RFID Readability on Different Materials in Motion Testing

Dr. Erick C Jones[1], Angela Garza[2*], Srinivasan Venkatesan[3]

University of Nebraska-Lincoln

Industrial and Management Systems Engineering

342 Nebraska Hall

Lincoln, NE 68588-0518

*** garza1324@gmail.com, o: (770)-472-3495, f: (402)-472-1384**

Abstract

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. Approaches such as random screening do not allow for the correct attention to be placed upon those carriers and vehicles most likely to be in violation of the law; thus, they are an inefficient use of enforcement resources which can be improved with modern data collection technologies. Automated technologies can allow for the accessibility of pertinent information to be collected in a reliable manner. Unlike typical systems currently available, we envision a mile marker Radio Frequency Identification (RFID) reader which captures data and works with an RFID embedded license plate. Although RFID provides an efficient means for capturing data, interference from metal demonstrates a hurdle that must be overcome to develop a cost-efficient and reliable prototype that can be used in the future for officers to capture data automatically. In this article, we evaluate the feasibility of such a system by hypothesizing that different material spacers within a license plate prototype and reading at different speeds have a significant effect on the reader signal strength indicator (RSSI) value.

Keywords: Radio-frequency Identification (RFID), transportation, automated identification technologies, commercial vehicle operations

1.0 Introduction

Radio Frequency Identification (RFID) technologies have made a considerable contribution to the transportation industry. Applications include toll tags such as E-Z Pass which utilize active RFID technology to collect payment throughout toll roads. These tags are commonly placed on a vehicle's windshield and the readers are placed over the lanes. RFID has transformed the transportation industry because it provides the means to collect information on a vehicle in a reliable and cost-effective manner. Enforcement agencies that monitor commercial vehicle operations (CVOs) can benefit from these automated technologies as well due to its ability to efficiently capture data for inspection purposes. Currently, these enforcement agencies utilize a manual screening approach for safety and registration guidelines, which allows for random screening of vehicles. Random screenings are inefficient and a poor use of enforcement resources. Automated technologies can be used to replace these screenings by embedding an RFID tag within a license plate. Although this is a feasible solution, the issue of mental interference must be addressed in order to provide a reliable and cost-effective solution.

1.1 Literature Review

Automated identification technologies (AITs) include a variety of technologies such as RFID and barcodes that are used to identify objects. Some aims of AITs are to increase efficiency and reduce data entry errors. RFID is an AIT that uses radio waves to automatically identify objects. There are several aims of RFID but two of the most important ones are to reduce administrative errors and labor costs associated with lack of an efficient means to capture data. 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.

RFID systems consist of three main components: readers, antennas, and tags. The antenna emits radio signals that the tags respond to with their own unique code. The reader then receives and decodes the tag information and sends it to a computer through standard interfaces. There are three types of RFID tags: active, passive, and semi-passive (Angeles, 2005). There are several differences between the types of tags. Active tags are battery powered which allows for longer read ranges and a greater memory capacity. One disadvantage of active tags is that they are typically more expensive than their counterparts (Want, 2006). Passive tags have no battery and much less expensive than active tags, but their read ranges are significantly lower than their counterparts (Want, 2006). Semi-passive tags are similar to active tags in that they have long read ranges and they are more expensive than passive tags. These tags utilize a battery to run the chip's circuitry, but draw power from the reader in order to communicate.

To further explore the differences between active and passive systems, Table 1 provides a SWOT (Strengths, Weaknesses, Opportunities, and Threats) Analysis of these two technologies. The SWOT Analysis is utilized to identify opportunities and threats of each technology and uses this information to see how those elements may be used to a strength or weakness once applied. The opportunities and threats are elements unique to the technology that are examples of positive and negative aspects. The strengths and weaknesses are how those aspects of the technology are applied and their impact. The opportunity/strength box are the opportunities inherent to the technology that will also serve as strengths for the system, the opportunity/weakness box lists the elements of the technology that may seem to be an opportunity that may cause hindrance in the long run, the threat/strength box lists the elements of the technology that are considered threats to the technology that can be strengths in certain instances of the application, and the threat/weakness box lists all the elements that are considered threats to the technology which are also weaknesses once implemented into certain systems.

Table 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 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 interferes with signal • Difficult to hide	• Lack of battery results in shorter read ranges than active technologies

One challenge found within the design of RFID tags is that tags are not resilient to all types of materials (Want, 2006). Metal has long been an issue for the readability of RFID tags. RF waves are unable to penetrate metal; instead, metal reflects these waves, which makes it difficult to read the tags placed on metal surfaces. Research has shown that when RFID tags are directly attached to a metal surface, they are often undetected (Floerkemeier, & Lampe, 2004). Most liquids absorb RF waves which again reduces the read range. Highly dielectric materials (liquids) and conductors (metal), even in small amounts, can drastically change the properties of a tag antenna, reducing efficiency, and shortening the read distance, sometimes to the point of becoming completely unreadable at any distance (Singh, Vorst, & Tripp, 2009).

