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Investigation of RFID Readability for License Plates in Static and Motion Testing

Srinivasan Venkatesan
University of Nebraska-Lincoln, srini@huskers.unl.edu

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License Plates in Static and Motion Testing

by

Srinivasan Venkatesan

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Srinivasan Venkatesan, M.S

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Adviser: Robert E. Williams

The most important function of RFID in vehicle tracking is to store information concerning tagged elements in order to improve the overall performance of movable asset management. There is a need to discover an RFID system for the tracking of vehicles, as existing vehicle tracking systems are undependable. Experiments were performed with SIRIT, SAVI, and RF code RFID systems under differing conditions, attaching the tag to the license plate instead of the windshield. Different spacers were also tested to reduce the effect of metal surfaces on RFID signals.

Preliminary experiments were performed before stationary and motion testing in order to better understand the RFID systems. Testing was also conducted to identify the angle at which the reader should be fixed and the ideal placement of the tag on the license plate. Stationary and motion testing were then performed on the three RFID systems, using different spacers and speeds, and the effect of spacers and speed on signal strength was found to be significant.

In addition, environmental testing was performed on RF code systems in low temperature conditions. Upon completion of these experiments, the resulting data was analyzed to identify not only the best material to embed between tag and license plate in

practical situations, but also the most effective thickness of that material and the optimum height of the reader. Finally, a benefit cost analysis was performed comparing both the RF code RFID and mobile plate hunter (MPH)-900 camera system. Results were compared for varying amounts of cars, and the analysis clearly showed that the RFID RF code system is better, compared to camera systems, for use in the tracking of vehicle license plate.

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CHAPTER 1

INTRODUCTION

1.0 Overview

Radio Frequency Identification (RFID) is evolving as a major technology for the identification and tracking of goods and assets around the world. It can help hospitals improve patient care by locating expensive equipment more quickly, it can help pharmaceutical companies reduce counterfeiting, and it can help logistics providers improve the management of movable assets. It also promises to enable new efficiencies in the supply chain by tracking goods from the point of manufacture to the retail point of sale (POS).

RFID systems consist of three main components: readers, antennas, and tags. The antenna emits radio signals, the tags respond to their own unique code, and the reader receives the signal from the tag, decodes the tag information, and sends it to a processor through standard digital interfaces. There are three types of RFID tags: active, passive, and semi-passive. A Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis explains more about these different types of tags in the literature section of this thesis.

There are several unique advantages of RFID technologies; first, they can manage collected data through databases, some of which are portable by virtue of being embedded into the tag. Second, they can communicate instructions to other devices. These instructions can be automatically routed and are utilized to control other equipment. Finally, their performance is more reliable than any other technologies (camera or GPS tracking system) in harsh environments. In certain applications, RFID tags outperform other automatic data capture (auto-id) technologies. One example of RFID's superior performance is a situation in which the surface is dirty. If a barcode were used in this situation, the data could not be read. RFID performs better than barcodes due to the fact that RFID tags don't necessarily need to be 'seen' to be scanned by a reader. Also physical contact is not required for RFID tags, which gives them an additional advantage over magnetic strips and touch buttons.

Because of the advantages of the RFID system, it is being implemented in a variety of important applications, including the tracking of vehicles. The most important function of RFID in vehicle tracking is to store information concerning the tagged elements in order to improve the overall performance of movable asset management (Kumar and Moore, 2002). Implementing RFID in commercial vehicle operation (CVO) will eventually decrease the number of vehicles with damage, loss, or theft. A previous study by Anala et al. (2009) demonstrated how RFID can be effectively used to track traffic density along routes of various cities in order to implement actions in reducing traffic congestion.

Many mining accidents could have been avoided if only the workers had been properly warned by vehicle operators. Research by Todd and Drew (2001) indicated that accident rates were constantly increasing and that accidental control methods in underground mining were unreliable.

RFID technology can be further extended to the tracking of fuel consumption rates, driving patterns, license updates, and the statistical analysis of vehicular traffic for road development. Furthermore, it can be implemented in such varied applications as tax collection, insurance, speed, cross border control, traffic ticketing, fleet, and parking management (Jonathan, 2004).

Technologies such as Doppler radar units, video cameras, ultrasonic, and infrared sensors are inefficient in tracking vehicles. For example, camera systems are only 90% accurate in tracking the license plates (Tom, 2003), and also numerous cars carry false number plates (Niraj, 2003). In 2006 more than 40,000 number plates were stolen, and since the information from cameras is completely unreliable, it is impossible to locate any information about the stolen vehicle (Claire, 2007).

There is a need to discover an RFID system to track vehicles, since existing systems are undependable. Research performed by Jonathan (2004) tested passive tags to track cars in South Africa. The tags were fixed on the vehicle's windshield and the readers were placed along the roadside. Likewise, in Florida, RFID tags were also located on the vehicle windshield (Claire, 2004). Anala et al. (2009) also located the tag on the windshield and used RFID to track traffic density along the routes of various cities. In all the above mentioned applications the tags were placed on the windshield, so the probability of damage is high and, also the number of reads of the tags is inconsistent during harsh environmental conditions (Jonathan, 2004).

According to Joseph (2007), an RFID system should be tested under different conditions before implementing it to any application. Different conditions like noisy environment, read range, performance near water or metal, technological maturity, operational speed, and cost need to be analyzed before successfully implementing an

RFID system. Similarly, important factors like tag configuration; frequency; type of antennas, reader compliance, interface capability, and scalability are the basic considerations in choosing an RFID system for any application (Eckfeldt, 2005 and Claire, 2004). Certain materials always have a negative effect on RFID. For example, RFID tag on metal surface always deteriorates the performance level of RFID. Research by Darmindra et al. (2007) used anechoic foam spacer between the tag and the metal surface to reduce this negative effect.

1.1 Purpose of the Research

Considering the drawbacks of other tracking systems, an existing RFID system must be tested and identified for the vehicle tracking application. This RFID system must be tested under different conditions before implementation. Moreover, to avoid damage or removal of tags, experiments need to be performed attaching the tag to the license plate instead of the windshield. Furthermore, different spacers need to be tested to reduce the effect of metal surfaces, because RFID tags that are directly attached to a metal surface are often undetected (Christian and Matthias, 2004).

The overall goal of this thesis is to identify an existing RFID system suitable for the vehicles tracking application. To accomplish this goal, four objectives were developed. The first objective is to test the three different types of RFID systems (active and passive) for vehicle tracking application. The second objective is to test the systems under stationary and motion condition. The third objective is to identify whether the speed, spacer and distance have an effect on the performance rate of the system. The last objective is to test the system under an adverse weather condition (Snow) and identifying the best spacer, reader height and spacer thickness.

CHAPTER 2

BACKGROUND LITERATURE

2.0 Architecture of the RFID

RFID technology is generally described as the concept of using radio waves to identify objects (Chow et al., 2006 and Jones et al., 2004). RFID readers can identify such information as the identification number, barcode number, and serial number of an RFID tag (Joseph, 2007). The various types of RFID systems are distinguished by their architecture, and a SWOT analysis gives more detailed information about each of these systems' advantages and disadvantages.

There are three different types of RFID systems (Robertson and Jaialy, 2003):

1. Reader powered active tags
2. Passive tags, that require no power supply
3. Semi-Passive tags

Active tags are energized by a battery, whereas passive tags receive their power from the electromagnetic waves sent out by the reader (Angeles, 2005). Semi-passive tags make use of both battery and electromagnetic waves to obtain their power. These tags can be differentiated as Read-Write, Read-Only or Write-Once, Read Many (WORM) tags. Read-Write tags can be overwritten by the reader, but WORM tags can be written only once. Because of this ability to be changed or over-written, Read-Write tags are more expensive than WORM tags (Ustundag, 2005).

Just as there are different types of tags and antennas, there are also different frequencies of RFID systems. These frequencies decide the read range of the tags. There are three different types of frequencies (Ngai et al., 2007):

1. Low Frequency (LF, 30 kHz-300 kHz)

2. High Frequency or Radio Frequency (HF, RF 3 MHz-30 MHz)

3. Ultra High Frequency (UHF, 300 MHz-3 GHz) or Microwave (>3 GHz) (Ustundag, 2005)

RFID operates on several frequencies: low-frequency (125 KHz), high-frequency (13.56 MHz), ultra-high-frequency (UHF) (860-960 MHz), and microwave (2.45 GHz). Each frequency has different characteristics, which in turn allows different frequencies to be useful in different applications. For example, low-frequency tags use less power and have the best ability to penetrate non-metallic substances in comparison with the other frequencies while high-frequency tags work better than the others on objects made of metal.

To further explore the differences between active and passive systems, Table 2.1 provides a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of these two technologies. The SWOT analysis is utilized to identify opportunities and threats related to each technology (otherwise known as positive and negative aspects), and the strengths or weaknesses of these elements are found by applying this information. The opportunity/strength box contains the opportunities that will also serve as strengths for the system.

Table 2.1 SWOT Analysis of Active and Passive RFID Technologies

	Strength		Weakness	
Opportunity	**Active**	**Passive**	**Active**	**Passive**
	• Battery leads to longer read range • Greater memory for information to be stored • Accurate data capture	• No Battery makes it less expensive • Accurate data capture • Bulk orders make it less expensive • Easy to hide	• Small quantities can be purchased (expensive) • The longer read distance can be less secure with data protocols	• Less expensive than active tags • Increased security due to short read ranges
Threat	**Active**	**Passive**	**Active**	**Passive**
	• Proprietary system increases security	• Less expensive technology limits the amount of information • Only available in bulk quantity • No battery power for backup	• Battery life is finite • More expensive than passive tags • Metallic ducts interfere with signal • Difficult to hide	• Lack of battery results in shorter read ranges

The opportunity/weakness box lists the opportunities that may also become hindrances in the long run. The threat/strength box lists the elements that are considered threats that can act as strengths in certain instances of the application, and the threat/weakness box lists all the elements that are considered threats (which are also weaknesses once implemented into certain systems).

Low and high frequency tags usually comprise passive systems while ultra high frequency tags are used in active systems. The SWOT analysis table explains the advantages and disadvantages of using passive vs. active tags. Low and high frequency tags are less expensive but the read range is less, while ultra high frequency tags are more expensive but, because of their battery power, are capable of reading over longer distances. Moreover, the active tags' battery life span is finite whereas passive tags do not carry batteries. In addition, more information can be stored in active tags whereas passive tags have limited storage capabilities. Finally, the size of active tags makes difficult to hide them, but passive tags are compact and can be hidden easily.

2.1 Applications of RFID

RFID technology is used in a variety of applications, especially in relation to supply chain activities. Examples of these applications include manufacturing, distribution of physical goods, shipping and port operations, livestock tracking, access control, point of sale (Potter, 2005), prepaid cards, payment processes, (Wu et al., 2006), libraries (Coyle, 2005), parts and packages unification for construction (Yagi et al., 2005), health care, ticketing, road toll electronic purse (Knospe and Pohl, 2004), asset management, and baggage and package tracking. RFID technology can be used both to develop and to reduce a variety of activities including spoilage prevention (Karkkainen, 2003), theft reduction (Atkinson, 2004), flexible and timely resource data access and collection framework for the system, operating cost reduction, customer satisfaction, and resource management (Chow et al., 2006).

This literature section will discuss how RFID is used in both indoor (supply chain management) and outdoor (vehicle tracking) applications. Section 2.2 explains how RFID is used in supply chain management, Sections 2.3 and 2.4 discuss the parameters that must be considered before implementing RFID in vehicle tracking, Section 2.5 presents an example of how some of these parameters are analyzed in an RFID system, and Section 2.6 explains the different applications of RFID technology in vehicle tracking. Section 2.7, discusses other tracking technologies as well as a new hybrid system which integrates RFID with GPS and GSM technology. Finally, a summary of the literature is presented in Section 2.8.

2.2 RFID in Supply Chain

Supply chain is a process of material procurement, transformation of materials into intermediate and finished products, and distribution of those products to customers (Ganeshan and Harrison, 1995). Companies are constantly trying to enhance the efficiency and effectiveness of their supply chain operation by implementing such techniques as just in time (JIT), manufacturing resource planning (MRP II), and enterprise resource planning (ERP) (Williamson et al., 2004). The success of a company totally depends on exact and real-time information flow from the above mentioned processes. In order to get this real time information, companies have begun to utilize RFID technology.

RFID technology processes and displays information in an accurate, exact, visible, real-time, and transparent manner, and plays an important role in supply chain management. This technology can be deployed in an enterprise to achieve a transparent and visible information flow.

Because of the advantages of RFID technology, an innovative model was proposed by Zhou et al. (2007) which use RFID, bluetooth, and the internet to track items in an enterprise. In this model, bluetooth and internet are combined with RFID to achieve wireless communication not only within an enterprise but also as an interface with external systems. Using the World Wide Web, any valuable information can be transmitted to any part of the world at any point in time. A novel system has been built using this combined RFID, internet, and Bluetooth technology to manage an enterprise's internal production system, warehouse management system, sales management system, production management system, and integration of transportation management system.

In the working model of the system proposed by Zhou et al. (2007), RFID passive tags are placed on each item (raw material, component, and steel roll) as they are received at the dock. These tags carry information like item identification number and item name. Next, RFID readers at the ingress and egress of the warehouse track each item as it enters or exits the premises, transferring that information to the local central monitoring terminal. Through this process, inventory in the warehouse is visible to the management of the enterprise aiding significantly in the development of an optimal raw material and outsource plan for purchasing. Similarly, RFID readers are deployed at manufacturing workshops, production workshops, and assembly workshops in order to track the inflow and outflow of tagged items in these environments.

Information from an RFID reader at the production workshop calculates the number of parts produced on each line at the end of every day. Based upon these results, decisions are made to either expedite or retard the process in order to meet production targets. RFID-based monitoring systems make this information transparent to the management department and assist in making optimal plans for raw material purchasing, production progress, sales order processing, and even financial flow management. This new technology helps the company to visualize their processes and facilitates the improvement of production efficiency.

2.3 Parameters to Experiment before Implementing RFID

Previous research by Joseph (2007) focused on the performance level of RFID technology in different environments. In this research, the three main environmental parameters tested were control, noise (wireless communications or power lines in or near an organization that can cause interference on various RFID frequencies), and surrounding material**.** Implementation of an RFID system is practically impossible in an uncontrolled environmental condition (Joseph, 2007). Even though RFID systems do perform well in noisy environments, onsite testing is mandated to confirm that their performance level is not affected by this noise.

Certain materials can also have a negative effect on RFID. For example, metal always deteriorates the performance level of RFID, since the metal surface reflects the radio frequency (RF) signal (Floerkemeier and Lampe, 2004). Likewise, when tags are placed near water or human bodies, performance levels are also greatly affected (Joseph, 2007). The reason for this is not only that the human body or water is in close proximity to the tag; it also depends on the configuration of the reader and tag and the quality of the RFID equipment (Want, 2006). These factors should therefore be considered and evaluated before implementing RFID systems in any application.

2.4 Performance Criteria in Vehicle Tracking Systems

According to Seda et al. (2006), before implementing RFID technology in vehicle tracking applications there are some important parameters that must be considered. Since research on how RFID performance should be evaluated is only briefly covered in previous research, however, the performance criteria and evaluation methods used in analysis of RFID technology were therefore determined using the 16 model theory proposed by Heine et al. (2003). Findings of this research include such information as vehicle identification system (VIS) performance criteria as well as both advantages and limitations of RFID technology.

Performance criteria for RFID technology are classified into two parts: technical criteria and organizational criteria. Technical criteria for RFID performance include the characteristics of tags and readers, transponder thickness, middleware software, frequency, speed, and the distance at which data can be read (Ngai et al., 2007). Tag configuration; frequencies; and types of antennas, readers, and systems are the basic considerations to consider in choosing the best RFID system for any specific application (Eckfeldt, 2005). Moreover, the orientation of the tag, the power supply to the tag, and the material on which the tag is attached all play a vital role in RFID system performance.

Organizational criteria, on the other hand, include parameters such as environmental, behavioral, cultural, consumer acceptance levels, and security (Ohkubo et al., 2005). Environment is an essential parameter to be considered in RFID performance, since RFID systems are very sensitive to environmental changes. Environmental issues to consider include moisture, which can absorb radio waves; metal surfaces, which can destroy, reflect, or hide radio waves; and noise, which can block RFID communication (Jones et al., 2004).

This section further discusses the important criteria to consider before implementing RFID in vehicle identification technology. RFID is an emerging technology, and research has been performed in various applications (Porter et al., 2004). One of these applications is the vehicle identification system (VIS), which provides information such as vehicle identity, corporation identification, fuel type, vehicle engine-hours, and odometer reading. As mentioned before, information on RFID usage has not been explored much in the academic sector. Therefore, RFID systems can only be studied via the companies where such systems have already been implemented (Seda et al., 2006).

In Petrol Ofisi (PO), company interviews were conducted to discover both the reason for adopting the RFID system as well as the issues related to the implementation of that system. Questions were framed based on both technical and organizational criteria and rated on a scale of 1 (least important or effective) to 10 (most important or effective).

Results from these interviews illustrated the importance of factors like environment, ease of use, timeliness, usefulness, and loyalty and also proved that these factors must be considered before implementing RFID in vehicle identification technology. After the implementation of RFID, consumer's saved time, loyalty increased, and fuel theft has been prevented in the range of 3-30 percent (Seda et al., 2006).

