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Final Report

Investigating RFID for Roadside Identification Involving Freight Commercial Vehicle Operators (CVO)

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MATC

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16. Abstract

Radio Frequency Identification (RFID) is an emerging technology to track commercial vehicles. This transcript describes research that investigates the ability for RFID technologies to work in license plates. Mile markers are common fixtures on the roadside and may provide infrastructure to support identifying RFID to enabled Commercial Vehicle Operators (CVO). This research considers variables that affect the performance of a RFID License Plate System that uses a scanner located at the mile marker. Mile marker characteristics, such as horizontal distance and vertical height, were evaluated along with RFID tag characteristics, such tag type and license plate location.

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Abstract

Radio Frequency Identification (RFID) is an emerging technology to track commercial vehicles. This transcript describes research that investigates the ability for RFID technologies to work in license plates. Mile markers are common fixtures on the roadside and may provide infrastructure to support identifying RFID to enabled Commercial Vehicle Operators (CVO). This research considers variables that affect the performance of a RFID License Plate System that uses a scanner located at the mile marker. Mile marker characteristics, such as horizontal distance and vertical height, were evaluated along with RFID tag characteristics, such tag type and license plate location.

Chapter 1 Introduction

RFID tags have been used for transportation toll systems since the early 1970s (Jones 2008). Transponder or tag based Radio Frequency systems have been utilized for weigh-in-motion and other enforcement actions over the last several decades through systems such as Pre-Pass and Nor-Pass. The foundation for this research is the idea that one RFID based system that can be integrated for use with both RFID toll systems, other transponder based systems, and additional state systems that can utilize common information. We envision such as system can be created by embedding standardized (ISO) RFID tags, which can be scanned or read by a mile marker with a reader, into license plates. This idea allows states to expand extra scanning capacity in an incremental manner. Yet it also is economical by relying on pre-existing technology: existing readers that interrogate other transponders could read the common information since the systems are on an official standard. For this type of system to be successful, multiple aspects must be tested. The physical capability of the system is described in this transcript.

One of the biggest challenges for the transportation industry is to investigate and test the feasibility of emerging technologies such as RFID. Our transcript utilizes reliability testing to determine the opportunities and shortcomings of a RFID license plate system.

Reliability is the capacity for a product or a system to perform consistently. In this transcript we utilize quality measurements, such as statistical reliability, to test the feasibility of our proposed system.

Radio Frequency Identification (RFID) is an emerging technology which has been introduced into the transportation system. Enforcement operations have a critical need to provide a more efficient means of capturing data for inspection purposes in comparison to manual "screening" approaches for enforcement of safety and registration guidelines. In order to utilize automated technologies for more effective roadside data collection—for traffic counts, enforcement data collection, and toll usage—information must be accessible and collected in a reliable way (Mid-America Transportation Center 2008). We tested RFID technology's ability to work in license plates in order to make information collection for CVO more efficient.

1.1 Background and Literature Search

1.1.1Reliability and System Testing

Reliability is defined as the propensity for a product to perform consistently over its useful design. A subfield in quality management has emerged, called reliability management and it is based on the application of probability theory to quality. A product is considered reliable if the chance that it will fail during its design life is very low. If a refrigerator has a 2% chance of failure in a useful life of 10 years, we say that it is 98 % reliable (Foster 2007).

In product and process design a common methodology for testing quality in an efficient manner is described as Design of Experiments (DOE). DOE is a quality analysis tool that uses information learned from the initial or previous experiments to eliminate unnecessary or undesirable experimentation within the previous series of experiments. This method provides a powerful means to achieve breakthrough improvements in product quality and process efficiency (Jones and Silveray 2007).

1.1.2 RFID Background

RFID technologies originated from radar theories that were discovered by the allied forces during World War II and have been commercially available since the early 1980s (Landt 2001). Over the last two decades, RFID has been used for a wide variety of applications such as highway and bridge tolls, livestock tracking, transportation freight tracking and motorcycle manufacturing. Until recently, the technologies were considered expensive and limited but as the tags, readers, and the associated equipment costs continue to decrease, a growing number of organizations have begun to explore the feasibility of using RFID systems (Jones and Silveray 2007).

There are several methods of identifying items that use RFID. A standard RFID system consists of a tag, reader, air interface, and middleware software (Clampitt 2006). Tags often consist of a microchip with an internally attached coiled antenna. Some include batteries, expandable memory, and sensors (Ranky 2006). A reader is an interrogating device that has internal and, often times, external antennas that send and receive signals.

1.1.3 Related Automation in Transportation

A weigh station is a checkpoint where trucks and commercial vehicles' weights are inspected along a specific highway. All weigh stations contain scales which decide if the trucks may proceed along their path. The International Fuel Tax Agreement (IFTA) was the primary reason for the creation of weigh stations in order to collect road use taxes. Furthermore, at present, weight stations also carry the responsibility of enforcing tax and safety regulations. The taxes include checking freight carrier compliance with fuel tax laws, weight restrictions, equipment safety, and compliance with Hours of Service Regulations (Weigh Station 2009). Weight stations are typically operated by a state's Department of Transportation (DOT) in conjunction with the state highway patrol or state police (Weigh Station 2009).

Many states have technology that allows a continuous flow of truck weighing called "Weigh-in-Motion." Furthermore, many states now use electronic bypass systems to alleviate some of the truck traffic through the weigh station (Weigh Station, 2009). The electronic bypass systems are widely known as A.V.I. (Automatic Vehicle Identification). Systems like Prepass and Norpass fall under this category. These and other specific A.V.I. systems consist of equipment at the weigh stations and in the truck. In the truck there is a transponder which is directly registered to that specific vehicle. It contains information such as carrier name, unit number, and elected gross weight to weigh stations (Weigh Station, 2009).