Recent research in the field of RFID reliability has pointed out weakness with achieving 100% read rates. Lack of 100% reliability is mainly attributed to the fact that radio frequency operates differently depending on the environment. The effect of various materials on read rates was highlighted in several recent studies. The effects on RF field of different materials is summarized in the Table 2 below (Singh, Vorst, & Tripp, 2009):

Table 2: Effects of Different Materials on RF Field

Material	Effect on RF field
• Cardboard	Absorption (moisture), detuning (dielectric)
• Conductive liquids	Absorption
• Plastics	Detuning (dielectric)
• Metals	Reflection
• Groups of cans	Complex effects (lenses, filters), reflection
• Human body/animals	Absorption, detuning (dielectric), reflection

In the research, RFID alien “higgs” tags were used to analyze specific variables that may affect the read accuracy of multiple RFID tags on a pallet when driving a pallet through an RFID portal. The study found that there is a significant relationship between the read rate and forklift speed. Three types of pallet pattern where studied in the research column, interlocking and pinwheel. The best read rate (100%) was achieved for paper towels; this is because of the papers transparency to RF signals (Singh, Vorst, & Tripp, 2009) . Carbonated beverages in aluminum cans had the greatest difficulty in achieving 100% read rate, they achieved a read rate of little over 25% (Singh, McCarney, Singh, & Clarke, 2008) (Singh, Holtz, Singh, & Saha, 2008) . The lowest speed used to move the palletized load through a portal increased the probability of reading the tags applied to the cases. The rice – filled jars had a higher read rate. Presence of air gaps created in secondary packaging (trays and shippers) configurations between the locations and positioning of RFID tags and primary packages or products (bottles and cans) allows RFID readers to get more effective reads and reduce interferences and reflectance or blockage by water and metal. The research also showed that reducing the number of cases in a palletized load does not always guarantee a more efficient read rate. It was demonstrated that fewer cases provided better readability of case level tags for bottled water, but not for beverage cans (Singh, Vorst, & Tripp, 2009).

Although the idea of RFID has been explored since the 1950s, wide deployment of this technology did not occur until the 1990s. Within the transportation industry, the Port Authority of New York and New Jersey tested systems with favorable results in the 1970s. As RFID research progressed, the first electronic toll collection became available in Europe and followed by the United States in the late 1980s. By the 1990s, RFID was widely deployed throughout the United States as an electronic toll collection application. Highway electronic tolling systems were introduced in 1991. These systems allowed vehicles to cross collection points at highway speeds (Landt, 2005).

1.2 Problem Statement and Hypothesis

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. Approaches such as random screening do not allow for the correct attention to be placed upon those carriers and vehicles most likely to be in violation of the law. These random screenings generally can be an inefficient use of enforcement resources which can be improved with modern data collection technologies. By using automated technologies, information can be readily accessible in a reliable manner.

Unlike typical systems currently available like those used in electronic toll systems, we envision a mile marker RFID reader which captures the data on the roadside and works with a license plate with a tag embedded. Although RFID provides an efficient means for capturing data, interference from metal demonstrates a hurdle that must be overcome in order to develop a cost-efficient and reliable license plate that can be used in the future for officers to capture data automatically. In this article, we evaluate the feasibility of such a system by hypothesizing that different material spacers within a license plate prototype and reading at different speeds have a significant effect the received signal strength indicator (RSSI) value, which is the measured power in a radio signal that is received.

2.0 Methodology

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

Step 1: Data Collection

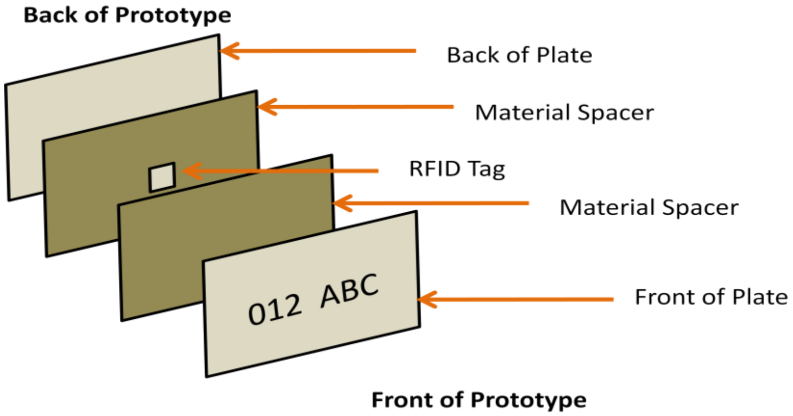
Step 2: Two Factor ANOVA

Step 3: Tukey Test.