Further interviews were conducted in the automobile factory to understand their priorities in selecting RFID systems for vehicle tracking. Top priorities identified by these interviews included read range, integration of the system, cost of the system, data transmission type, ease of use, and tag life (Seda et al., 2006). In the next section, an example of how some of these parameters are considered and analyzed before the implementation of an RFID system is used.

2.5 Analyzing the RFID System under Different Environment Condition

A study by Darmindra et al. (2007), analyzed the performance of 2.45 GHz surface acoustic wave (SAW) radio frequency identification (RFID) systems. The mechanism and principle of an SAW tag are different from those of regular RFID systems. The working principle of this device is as follows: first an RF signal is received from the interrogator and converted into an acoustic wave using an inter-digital transducer (IDT). Next the acoustic wave from the reader activates the tag facilitating two-way communication between tag and reader. The tag's temperature is dependent upon the acoustic wave velocity, and when the temperature increases the total travel time of the acoustic wave also increases (expansion of piezoelectric crystal). An increase in temperature will decrease the wave's velocity while increasing the time delay. Since time delay is proportional to temperature, an SAW device can actually be used as a temperature sensing mechanism (Bao et al., 1987).

This innovative system should be tested before implementation in any applications. In order to conduct this testing, the system was simulated under different environmental conditions to identify system performance with particular focus on the following parameters: actual reads, read attempts, maximum correlation, tag temperature, and tag range.

2.5.1 Test Set-up

The center of the tag and the reader were fixed 4.3 ft above the ground and initially separated by a horizontal distance of 30 ft. This 30 ft distance was used to estimate the maximum operable read distance of the system. The experiment was carried out in open ground in order to test for temperature and humidity variations. The results of this experiment showed that a monopole antenna is capable of reading from a distance of around 10 ft. Similarly, the single patch antenna and double patch antenna could both read from approximately 24 ft.

2.5.2 Environmental Analysis

Environmental parameters like temperature, humidity, altitude, and vibration/mechanical stress were simulated in a chamber located in Texas **(**Darmindra et al., 2007, Radio Frequency Innovation and Technology Center at the University of Texas at Arlington)**.** A single patch antenna was used for this analysis since it outweighed the other two antennas and, because the chamber was constructed of metal, temperature tests were performed with anechoic foam placed behind the tag and the reader. Anechoic foam was used for several reasons, including reduction of multipath occurrences, absorption of all other radiated rays, and improvement of system performance. The testing was conducted in two levels: hot (70 to 180 deg F) and cold (60 to -40 deg F) (Darmindra et al., 2007).

Results of this testing demonstrated that temperature is inversely proportional to maximum correlation, which is defined as the performance level of the tag measured by its average read range. When temperature increases, maximum correlation decreases. Therefore, from the experimental result, the read range of the tag is completely dependent upon the temperature. The maximum temperature of the tag effectively read by the reader without any disturbance was 120 deg F. Likewise; humidity, altitude, and vibration tests were also performed and correlated to system performance. Relative humidity was found to have an insignificant effect on readability.

Next, altitude tests were performed up to a limit of 105,000 ft with the temperature kept constant between 72 deg F and 83 deg F. Negligible changes were observed in the maximum correlation when altitude was increased over 75,000 ft. At increased altitudes, the lack of air makes for a decrease in radio wave scattering and absorption. Therefore, as height increased system performance was improved.

Vibration testing is also an essential part of any environmental test. Frequencies of 20 to 2000 Hz were found to have no significant effect upon maximum correlation. In conclusion, SAW tag performance levels were studied in several different environmental conditions including temperature, humidity, altitude, and vibration. This section discussed and provided examples of the important parameters and criteria to consider before implementing an RFID system. Section 2.6 will explain the different sectors in which RFID technology is used for vehicle tracking applications.

2.6 RFID in Vehicle Tracking

This section discusses the different sectors in which RFID technology is used for vehicle tracking applications. The purpose of this section is to understand the issues involved in vehicle tracking and to determine the steps necessary for overcoming those obstacles in my research. This section discusses a variety of issues involved in the tracking of vehicles via RFID systems, including:

1. RFID in underground mining
2. RFID to track traffic density
3. RFID passive tags to track cars
4. RFID in parking lots and
5. RFID in parking lots, to estimate average travel time of the car

2.6.1 RFID in Underground Mining

Todd and Drew (2001) conducted research at the National Institute for Occupational Safety and Health (NIOSH) to reduce the number of accidents associated with collisions between mobile mining equipment and pedestrian workers or smaller vehicles in underground mining situations. Accident rates were constantly increasing and the methods used to control these accidents were not completely reliable (MSHA mining accidents database). Most of these accidents could have been avoided if only the workers had been properly warned by machine operators. The technologies applied to alert these workers are Doppler radar units, video cameras, ultrasonic and infrared sensors, and radio frequency transponders.

Multiple issues were identified regarding these systems during experimentation. Radar systems were prone to providing false alarms; when read ranges increased over 20 to 30 ft, radar inappropriately detected a building located 100ft away (Todd and Drew, 2001). Because of low brightness in underground mines, video cameras were also not viable for detecting pedestrians. Size and cost were also an issue in the implementation of cameras. Ultrasonic based systems are not robust enough to function properly in harsh environments, and their performance rate was affected badly by the vibration of mining equipment. Finally, infrared systems are also liable to give false alarms due to the effects of direct sunlight, reflections, and hot equipment (Johnson et al., 1986).

The most successful system for avoiding collisions in underground mining is radio frequency identification technology (Todd and Drew, 2001). The working methodology is, when a tag is detected by the reader, the equipment driver is immediately notified, it is verified that there is a person in the blind spot, and the vehicle is made to slow down. Also, the chance of false alarm is greatly decreased when RFID is implemented in this harsh, robust environment. This RFID system is manufactured by a foreign company, however, and it is too costly for most companies to afford. More research should be focused on the cost and size of this technology.

In order to overcome the cost and size issues related to this current technology, two different RFID systems have been tested. Firstly, an active UHF RFID system, where the read range was over 200ft. This system was not convincing, since there is a delay period of 6 seconds between read times (which is not acceptable when equipment is moving fast). On the other hand, the other system is passive and is economical, but the read range was less; only about 7ft (Todd and Drew, 2001).

After these experiments, researchers decided to build a new RFID system that would meet the requirements of an underground mining operation. This innovative RFID system is an active system configured to adjust its range and sensitivity, where range can be selected from three different options: nearby, in-between, and far-off. Whenever a tag is read by this reader, it displays an “I’m here” signal three to four times per second. If two tags are detected at the same time, a double buzz will alert the driver and indicate the presence of people in his blind spots (Todd and Drew, 2001).

Results from this prototype system are better and more viable for implementation in underground mining. The reader detects the tag 100% of the time and was not dependent upon the pedestrian’s physical orientation. There were some misreads, however, when the tag was folded by the user. Also, the frequency of the tag should be tested to make sure it is not affecting the users.

To summarize, a novel RFID system was built and tested for implementation in underground mining. Results were convincing when compared to other RFID systems, though more research is required to avoid misreads if this system is to be successfully implemented by the mining industry (Todd and Drew, 2001).

2.6.2 RFID to Track Traffic Density

A study by Anala et al. (2009) used RFID to track traffic density along routes of various cities with the goal of reducing traffic congestion. RFID tags were affixed on the windscreen and the RFID reader activated the tag. Once the tag was activated, information was sent to the reader which, in turn, relayed that information to the server.

This system was comprised of three different modules. First was the client module where users track their vehicles and receive information on the current traffic situation, toll/tax/fines paid on their vehicle, the quickest route to reach their destination, their insurance policy, and the registration details of their vehicle. Next was the system user module, where processes like managing user accounts, registering clients, generating bills, taking feedback to improve the process, and the tracking of services took place. The final module was the traffic management module which calculated the shortest route between locations as well as determining timing intervals for traffic signals in order to mitigate traffic congestion.

The traffic management module plays a major role in this model; it stores various links between two RFID readers, the length and width of the road, and the speed limit of the vehicles. This information allows the system to calculate the traffic quotient of the road, which is inversely proportional to the length and width of the road and the speed limit of the vehicle and directly proportional to number of vehicles and the average area occupied per vehicle (Anala et al., 2009).

Traffic quotient = F (length, width, speed limit, number of vehicles, projected average area per vehicle)

TD = Avg (Area (Vehicle)*N/Area (Road)

TQ= TD* (Speed Limit in kmph/60kmph)

Where TD= Traffic density, TQ= Traffic quotient, Avg= Average, and N= Number of vehicles (Anala et al., 2009).

This formula calculates the current traffic density and that information are sent to users through GPRS or short messaging services with the help of RFID systems. The RFID system also stores the travel history of the vehicle as well as the current traffic situation. This RFID method of tracking outperforms camera-based tracking methods, as camera systems have only a 90% accuracy rate in tracking license plates (Tom, 2003) due to the fact that numerous cars carry false number plates (Niraj, 2003). On the other hand, the RFID system is completely dependable, and its accuracy rate is very high compared to that of cameras (Anala et al., 2009).

Apart from calculating the traffic density, this methodology can also be extended to identify stolen vehicles. Vehicle thefts are being continuously reported and their incidence is increasing every day. In 2006 alone, more than 40,000 number plates were stolen (Claire, 2007). If an RFID tag is embedded on the windshield of a vehicle, and someone attempts to break that windshield or scratch the RFID tag, a windshield damage report would be sent immediately. This new method will also provide the path followed by the thief, aiding considerably in the identification of the stolen vehicle, and can also be extended to track other useful information, such as fuel consumption rates, driving patterns, license updates, and statistical analyses of vehicular traffic for road development. This methodology calculates the traffic quotient and spreads traffic density among various routes in order to help reduce environmental pollution. The results from this analysis could also be interpreted and used in the construction of new roads, flyovers, and railway lines.

2.6.3 RFID Passive Tags to Track Cars

RFID passive readers are meant to be used in supply chain management and tire-tagging application (monitor the vehicle tire by attaching the tag inside the tire). But, research by Jonathan (2004) in South Africa tested passive tags in the tracking of cars. The RFID passive system used for this testing was a UHF IPico RFID system. Its frequency is between 860 MHz and 960MHz and it was envisioned to track a vehicle from a distance of 17 feet while traveling at 160mph.

Experiments were performed with eight vehicles, and the results showed that this system can read up to 200 tags per second. Also, the read range would allow users to place the reader at a distance of 6.5 feet from the side of the road and at an overhead clearance distance of 17 feet. This system was successful at two extreme speed conditions: low speed, (50 mph) and high speed, (75 mph). Furthermore, this RFID system was also tested on the Mercedes Benz C55 model traveling at 160 mph, and the reader read the tags easily without any misreads.

The cost of these tags is 60 U.S cents for a volume of 5 million and 50 U.S cents if over 20 million are purchased. They were designed to be placed on a vehicle's windshield with the readers stationed along the roadside. This technology is called Electronic Number Plate (ENP) and is used for the tracking of electronic licensing, traffic, speed, border control, traffic ticketing, road toll collection, fleets, and parking management.

2.6.4 RFID in Parking Lots

Mary (2007) used RFID technology to track cars in a parking lot. This RFID system was implemented in a parking lot in Turkey. This country faces a problem of tracking cars due to the fact that their parking lots have four gates and the ingress and egress of a single car occurs four or five times in a given day. They didn’t want to hire four employees to track cars, nor did they want to funnel traffic down to a single gate, so they needed an automated system to track the ins and outs of the vehicles. They chose to implement an Ultra high Frequency 866 MHz Alien RFID system.

Each entrance and exit gate was equipped with an Alien ALR-8800 reader and a circular antenna. An Alien M tag was placed inside each vehicle’s windshield. The readers read the tags from a distance of five to six meters without any flaws, and the database stored 4000 transactions every day and the municipality was able to overcome their problem without any human intervention in the tracking of vehicles.

Preliminary testing was a key factor in the successful implementation of this RFID system. It is very important to test hardware and software both in laboratory conditions and on-site. After this successful implementation, the municipality also planned to implement RFID in the tracking of vehicles.

2.6.5 RFID to Estimate Average Travel Time of the Car

An RFID traffic monitoring system was deployed in Florida by the Orlando/Orange County Expressway Authority (OOCEA) (Claire, 2004). This project was intended to estimate the average travel time of a car in a trip and provide that information to the public. For this purpose, 915 MHz RFID transponders and readers were deployed along the side of the roads in Orlando and Orange County.

Transponders were placed on the windshield of each customer's vehicle, and around 1 Million E-pass and Sun Pass transponders were deployed. In the initial phase of this experiment, 128 RFID readers were placed covering approximately 228 miles of toll roads and non-toll highways (Claire, 2004).

Similarly, Traffic Management System (TMS) in Colorado experimented with an SIRIT RFID system, which is manufactured by a Canadian company. The SIRIT system was successful both in tracking the travel time of a vehicle and in transferring traffic flow data to the central monitoring system. Since the SIRIT RIFD system showed better results, the Florida Department of Transportation (FDOT) and OOCEA both decided to use SIRIT systems for their applications.

The working principle of the SIRIT technology is the capture of the identity of a car with a transponder on its windshield as it passes through a reader, the tag's information is captured by that reader and transmitted to the FDOT. Next, further along the road, another reader will again capture the same tag's information. By comparing the information from the first reader with that of each subsequent reader, the distance traveled by a car in a given period of time can be calculated.

Any distance can be calculated using the information from these successive readers. Moreover, due to privacy issues, the driver's information will be erased after they receive the required information**.** Thus, the distance traveled by individual cars can be calculated using this innovative RFID technology.

2.7 RFID with GPS and GSM in Vehicular Communication

This section explains how RFID is integrated with other technologies such as GPS, GSM, and GIS for the purpose of vehicle tracking. RFID is a promising technology in vehicle tracking, making for improved logistics management, supply chain operation, and asset tracking. Similarly GPS is always preferred in the tracking of vehicles, assets, and staff over long distances (Williamson et al., 2004). For example, a system integrating RFID, global positioning system (GPS), global system for mobile communication (GSM), and geographic information system (GIS) technologies was constructed to track elderly people without interfering in their activities (Chung eta l., 2006). Also, Manon et al. (2008) tested a new system combining RFID with GPS to provide real time location of human resources both indoor and outdoor. An example of such a hybrid system is described in detail below.

Huiping et al. (2010) implemented a system combining RFID/GPS in vehicular communication. The purpose of this system is to track cargo and containers and guard against damage, loss, or theft. The software and hardware used to identify, monitor, track, localize, and manage key mobile supply chain assets are: microprocessor 16-bit MCUMSP430, RFID system, receiver module of GPS information, the GSM wireless communication module, and the human machine interface.

The main purpose of the microprocessor is to make logical decisions, command execution, and analyze signals (Huiping et al., 2010). First, original information about products and their GPS coordinates are recorded in the microprocessor, and the signal is transferred at a preset time**.** The function of the RFID is to store this information and improve the overall performance of movable asset management. GPS modules help us to locate the vehicle and provide such vehicle information as latitude, longitude, altitude, speed, time, and direction **(**Kumar and Moore, 2002).

Likewise, GSM serves as a communication tool between the GPS and the remote monitor center. It transfers information like tagged item description, geographic location, and emergency rescue messages. Also, it receives commands from both sides and alarms in case of emergency. The final module in this architecture is the human machine interface, which has a 4 * 4 keyboard matrix to allow for intercommunication and an LCD monitor to display the current status of the vehicle (Huiping et al., 2010).

In the case of vehicle theft, an error will occur when current information no longer coincides with the original information in the microprocessor. In this scenario, an automatic error will be reported to the microprocessors through GSM, which turns on the alarm immediately. Similarly, vehicle location and product description will also be reported to the monitoring terminal. The description of the stolen product will be tracked by RFID and then GPS will help to locate the vehicle. Finally, GSM will facilitate the sending of an emergency message to alert remote users that the product has been stolen. The remote users will make use of this information and, with the help of the modules, trace and locate the stolen product. This hybrid system combining RFID, GPS, and GSM enhances automatic management, information security, real-time trace and location, and anti-theft in digital logistics management.

There are few other technologies which could be used in tracking vehicles. Table 2.2 shows the overview, advantages and disadvantages of other technologies which can be effectively used to capture data. These technologies, along with a benefit cost analysis, are discussed in detail in Chapter 5. They include:

1. Automated license plate recognition system (ALPR) (Dileep et al., 2009)
2. RFID tag system with some limited functionalities
3. RFID tag system with interfaces with other onboard systems (Manon et al., 2008)
4. On board systems such as GPS and wireless communication (Rashmi et al., 2002 and Shyang-Lih et al., 2004).

Table 2.2 Automatic Data Capture Technologies

Data Capture Technologies	**Overview**	**Advantage**	**Disadvantage**
RFID (Laura, 2005).	- A reusable RFID tag is used to inspect vehicles as they pass through RFID enabled checkpoints.	-Powerful and dynamic data acquiring capabilities of the technology. -Lower-cost tag option. Rugged EPC tags will last for years (Laura, 2005). -No batteries in the tag to replace.	-Vehicles must pass through a series of RFID-enabled checkpoints for visibility. -Vehicles visibility is lost outside of the range.
GPS (Rashmi et al., 2002 and Kumar et al., 2002).	A tag leveraging cellular and GPS triangulation is placed on each vehicle to identify (What is GPS, gpswildmap).	-Vehicle continues to be tracked outside of the facility/yard and regardless of transport mechanism. -GPS provides location data even when obstructed. -Simplified deployment schema and little onsite infrastructure requirements. -Assemble and process data from diverse sources and present it in an easily understood graphical format.	-Cost may be prohibitive for large volumes of tagged vehicles. -Ongoing operational costs in the form of airtime charges. -Battery life may be an issue. -It is not possible to deploy in many cities due to issues like adequacy of satellites (Mary, 1993).