This research intends to investigate how RFID and weigh-in-motion stations can be integrated in a cost effective manner.

Chapter 2 Problem Statement, Hypothesis and Research Methodology

In this section we introduce our problem statement and overall hypothesis. The research problem is too large to describe in one transcript, thereby we will discuss the results of initial testing of mile marker characteristic testing and RFID tag placement testing in this report. This section highlights the overall research methodology and hypothesis. We hypothesize that RFID technology can be used to improve data collection by making timely information available. It is envisioned that this technology will allow an officer real-time information about a vehicle prior to its arrival at a weigh station or that this data will be transmitted to a portable unit before the vehicle crosses the Weigh–in–Motion (WIM) scale located on a highway.

2.1 Hypothesis Statement

We hypothesize that RFID technology can be used to improve the data collected on the mile marker based on the distance and speed of the vehicle with respect to the tag embedded inside the license plates and the antenna on the mile marker. In order to investigate our hypothesis, first, we examine the capability of RFID tags to be interrogated at a mile marker, and, second, we consider the performance of RFID tags located on different areas of a license plate.

2.2 Overall Research Methodology

The overall methodology used for this paper was derived from the RFID Supply Chain lab at the University of Nebraska (RfSCL) and is known as Design for Six Sigma Research (DFSS-R). Traditional research methods were fused with the industrial continuous improvement methodology (DFSS-R). This methodology is based on recognition by many companies as a means for reducing defects, increasing company productivity and improving company profitability. Six Sigma can be considered an extension of Total Quality Management (TQM) initiatives. The advantage that this methodology has over quality initiatives is that it applies statistical techniques not only to product quality but also to many aspects of business operations in order to improve the overall organizational efficiency (Jones and Silveray 2007).

The distinction “Six Sigma” originates from statistical terminology. In statistics the sigma (σ) represents the standard deviation. Given a normal distribution curve the probability of falling within a plus or minus six sigma from the mean is approximately 0.9999966. It is more commonly expressed in production processes as a defective rate for processes that will be 3.4 defects per million units (Yang 2003). Accordingly, Six Sigma promotes a high degree of consistency by designing operations with extremely low variability. The objective for Six Sigma methodologies is to reduce the operational variation to achieve small process standard deviations.

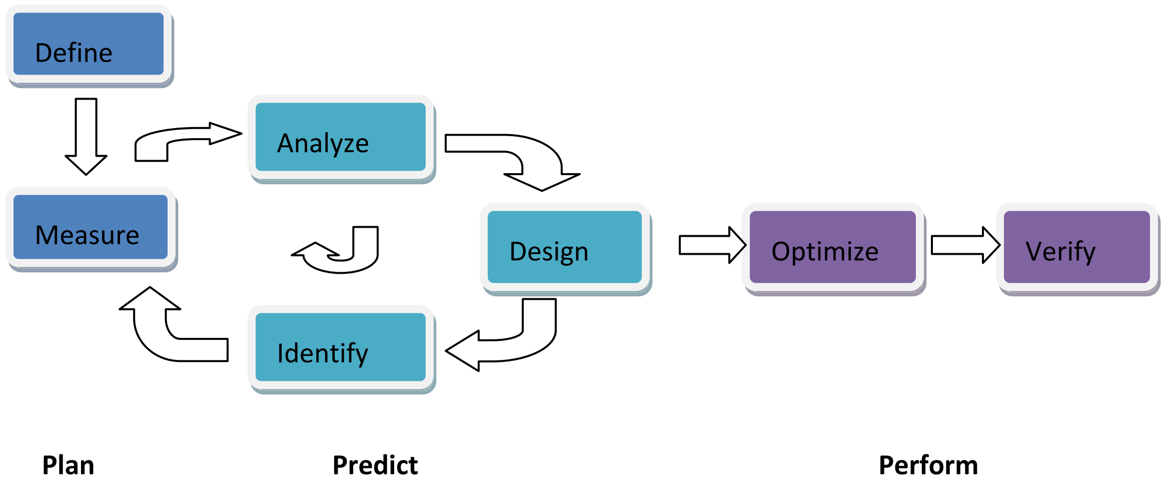


Figure 2.1 Design for Six Sigma Research Plan, Predict and Perform Methodology

To conduct a thorough investigation into the possibility of embedding RFID chips in license plates and its future implementation, all phases of this model will be used in this project. As depicted in figure 2.1, we first bring clarity to the problem and set up accurate metrics. In the predict phase an analysis is made, relevant technologies are identified and a design is formulated. In the past phase of our model we attempt to conduct tests in real life situations and to validate the technology.