2.1 Step 1: Data Collection

Two factors were evaluated to determine their significance to the RSSI value: material and speed. For material, the four levels consisted of rubber, plastic, cardboard, and no material. To evaluate the effects of each material, the RSSI value was captured for ten replications. Each material was used as a spacer between the tag and the outer plate. Figure 1 depicts the license plate prototype which was experimented on. The material spacer consisted of one of the materials (plastic, rubber, cardboard, no material) and provided a barrier between the front and back plate.

Figure 1 – Prototype Used in Experimentation



Speed was the other factor to be evaluated throughout the ten replications and consisted of three levels (25 mph, 30 mph, and 35 mph). These speeds represent common speed limits of a weigh station where data on CVOs could typically be captured.

Each material was experimented at the three speed levels. The distance between the tag and reader was 25 feet. The width of one lane is a minimum of 12 feet, so the experiment examines the strength of the RSSI values if a car was traveling on the outer lane of a two lane highway. Figure 2 depicts the distance between the reader and car with the RFID embedded license plate. The height of the reader was 2 feet to simulate a mile marker with a reader attached while the license plate was at a height of 3.5 feet. The RFID reader used has an RSSI range of (-58 to -108 dbs). The closer the RSSI value is to 0, the greater the RSSI strength. For ease of interpretation, all values are shown as positive, so the smaller the RSSI value, the greater the strength.

Figure 2 – Experimental Setup

2.2 Step 2: Two Factor ANOVA

Once all the RSSI values were collected, a two-way ANOVA was used to evaluate whether material, speed, or the interaction between material and speed significantly affected the RSSI value (the dependent variable) at 0.05 alpha level. The general model used for the ANOVA test is

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

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

ε_{ijk} is the error.

There are three hypotheses for the ANOVA:

1. H_0: $\alpha_1 = \alpha_2 = \alpha_3$
2. H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4$
3. H_0: $\gamma_{ij} = 0$ for all i and j

These hypotheses can be interpreted as follows

1. The means for each speed are the same.
2. The means for each material are the same.
3. There exists no interaction between materials and speed.

2.3 Step 3: Tukey Test

Once a factor was found significant, a Tukey test was performed to find if there was a difference between the means of that factor and which level provided the greatest RSSI value strength. This test would help determine which material or which speed was the most reliable with regard to RSSI value strength.

3.0 Results

3.1 Results of Step 1: Data Collection

A total of 90 trials were conducted for the three different speeds and three different materials. The mile marker reader detected an RSSI value for every trial and the values ranged from -79.5 to -108. The results for each material and no material are seen in Table 3.

Table 3(a) – RSSI Values for Rubber

	Trial										
Speed	1	2	3	4	5	6	7	8	9	10	Average
25	107.0	87.5	98.5	102.0	102.5	86.0	88.5	92.5	100.5	89.0	94.8
30	102.0	105.5	97.0	98.0	101.5	108.0	103	97.5	102.5	93.5	100.9
35	92.5	87.0	99.0	104.5	96.5	97.5	99.0	99.0	97.0	101.5	97.4

***Note: all values are negative.**

Table 3(b) – RSSI Values for Plastic

	Trial										
Speed	1	2	3	4	5	6	7	8	9	10	Average
25	99.5	102.0	102.0	89.5	101	82.5	103.5	93.0	101.0	102.0	97.6
30	90.5	88.0	101.0	93.0	99.0	101.5	96.0	93.0	91.0	96.5	95.0
35	90.0	97.5	101.0	99.0	87.5	97.5	97.5	87.5	95.0	95.5	94.8

***Note: all values are negative.**

Table 3(c) – RSSI Values for Cardboard

	Trial										
Speed	1	2	3	4	5	6	7	8	9	10	Average
25	79.5	95.5	82.5	82.5	97.0	97.5	84.5	95.0	81.0	80.5	87.6
30	95.5	98.5	83.5	93.5	87.5	97.5	97.5	94.5	99.5	87.5	93.5
35	95.5	81.5	98.5	88.5	94.0	82.0	95.5	87.0	81.5	91.0	89.5

***Note: all values are negative.**

Table 3(d) – RSSI Values for No Material

	Trial										
Speed	1	2	3	4	5	6	7	8	9	10	Average
25	101.0	106.0	111.0	103.0	98.0	93.0	108.0	103.0	95.0	100.0	101.8
30	102.0	100.0	111.0	101.0	102.0	108.0	104.0	98.0	105.0	101.0	103.2
35	97.0	98.0	101.0	96.0	96.0	98.0	104.0	95.0	95.0	98.0	97.8

***Note: all values are negative.**

3.2 Results of Step 2: Two Factor ANOVA

Using the RSSI values collected, ANOVA was performed to find the significant factors. The results of the ANOVA test are shown in Table 4.