Table 2.2 Continued			
PIPS Technology (Meynberg et al., 2010 and Shyang-Lih et al., 2004).	-Mobile plate hunter (MPH) 900 cameras (Elsag, North Carolina). -Travel Time software engine. -Server, communication, wiring and installation.	-Easy to mount low-maintenance and reliable sensor. -A variety of communication options are available. -Widely accepted technology used throughout the world.	-Its reliability and accuracy depends on many environmental factors (Tom, 2003). -Camera-captured images can suffer from low resolution, blur, and perspective distortion, as well as complex layout and interaction of the content and background (Anthony, 2010).

2.8 Summary of Literature Review

The literature review section has discussed how RFID technology was effectively used in a variety of applications, including supply chain management, underground mining, tracking traffic density, tracking vehicles in parking lots, estimating average travel time of vehicles, and vehicular communication.

Before selecting an RFID system, there are certain parameters that need to be considered and evaluated. A literature survey was carried out to identify those parameters in order to consider and evaluate them in this research work. Even though there are many factors that need to be evaluated, according to the previous research the three main factors were control, noise, and surrounding material. Also, tag configuration, frequencies, and types of antennas, readers and systems were identified as the basic considerations in choosing the best RFID system for any specific application.

Moreover, orientation of the tag, power supply to the tag, and the material on which the tag is attached all play a vital role in system performance. If the tag is attached to a metal surface, performance rate is always affected. Research showed that anechoic foam can be used to reduce the effect of metal surfaces. The anechoic foam serves many purposes, including reduction of multipath occurrences, absorption of all other radiated rays, and improvement of system performance.

Different applications of RFID technology in vehicle tracking were also discussed in the literature section. RFID technology was implemented in underground mining to avoid collisions between mobile mining equipment and pedestrian workers, and was more successful in alerting pedestrian workers in these situations than other technologies (Doppler radar units, video cameras, and ultrasonic and infrared sensors).

Likewise, RFID technology was deployed to track traffic density along routes of various cities to reduce traffic congestion. Information such as length and width of the road, speed limit, number of vehicles, and projected average area per vehicle will calculate the current traffic density and send that information to users through GPRS or short messaging service with the help of RFID systems. In Florida, RFID was utilized to calculate the distance traveled by a car in a trip. The information from two successive readers located along the roadside helped the traffic management department calculate these distances. Also discussed in the literature review section was the way in which RFID passive tags were used to manage and track cars in parking lots. Moreover, RFID technology was incorporated with microprocessor, GPS, GSM, and human machine interface to track stolen items in moving vehicles. This hybrid system enhanced automatic management, information security, real-time trace and location, and anti-theft in digital logistics management.

CHAPTER 3

EXPERIMENT ON DIFFERENT RFID SYSTEMS

3.0 Introduction

The commercial vehicle inspection system and network (CVISN) project investigated three different RFID systems in order to choose the one best suited to the tracking of vehicles. These three RFID systems included SIRIT, a passive system in which the antenna and reader were separated, and SAVI and RF code, which were active systems in which the reader and antenna were integrated. This CVISN testing was performed in two different stages: motion testing, in which the vehicle traveled at three different speeds (25, 30, and 35 mph); and stationary testing, in which the vehicle remained static. The speeds used during the motion testing phase of this experiment represent speed limits commonly enforced at weighing stations, where data on commercial vehicle operations (CVO) would typically be captured. In both cases, the tags were placed on the vehicle's license plate and the prototype of how the tags were embedded between the license plate is showed later in the Section 3.2.2.

The purpose of stationary testing was to determine the average read range of the tags, the effects of metal on system performance, and the optimum type and number of spacers to use between the RFID tag and license plate. This information was then utilized in carrying out the motion testing phase of the experiment.

This chapter describes the preliminary experiments which were performed before the stationary and motion testing in Section 3.1. The stationary and motion testing performed on SIRIT, SAVI, and RF code systems are explained in Section 3.2 and 3.3.

The experimental design developed to perform this experiment is outlined in Section 3.4. Section 3.5 explains the method used to analyze the data. The effect of material and speed on signal strength is discussed in the Section 3.6.

3.1 Preliminary Testing

Preliminary tests were performed on the SIRIT system before stationary and motion testing took place. This was done for several reasons, including determining how the antenna should be angled in relation to the tag, where exactly the tag should be attached to the license plate, and the average read range of the systems when placed on metal surfaces. The experiments were performed on the 16th street beside Nebraska Hall in 2010 summer. For example, Figures 3.1 and 3.2 illustrate how the antenna was placed at 45 and 90 degree angles during these preliminary experiments.

The experiment was performed with a SIRIT RFID system in order to identify the angle at which the antenna should be fixed. The angles tested were 0, 45, 90, 135 and 180 deg. When the tag and reader were separated horizontally by a distance of 25 ft, the maximum distance the reader was able to read the tag was measured at the above mentioned angles. The results showed that, at an angle of 90 deg, the reader was able to read from a maximum distance of 25ft. The preliminary testing determined that the antenna should be fixed at a 90 degree angle facing the tag. The results of this testing is shown in Appendix A.

Figure 3.1 Antenna at 45 Deg with Street Direction

Figure 3.2 Antenna at 90 Deg with Street Direction

Also the experiment identified that the tag must be attached to the center of the license plate. The read range of the tag was found to be affected by the metallic license plate, and in order to reduce this effect different spacers composed of cardboard, plastic, or rubber were used between the tag and license plate. The specifications obtained from this preliminary testing were used in the performance of all subsequent stationary and motion testing.

3.2 Stationary Experiment

3.2.1 Experimental Setup

To perform this experiment, a mile marker was constructed to the exact specifications of actual roadside mile markers. The reader was attached to this mile marker and located by the roadside.

Figure 3.3 Position of the Tag and Antenna

Initially, the distance between tag and reader was set at 25 feet to match the specifications of a two lane highway. By increasing the number of readers, vehicles may also be tracked on multiple lane highways. The reader height was varied on the mile marker in order to determine its optimal placement, and it was found that when the height of reader and tag coincide, the performance rate or read range of the system was improved. Since the average height of the license plate was 3ft, the reader was fixed at 3ft above the ground in order to remain parallel to the tag. This same height was maintained throughout all initial stationary and motion testing.

As shown in the Figure 3.3, the antenna was placed 3ft above the ground on the mile marker and the tag was placed at the center of the license plate. The horizontal distance between tag and reader was 25 ft. Stationary testing on SIRIT, SAVI, and RF code systems was performed, and the received signal strength indicator (RSSI) value of the reader was measured from their respective RFID system software, which was installed in a computer. The computer was connected to the reader through a USB cable which displays the RSSI value in a digital format.

3.2.2 SIRIT System

The performance rates of these systems are measured by a received signal strength indicator (RSSI), which is defined as a circuit for measuring the strength of an incoming radio signal (Saxena et al., 2008). Though RSSI is most widely known for providing a low-cost estimation of distance between vehicles (Choi et al., 2008 and Bin et al., 2006), it has also been implemented by many users in a variety of location tracking applications (Lau and Chung, 2007 and Saxena et al., 2008). RSSI operates by picking up RF signals and generating an output equivalent to the signal strength, thereby identifying the ability of the receiver to pick up the weakest of signals (reader sensitivity). The advantage of this RSSI method is that it does not require any specialized hardware.

Stationary testing was performed with the antenna perpendicular to street direction and the tag attached at the center of the license plate. Figure 3.4 shows the prototype used in these experiments along with material spacers to reduce the effect of the metal surface. The spacers were composed of several different materials such as corrugated fiber cardboard, thermo softening plastic or natural rubber were used and provided a barrier between the front and back plate.

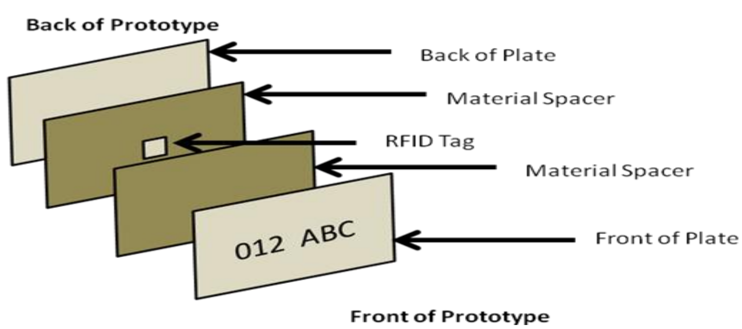


Figure 3.4 Prototype used in Experimentation

Table 3.1 SIRIT System Configuration

Operating Frequency	860-960 MHZ
Reader	Nfinity TM 510 UHF
Read Range	Up to 1000 feet
Power	Power over Ethernet
RSSI value Range	-300 to -600dB
Tag density	Up to 513 tags per second

The configuration of the SIRIT system is shown in Table 3.1. The RSSI value for the SIRIT system ranges from -300dB (signifying a stronger signal) to -600dB. The SIRIT system reader was unable to detect the tag in this configuration. The reason may be that the metallic license plate did not allow the tag to transfer signal back to the reader. Different spacers (cardboard, plastic and rubber) were tested to reduce the negative effect of the metallic license plate, but the SIRIT system reader was not able to receive the signal from the tag.

3.2.3 SAVI System

The configuration of the SAVI system is shown in Table 3.2. The SAVI received signal strength indicator (RSSI) value was between +110dB to +160dB. An RSSI value closer to 160dB indicates the reader received the stronger signal strength.

The major purpose of stationary testing on an active system is to ensure that the reader easily reads the tag that has been placed on a metal surface. This experiment was performed by enclosing the tags with different spacers, and RSSI values were measured for each type of spacer as well as for spacers of varying thicknesses.

Table 3.2 SAVI System Configuration

Operating Frequency	433MHz
Reader	SAVI ECHO Point
Read Range	100m
Power	Power over Ethernet
RSSI value range	+110 to +160dB
Tag density	Up to 100 tags per second

The tags were enclosed by three different thicknesses of cardboard, plastic, and rubber, and the results of these experiments determined that the minimum thickness of cardboard (0.2inch), plastic (0.01inch), or rubber (0.09inch) resulted in the best RSSI values. The results of this stationary testing are shown in Appendix A2, and were utilized in the performance of subsequent motion tests.

3.2.4 RF Code System

The configuration of the RF code system is shown in Table 3.3. The RF code received signal strength indicator (RSSI) value was between -58dB (stronger signal) to -108dB. Moreover an experiment was performed to understand the variation of the RSSI values between different RFID tags. The results clearly demonstrated that there is a negligible variation between the tags which can be ignored in practical situations. The results of this testing are shown in Appendix A3 (The tag with the I.D number IR code 00026074 was used throughout these experiments).

Spacers of three different types and thicknesses were used. The best RSSI values were obtained when using the minimum thickness of cardboard (0.2in) or rubber (0.09in). For the plastic spacer, however, the second level of thickness (0.03in) produced the best RSSI value. In general, the distraction of the radio signal due to presence of metal is reduced by placing spacers between the tag and the metal surface.

Table 3.3 RF Code System Configuration

Operating Frequency	433.92 MHZ
Reader	RF code M200 fixed reader
Tag I.D number	IR code 00026074
Read Range	Up to 1000 feet
Power	Power over Ethernet
RSSI value Range	-58 to -108dB
Tag density	Up to 140 tags per seconds

3.2.5 Summary of the Stationary Experiment

Stationary testing was conducted with three types of RFID systems: SIRIT, SAVI, and RF code. The SIRIT system was unable to detect a tag that had been placed on the license plate, even when spacers of cardboard, rubber, or plastic were used, due to the negative effect of the metal surface. The SAVI and RF code systems, however, read the tags with no interference in each and every condition tested. RSSI values of both RF code and SAVI systems were best when using the minimum thickness of cardboard (0.2in) or rubber (0.09in) spacers. For plastic, however, the second level of thickness (0.03in) compared to first level of thickness (0.01in) yielded the best RSSI value.

3.3 Motion Testing

In motion testing the reader was placed on the mile marker at a height of 3ft and the tag was fixed on the license plate of the car. Figure 3.5 depicts how the tag was placed on the license plate. The tag and reader were separated by 25ft and the car was driven at three different speeds (25, 30 and 35mph).

Figure 3.5 Tag Embedded on the License Plate

Figure 3.6 RSSI Value Measured in Motion Test

Figure 3.6 portrays the measurement of the RSSI value when the tagged car and reader were separated by a distance of 25ft. Thickness of the different spacers (cardboard (0.2in), rubber (0.09in), and plastic (0.03in)) which resulted from stationary testing was used to perform the motion testing. Experiments were performed using these measurements, and the corresponding received signal strength indicator (RSSI) values were measured.

3.3.1 SIRIT System

The SIRIT system was tested under moving conditions by placing the passive tag on the license plate. Initially the car was driven at 25mph and the reader was unable to read the tag. Even after placing different spacers between the tag and reader, the SIRIT system was still unable to detect the tag. In general, the SIRIT system yielded poor results under both stationary and motion testing conditions.

3.3.2 SAVI System

This same setup was followed for SAVI motion testing; the car travelled at 25mph with the tag attached to the license plate. Under these conditions, the reader was unable to read the tag. Next, spacers composed of cardboard, plastic, and rubber were placed between the tag and license plate, beginning with minimum thicknesses, but increasing in thickness as the reader continued to fail at recognizing the tag. Different combinations of spacers, thicknesses, and speeds were tried, but the reader only sporadically read the tag. The incomplete data sheet is shown in Appendix A4.

3.3.3 RF Code System

The RF code tag was enclosed by the license plate and the vehicle again traveled at all three speeds as different spacers with different thicknesses were utilized to study the best combination of variables. The RF code read the tag at all three different speeds with varying thicknesses of spacers. RSSI values were measured for all different settings and statistically analyzed to determine whether speed and material were significant factors in RF code system performance. These experimental design results are discussed in the upcoming section.

3.3.4 Summary of the Motion Test

Motion testing on the SIRIT RFID system was conducted, and its performance rate was very low. Even after placing different spacers of varying thicknesses, the SIRIT system failed to read the tag. Next, the SAVI system was tested under motion conditions by placing the tag on the license plate. The SAVI RFID system was not consistent in reading the tag, and when speed was increased, the number of reads decreased. Finally, RF code was tested, and was the only system which was capable of reading the tag at all different speeds with different spacers in place. The RF code RFID system outperformed both the SIRIT and SAVI systems. While the RF code reader could read the tag at all the three speeds, the spacers were found to be helpful in reducing the negative effect of the metal surface.

The RF code system was the only successful system and yielded the best RSSI values for all different combinations of variables. Statistical testing was performed to determine what effect independent variables of spacers and speeds had on the dependent variable (RSSI).

3.4 Experimental Procedure

This section outlines the experimental design used in the motion testing of the aforementioned RFID systems. As shown in Table 3.4, speed and material are the input variables while the output variable is the received signal strength indicator (RSSI) which is measured in decibels (dB).

Table 3.4 Experimental Design

Variables	**Dependent variable**	**Independent variables**	**Levels**	**Control variables**
Factors	Received Signal Strength Indicator(RSSI)	Speeds(mph)	• 25 • 30 • 35	• Reader height(ft), • Tag height(ft) • Material thickness(in) • Distance between tag and reader(ft)
		Materials (inches)	• Cardboard • Plastic • Rubber and • No material	

The independent variable, "speed" has three levels (25, 30 and 35 mph) and the "spacer" or "material" variables have four levels (cardboard, plastic, rubber and no material) respectively. The control variables in this experimental design were the height of the reader and tag, material thickness (cardboard 0.2in, rubber 0.09in, and plastic 0.01in), and the distance between tag and reader.

Table 3.5 Partial Randomization (Trial Numbers)

Material	**25**	**30**	**35**
Rubber	2	15	6
	7	3	16
	19	24	1
	12	10	30
	22	26	13
	11	5	29
	14	25	20
	18	4	23
	8	28	9
	17	21	27

All these measurements were identified from the preliminary experiments. Each set of experiments was replicated 10 times. The design was not completely randomized, due to a lack of facilities, but was randomized within each group. Table 3.5 shows the partial randomization for rubber spacer material over 30 trials. These experiments were randomized between three speeds (25, 30 and 35 mph) and all other materials (see Appendix A5).

3.4.1 Methodology

To determine the significance of two factors (speed and material) on RSSI value, three steps were performed.

3.4.1.1 Data Collection

Two factors were evaluated to determine their significance to the RSSI values of RFID systems. The first of these factors was material. Figure 3.7 depicts placement of the RF code tag between cardboard and license plate.

Speed was the other factor to be evaluated throughout these ten replications and consisted of three levels (25 mph, 30 mph, and 35 mph). Figure 3.8 depicts the horizontal distance of 25 ft between the reader and car with the RFID tag embedded license plate. The RFID reader used an RSSI range of -58dB to -108dBs. For ease of interpretation, all values are shown as positive, so the smaller the RSSI value, the greater the strength.