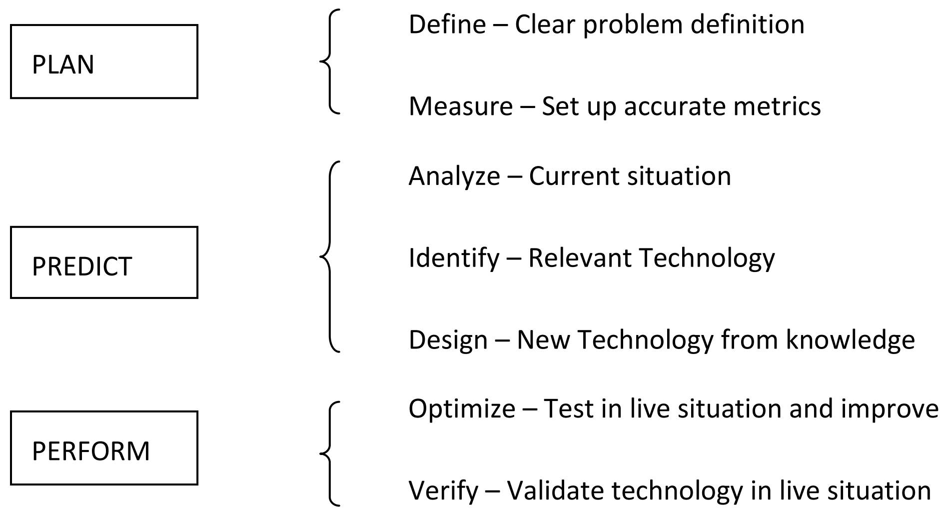


Figure 2.2 Explanation of Plan, Predict and Perform Process Steps

2.2.1 Predict

This paper focuses on the first stage of the research: the Predict stage. An earlier transcript describes the planning stage with the use of Transportation Shareholder Analysis. Using stakeholder input provides the focused effort necessary to move on to the additional stages of development of prototype systems for experimentation.

Design of Experiments (DOE) is a quality analysis tool which uses a systematic approach to investigate a system or process. A number of structured tests are designed in which a planned change is made to the input variables of a process or system. The outcomes of these particular changes on a pre-defined output are then appraised. This particular tool uses information learned from the first or previous experiments to eliminate unnecessary or undesirable results within the previous series of experiments.

DOE is essential in providing a formal way of increasing information gained with the resources required. With this said, DOE has more to give than changing one experimental method at once, because it allows a judgment on the significance of input variables—either acting independently or in combination with one another—to the output. The DOE can be utilized to find answers in specific situations such as: what is the main contributing factor that is being prolonged making the problem more complex?; how well does a system perform under the effect of noise?; what is the best model of configuration to minimize the variation in a response?

This method provides a powerful means to achieve breakthrough improvements in product quality and process efficiency (Jones and Silveray 2007).

Mile Marker Study (Figure 2.3)

2.2.2 Equipment and Testing Protocol

The equipment included two RFID antennas, a computer, TagDemo software, a Samsys reader, Generation 2 tags, and a stopwatch. From these components, a basic Passive RFID system was constructed. A Passive RFID system has 3 components: a scanning antenna, a transceiver with a decoder to interpret the data, and a transponder that has been programmed with information. The antenna emits radio frequency signals and provides a means of communication with the transponder and also provides the RFID tag with energy to communicate.

Experiment one was conducted in the RFID lab at Prairie View A&M University. The experiment tested the reading range of the Generation 2 tags at two different antenna and tag heights.

Figure 2.3 Mile Marker

The heights utilized were designed to prototype the height of the mile marker. The reason for this issue is because, given the height of the mile marker, we would be able to make accurate measurements given the position of the tag. The angle of the tag also has a major contribution in the read rate because of the dynamics that are in involved in an achievable reading.

Because of the different heights, the experiment had four separate parts. Each part corresponded to a different antenna or tag height. These heights for the antennas were 3' and 6.' Markers on the ground were marked precisely measuring distance in feet. The test was ranged from 0' to 20.' With two different antenna heights, two different testing heights of the tags were necessary and these heights were 2.5' and 5.'

The STI scholars were instructed to start at different distances from the antennas depending on the strength between antenna and tag. The scholars held a designated tag in the specified tag height on their bodies. When the tag was read by the antenna, the assigned name for that tag was displayed on the computer screen along with a designated tune. This experiment was done 77 times.

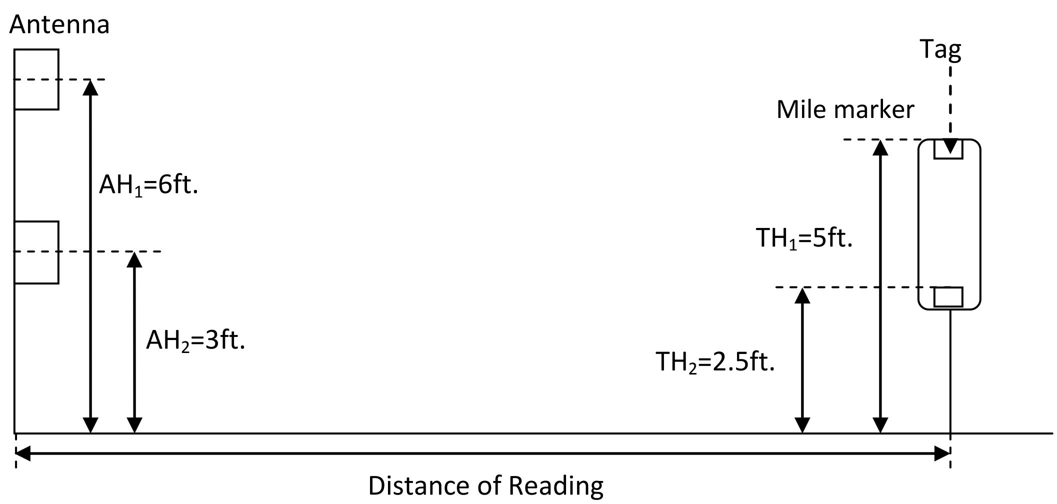


Figure 2.4 Design of the Experiment

2.2.3 Mile Marker Study Results

Table 2.1 RFID Tags Distance at First Reading (Antenna Height: 3 ft., Tag Height: 2.5 ft.)