Table 4 – 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	1110436.602	35407.292	.000
Speed	236.717	2	118.358	3.774	.026
Material	1848.356	3	616.119	19.646	.000
Speed * Material	309.500	6	51.583	1.645	.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 seen by the ANOVA table, material is the only significant effect on RSSI value. Since it is significant, we can reject the null hypothesis that all the material means are equal (second null hypothesis of ANOVA). We fail to reject the null hypothesis that all the speed means are equal and no interaction occurs between each material and each speed; thus, both speed and the interaction of speed and material do not have a significant effect on RSSI value.

3.3 Results of Step 3: Tukey Test

Further analysis was necessary to determine if there existed a material that allowed for a stronger RSSI. The Tukey test was conducted on the data (30 samples) at a 0.05 alpha level and the results are shown in Table 5.

Table 5 – Tukey Test on Material (RSSI)

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

As seen in the table, cardboard has a mean RSSI value that is significantly different than the other two materials' means and the mean of readings when no material is used.

4.0 Discussion

Designing a license plate that has an embedded RFID tag is a daunting task largely due to the interference of metal with RF waves. By adding spacers made of different materials to surround the RFID tag, the interference may be minimized but this added material also provides one more object that the RF waves must pass through. Previous research conducted on RFID tags on different materials showed that both speed and materials had a significant effect the readability of the tags. Results of these experiments only found material to be significant. All material performed better than having only a metal license plate with RFID tags embedded within it shown by the highest mean RSSI value resulting from this experiment. Cardboard was found to provide the strongest RSSI value since a lower RSSI value means the strength of the value is greater. One reason for this finding is the composition of this material allows for better penetration of the RF waves as oppose to rubber, plastic, and metal.

5.0 Conclusions

A license plate with an RFID tag embedded into would be a valuable asset to enforcement agencies. This system would allow for the automatic data capture of important information regarding CVOs and would be a beneficial replacement to the current approach of randomly screening CVOs. Not only would this new system reduce the unnecessary use of valuable resources, it would provide a cost-effective means to track all CVOs that travel on the interstates.

Current transportation systems that utilize RFID exist, but are utilized mainly for electronic tolling. These active tags are commonly placed on the windshield of vehicles unlike the prototype tested within this paper. Embedding a tag within license plate does not come without its barriers. Metal from the license plate interferes with the RF waves and disrupts the readability of tags.

By adding spacers of various materials to act as barriers to this disruption, experimentation showed that readability can increase. Also the materials significantly affect the RSSI value. Cardboard had the greatest readability out of all the materials. Results showed that speed had no effect on the RSSI values, so any of the speeds would allow for reliable read rates. Results of this research allow for further experimentation on designing a license plate with an embedded RFID tag.

Further testing can be conducted on other materials and other speeds. Other types of vehicles could be used to see if height of the license plate affects the readability. More trials may be necessary to get a better depiction of the material and speed effect on RSSI.

Acknowledgements

This study is part of a Commercial Vehicle Information Systems and Networks (CVISN) grant funded project (2008-2010). We would like to thank the Nebraska Department of Motor Vehicles for their ongoing research support.

References

Angeles, R. (2005). RFID Technologies: Supply-Chain Applications and Implementation Issues. *Information Systems Management, 22(1),* 51-65.

Floerkemeier, C., & Lampe, M. (2004). Issues with rfid usage in ubiquitous computing applications. *IEEE Pervasive Computing, 3(1),* 188-193.

Landt, J. (2005). The history of RFID. *IEEE Potentials, 24(4),* 8-11.

Singh, E., Vorst, K., & Tripp, K. (2009). Rfid tag readability issues with palletized loads of consumer goods. *Packaging Technology Science, 22*, 431-441.

Singh, J., Holtz, R., Singh, S.P., & Saha, K. (2008). Effect of unitization and product types on readability of tagged packages of consumer goods. *Journal of Applied Packaging Research*, *2*(3).

Singh, S.P., McCarney, M., Singh, J., & Clarke, R. (2008). Rfid research and testing for packages of apparel, consumer goods and fresh produce in the retail distribution environment. *Packaging Technology Science*, *21*, 91-102.

Want, R. (2006). An introduction to RFID technology. *IEEE Pervasive Computing, 5(1),* 25-33.