Statistics(a)

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	62.6246	111.1495	87.3719	12.67405	28
Std. Predicted Value	-1.953	1.876	.000	1.000	28
Standard Error of Predicted Value	1.604	3.346	2.503	.520	28
Adjusted Predicted Value	65.5762	114.2182	87.4953	12.73802	28
Residual	-18.51178	10.09593	.00000	7.50891	28
Std. Residual	-2.372	1.294	.000	.962	28
Stud. Residual	-2.533	1.328	-.007	1.026	28
Deleted Residual	-21.09849	10.70115	-.12340	8.54913	28
Stud. Deleted Residual	-2.878	1.350	-.029	1.079	28
Mahal. Distance	.176	4.000	1.929	1.143	28
Cook's Distance	.000	.299	.047	.086	28
Centered Leverage Value	.007	.148	.071	.042	28

a Dependent Variable: Detection_Rate

Charts


Histogram
Dependent Variable: Detection_Rate
Frequency
Regression Standardized Residual
0
2
4
6
-2
0
2
Mean =-2.07E-15
Std. Dev. =0.962
N =28


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: Detection_Rate
1.0
0.8
0.6
0.4
0.2
0.0
Expected Cum Prob
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob

VITA

Naresh Kalla received his Bachelor of Architecture degree from the National Institute of Technology in 2005. He entered the master's program at Texas A&M University in August 2005, and he received his Master of Science degree in May 2007. His research interests include emerging technologies in construction industry, 4D visualization, simulation, and project controls.

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