Experiment	Tag Name	Starting Distance (ft)	Antenna Height (ft)	Tag Height (ft)	Distance of Reading Result (ft)
1	No. 1	16	3	2.5	10
2	No. 2	16	3	2.5	9
3	No. 3	16	3	2.5	9
4	No. 3	16	3	2.5	10
5	No. 4	16	3	2.5	8
6	No. 5	16	3	2.5	8
7	No. 6	11	3	2.5	9
8	No. 7	14	3	2.5	7
9	No. 8	12	3	2.5	9
10	No. 9	12	3	2.5	9
11	No. 10	18	3	2.5	18
12	No. 11	19	3	2.5	9
13	No. 12	14	3	2.5	4
14	No. 13	16	3	2.5	8
15	No. 14	12	3	2.5	9
16	No. 15	14	3	2.5	8
17	No. 16	13	3	2.5	11
18	No. 17	13	3	2.5	11
19	No. 18	19	3	2.5	11
20	No. 19	13	3	2.5	10

Range	**14 ft.**
Mode	**9 ft.**
Mean	**9.35 ft.**

In experiment number one the longest reading distance was 18 feet and the shortest reading distance was 4 feet, therefore bringing the range to 14 feet. The mode and mean for the experiment were 9 feet and 9.35 feet.

Table 2.2 RFID Tags Distance at First Reading (Antenna Height: 3 ft., Tag Height: 5 ft.)

Experiment	Tag Name	Starting Distance (ft)	Antenna Height (ft)	Tag Height (ft)	Distance of Reading Result (ft)
21	No. 18	18	3	5	10
22	No. 17	17	3	5	16
23	No. 16	17	3	5	10
24	No. 15	17	3	5	8
25	No. 14	19	3	5	11
26	No. 13	19	3	5	8
27	No. 12	19	3	5	10
28	No. 11	17	3	5	17
29	No. 10	18	3	5	6
30	No. 19	18	3	5	10
31	No. 1	17	3	5	10
32	No. 2	17	3	5	9.5
33	No. 6	17	3	5	9
34	No. 3	15	3	5	11
35	No. 4	15	3	5	10
36	No. 5	15	3	5	9
37	No. 7	18	3	5	5
38	No. 8	14	3	5	11
39	No. 9	17	3	5	9.5

Range	**12 ft.**
Mode	**10 ft.**
Mean	**10 ft.**

In experiment number two the longest reading distance was 17 feet and the shortest reading distance was 5 feet, therefore bringing the range to 12 feet. The mode and mean for the experiment were 10 feet.

Table 2.3 RFID Tags Distance at First Reading (Antenna Height: 6 ft., Tag Height: 2.5 ft.)

Experiment	Tag Name	Starting Distance (ft)	Antenna Height (ft)	Tag Height (ft)	Distance of Reading Result (ft)
40	No. 9	18	6	2.5	4
41	No. 8	12	6	2.5	10
42	No. 7	14	6	2.5	7
43	No. 5	13	6	2.5	6
44	No. 4	11	6	2.5	5
45	No. 3	10	6	2.5	8
46	No. 6	10	6	2.5	10
47	No. 2	11	6	2.5	5
48	No. 1	11	6	2.5	10
49	No. 19	11	6	2.5	7
50	No. 18	10	6	2.5	7
51	No. 10	10	6	2.5	7
52	No. 11	10	6	2.5	10
53	No. 12	10	6	2.5	7
54	No. 13	10	6	2.5	6
55	No. 15	11	6	2.5	N/A
56	No. 17	10	6	2.5	7
57	No. 14	10	6	2.5	7
58	No. 16	10	6	2.5	5

Range	**6 ft.**
Mode	**7 ft.**
Mean	**6.74 ft.**

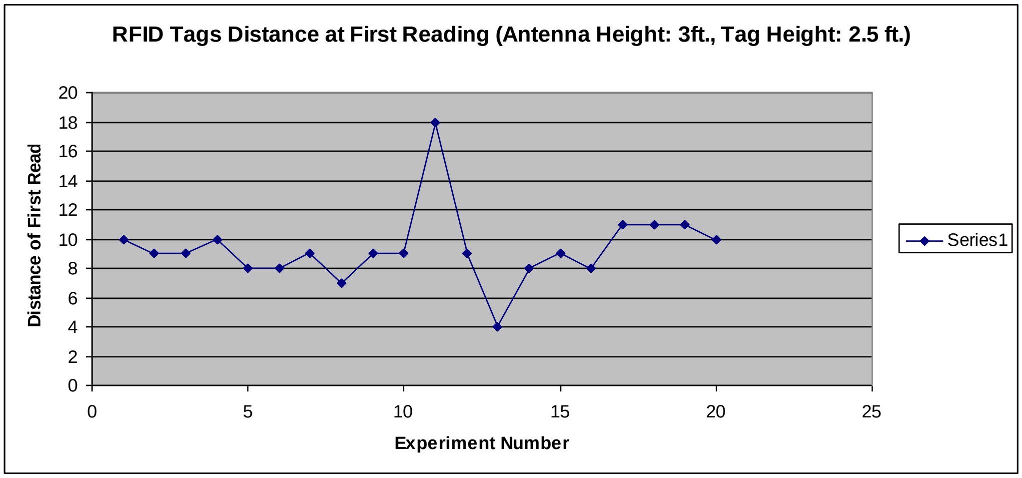
In experiment number three the longest reading distance was 10 feet and the shortest reading distance was 4 feet, resulting in a range of 6 feet. The mode and mean for the experiment were 7 feet and 6.74 feet. There was also a N/A reading that affected the results greatly.