Figure 3.7 Placement of Tag between Cardboard and License Plate

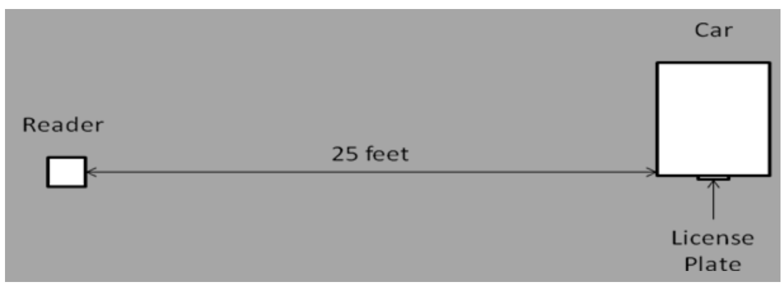


Figure 3.8 Experimental Setup

3.4.1.2 Two Factors ANOVA

Once all the RSSI values were accumulated, a two-way ANOVA was used for evaluation to check whether material, speed, or the interaction between material and speed had a statistically significant effect on the RSSI values (the dependent variable) at 0.05 alpha (α) levels.

3.4.1.3 Tukey Test

Once a factor was found statistically significant, a Tukey test was performed to find if there was a difference between the means of that factor and which level had the greatest RSSI value. This test may help to determine which material or which speed was the most reliable with regard to RSSI value strength. The result of this analysis is showed in the next section.

3.5 Results

3.5.1 Data Collection

A total of 90 trials were conducted for three different speeds and three different spacers. The mile marker reader detected an RSSI value for every trial and the values ranged from -79.5dB to -108dB. The results for each types of spacer are shown in Tables 3.6- 3.9.

Table 3.6 RSSI Values for Rubber Spacer

Trials											
Speed (mph)	1	2	3	4	5	6	7	8	9	10	Avg.
25	107	87.5	98.5	102.0	102.5	86.0	88.5	92.5	100.5	89.0	95
30	102	105.5	97.0	98.0	101.5	108.	103	97.5	102.5	93.5	101
35	92.5	87.0	99	104.5	96.5	97.5	99.	99.	97.0	101.5	97

***Note: all values are negative (dB)**

Table 3.7 RSSI Values for Plastic Spacer

Trials											
Speed (mph)	1	2	3	4	5	6	7	8	9	10	Avg.
25	99.5	102	102	90	101	82	103	93	101	102	98
30	90.5	88.0	101	93	99	101	96	93	91	96.5	95
35	90	97.5	101	99	87.5	97.5	97.5	87.5	95.0	95.5	95

***Note: all values are negative (dB)**

Table 3.8 RSSI Values for Cardboard Spacer

Trials											
Speed (mph)	1	2	3	4	5	6	7	8	9	10	Avg.
25	79.5	95.5	82.5	82.5	97.0	97.5	84.5	95.0	81.0	80.5	88
30	95.5	98.5	83.5	93.5	87.5	97.5	97.5	94.5	99.5	87.5	93
35	95.5	81.5	98.5	88.5	94.0	82.0	95.5	87.0	81.5	91.0	89

***Note: all values are negative (dB)**

Table 3.9 RSSI Values for No Spacer

Trials											
Speed (mph)	1	2	3	4	5	6	7	8	9	10	Avg.
25	101	106	111	103.0	98.0	93.0	108.0	103.0	95.0	100.0	102
30	102	100	111	101	102	108	104	98.0	105.0	101.0	103
35	97.0	98.0	101	96.0	96.0	98.0	104	95.0	95.0	98.0	98

***Note: all values are negative (dB)**

3.5.2 Two Factors ANOVA

The data were analyzed using SPSS statistical software (SPSS Inc., 16, Chicago, IL, USA). The ANOVA was performed to find the statistically significant factors. The results of the ANOVA test are shown in Table 3.10. The general model used for the ANOVA test was

$$y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_{ij} + \varepsilon_{ijk} \qquad \text{for } i = 1,2,3;\ j = 1,2,3,4;\ \text{and } k = 1$$

where,

y_{ijk} is the RSSI value,

μ is the overall mean response,

α_i is the effect due to the i^{th} level of speed,

β_j is the effect due to the j^{th} level of material,

γ_{ij} is the effect due to any interaction between the i^{th} level of speed and the j^{th} level of material, and

ε_{ijk} is the error.

Table 3.10 Analysis of Variance (ANOVA) of Material and Speed

Dependent Variable: RSSI					
Source	**Type III sum of squares**	**Df**	**Mean square**	**F**	**Sig.**
Corrected Model	2394.573[a]	11	217.688	6.941	.000
Intercept	1110436.602	1	1110436.6	35407.2	.000
Speed	236.717	2	118.358	3.7	.026
Material	1848.356	3	616.119	19.6	.000
Speed * Material	309.500	6	51.583	1.6	.142
Error	3387.075	108	31.362		
Total	1116218.250	120			
Corrected Total	5781.648	119			
a. R Squared = .414 (Adjusted R Squared = .354)					

As shown by the ANOVA in Table 3.10, material and speed were statistically significant and did have an effect on RSSI values. The interaction of speed and material, however, did not have a statistically significant effect on RSSI values with an alpha value of 0.05.

3.5.3 Tukey Test

Further analysis was necessary to determine if there was an existing material that allowed for a better RSSI reading. Tukey's test was conducted on the data (30 samples) at 0.05 alpha (α) level and the results are shown in Table 3.11.

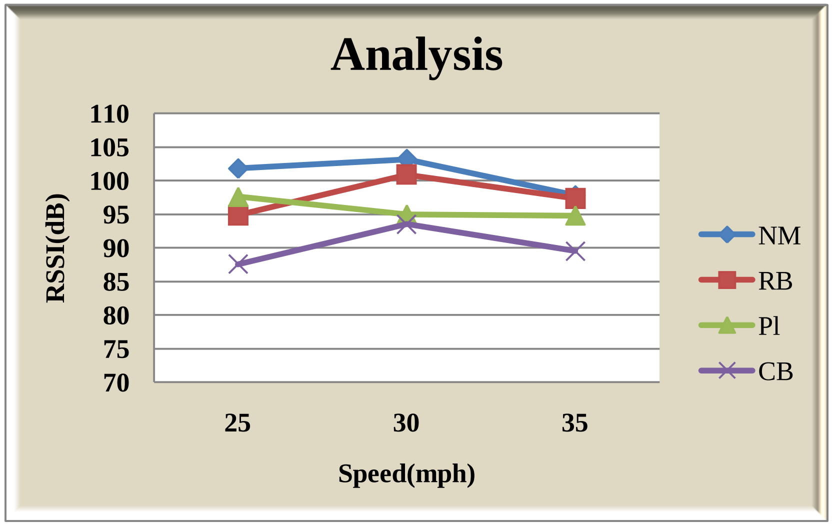
Table 3.11 Tukey Test on Material (RSSI)

		Subset		
Material	**N**	**1**	**2**	**3**
Cardboard	30	90.18		
Plastic	30		95.78	
Rubber	30		97.88	97.88
No Material	30			100.93
Significant		1.000	.470	.157

The significant row in table 3.11 clearly shows that the p value (0.470) is greater than the assigned alpha value (0.05) which proves that there is not much difference between plastic and rubber means. Likewise, there is no difference between rubber and no material mean levels with a p value of 0.157 which is significantly greater than the assigned alpha value (0.05). On the other hand, only cardboard has an RSSI value that was statistically significantly different from the other two materials' means as well as the mean of readings when no material was used.

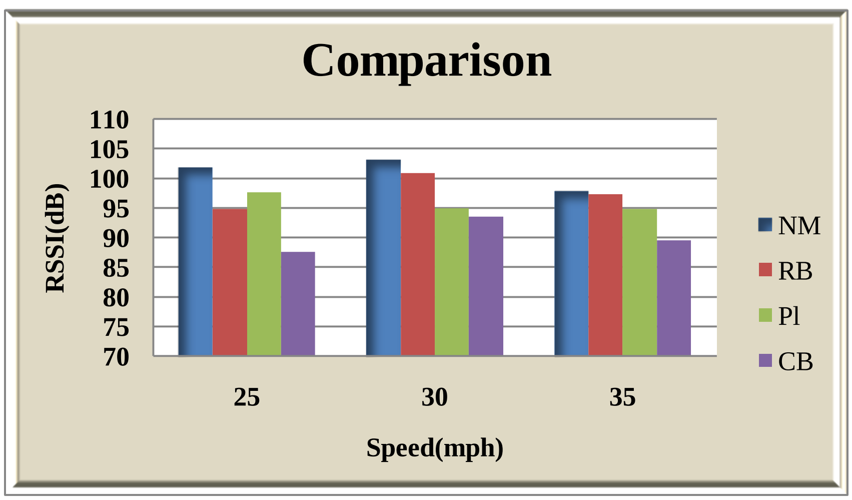
3.6 Discussion

A graph (Figure 3.9) between RSSI value and speed was plotted to display the variation of RSSI values among different spacers. The abbreviation NM means No material, RB means rubber, Pl means plastic and CB means cardboard. Figure 3.9 shows how the RSSI values for different materials varied at differing speeds. When speed was increased, RSSI values decreased. This means the distraction of radio waves is greater when the speed of the car is increased. For example, the cardboard (cb) material RSSI value at 25mph was -87dB, but when the speed increased to 30mph, the RSSI decreased to -93.5dB.



***Note: all values are negative**

Figure 3.9 RSSI vs Speed



***Note: all values are negative**

Figure 3.10 Comparison between Spacers

It was found that cardboard provided the strongest RSSI value, since a lower RSSI value means the received signal strength is greater. Figure 3.10 shows the comparison of RSSI values for different materials at three speeds. The cardboard material RSSI value was best when compared to other materials at all three different speeds.

Therefore, from these experiments it is clearly evident that both material and speed have an effect on the RSSI value. Also, among different materials, cardboard's RSSI value was stronger, which means that it can be embedded along with the tag to reduce the negative effects of metal on RFID signals.

In real-case vehicle tracking scenarios, tags can be placed on the license plate instead of on the windshield. But if the tag is directly attached to the license plate, it is often undetected. Therefore, based on these experimental results, the tag must be enclosed with cardboard material in order to reduce the negative effect of metal on the RFID signal. Furthermore, speed also has significant effect on RSSI value. It is impossible, therefore, to implement a SIRIT passive RFID system for the tracking of vehicles since the results of these experiments indicated that the performance rate of those systems was significantly inferior to active RFID systems. In summary, in practical vehicle tracking situations, active RFID systems should be used, and the tags should be attached to the license plate and enclosed with cardboard material so as to avoid the negative effects of metal on RFID signals. In chapter 4, further experiments were carried out to see how the RF code system performs when the temperature is reduced. Along with the cardboard spacer, foam was tested in order to reduce the effect of metal surfaces on the RSSI values. These experiments also investigated how the system performs when the distance between the tag and the reader was increased.

CHAPTER 4

ENVIRONMENTAL TESTING

4.0 Introduction

Environment is an essential factor to be considered in RFID performance, since RFID systems are very sensitive to environmental changes. Environmental issues that may affect RFID performance include moisture, which absorbs radio waves; metal surfaces, which destroy, reflect, or hide radio waves; and noise, which blocks RFID communication (Jones et al., 2004). To evaluate these adverse effects, environmental testing was performed on the RFID system which scored highest in the experiments outlined in Chapter 3. These previous experiments determined that RF code was the best RFID system, and that cardboard spacers reduced the adverse effect of metal surface most effectively compared to other materials tested. In this chapter, anechoic foam spacers will be tested alongside corrugated fiberboard cardboard in order to determine which of these two materials is most effective. As shown in the Figure 4.1, anechoic foam wedges were placed between the tag and the metal surface in order to reduce the adverse effect of the metal surface on the RFID signals.

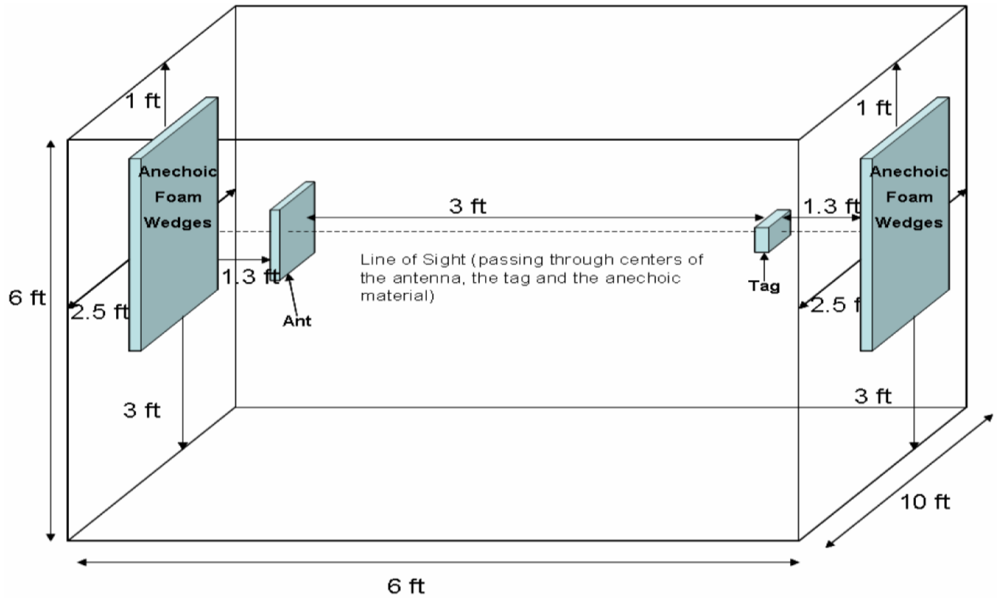


Figure 4.1 Anechoic Foam between Tag and Metal Surface (Darmindra et al., 2007)

Anechoic foam was chosen for a variety of purposes, including reduction of multipath occurrences, absorption of all other radiated rays, and general improvement of system performance (Darmindra et al., 2007). In order to test the advantages of anechoic foam, experiments were performed placing both anechoic foam and corrugated fiberboard cardboard in between the tag and the license plate. The results of these experiments are discussed below.

The main objective of this environmental testing was to determine the performance of RFID systems in cold conditions when the tag was positioned on a metal license plate. RFID systems should able to read these tags even when the temperature drops below zero degrees Celsius. Before implementing RFID systems, especially in places like Nebraska, testing under snow conditions is essential.

Upon completion of these experiments, the resulting data was analyzed to identify not only the best material to embed between tag and license plate in practical situations, but also the most effective thickness of that material and the optimum height of the reader.

This chapter describes the experimental setup in Section 4.1 used in these experiments. Sections 4.2 describe the experimental procedures in detail as well as outlining the experimental variables, experimental design, data collection methods and results of the experimental design. The summary and discussion of these experiments are contained in Section 4.3.

4.1 Experimental Setup

As shown in the Figure 4.2, the RFID tag was attached to a license plate and then enclosed by yet another license plate. Likewise, the tag was also placed on both cardboard and foam materials (Figure 4.3 shows the placement of a tag on foam material)

Figure 4.2 Tag on the Metallic License Plate

Figure 4.3 Tag on the Foam Spacer

Figure 4.4 Tag Embedded between the Foam Spacer

After attaching the tag to the foam, it was then enclosed by same thickness of foam and affixed to the license plate as shown in Figure 4.4. The distance between tag and reader was varied between 25, 50, and 75ft and the corresponding RSSI values were measured. Figure 4.5 depicts a tag distance of 50ft where the experiment was performed in front of the Whittier building, located at 23rd and Vine Street.

Figure 4.5 Distances of 50ft between Tag and Reader

Figure 4.6 Reader Height 3ft above the Ground

The height of the reader was also varied between 3 and 6ft in order to identify the optimum height at which the reader should be fixed (Figure 4.6 shows the reader at a height of 3ft).

Experiments were performed under two different conditions, snow and no snow. Under snow conditions the tag was completely covered with a measured quantity of snow as shown in Figure 4.7. A rectangular container, with a volume of 4.5inches*0.58inches*4.13inches was used to measure the quantities of snow used in the experiment. The snow was completely packed into that container and poured on and around the tag embedded license plate as shown in the figure 4.7. In order to maintain consistency, the same amount of snow was measured and used throughout the experiment. On the other hand, under no snow conditions, the tag was not covered by snow. The temperature was -5 degree Celsius during snow conditions and -1 degree Celsius during no snow conditions.

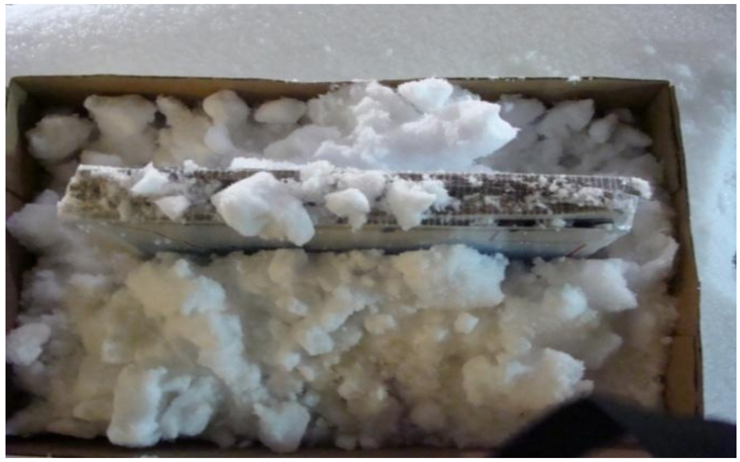


Figure 4.7 License Plate Covered with Snow

4.2 Experimental Procedures

This section explains the variables and variable levels used in these experiments while the next section outlines the design of experiment. Further sections describe the methods used in collecting the data and results of the analysis explained in the final section.

4.2.1 Experimental Variables

Table 4.1 lists the variables used in this experiment. The dependent variable was the received signal strength indicator (RSSI), while the Independent variables included the distance of the tag (25, 50, and 75ft), the height of the reader (3 and 6ft), the materials used (no material, cardboard, and foam), and the thickness of that material X (0.007in and 0.019in for cardboard and foam) and 2X (0.015in and 0.03in for cardboard and foam). Snow volume, temperature, and tag height were the control variables, all of which were kept constant throughout the testing process.

Table 4.1 Experimental Variables

Dependent variable	Independent variables	Control variables
• Received Signal Strength Indicator (RSSI)	• Distance between the tag and reader • Height of the reader • Different types of spacers • Thickness of the spacers • Condition(snow, no snow)	• Volume of Snow • Temperature • Tag Height

Table 4.2 shows the different levels of the variables used in this experiment. The distance between tag and reader was varied between 25, 50 and 75ft in order to determine the effect of these varying distances on signal strength.

Table 4.2 Levels of the Variables

Variables	**Levels**
Different types of spacers	• No material(nm) • Cardboard(cb) • Foam(fm)
Distance between the reader and tag	• 25 • 50 • 75(ft)
Height of the reader	• 3 • 6 (ft)
Thickness of the spacer	• X • 2X
Condition	• Snow • No snow

4.2.2 Experimental Design

A nested design was used (thickness was nested under material) considering all independent variables in the model (snow, no snow, material, height, distance, and thickness). The main reason to use this nested design is that the material and the thickness of that material are directly correlated. Moreover, each material has two different levels of thickness which must assign to that particular material, rather than allowing each level of thickness to interact with all materials, which would basically become a crossed design. This model was analyzed to identify the most effective material thickness and reader height. All independent variables considered in the model were found to be statistically significant. Further, the results did indicate that a minimum thickness of 0.007in for cardboard, as well as a reader height of 6ft, should be maintained in order to most effectively reduce the distraction of the radio signal.

The next section explains the analysis method carried out to identify the most effective materials as well as the difference between snow and no snow conditions. The model considered for next analysis was snow (0 and 1), distance (25, 50 and 75ft), and material (cardboard, foam and no material). The combined effect of this analysis showed that all independent variables significantly affected the received signal strength indicator (RSSI) value. Analysis of individual effects was also performed in order to discover the best material at each condition (snow and no snow). Initially, the materials were compared under snow conditions and cardboard was found to be more effective than foam in reducing the negative effect of metal surface. These materials were then compared under no snow conditions where no significant difference was found.

Further analysis was carried out to discover the best material under both conditions (snow and no snow). This analysis identified that cardboard was more effective in reducing the negative effect of metal when compared to foam. After finding the most effective material to use, analysis was extended to identify system performance when the temperature is reduced from no snow to snow conditions. The results clearly showed that the performance rate of the RFID system was not affected when the temperature moved from no snow to snow conditions.

4.2.2.1 Nested Design with Complete Independent Variable

The full factorial experimental model includes all of the independent variables (material (M), height (H), distance (D), snow (1) and no snow (0)) as well as thickness (T), in relation to cardboard and foam spacer materials.

Table 4.3 Nested Design to Identify the Best Thickness and Height

Dependent Variable	Independent Variables	Levels	Control Variables
Received Signal Strength Indicator (RSSI)	• Different types of spacers	• No material(nm) • Cardboard(cb) • Foam(fm)	• Volume of snow • Temperature • Tag height
	• Thickness of the spacers	• X • 2X(in)	
	• Height of the reader	• 3 • 6 (ft)	
	• Distance between the tag and reader	• 25 • 50 • 75(ft)	
	• Condition	• Snow • No snow	

Different levels of thickness were used in testing the cardboard and foam materials, ranging from 0 for no material (NM) to 0.007in and 0.015in for cardboard (CB) and 0.019in and 0.03in for foam (F). The main objective in testing different thicknesses was to identify the best thickness for use in practical situations. Table 4.3 shows this complete nested design, including all the independent variables described above. In this model, thickness was nested within material and analyzed in two, three, and four way interactions. Only the main and two way interactions were considered for discussion here, however, some of the higher interaction terms were not statistically significant so not considered for discussion.

4.2.2.2 Effect of the Independent Variables on Signal Strength

The previous design was again analyzed in order to determine how RSSI is affected by the below mentioned variables, both individually and in combination with each other. Also analyzed were the differences between materials under snow and no snow conditions. The variables considered for this analysis are shown in Table 4.4, which shows the different levels of snow (no snow (0) and snow (1)), distance (d) (25, 50 and 75), and material (m) (cardboard (cb), foam (fm) and no material (nm)).

Table 4.4 Variables Analyzed to Identify Best Material

Dependent Variable	Independent Variables	Levels	Control Variable
Received Signal Strength Indicator (RSSI)	• Condition	• Snow • No snow	• Volume of Snow • Temperature
	• Distance between the tag and reader	• 25 • 50 • 75(ft)	
	• Different types of spacers	• No material(nm) • Cardboard(cb) • Foam(fm)	

4.2.2.3 The Effect of Materials Across all Snow Levels

The result from the previous design showed that cardboard was a more effective spacer material than foam under no snow conditions. Under snow conditions, no significant difference was found between cardboard and foam spacers. Further analysis was necessary to identify the best material common to both snow and no snow conditions.

Table 4.5 Material at Combined Snow Level

Class Level Information		
Class	Levels	Values
M	3	cb fm nm

In order to determine this, an Analysis of Variance (ANOVA) was performed to identify the best spacer material at combined snow levels (0 and 1). Table 4.5 shows the experimental design for assessing these materials at combined snow levels.

4.2.2.4 Difference between Snow and No Snow Condition

In order to identify the differences between snow and no snow conditions, ANOVA was performed, and the mean RSSI value was compared over combined snow levels. By this method, it was possible to track the performance level of the RFID system when temperatures decreased from no snow to snow conditions. There were two levels in this model, as shown in Table 4.6: snow (1) and no snow (0).

As explained in the experimental setup section, under snow conditions the license plate was completely covered by a measured volume (4.5in*0.59in*4.13in) of snow. Under no snow conditions the license plate was not covered with snow. Therefore, by comparing RSSI values under both snow and no snow conditions we can identify to what extent RF code RFID systems were dependent upon the temperature

Table 4.6 ANOVA between Snow and No Snow

Class Level Information		
Class	Levels	Values
S	2	0 1

4.2.3 Data Collection Method

RFID systems, materials, cold conditions, and experimenters, all variables were randomized within each group before testing commenced. These randomized variables included materials, thickness, reader height, and distance between tag and the reader.

For example, in partial randomization Table 4.7, under no snow conditions, variables of the first trial were foam of X thickness with a reader height of 3ft and a tag distance of 25ft (marked as 1 on the table). The next trial maintained foam of X thickness, but the reader height was set at 6 ft and tag distance was 25 ft (marked as 2 on the table). Reader height and tag distance were completely randomized for each and every set of experiments. R1 and R2 indicate replication levels; R1 was the first replication and R2 was the second replication. The second replication trials were also randomized to minimize variations. Complete randomization table for snow and no snow condition is shown in Appendix B1 and B2.

After this randomization of variables, experiments were performed in a randomized sequence, and for each setup the RSSI value was measured. These measurements were taken when reader and tag were separated by a certain distance using a specific spacer with thickness of X (0.007in and 0.019in for cardboard and foam) and 2X (0.015in and 0.03in) and a reader height of 3 or 6ft. For example, Figure 4.8 displays the RSSI value when tag and reader were separated by 50ft with 0.007in thickness of cardboard and reader height 6ft.

Table 4.7 Randomization of the Test Trials

Material	Thickness	Height of the reader	Distance between tag and reader			
			25		50	75
Foam(1)	X(1)	3	R1	1	4	3
			R2	4	5	2
		6	R1	2	6	5
			R2	3	6	1
	2X(2)	3	R1	1	5	3
			R2	3	1	4
		6	R1	2	4	6
			R2	2	5	6

Figure 4.8 shows such tag information as tag i.d, static or motion conditions, tamper proof, battery status, and RSSI value. The RSSI value indicates signal strength, and its values range from between -58dB to -108dB. If the signal strength was stronger the RSSI value would be closer to -58dB. For weak signals the RSSI value would be closer to -108dB. Total of 120 trials were conducted (60 for snow and 60 for no snow) and the corresponding RSSI values were tabulated.

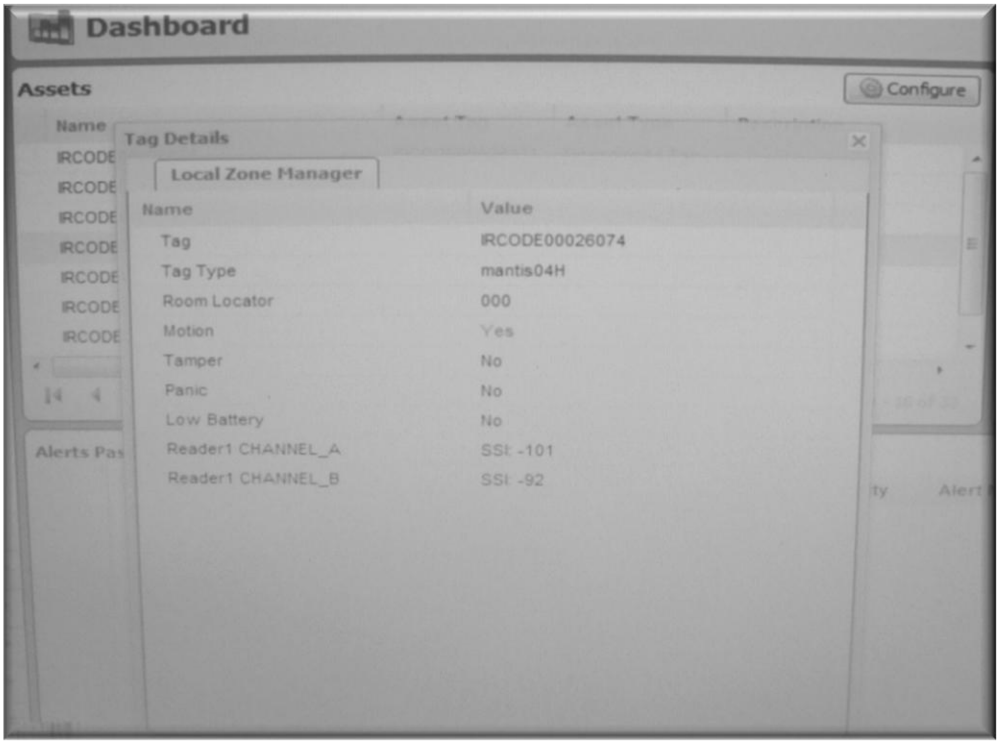


Figure 4.8 RSSI Value for Cardboard Spacer with Distance 50ft

Table 4.8 shows the partial data table and the complete data table is shown in the Appendix B3. The independent variables of snow, distance, height, thickness, and material were varied at different levels and the corresponding RSSI values were measured and tabulated.

The snow column on the Table 4.8 has two levels (0 for no snow conditions and 1 for snow), distance (D) has three levels (25, 50 and 75ft), height has two levels (3 and 6ft), thickness has two levels for each material (for cardboard 0.007in and 0.015in and for foam 0.019in and 0.03in), and material (M) has three levels (cardboard (cb), foam (fm) and no material (nm)).

Table 4.8 Partial Data Table

Snow	Distance	Height	Thickness	Material	RSSI
0	25	3	0	nm	108
0	25	3	0.2	cb	77
0	25	3	0.4	cb	90.5
0	25	3	0.5	fm	85.5
0	25	3	1	fm	105
0	25	6	0	nm	112.5
0	25	6	0.2	cb	72.5
0	25	6	0.4	cb	93
0	25	6	0.5	fm	81
0	25	6	1	fm	106
0	50	3	0	nm	107.5
0	50	3	0.2	cb	84
0	50	3	0.4	cb	99.5
0	50	3	0.5	fm	103.5
0	50	3	1	fm	103
0	50	6	0	nm	110
0	50	6	0.2	cb	81.5
0	50	6	0.4	cb	94
0	50	6	0.5	fm	94
0	50	6	1	fm	106.5

In table 4.8, the first RSSI was measured at no snow conditions (0), when the distance between the tag and the reader was separated by 25ft, when the reader was placed at a height of 3ft, and when no material (0) was placed as spacer. The resulting RSSI value was -108dB. Likewise, the RSSI value was also measured under different combinations of variables, and the results are interpreted in the next section.

4.2.4 Results of the Experimental Designs

4.2.4.1 Identification of Material Thickness

The measured data was analyzed using the SAS Institute Inc. 2008, SAS/STAT® 9.2. The output of the nested design is shown in Table 4.9. In conducting this analysis, an alpha value of 0.05 was chosen as a level of significance. If the value of P is less than this assigned alpha value we can reject the null hypothesis and confirm that there is a significant effect upon the dependent variable (RSSI). If the P value is greater than 0.05, we can accept the null hypothesis and confirm that the dependent variable is not statistically significant.

Table 4.9 Output to Identify the Best Thickness and Height

Type III Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
S	1	60	410.71	<.0001
D	2	60	207.03	<.0001
D*S	2	60	2.33	0.1060
H	1	60	16.84	0.0001
H*S	1	60	2.13	0.1494
H*D	2	60	0.68	0.5126
H*D*S	2	60	3.30	0.0436
T(M)	2	60	337.68	<.0001
T*S(M)	2	60	19.60	<.0001
T*D(M)	4	60	3.60	0.0108
T*D*S(M)	4	60	4.23	0.0044
T*H(M)	2	60	1.00	0.3756
T*H*S(M)	2	60	6.91	0.0020
T*H*D(M)	4	60	2.39	0.0610
T*H*D*S(M)	4	60	1.67	0.1679
M	2	60	446.69	<.0001
M*S	2	60	60.42	<.0001
M*D	4	60	6.57	0.0002
M*D*S	4	60	2.12	0.0894
M*H	2	60	2.84	0.0664
M*H*S	2	60	1.81	0.1728
M*H*D	4	60	1.79	0.1421
M*H*D*S	4	60	3.06	0.0233

The main effects (snow, no snow, distance, height, and materials) were found to be statistically significant, and the data implies that, in practical scenarios, all of main effects had an effect on the RSSI value. ANOVA was also performed to compare the means of these individual independent variables, and the results of this analysis are shown in the Appendix B4.

Table 4.10 Comparison of Thickness

T*D(M) Least Squares Means							
M	T	D	Estimate	Standard Error	DF	t Value	Pr > |t|
cb	0.2	25	73.5000	1.8513	42	39.70	<.0001
cb	0.2	50	83.5000	1.8513	42	45.10	<.0001
cb	0.2	75	90.1250	1.8513	42	48.68	<.0001
cb	0.4	25	92.7500	1.8513	42	50.10	<.0001
cb	0.4	50	100.88	1.8513	42	54.49	<.0001
cb	0.4	75	104.50	1.8513	42	56.45	<.0001
fm	1	25	101.00	1.8513	42	54.56	<.0001
fm	1	50	105.13	1.8513	42	56.78	<.0001
fm	1	75	112.75	1.8513	42	60.90	<.0001
fm	0.5	25	82.1250	1.8513	42	44.36	<.0001
fm	0.5	50	99.8750	1.8513	42	53.95	<.0001
fm	0.5	75	102.50	1.8513	42	55.37	<.0001
nm	0	25	108.38	1.8513	42	58.54	<.0001
nm	0	50	110.00	1.8513	42	59.42	<.0001
nm	0	75	112.63	1.8513	42	60.84	<.0001

Since two thickness levels were tested for each material, however, it was necessary to identify the optimum thickness of material to use. For that purpose, ANOVA was performed to determine the mean differences between the various combinations of material, thickness, and distance (see table 4.10). As shown in the above Table 4.10, thickness is statistically significant in all three different combinations of variables. For example, the first row shows that, when cardboard was used at the first level (0.007in) of thickness and a reader distance of 25ft, the average RSSI is -73.5dB.

In order to identify the best thickness for spacer materials in RFID systems, a maximum distance of 75ft was selected and mean readings for various thicknesses were compared. Figure 4.9 shows the difference in RSSI values at both minimum and maximum thickness levels for both foam and cardboard materials. At minimum thickness, both cardboard and foam achieved the best RSSI values.