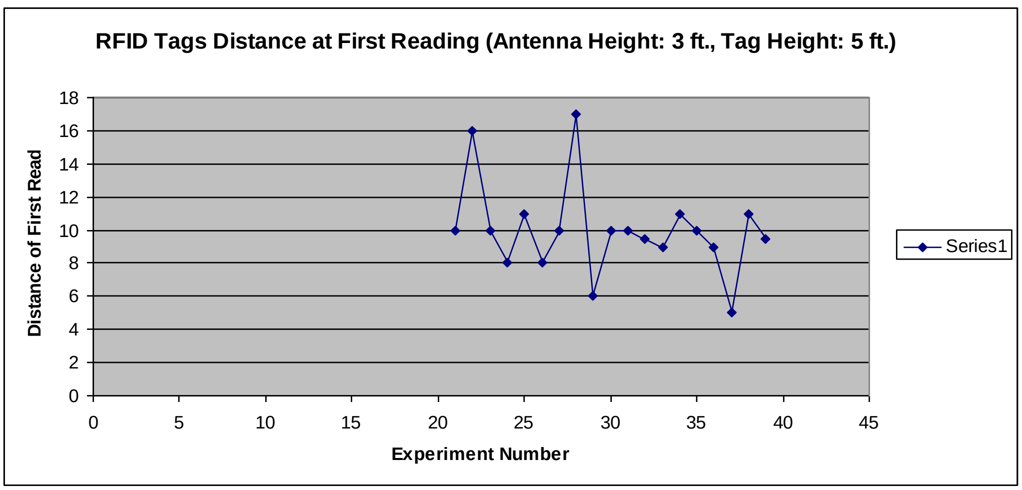
Table 2.4 RFID Tags Distance at First Reading (Antenna Height: 6 ft., Tag Height: 5 ft.)

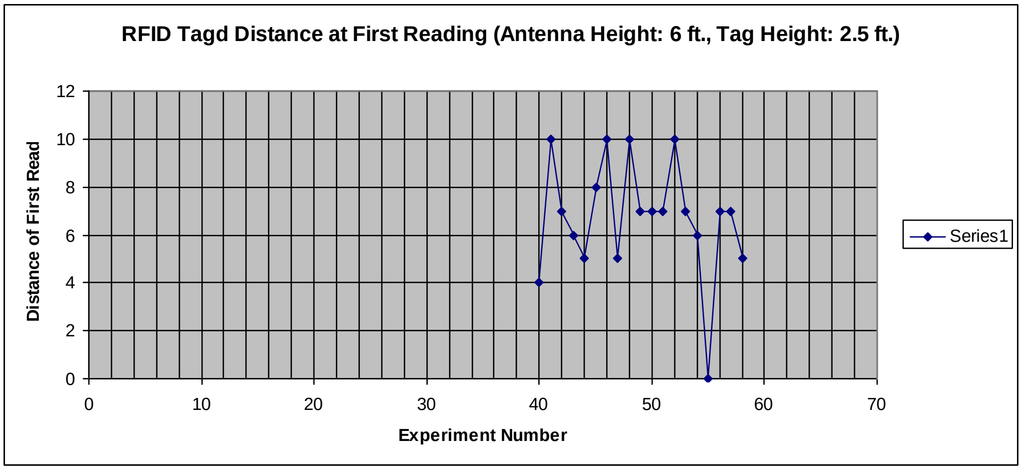
Experiment	Tag Name	Starting Distance (ft)	Antenna Height (ft)	Tag Height (ft)	Distance of Reading Result (ft)
59	No. 13	19	6	5	9
60	No. 15	14	6	5	5
61	No. 12	11	6	5	9
62	No. 11	10	6	5	9
63	No. 17	12	6	5	5
64	No. 10	12	6	5	9
65	No. 18	11	6	5	9
66	No. 19	11	6	5	9
67	No. 1	14	6	5	12
68	No. 2	14	6	5	14
69	No. 6	14	6	5	9
70	No. 3	13	6	5	13
71	No. 4	15	6	5	9
72	No. 5	13	6	5	8
73	No. 7	13	6	5	9
74	No. 8	13	6	5	9
75	No. 9	13	6	5	13
76	No. 14	13	6	5	13
77	No. 16	13	6	5	9

Range	**9 ft.**
Mode	**9 ft.**
Mean	**9.6 ft.**

In experiment number four the longest reading distance was 14 feet and the shortest reading distance was 5 feet therefore the range was 9 feet. The mode and mean for the experiment were 9 feet and 9.6 feet.







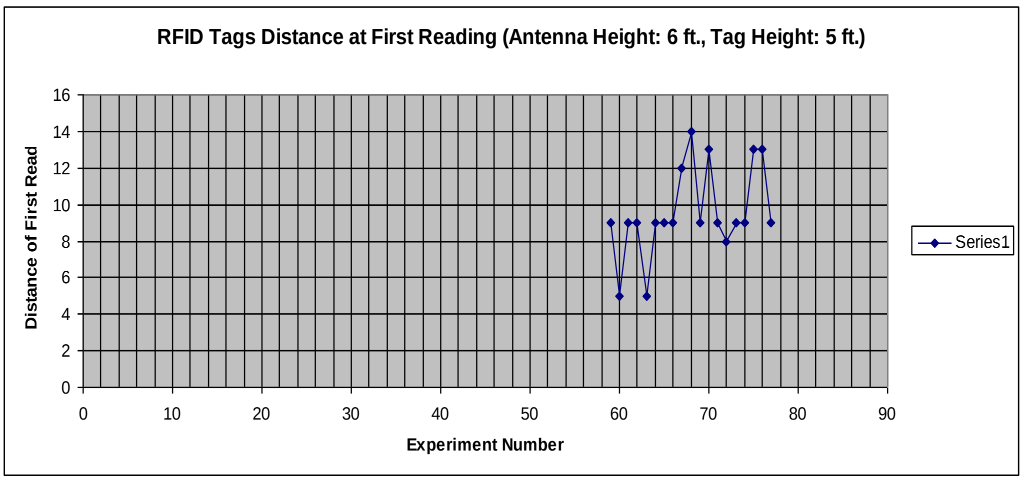


Figure 2.5 Performance of Results

The results from the experiments indicate that the two specified factors—Antenna Height and Tag Height—have a significant impact on the readability of tags. The furthest readings were obtained when the antenna was at six feet and the tag was at 5 feet. The shortest reading occurred when the antenna was at six feet and the tag was at 2.5 feet.