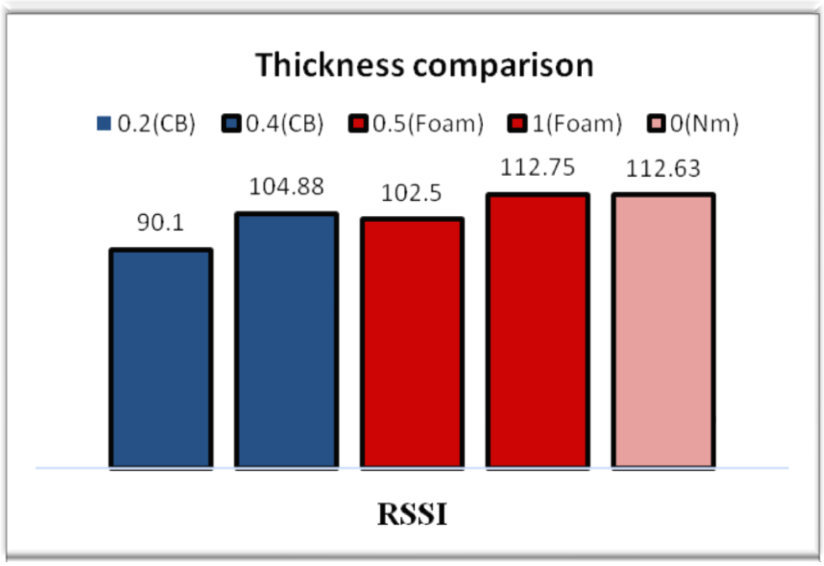


Figure 4.9 Identification of the Best Thickness

Cardboard, in particular, showed a decrease in RSSI values from -90.1dB to -104.88dB when thickness was increased from 0.007in to 0.015in. In general, when thickness was increased, performance rate declines. Therefore, minimum thicknesses of spacer material would seem to be most effective in reducing the negative effects of metal surfaces on RFID systems.

4.2.4.2 Identification of Reader Height

Further analysis was conducted to determine the optimum height at which the RFID reader should be positioned. As in previous analysis, heights were varied between 3 and 6ft, and ANOVA was performed to compare the mean RSSI readings of each reader position.

Table 4.11 Comparison of Reader Height Means

Height

Dependent Variable:RSSI

Height	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
3	94.008	1.870	90.306	97.711
6	91.550	1.870	87.847	95.253

Table 4.11 shows the mean RSSI value of the RFID reader at both 3 and 6ft in height. At a height of 3ft, the RSSI value is -94.00dB, and at a height of 6ft the RSSI value is -91.55dB. While there is not much difference between these two heights, the RSSI value was higher when the reader was placed at 6ft.

Figure 4.10 graphically shows that the RSSI value was better when the reader height was increased. The data indicates, therefore, that a reader height of 6ft above the ground was ideal for achieving optimum RFID performance levels.

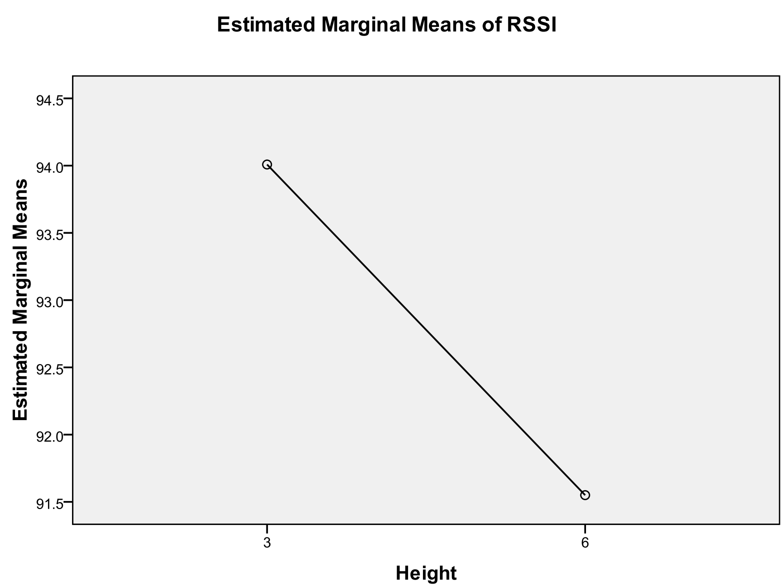


Figure 4.10 Difference in RSSI Value at 3 and 6ft Reader Height

4.2.4.3 Combined Effect of Variables

Even though the nested design identified cardboard as the best material, further analysis was carried out to validate the result and more accurately identify the best material in snow and no snow conditions. Table 4.12 displays the results of this analysis including all main effects and two way interactions.

Table 4.12 Significance Level of the Variables

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
S	1	102	38.97	<.0001
D	2	102	20.32	<.0001
S*D	2	102	0.33	0.7180
M	2	102	50.71	<.0001
S*M	2	102	6.86	0.0016
D*M	4	102	0.75	0.5628
S*D*M	4	102	0.24	0.9147

The data in table 4.12 clearly shows that all main effects snow and no snow (S), distance (D), and material (M)) were statistically significant, and that they, along with two-way interactions between snow and material, do have a meaningful effect upon the dependent variable (RSSI).The data also showed that two and three way interactions between other variables were statistically not significant.

4.2.4.4 Individual Effect of Variable

Analysis in the previous section took into account of all independent variables and showed their combined effect upon reader strength in an RFID system. This section concentrated only on the individual significance of snow, distance, and material since the previous result showed that the three way interactions of combined snow, distance and material is not statistically significant.

In order to discover the effect of these variables on the RSSI value, in all their various permutations, ANOVA was performed to compare and identify the best materials at each level of snow (1) and no snow (0) conditions. Table 4.13 outlines the individual effect of each variable. Column M on Table 4.13 indicates the individual effect of the various materials (cardboard, foam and no material), column S denotes no snow (0) and snow (1) conditions, and column D represents the individual level of distance (25, 50 and 75ft).

Table 4.13 Individual Effect of Variables

Least Squares Means								
Effect	M	S	D	Estimate	Standard Error	DF	t Value	Pr > |t|
S*D*M	cb	0	25	83.1250	3.0800	102	26.99	<.0001
S*D*M	fm	0	25	91.5625	3.0800	102	29.73	<.0001
S*D*M	nm	0	25	108.38	4.3557	102	24.88	<.0001
S*D*M	cb	0	50	92.1875	3.0800	102	29.93	<.0001
S*D*M	fm	0	50	102.50	3.0800	102	33.28	<.0001
S*D*M	nm	0	50	110.00	4.3557	102	25.25	<.0001
S*D*M	cb	0	75	97.3125	3.0800	102	31.60	<.0001
S*D*M	fm	0	75	107.63	3.0800	102	34.94	<.0001
S*D*M	nm	0	75	112.63	4.3557	102	25.86	<.0001
S*D*M	cb	1	25	73.3750	3.0800	102	23.82	<.0001
S*D*M	fm	1	25	73.1875	3.0800	102	23.76	<.0001
S*D*M	nm	1	25	99.3750	4.3557	102	22.81	<.0001
S*D*M	cb	1	50	85.3125	3.0800	102	27.70	<.0001
S*D*M	fm	1	50	82.6250	3.0800	102	26.83	<.0001
S*D*M	nm	1	50	109.00	4.3557	102	25.02	<.0001
S*D*M	cb	1	75	88.2500	3.0800	102	28.65	<.0001
S*D*M	fm	1	75	89.8750	3.0800	102	29.18	<.0001
S*D*M	nm	1	75	110.13	4.3557	102	25.28	<.0001

The column “Effect” shows the individual effect of snow (1) and no snow (0), distance, and material on the RSSI value. For example, the first row explains that, when cardboard material was used in no snow (0) conditions with a distance between tag and reader of 25ft, the resulting RSSI value was -83.125dB. In this way, table 4.13 shows the variation of RSSI values, and their significance level, under all possible combinations of variables.

4.2.4.5 Comparison between the Materials under No Snow Conditions

The results of the above analysis were used to identify the best spacer materials for use under no snow conditions, and, a graph was plotted between the RSSI value and distance for each individual material. Data is shown in the table above. Figure 4.11 compares the RSSI values of cardboard, foam and no material and shows that, at a distance of 75ft, cardboard achieved an RSSI value of -97.31dB while RSSI with foam spacer reading was -107.63dB. This data would indicate that cardboard spacers were more effective than spacer foam at reducing the effect of metal surface in the RFID systems.

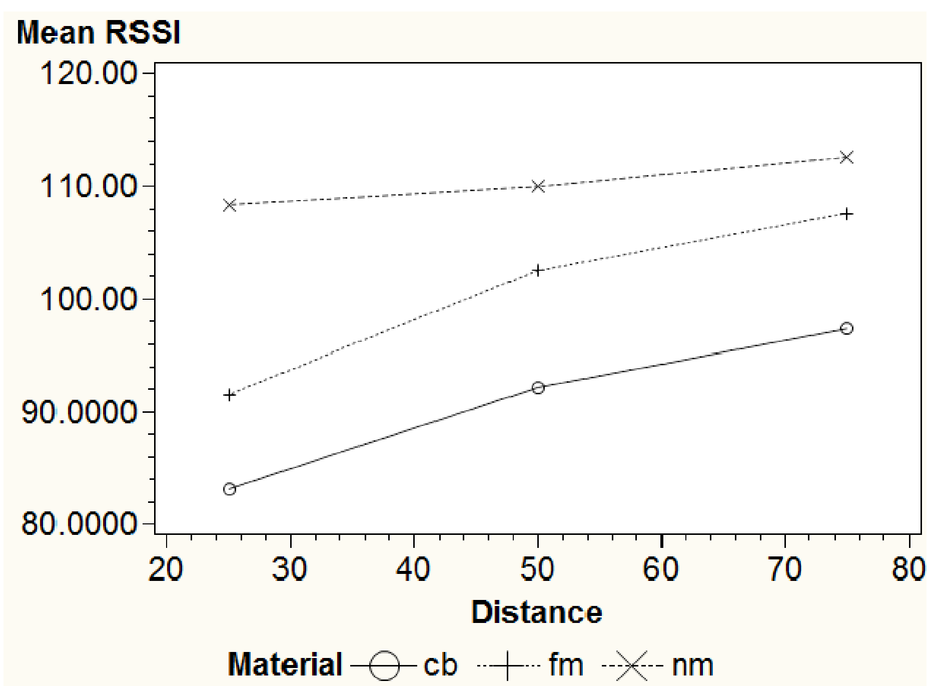


Figure 4.11 Signal Strength Comparison between Materials (No Snow Condition)

Figure 4.11 also proves that metal surfaces have a significant negative effect on the received signal strength indicator (RSSI). For example, when no material was placed between tag and license plate, the RSSI value at 75ft was -112.63dB. This indicates an extremely low signal strength in comparison to that achieved when cardboard or foam spacers are in place. Moreover, Figure 4.11 also illustrates the effect of distance upon signal strength, showing a marked decline in RSSI as distance increases from 25 to 75ft.

4.2.4.6 Comparison between the Materials under Snow Condition

Figure 4.12 explains the difference in RSSI values for cardboard and foam material under snow conditions. For example, at a distance of 75ft, the RSSI value for cardboard is -88.25dB compared to a reading of -89.8dB for foam.

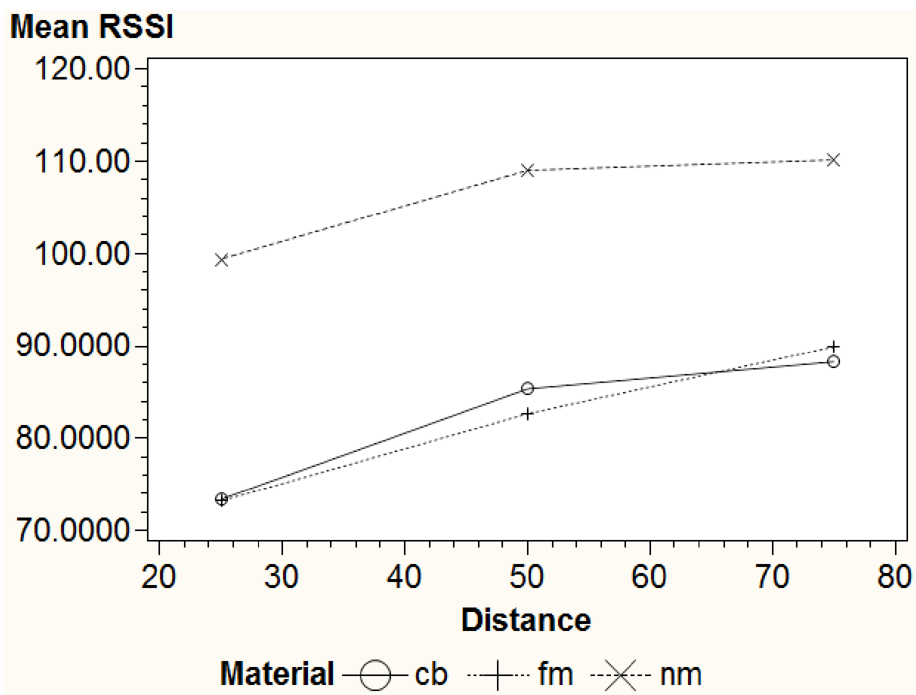


Figure 4.12 Signal Strength Comparison between Materials (Snow Condition)

This would indicate no statistically significant difference between cardboard and foam materials under snow conditions. There was, however, a significant difference when no materials were used under these same conditions, with the addition of cardboard spacers improving RSSI values from-110.13dB to -88.25dB (under snow conditions at 75ft). It should also be noted that, even under snow conditions, when distance increased from 25 to 75ft, the signal strength of the reader was significantly reduced.

4.2.4.7 Comparison between Materials on all Snow Levels

As mentioned earlier in the experimental design, analysis was performed to compare and identify the most effective spacer material at combined snow levels. Since two different results were obtained between snow and no snow conditions, it is important to identify the most effective common spacer for use at combined snow levels. On Table 4.14, the column "Estimate" indicates the mean difference between these materials (cardboard (cb), foam (fm), and no material (nm)) at combined snow levels. The mean RSSI value increased from -108.25dB to -86.59dB after placing cardboard as a spacer where none was previously in place. When materials were compared, RSSI cardboard spacer average mean was -86.59dB compared to mean of -91.22dB for foam spacer. These data indicated that cardboard spacers were most effective at improving system performance in RFID systems under both snow and no snow conditions.

Table 4.14 RSSI Means with Different Material on all Snow Levels

Least Squares Means						
Effect	M	Estimate	Standard Error	DF	t Value	Pr > |t|
M	cb	86.5938	1.7520	117	49.43	<.0001
M	fm	91.2292	1.7520	117	52.07	<.0001
M	nm	108.25	2.4777	117	43.69	<.0001

4.2.4.8 Difference between Snow and No Snow

The results of this analysis can be interpreted to identify the difference between snow and no snow conditions in relation to RFID system performance (Table 4.15).

Table 4.15 Significance Level of Combined Snow and No Snow Condition

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
S	1	118	23.39	<.0001

Table 4.15 shows that snow and no snow conditions have a statistically significant effect on RFID signal strength (a relationship which is also evident from the P value). In order to find the difference between snow and no snow conditions, ANOVA was performed, and Table 4.16 shows the results of this analysis. When moving from no snow to snow conditions, the estimated mean increased from -98.64dB to -86.91dB. Table 4.17 clearly shows that a statistically significant difference of -11.71dB exists between snow and no snow conditions.

Table 4.16 Mean Estimate between Snow and No Snow

Least Squares Means						
Effect	S	Estimate	Standard Error	DF	t Value	Pr > |t|
S	0	98.6417	1.7144	118	57.54	<.0001
S	1	86.9167	1.7144	118	50.70	<.0001

Table 4.17 Mean Differences between Snow and No Snow

Differences of Least Squares Means							
Effect	S	_S	Estimate	Standard Error	DF	t Value	Pr > |t|
S	0	1	11.7250	2.4246	118	4.84	<.0001

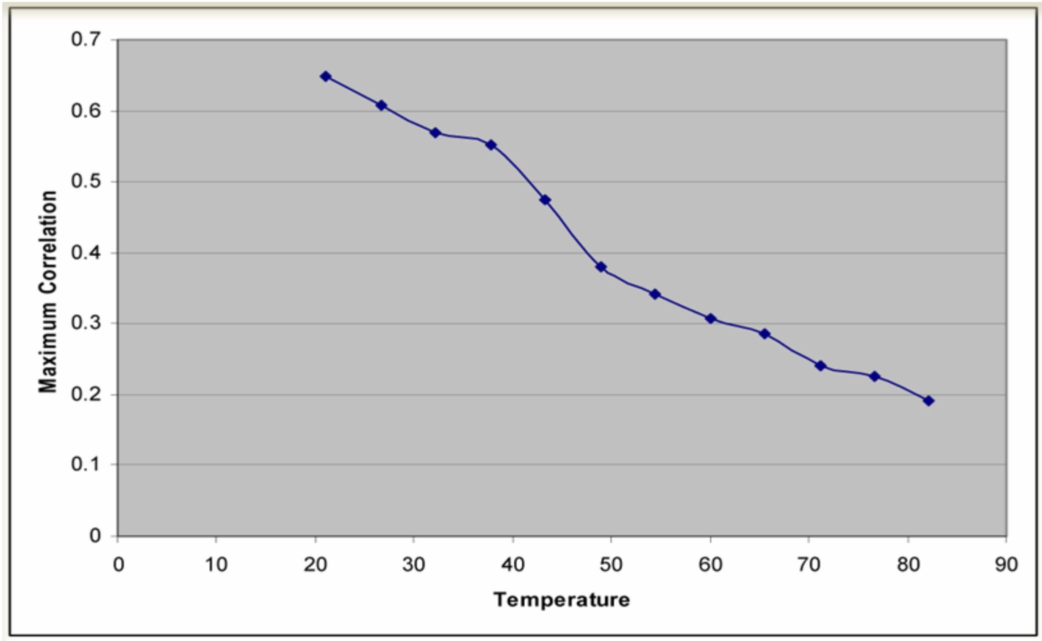


Figure 4.13 Temperature versus Maximum Correlation (Darmindra et al., 2007)

These results clearly show that, when the temperature is low, received signal strength indicator value was high, but when temperature is increased, the RSSI value declined. Previous research has also indicated that increased temperatures reduced maximum correlation (or RSSI) while decreased temperatures had the opposite effect (Darmindra et al., 2007). Figure 4.13 illustrates this relationship; in this instance, as the temperature reached 85 deg C the maximum correlation (or RSSI) decreased to 0.2 (Darmindra et al., 2007).

4.3 Summary and Discussion

RF code RFID system was tested under both snow and no snow conditions. Received signal strength indicator (RSSI) values were measured at various reader distances (25, 50 and 75ft), for specific spacers (cardboard and foam), with thicknesses of X or 2X, and at reader heights of 3 or 6ft. These experiments were performed for 60 trials each under both snow and no snow conditions, and the corresponding RSSI values were measured.

The collected data were analyzed using SAS software, and, for initial analysis, variables like snow, no snow, material, thickness, distance, and height were included in the model, and thickness was nested within the material. This analysis illustrated that all the variables do have significant effects on RSSI values. Furthermore, ANOVA was performed to identify the optimum thickness of the material and the most effective height of the reader. These results demonstrated that the minimum thickness of 0.007in for cardboard and a reader height of 6ft should be maintained in order to reduce the negative effect of the metal surface.

Moreover in the next analysis, variables like snow, distance, and material were considered. The results of this analysis showed that all these three variables were statistically significant and apparently have an effect on the RSSI. The output from this analysis was also used to compare material under snow and no snow conditions. These results showed that there is a significant difference between cardboard and foam material under no snow conditions. Also, between these two materials, cardboard effectively reduced the negative effect of the metal surface compared to foam. On the other hand, under snow conditions there is no statistically significant difference between these two materials. Since two different results were generated, this data did not aid in determining the best material for implementation in practical situations.

In order to discover the best spacer material, ANOVA was performed between the materials under combined snow and no snow conditions. The cardboard spacer mean was significantly higher than the RSSI foam mean, indicating that cardboard material should ideally be embedded between tag and license plate in order to counteract the negative effect of metal.

In pragmatic situations, when cardboard material is embedded between tag and license plate at a thickness of 0.007in with a reader height of 6ft, the signal transmitted from reader to tag can be absorbed without any distortion. In this way, the negative effects of the metal surface can be reduced and the RSSI value would not be affected, resulting in better performance.

CHAPTER 5

BENEFIT-COST ANALYSIS

5.0 Introduction

This chapter outlines the cost saving analysis of two different systems in tracking vehicle applications. The two systems considered for this analysis is RFID and non-RFID (camera) systems. The RFID system considered for cost saving analysis was the RF code system and the non-RFID system considered for the analysis was the mobile plate hunter (MPH) camera. These two systems were compared to identify the overall benefits in selecting the RF code system.

Section 5.1 explains the different types of tracking systems. The details of the two systems considered in analysis were described in Section 5.2. Section 5.3 elaborates on the expenses considered in the analysis and compares the cost benefits of the system. Prediction of future expenses is explained in Section 5.4. Section 5.5 compares the processing time of the system. The price reduction of these systems in recent years was discussed in Section 5.6 and Section 5.7 explains the results of the analysis.

5.1 Different Types of Tracking Systems

The three most ubiquitous systems used in vehicle tracking are RFID, camera, and GPS. Nowadays the RFID system is preferred when compared to other tracking systems because of such benefits as processing time, cost, high speed, data collection management, ease of use, and increased security (Laura, 2005). In short, GPS and camera tracking systems were very expensive to implement. They consume more time in tracking and processing data (Rashmi et al., 2002).

5.1.1 Drawbacks of GPS and Camera Systems

Implementation of GPS is restricted by many factors, including water vapor in the atmosphere (which can deteriorate signal flow causing propagation delay), multi-path fading (the blocking of a signal by buildings or terrain), atomic clock discrepancies, and receiver noise (Rashmi et al., 2002). Moreover, the cost of a GPS system was much higher compared to other tracking system, ranging from $5000 to $40000 (What is GPS, gpswildmap), and the average read range of the system was much lower (60 to 300ft) (Rashmi et al., 2002). Finally, it was not possible to deploy GPS systems in many cities due to such issues as inadequate satellite signal (Mary, 1993).

Research performed by Meynberg et al (2010) explained the stages in which data captured by camera tracking systems was processed. These stages include ortho rectification, geo-referencing, and road-traffic data extraction. The processing time of a captured image at each of these stages can be as high as 3 minutes, which is not acceptable in a vehicle tracking application (Meynberg et al., 2010). Moreover, several other common problems with camera-based systems were identified in a study conducted by Shyang-Lih et al (2004). The most common of these problems was the inability of the system to identify the boundaries of a license plate when the car and license plate were similar in color as well as a tendency to misread certain numbers (for example, confusing a "1" for a "7") (Shyang-Lih et al., 2004).

These were the most common issues, however. Many other problems have also been identified with camera-based tracking systems, including poor image resolution, blurry images, poor lighting and low contrast due to overexposure, reflection and/or shadows, an object partially obscuring the plate (such as a tow bar or dirt), different fonts that are popular for vanity plates (although some countries prohibit them, thereby effectively eliminating the problem), circumvention techniques (obscuring the license plate to prevent or create false reads), lack of coordination between countries or states (two cars from different countries or states can have the same license plate numbers, but different design elements) (Anthony, 2010).

5.2 Analysis Details

Considering the drawbacks stated above, RIFD systems would seem to be the preferred technology for use in vehicle tracking applications, as they have shown promising results in multiple vehicle tracking research studies. In order to verify the advantage of the RFID system, however, a cost saving analysis was performed comparing both RF code (RF code, Texas) RFID systems and non RFID technology. In this research, the Non RFID system considered for analysis was the mobile plate hunter (MPH)-900 (Elsag, North Carolina) camera systems. In comparing costs, an RFID reader sells for $950 (RF code, Texas) while the MPH camera costs $8975 (Elsag, North Carolina). Also, in RIFD tracking systems, one computer is enough for processing the data, whereas in camera tracking systems 4 computers are necessary since the data needs to be processed in different stages (Meynberg et al., 2010). These and other expenses considered in the analysis were explained in the upcoming section.

5.3 RFID and Non RFID System Expenses

In benefit-cost analysis of RFID vs. non-RFID systems, several expenses were considered, including system cost, labor charges, computer installation and maintenance, implementation charges, system maintenance, and miscellaneous expenses.

- System

  RFID reader - RF code M220 fixed reader (RF code, TEXAS)

  Non-RFID - Mobile Plate Hunter camera (Elsag, NC)

- Labor

  Implementation charges

  Operating cost

  Data processing

- Computer

  Software installation

  Power supply to the reader

  Storage and analysis of the collected data

- Implementation

  Manufacturing license plate with embedded RFID tag

  Locating system on a mile marker

  System set-up

- Miscellaneous

  Cost of spacers

  Time spent by the user during implementation process

Electricity charges

Cables to connect the reader and computer

- Maintenance

Cost of tag

Battery replacement

Troubleshooting of the system.

The costs associated with implementing both the RFID and non RFID systems are explained in Table 5.1. The non-RFID system requires 3 workers and 4 computers (Meynberg et al., 2010) to process the data captured, since various steps are involved in evaluating the camera's images. The data in Table 5.1 represents expenses involved in the tracking of 100 cars.

The calculations of total expenses for RFID and non-RFID systems are explained below. These data represent the total cost of tracking 100 cars. The expense calculations for 500 and 1000 cars are shown in Appendix C.

5.3.1 RFID System Cost Calculation (100 cars)

The total cost of the implementation process is a summation of system, labor, computer, implementation, miscellaneous, and maintenance costs (Joel and Shawn, 2006 and Shayne, 2010).

In this analysis system and computer cost are one time costs whereas labor, miscellaneous and maintenance are annual costs. For the analysis, it is assumed that the system and computer will sustain for three years and are capable of tracking 1000 vehicles. Also, the total cost savings of implementing the RFID system over non-RFID was considered instead of the individual cost saving of the system, labor, computer, implementation, miscellaneous, and maintenance expenses.

Total cost = System (S) + Labor (L) + Computer (C) + Implementation (I) + Miscellaneous (Mi) + Maintenance (Ma)

Total cost = (950+40000+1500+1500+500+3000) = $47450

Non-RFID System (100 cars)

Total cost = (8975+120,000+6000+500+1000+2000) = $138475

Table 5.1 Benefit-Cost Compared to Non-RFID System

Equipments	**Qty**	**RFID**	**Qty**	**Non-RFID System**	**Difference**
System (S)	1	$950	1	$8975	$8025
Labor (L) (no. of workers)	1	$40000	3	$120000	$80000
Computer (C)	1	$1500	4	$6000	$4500
Implementation (I)	100 cars	$1500	100 cars	$500	-$1000
Miscellaneous (Mi)	100 cars	$500	100 cars	$1000	$500
Maintenance (Ma)	100 cars	$3000	100 cars	$2000	-$1000
Total		**$47,450**		**$138,475**	**$91,025**

The total expenses incurred in implementing the RFID system is $47,450 and, for non-RFID system, $138,475. The cost saving in implementing the RFID system is $91,025. These benefits of cost were discussed in the result section of this thesis.

5.4 Prediction of Future Expenses

As part of the benefit-cost analysis, the future expenses of both RFID and non-RFID systems were predicted. At the initial stages of the implementation process, all of the above mentioned expenses were considered. After this initial deployment, however, the only recurring expenses will be labor and maintenance costs (Joel and Shawn, 2006).

It is assumed that both RFID and non-RFID systems and computers will last for 3 years and that implementation and miscellaneous costs are onetime expenses. The only recurring expenses which would change over time are labor and maintenance costs, which are negligible compared to current values.

The two future expenses considered are the battery of the system, which will need to be changed (this cost is included in the maintenance expenses) and labor charges incurred for system maintenance and data processing. The expenses calculated for 2012 and 2013 are shown below and their values are depicted in Table 5.2. The outcomes of this analysis are discussed in the results section.

For the year 2012 and 2013

100 Cars

RFID system=Labor + Maintenance = 40,000+3000 = $43000

Non-RFID system= Labor + Maintenance = 120000+2000 = $122000

500 Cars

RFID = 40,000+15000 = $55,000

Non-RFID system = 120000+10000 = $130000

1000 cars

RFID = 40,000 + 30000 = $70000

Non-RFID system = 120000 + 20000 = $140000.

Table 5.2 Prediction of Future Annual Cost

Cars	2011		2012		2013	
	RFID	**Non-RFID system**	**RFID**	**Non-RFID system**	**RFID**	**Non-RFID system**
100	$47,450	$138475	$43000	$122000	$43000	$122000
500	$67450	$152475	$55,000	$130000	$55000	$130000
1000	$92450	$169975	$70000	$140000	$70000	$140000

5.5 Comparison of Data Processing Time

The next step in benefit cost analysis was to assess the processing time of the collected data for both RFID and non-RFID systems. According to Meynberg et al. (2010) the average processing time of a captured image by a camera is 3 minutes.

On the other hand, from the results of this research, the average time taken to process the data in an RF code RFID system was approximately 2 seconds. This information was used to calculate the time benefit in using an RFID system. Table 5.3 shows the processing time for different numbers of cars (1,500 and 1000) and the results are discussed below.

Table 5.3 Time Taken to Process the Data

Processing time	Non RFID system	RFID system	Time saved
1 car (secs)	180	2	178
500 cars (hrs)	1500	16.6	1483.4
1000 cars (hrs)	25000	33.3	24966.7

5.6 Future Price Prediction of the Systems

Next, the price history of the RFID tag, reader, and camera were compared in order to determine the price reduction of this system in recent years (Joel and Shawn, 2006). It was found that the price of RFID readers and tags is continually decreasing from year to year (Richard, 2003 and Ertunga et al., 2006). These 2011 price figures were acquired from the manufacturer (MPH Elsag, North Carolina and RF code, Texas). For analysis purposes, future prices were approximately estimated by comparing the previous and current price of the systems. These are the prices quoted if the systems are bought in a larger quantity.

Table 5.4 Prediction of Future Price of the Systems

Years	RFID active tag	RFID reader	Non-RFID system
2005	$30	$2800	$15000
2007	$28	$2300	$13000
2009	$24	$2000	$10500
2011	$18.50	$950	$8975
2013	$12	$500	$7500

5.7 Results

The cost benefit of implementing an RFID system as compared to a Non-RFID system is analyzed and presented in Table 5.5, and the costs incurred in deploying these systems on different numbers of cars (100, 500 and 1000) are listed. A savings of $91,025 is achieved when an RFID system is implemented for the tracking of 100 cars as compared to a non-RFID system. In the same way, after implementing this system, if the number of cars increased from 100 to 1000 cars, the cost saving would be approximately $77,525. The savings is reduced as the number of cars is increased, because the only real differences in tracking 100 cars as opposed to 1000 include such minor expenses as implementation, maintenance, and miscellaneous charges. Major expenses like system, computer, and labor remain constant for both 100 and 1000 cars.

Table 5.5 Annual Benefits

Cars	**2011**		
	RFID	**Non-RFID system**	**Benefit of RFID**
100	$47,450	$138475	$91025
500	$67450	$152475	$85025
1000	$92450	$169975	$77525

Table 5.6 shows the future prediction of cost savings in implementing this system for different numbers of cars (100, 500 and 1000). Once the system is implemented,

future costs are limited to labor and maintenance expenses. A cost savings of $70,000 will be accomplished if an RFID system is selected to track 1000 cars.

Table 5.6 Prediction of Future Expenses

Cars	2012 and 2013		
	RFID	**Non-RFID system**	**Benefit of RFID**
100	$43000.00	$122000.00	$79000.00
500	$55,000.00	$130000.00	$75000.00
1000	$70000.00	$140000.00	$70000.00

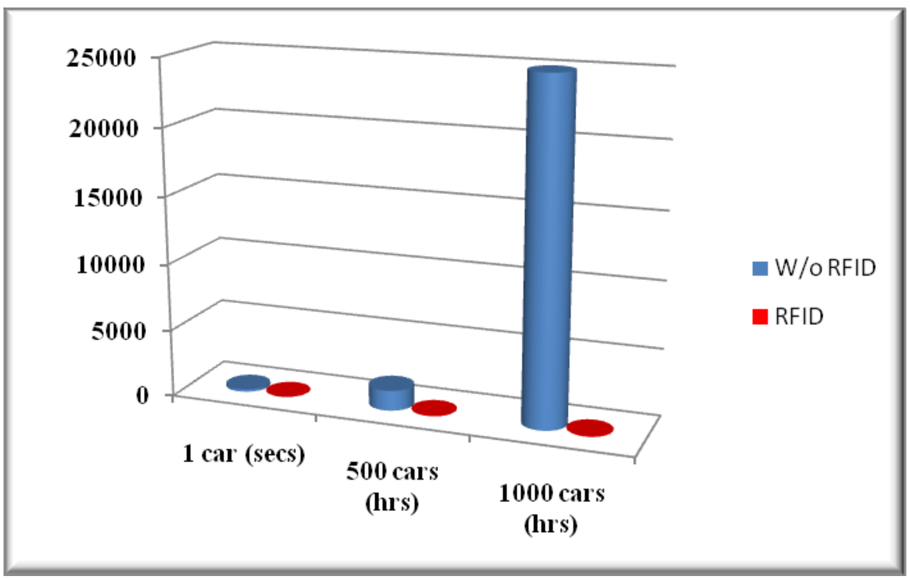


Figure 5.1 Comparison of Processing Time

The processing time of the collected data were also compared between RFID and Non-RFID systems, and the resulting data is shown in Figure 5.1. A graph was plotted between processing time and the number of cars, and a huge time difference between the processing times of the two systems were identified. For example, an RFID system takes only 33.3 hours to process 1000 cars while a non-RFID system consumes 25,000 hours for the same amount of work.

In conclusion, benefit cost analysis was performed comparing both the RF code RFID and mobile plate hunter (MPH)-900 camera systems. Expenses such as cost of the system, labor, computer installation and maintenance, implementation, maintenance, and miscellaneous charges were included in this analysis and the results were compared for varying amounts of cars. The results of this analysis clearly showed that RFID is the best system for use in the tracking of license plates. The other tracking systems were more expensive and demand more processing time as well. More importantly, the cost of the RFID reader and tag are reducing every year which will enhance the usage of RFID systems in the future. In summary, for practical vehicle tracking scenarios, RFID systems should be considered the superior choice when compared to other, camera-based systems.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

In order to choose the most viable alternative from among the available systems (active and passive), stationary and motion testing on the three systems have been performed. RF code was identified as the most viable system compared to the other two systems. Further experiments were performed on the RF code system to identify the best spacer, effect of speed on the system, performance rate of the system in adverse (snow) weather condition, optimum height to locate the reader on the mile marker, and spacer thickness to use. Results of this thesis have led to some valuable conclusions that are discussed in Section 6.0. Section 6.1 presents some recommendation that should be helpful for future study.

6.0 Conclusions

- In experimenting three different types of RFID systems (SIRIT, SAVI and RF code), the success rate of the RF code system in reading the tag was better compared to the SIRIT and SAVI systems.
- There is a substantial amount of negative effect of the metal surface on the performance rate of the RFID system, which is evident when the RSSI value significantly improved after placing spacers between the tag and license plate
- Among the three different materials (cardboard, rubber and plastic) tested, cardboard material significantly reduced the effect of the metal surface.