2.3 RFID Tag License Plate Location Study

2.3.1 Equipment and Testing Protocol

The overall research testing protocol focused on testing of RFID tags on license plates so that performance could be determined. The sequence of testing included (1) baseline testing of passive tags on cardboard, (2) testing passive tags imbedded between license plates, and (3) testing of active tags imbedded between license plates. The main goals were to determine if the performance of the cheaper passive tags imbedded within a license plate was comparable to the more expensive active tags. The performance results were based upon Received Signal Strength Indication (RSSI). There were 20 trials taken for each variable for each condition tested.

2.3.2 Equipment Used

The equipment used for testing passive technologies met the ISO 18000 standard or was compliant with EPC Global readers and tags. The equipment tested for active technologies were based upon the ISO 18000–7 standards. This standard is proposed to be called the DASH 7 protocol at the time of the writing of this paper.

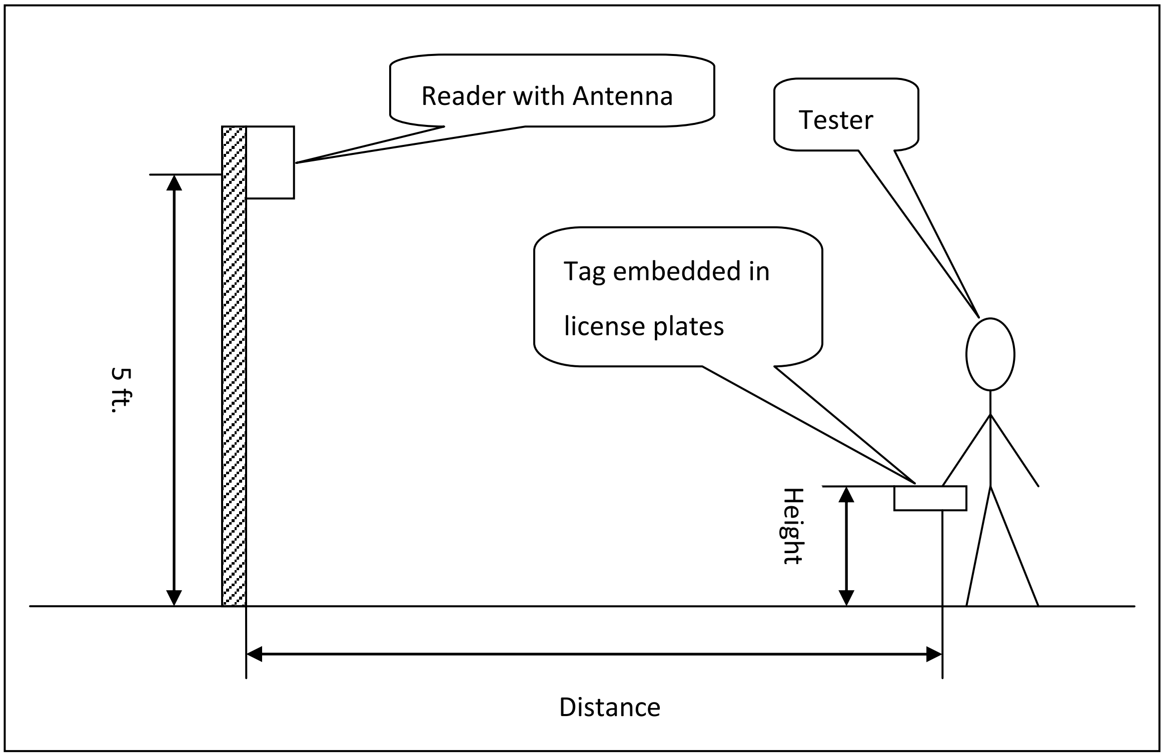


Figure 2.6 Design of the experiments

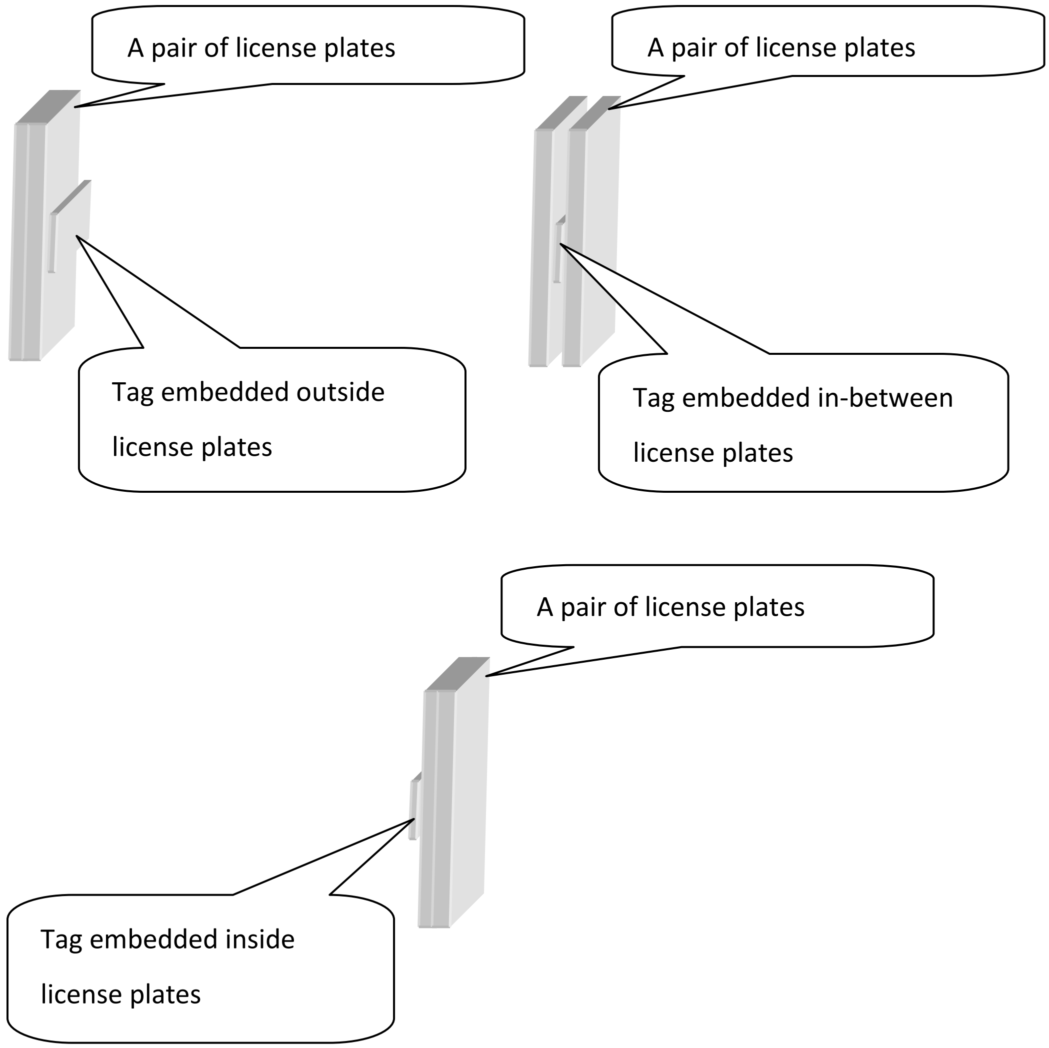


Figure 2.7 Location of the tag embedded in license plates (Factor: Location)

2.4 RFID Tag License Plate Location Study Results

2.4.1 ANOVA Analysis

Table 2.5 P-value in ANOVA

Baseline Passive testing		**Passive testing**		**Active testing**		
Source	**P-value**	**Source**	**P-value**	**Source**	**P-value for RSSI**	**P-value for Confidence**
Location(L)	**0.090**	**Type(T)**	**0.002**	**Location(L)**	**0.000**	**0.000**
Height(H)	**0.000**	**Height(H)**	**0.000**	**Height(H)**	**0.001**	**0.072**
Distance(D)	**0.000**	**Distance(D)**	**0.000**	**Distance(D)**	**0.000**	**0.000**
L*H	**0.929**	**T*H**	**0.003**	**L*H**	**0.014**	**0.180**
L*D	**0.306**	**T*D**	**0.000**	**L*D**	**0.005**	**0.000**
H*D	**0.000**	**H*D**	**0.000**	**H*D**	**0.000**	**0.010**
L*H*D	**0.572**	**T*H*D**	**0.000**	**L*H*D**	**0.057**	**0.010**
R^2=61.24%		**R^2=88.58%**		**R^2**	**79.73%**	**73.48%**

In the baseline passive testing experiment from the ANOVA analysis result we can find that height level, distance level, and the interaction of height and distance are extremely significant to one another (using an alpha value of $p < 0.05$). The location factor known as the placement of the tag is non-significant as we originally interpreted. The reason that there is insignificance in location factor is because the cardboard does not have a significant effect on the transmission and overall broadcasting of radio frequency (RF) signals. The R square value for passive testing in the ANOVA model is 61.24%, which is valid, but not achievable.

In the passive tag experiment, the effects of testers are absolutely not significant. The type of tag, height and distance, as well as the effects of the interactions of these three factors are all significant. By comparing and contrasting, it is evident that the type of tags has less significant effect than the other two main factors. Also the interaction between tag type and height has a less significant effect than the experiments. The R square value for this model is 88.58%. When the tag is 1 or 2 feet high, the reads per second are much lower than when the tag is 3 feet high. When the vertical distance between the tag and the antenna is 5 feet, the reads per second are much higher than the two others, respectively.

In this active tag experiment, analyzed using ANOVA, the effect of vertical distance of the tag was found to be less significant than the other two main factors, though the three main factors are all significant. The best predicted location for the tag is 2 feet high, in-between license plates, and with a 1 foot horizontal distance from the antenna, respectively. The interactions of location and horizontal distance, and vertical distance and horizontal distance have more significant effect to results than the others. The R square value for this model is 79.73%.

2.4.2 Performance of 2nd Active Tag System with a pair of License plates

First, the data was collected and then the given data for each horizontal distance were calculated to an average number. Second the plot was determined by the average numbers for every distance on a graph by using Microsoft Excel. After this process, it is evident by analyzing the trend of the RSSI changing with horizontal distance, that RSSI is reduced with the tag further from the fixed reader as a whole direction. But after 35 feet, RSSI is increased with the tag further until arriving at a small peak with 45 feet long. It is evident that RSSI is decreased when the distance is smaller than 20 feet.