- There is huge difference in implementing the RFID system in stationary and motion conditions. The performance rate of the system deteriorated when the tag was kept in motion. The RSSI value was better when the tag was in a static condition.
- There is a statistically significant effect of the speed, spacer, and distance on the received signal strength indicator (RSSI) value.
- Further environmental testing on the RF code system concludes that, when the temperature is decreased, the RSSI value was increased.
- In environmental testing when foam and cardboard spacer were used, the result again proved that the cardboard was the better spacer to reduce the negative effect of the metal surface.
- In the process of manufacturing the RFID tag embedded license, the minimum thickness of cardboard material and reader at 6ft height should be maintained in order to have a strong RSSI value or decrease the effect of the metal surface.
- There is a significant amount of cost saving by implementing the RF RFID system instead of a camera tracking system.

6.1 Recommendation for Future Work

- More RFID systems must be tested to identify and compare the performance rate with the RF code RFID system. This research only compared three types of RFID systems.
- The cardboard material can be analyzed and any special composition of chemicals can be added in order to reduce the adverse effect of metal.

- The durability of the cardboard material needs to be improved because it should be firm enough to work in any climate conditions.
- Long run experiments need to be performed; the RF code system must be tested on multiple vehicles under different weather conditions, at least for a couple of months.
- Motion testing under snow conditions must be performed before implementing the system. The system could be tested under snow conditions to witness the effect of speed along with the effect of snow condition on the system.
- More environmental testing such as vibration, altitude and humidity tests could be performed on the RF code system.

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Appendix A

Experiment on Different RFID Systems

A.1 Preliminary Testing Results

Maximum distance tested 25ft			
Angle	**Trial 1**	**Trail 2**	**Average**
0	3	3	3
45	9	5	5
90	25	25	25
135	21	20	20
180	3	3	3

A.2 Stationary Testing Result

SAVI system Stationary Testing Result

The below tables shows the stationary test performed with varying thickness of material. This test was performed to identify the best thickness to use in the motion test.

Cardboard

Trials (RSSI dB)											
Thickness(in)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Avg**
1	150	152	146	150	152	152	152	152	151	150	151
2	150	153	150	153	150	150	150	150	145	147	150
3	142	150	149	144	146	145	149	150	151	144	147

Plastic

Trials (RSSI dB)											
Thickness(in)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Avg**
1	142	144	145	145	143	142	142	143	143	142	143
2	138	138	138	138	134	135	137	127	151	143	138

Rubber

Trials											
Thickness(in)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Avg**
1	135	133	133	137	138	136	136	136	134	133	135

RF Code Stationary Test

Cardboard

Trails (RSSI dB)											
Thickness(in)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Avg**
1	62	64	62	62	62	62	62	62	62	62	62
2	74	74	74	74	74	74	74	74	74	74	74
3	77	79	74.5	77	77	70	70	66.5	74	74	74

Rubber

Trials											
Rubber (in)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Avg**
1	85	85.5	85.5	85.5	85.5	81.5	81.5	81.5	81.5	81.5	83
2	97	97	97	97	97	97	98	98	97	97	97

Plastic

Trails											
Thickness(in)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Avg**
1	88.5	82.5	82.5	82.5	85.5	83.5	83.5	86	79.5	79.5	83
2	66.5	69.5	69.5	65	69.5	75.5	66	66	66	66	68
3	97	96.5	97.5	97.5	82.5	103	88	103	90	90	93.5

A3 Variation of RSSI between RFID tags

Number of trial	RSSI dB
1	64.5
2	65
3	61.5
4	61
5	62
6	62.5
7	62
8	62
9	62
10	62
Average	**62.45**
Std dev	**1.27**

A.4 Motion Testing Results

SAVI System Motion Testing Results

1 Plastic

Trials (RSSI dB)											
Speed(mph)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Avg.**
25	81	75	118	104	97	88	118	74	120	93	
30	95	100	-	-	-	-	-	-	-	114	
35	88	-	-	99	76	102	-	-	88	-	

1 Rubber

Trials (RSSI dB)											
Speed(mph)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Avg.**
25	72	-	101	-	-	93	87	-	69	-	
30	73	80	-	88	87	90	-	-	-	88	
35	-	-	88	83	-	67	-	92	91	81	

1 Cardboard

Trails (RSSI dB)											
Speed(mph)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Avg.**
25	-	-	-	83	82	-	-	-	-		
30	96	-	-	-	-	123	93	91	-	111	
35	-	-	-	-	-	-	81	-	-	100	

A.5 Randomization Table for Motion Testing on RF Code System

Material	25	30	35
Rubber	2	4	6
	7	3	9
	5	8	1
	12	10	30
	22	26	13
	11	19	29
	14	25	20
	18	15	23
	24	28	16
	17	21	27
	3	16	6
	10	2	20
	21	5	9
	1	14	22
	23	11	15

Cardboard	7	19	29
	26	8	12
	18	30	25
	13	24	27
	4	28	17
Plastics	7	18	17
	20	24	5
	4	26	21
	23	8	3
	18	16	28
	27	30	15
	14	1	19
	2	22	25
	11	13	9
	29	10	12
No Material	27	15	13
	12	3	1
	18	11	17
	26	19	16
	2	22	29
	4	25	30
	14	5	20
	28	24	21
	8	10	9
	6	7	23

Appendix B ENVIRONMENTAL TESTING

B.1 Randomization Table for Snow Condition

Snow	Thickness	Height in ft	Distance in ft		
			25	50	75
No material	X(1)	3	1	4	2
			3	6	4
		6	6	3	5
			2	1	5
Cardboard	X(2)	3	3	4	6
			5	6	3
		6	2	5	1
			1	4	2
	2X(1)	3	2	5	3
			2	6	4
		6	4	6	1
			1	5	3
Foam	X(1)	3	1	4	3
			1	3	5
		6	5	2	6
			4	2	6
	2X(2)	3	6	5	3
			3	6	1
		6	4	2	1
			5	2	4

B.2 Randomization Table for No Snow Condition

No Snow	Thickness	Height in ft	Distance in ft		
			25	**50**	**75**
No material	X(1)	3	5	3	2
			1	2	6
		6	6	1	4
			3	5	4
Cardboard	X(2)	3	5	1	3
			5	6	2
		6	2	4	6
			4	1	3
	2X(1)	3	1	6	3
			6	1	3
		6	4	5	2
			5	2	4
Foam	X(1)	3	1	4	3
			4	5	2
		6	2	6	5
			3	6	1
	2X(2)	3	1	5	3
			3	1	4
		6	2	4	6
			2	5	6

B.3 Complete Data Table

Snow	Distance	Height	Thickness	Material	RSSI
1	25	3	0	nm	102
1	25	3	0.2	cb	67
1	25	3	0.4	cb	85.5
1	25	3	0.5	fm	63.5
1	25	3	1	fm	81.5
1	25	6	0	nm	98.5
1	25	6	0.2	cb	64.5
1	25	6	0.4	cb	78
1	25	6	0.5	fm	61
1	25	6	1	fm	84
1	50	3	0	nm	108
1	50	3	0.2	cb	78
1	50	3	0.4	cb	92.5
1	50	3	0.5	fm	75.5
1	50	3	1	fm	96.5
1	50	6	0	nm	109
1	50	6	0.2	cb	86.5
1	50	6	0.4	cb	85.5
1	50	6	0.5	fm	68.5
1	50	6	1	fm	90.5
1	75	3	0	nm	104.5
1	75	3	0.2	cb	82.5
1	75	3	0.4	cb	99.5
1	75	3	0.5	fm	84.5
1	75	3	1	fm	103
1	75	6	0	nm	113.5
1	75	6	0.2	cb	79.5
1	75	6	0.4	cb	90
1	75	6	0.5	fm	75.5
1	75	6	1	fm	97.5
1	25	3	0	nm	103.5
1	25	3	0.2	cb	66
1	25	3	0.4	cb	83
1	25	3	0.5	fm	66.5
1	25	3	1	fm	85.5
1	25	6	0	nm	93.5

1	25	6	0.2	cb	64.5
1	25	6	0.4	cb	78.5
1	25	6	0.5	fm	60.5
1	25	6	1	fm	83
1	50	3	0	nm	107.5
1	50	3	0.2	cb	77.5
1	50	3	0.4	cb	97
1	50	3	0.5	fm	74
1	50	3	1	fm	96
1	50	6	0	nm	111.5
1	50	6	0.2	cb	82
1	50	6	0.4	cb	83.5
1	50	6	0.5	fm	68.5
1	50	6	1	fm	91.5
1	75	3	0	nm	108.5
1	75	3	0.2	cb	84.5
1	75	3	0.4	cb	98
1	75	3	0.5	fm	82.5
1	75	3	1	fm	105
1	75	6	0	nm	114
1	75	6	0.2	cb	79.5
1	75	6	0.4	cb	92.5
1	75	6	0.5	fm	75.5
1	75	6	1	fm	95.5
0	25	3	0	nm	108
0	25	3	0.2	cb	77
0	25	3	0.4	cb	90.5
0	25	3	0.5	fm	85.5
0	25	3	1	fm	105
0	25	6	0	nm	112.5
0	25	6	0.2	cb	72.5
0	25	6	0.4	cb	93
0	25	6	0.5	fm	81
0	25	6	1	fm	106
0	50	3	0	nm	107.5
0	50	3	0.2	cb	84
0	50	3	0.4	cb	99.5
0	50	3	0.5	fm	103.5
0	50	3	1	fm	103

0	50	6	0	nm	110
0	50	6	0.2	cb	81.5
0	50	6	0.4	cb	94
0	50	6	0.5	fm	94
0	50	6	1	fm	106.5
0	75	3	0	nm	115
0	75	3	0.2	cb	91.5
0	75	3	0.4	cb	108
0	75	3	0.5	fm	98.5
0	75	3	1	fm	115
0	75	6	0	nm	115
0	75	6	0.2	cb	87
0	75	6	0.4	cb	106
0	75	6	0.5	fm	109
0	75	6	1	fm	113.5
0	25	3	0	nm	106.5
0	25	3	0.2	cb	72
0	25	3	0.4	cb	87.5
0	25	3	0.5	fm	80
0	25	3	1	fm	97
0	25	6	0	nm	106.5
0	25	6	0.2	cb	72.5
0	25	6	0.4	cb	100
0	25	6	0.5	fm	82
0	25	6	1	fm	96
0	50	3	0	nm	115
0	50	3	0.2	cb	87.5
0	50	3	0.4	cb	104
0	50	3	0.5	fm	104.5
0	50	3	1	fm	106.5
0	50	6	0	nm	107.5
0	50	6	0.2	cb	81
0	50	6	0.4	cb	106
0	50	6	0.5	fm	97.5
0	50	6	1	fm	104.5
0	75	3	0	nm	113
0	75	3	0.2	cb	93.5
0	75	3	0.4	cb	104.5
0	75	3	0.5	fm	104

0	75	3	1	fm	114.5
0	75	6	0	nm	107.5
0	75	6	0.2	cb	88.5
0	75	6	0.4	cb	99.5
0	75	6	0.5	fm	98.5
0	75	6	1	fm	108

B.4 Identification of Material Thickness

ANOVA comparing means

T*H*D*S(M) Least Squares Means									
M	T	H	D	S	Estimate	Standard Error	DF	t Value	Pr > |t|
cb	0.2	3	25	0	74.5000	2.0754	60	35.90	<.0001
cb	0.2	3	25	1	66.5000	2.0754	60	32.04	<.0001
cb	0.2	3	50	0	85.7500	2.0754	60	41.32	<.0001
cb	0.2	3	50	1	77.7500	2.0754	60	37.46	<.0001
cb	0.2	3	75	0	92.5000	2.0754	60	44.57	<.0001
cb	0.2	3	75	1	83.5000	2.0754	60	40.23	<.0001
cb	0.2	6	25	0	72.5000	2.0754	60	34.93	<.0001
cb	0.2	6	25	1	64.5000	2.0754	60	31.08	<.0001
cb	0.2	6	50	0	81.2500	2.0754	60	39.15	<.0001
cb	0.2	6	50	1	84.2500	2.0754	60	40.59	<.0001
cb	0.2	6	75	0	87.7500	2.0754	60	42.28	<.0001
cb	0.2	6	75	1	79.5000	2.0754	60	38.31	<.0001
cb	0.4	3	25	0	89.0000	2.0754	60	42.88	<.0001
cb	0.4	3	25	1	84.2500	2.0754	60	40.59	<.0001
cb	0.4	3	50	0	101.75	2.0754	60	49.03	<.0001
cb	0.4	3	50	1	94.7500	2.0754	60	45.65	<.0001
cb	0.4	3	75	0	106.25	2.0754	60	51.19	<.0001
cb	0.4	3	75	1	98.7500	2.0754	60	47.58	<.0001
cb	0.4	6	25	0	96.5000	2.0754	60	46.50	<.0001
cb	0.4	6	25	1	78.2500	2.0754	60	37.70	<.0001
cb	0.4	6	50	0	100.00	2.0754	60	48.18	<.0001
cb	0.4	6	50	1	84.5000	2.0754	60	40.72	<.0001
cb	0.4	6	75	0	102.75	2.0754	60	49.51	<.0001
cb	0.4	6	75	1	91.2500	2.0754	60	43.97	<.0001
fm	1	3	25	0	101.00	2.0754	60	48.67	<.0001
fm	1	3	25	1	83.5000	2.0754	60	40.23	<.0001
fm	1	3	50	0	104.75	2.0754	60	50.47	<.0001
fm	1	3	50	1	96.2500	2.0754	60	46.38	<.0001
fm	1	3	75	0	114.75	2.0754	60	55.29	<.0001

fm	1	3	75	1	104.00	2.0754	60	50.11	<.0001
fm	1	6	25	0	101.00	2.0754	60	48.67	<.0001
fm	1	6	25	1	83.5000	2.0754	60	40.23	<.0001
fm	1	6	50	0	105.50	2.0754	60	50.83	<.0001
fm	1	6	50	1	91.0000	2.0754	60	43.85	<.0001
fm	1	6	75	0	110.75	2.0754	60	53.36	<.0001
fm	1	6	75	1	96.5000	2.0754	60	46.50	<.0001
fm	0.5	3	25	0	82.7500	2.0754	60	39.87	<.0001
fm	0.5	3	25	1	65.0000	2.0754	60	31.32	<.0001
fm	0.5	3	50	0	104.00	2.0754	60	50.11	<.0001
fm	0.5	3	50	1	74.7500	2.0754	60	36.02	<.0001
fm	0.5	3	75	0	101.25	2.0754	60	48.79	<.0001
fm	0.5	3	75	1	83.5000	2.0754	60	40.23	<.0001
fm	0.5	6	25	0	81.5000	2.0754	60	39.27	<.0001
fm	0.5	6	25	1	60.7500	2.0754	60	29.27	<.0001
fm	0.5	6	50	0	95.7500	2.0754	60	46.14	<.0001
fm	0.5	6	50	1	68.5000	2.0754	60	33.01	<.0001
fm	0.5	6	75	0	103.75	2.0754	60	49.99	<.0001
fm	0.5	6	75	1	75.5000	2.0754	60	36.38	<.0001
nm	0	3	25	0	107.25	2.0754	60	51.68	<.0001
nm	0	3	25	1	102.75	2.0754	60	49.51	<.0001
nm	0	3	50	0	111.25	2.0754	60	53.60	<.0001
nm	0	3	50	1	107.75	2.0754	60	51.92	<.0001
nm	0	3	75	0	114.00	2.0754	60	54.93	<.0001
nm	0	3	75	1	106.50	2.0754	60	51.32	<.0001
nm	0	6	25	0	109.50	2.0754	60	52.76	<.0001
nm	0	6	25	1	96.0000	2.0754	60	46.26	<.0001
nm	0	6	50	0	108.75	2.0754	60	52.40	<.0001
nm	0	6	50	1	110.25	2.0754	60	53.12	<.0001
nm	0	6	75	0	111.25	2.0754	60	53.60	<.0001
nm	0	6	75	1	113.75	2.0754	60	54.81	<.0001

Appendix C

Benefit-Cost Analysis

C.1 Total Cost Calculation

RFID System (500 cars)

Implementation charges = 15*500 = $7500

Miscellaneous chargers = 5*500 = $2500

Maintenance chargers = 30*500 = $15000

Total cost = (S+L+C+I+Mi +Ma)

Total cost = (950+40000+1500+7500+2500+15000) = **$67450**

Non-RFID System (500 cars)

Implementation charges= 5*500= $2500

Miscellaneous expenses= 10*500=$5000

Maintenance (Ma.) charges= 20*500= $10000

Total cost = (8975+120,000+6000+2500+5000+10000) = **$152475**

RIFD System (1000 cars)

Implementation charges= 15*1000= $15000

Miscellaneous charges = 5*1000 = $ 5000

Maintenance chargers= 30*1000= $30000

Total cost = (S+L+C+I+Mi +Ma)

Total cost = (950+40000+1500+15000+5000+30000) = **$92450**

Non-RFID System (1000 cars)

Implementation charges= 5*1000= $5000

Miscellaneous expenses= 10*1000=$10000

Maintenance (Ma.) charges= 20*1000= $20000

Total cost = (8975+120,000+6000+5000+10000+20000) = **$169975.**