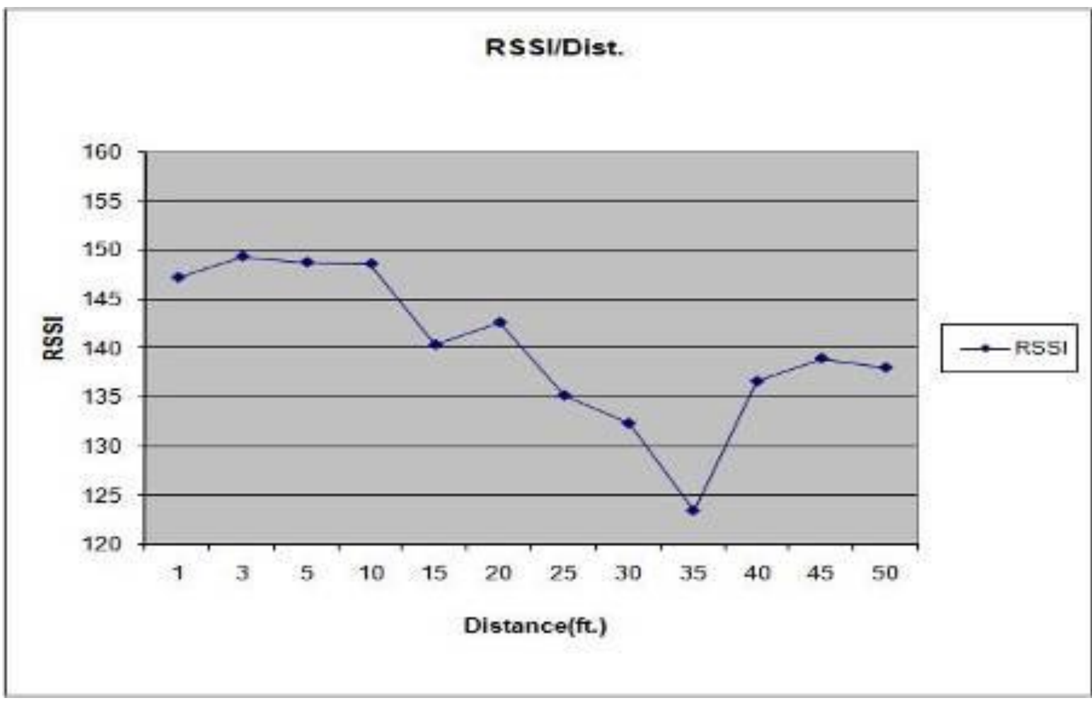


Figure 2.8 RSSI by Savi fixed read

Chapter 3 Observations and Limitations

3.1 Overall Results and Observations for both studies

In the passive testing experiment, an analysis of the results showed that one of the most significant factors was distance. The read numbers greatly decreased with increasing distance up to our maximum tested distance of 10 feet. In active testing the results were not as uniform. However, reads were easily obtained to distances of up to 50 feet. Given the critical distances needed for reading tags would usually lie between 10 and 50 feet, active technology had the definite edge in reliability. Further studies need to be done to determine if other factors, such as reader power, may allow passive technologies for the purpose of embedded license plates.

3.2 Limitations

Based on the results of this phase of research, the following steps are suggested for proceeding with the research.

1. Conduct interviews with individual stakeholders to gain a more specific understanding of project requirements and the implications of those requirements.
2. Conduct more thorough physical testing in outdoor environments and with embedded RFID transponders. Active technologies should also be further explored for this application.

3. Explore the nomenclature for the design of the RFID License Plate System.
4. Explore the current Way-in-Motion systems. By understanding these systems, improvements can be made allowing for a streamlined transportation process.
5. Expand how RFID can be used for traffic counts and pattern development. The use of RFID could allow for more accurate real-time monitoring of traffic trends used for planning and maintenance.

Chapter 4 Conclusion

The passive tags used in Experiment #1 are most often used for short read range applications. Because of the short read range, the experiment required a high powered reader. The strength of RFID related directly to frequency band. The frequency bands come in three categories, which are low, medium, and high. High ranges from 850 to 950 MHz and 2.4 to 5.8 GHz, while medium ranges from 10 to 15 MHz. On the other hand, the frequency band used for this particular project was "low" and ranged from 30 to 500 kHz. The characteristics for a Low Frequency include a short to medium read range, inexpensiveness, and a low reading speed. The applications that are usually tied to this particular frequency band are inventory and access control, car immobilizer, and animal identification. Experiment #1 results demonstrate that Gen 2 tags can read at higher distances than 10 feet but height is a major factor. There are 5 vital areas that are tied directly to the performance and readability and read range of RFID: power to tag, power to reader, internal attenuation of signal, transmittance frequency, and environmental conditions.

Most importantly, environmental conditions were a major factor in this specific experiment. These conditions include moisture, obstructions from objects (including metal), and interfering sources with the same frequencies as the reader. Signal strength relates directly to how many times the tag can be read per second or nanosecond. If the antenna/reader is not elevated high enough, the signal will not be strong enough. Based on the experiment results, a suitable height range for the RFID measurement is revealed. The best range of suggested height of passive tags is around 3 feet, and it means that it is better to be closer to the antenna in the horizontal level. For active tags, the good range of suggested height is around 2 feet, which means there is the best angle between the tag and antenna (5 feet high) in this level. This is because the earth's surface is an electron sink and also has a magnetic field that may interfere with the connection between the antenna and the tag. Thus, when using an electromagnetic device, a strong possibility exists that the RFID waves will experience interference. It is also stressed that when using equipment from a specific manufacturer it is vital that the manual is followed in order to get a good signal reading.

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